Synthesis and Optimization of Application-Specific Intranets

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SYNTHESIS AND OPTIMIZATION OF APPLICATION-SPECIFIC INTRANETS

by

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Dedication

In memory of my father.

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Abstract

Effective and efficient content-distribution networks are a requirement for data-intensive applications like multimedia, which are not only characterized by massive data storage and communication bandwidth requirements, but how these characteristics are integrated. This thesis describes the computer-aided design of large networked systems, including the data management and the network architecture. In particular, the systems focused on are intranets supporting specific application domains like animated feature production or telemedicine. We define and solve the complete intranet integration problem to be automated as a combination of two interdependent sub-problems: data management system design and network architecture design.

Data management system design consists of server placement and file allocation. The server placement problem is to determine the number, type, storage capacity, and process capacity of servers, while minimizing their placement costs. In addition, the problem includes binding each client to a server and uniting all servers as one logical distribution data system. The file allocation problem is to find locations to store copies of the files most frequently accessed by the clients in their local servers, while minimizing the storage and retrieval costs. The network architecture design problem is to determine the network topology along with the network technology that enables all clients to communicate and access servers efficiently, while minimizing the network cost.

The intranet integration problem is a large combinatorial optimization problem. Guaranteeing to find optimal solutions would require a prohibitive amount of time. The solution presented in the thesis is a custom-built genetic computer-aided design tool, *i*-CAD, that attempts to optimize the intranet design, but does not guarantee optimality. *i*-CAD is a novel software tool that is based on an evolutionary approach to search the design space for minimal intranet integration cost while satisfying both design and performance constraints. From the experimental results on several animation production studios' intranets, *i*-CAD demonstrates the feasibility of automatic intranet design in a short time.

Chapter 1

Introduction

1.1 Background

This thesis describes a new direction for *design automation* by focusing on the design of large hardware systems that involve a data management system and a network architecture. This new direction moves system-level synthesis from designing a system that consists of processors, memory and input/output, which all are integrated into a single multiprocessor; into a system that consists of many geographically-distributed network nodes (clients and servers), which need a communication network and a database system in order to perform a number of cooperative periodic tasks. This thesis addresses only the hardware design of application-specific intranets in order to reduce the problem to a form amenable to solution in a limited time, rather than including the intranet protocol configuration, and other related software problems.

A designer/planner of an enterprise's intranet must choose from literally millions of data management system and network architecture integration possibilities for a given intranet multimedia application. Applications supported by intranets have certain requirements, such as high communication bandwidth, large storage space, high transfer rate and delay bounds. Moreover, infrastructures designed for intranets have certain characteristics that must be determined by the designer, including a network topology, type of network technology (such as switch, multiaccess device, bridge, router, T-carrier, SONET and/or virtual private network) and data management system (the number, type, locations, process capacity, and storage capacity of servers/proxies, and the allocation of files into the servers/proxies). In many cases, the design space is too large for intranet designers/planners to determine manually which intranet integration can satisfy the enterprise application requirements with minimal design cost. Automated **capacity planning** tools are needed.

1.2 The Intranet Integration Problem

The automatic integration of a complete intranet has not been attempted previously, and has not been reported in the research literature, to our knowledge. The definition of the problem itself had never been performed previously, and constituted a research effort spanning more than three years. The intranet integration problem has three aspects that distinguish our research problem. These aspects are network heterogeneity, network hierarchy and data management. Our capacity planning tool is able to integrate a mix of network topologies and technologies (heterogeneity), design a multi-level network (hierarchy), and place storage locations for files (data management). All these aspects are performed simultaneously.

We define the intranet integration problem as a combination of two interdependent sub-problems: **data management system** design and **network architecture** design. The data management system problem consists of the **server placement** problem and the **file allocation** problem. The server placement problem is to determine the number, type, locations, storage capacity and process capacity of servers/proxies, while minimizing their placement costs. In addition, the problem includes binding each client to a server and uniting all servers as one logical distribution data system. The file allocation problem is to find a number of storage locations (servers) to store copies of the most frequently accessed files by clients in their local servers, while minimizing the storage and retrieval costs. The solution for the data management system design problem can be used by the intranet's clients to store/retrieve shared files; moreover, the database manager of an intranet can use such information for content distribution. The network architecture problem includes determining network topology along with the network technology, such as switch, multiaccess device, router, bridge, T-carrier, VPN and/or SONET, that enables all clients to communicate and access file servers efficiently, while minimizing the network hardware cost.

The outcomes of the two sub-problems, data management system design and network architecture design, are interrelated; therefore, we formulate them as one combined optimization problem. For example, if we design the network architecture without considering the number of file servers and their traffic flow, then the designed network may not handle the file servers due to the lack of network connection ports and/or network bandwidth capacity. Otherwise, for example if we place the file servers without considering the network's constraints, then we may not achieve a feasible network design because we cannot access the data to meet performance constraints. If we place the file servers without considering the number and size of the files, then the allocated file servers may not be able to store and process all the files, for example. Also, we cannot allocate the files without placing the file servers first. However, the combined optimization problem is a very complicated combinatorial optimization problem. Therefore, guaranteeing to find optimal solutions would may require a prohibitive amount of time, since there are literally millions of possible data management systems and network architectures for a given intranet.

In summary, the following are the problem inputs and outputs:

- The problem inputs include
  - A client location matrix, client traffic matrix and data request matrix.
  - An objective function specifying the overall intranet infrastructure cost.
  - A set of constraints specifying the network and data management design requirements.

  - A set of constraints specifying the network and data management performance requirements.
  - design libraries specifying all available network and server resources including their characteristics, such as capability, cost and performance parameters.

- The problem output is an optimized intranet infrastructure, including
  - the number, type, locations, processing capacity, and storage capacity of all file servers,
  - the storage locations for all files, and
  - the number, type and capacity of all network hardware devices, such as switch, multiaccess device, router, bridge, leased line, SONET leased line and virtual private connector.

1.3 *i*-CAD: A Capacity Planning Tool

To find a good solution for the intranet integration optimization problem, we developed an intranet computer-aided design tool, *i*-CAD, based on evolutionary approach [HP00, HPL01]. *i*-CAD is a suite of techniques and a software tool that can automatically synthesize data management systems and network architectures together as an application-specific intranet, while minimizing the design cost and satisfying the design and performance constraints. *i*-CAD uses a genetic algorithm, a probabilistic algorithm maintaining a population of possible intranets for each iteration of the algorithm. Each intranet is evaluated to give some measure of its fitness. Then, a new population is formed by selecting the more fit intranets. Some members of the new population undergo transformation by means of genetic operators to form new intranets.

The basic structure of *i*-CAD consists of three main procedures as depicted in Figure 1.1. The first procedure creates the initial intranet population by selecting all network and data management hardware resources randomly. The first procedure executes only once. The second procedure validates and evaluates each intranet in the current population. The third procedure selects the fit intranets, modifies some and discards the rest. The second and third procedures execute indefinitely until all the design and performance constraints are satisfied and either the cost is acceptable to the user or the cost improvements are diminishing and insignificant. All the design and performance constraints, and the objective function are encoded within the internal structure of *i*-CAD.

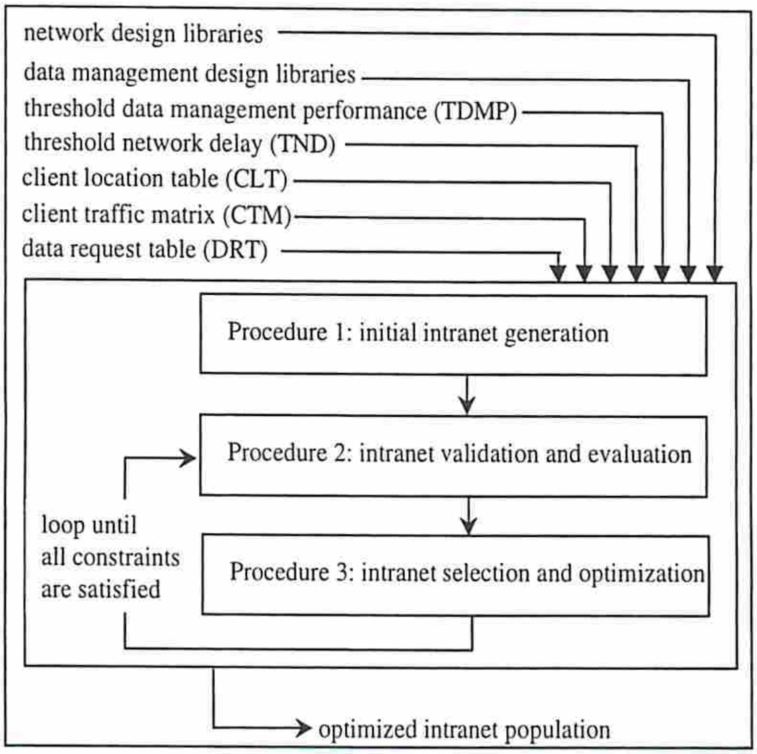

Figure 1.1: The view of the basic structure of *i*-CAD.

The inputs to i-CAD are application inputs that are specific to the problem and tool inputs that represent data independent of the application. The application inputs include the following: client location table (CLT), client traffic matrix (CTM), data request table (DRT), threshold network delay (TND), and threshold data management performance (TDMP). The client location table (CLT) represents the physical location of each client within the intranet. The client traffic matrix (CTM) represents the average traffic requirements between all clients. The data request table (DRT) represents the access rate of each file by all clients. The CLT, CTM and DRT vary from application to application. The threshold network delay (TND) is a real number given by the designer to insure that the average network delay (AND) of a synthesized intranet's network never exceeds the TND. The threshold data management performance (TDMP) is a real number given by the designer to insure that each placed server/proxy can minimally achieve TDMP.

The tool inputs are the design libraries and genetic algorithm's parameters. There are nine design libraries attached to i-CAD: Ethernet, ATM, bridge, router, T-carrier, SONET, VPN, server and hard disk. Each library contains specific information about all its components, such as cost, and capacity. The genetic algorithm's parameters refer to the population size (PS), number of generations (NG), crossover rate (CR), and mutation rate (MR). The output of the i-CAD tool is a population of optimized intranet infrastructures.

1.4 Motivation Behind i-CAD

The motivation behind this work is the need for an automatic capacity planning tool, such as i-CAD, to design application-specific intranets. We list some of the benefits and features of i-CAD; moreover, we describe some of the applications that may be executed by intranets. i-CAD is a novel software packages, which offer the following:

- Fast consideration of many network architectures,
- Fast consideration of server placement and file allocation,
- Rapid feedback to the designer as performance is evaluated,
- Rapid feedback to the designer as application inputs, such as client traffic matrix, are varied,
- Rapid adaptation to new network and data management technologies and design styles, and
- Feedback to the designer on how to modify existing intranet infrastructures.

i-CAD creates an intranet, based on the application requirements, out of many possible designs in less time and cost than the manual design process. For example, consider an enterprise with six physical sites, where each site contains four local area networks (LAN) for a total of 24 LANs. Each LAN contains a number of client nodes that need to communicate among themselves and with other clients, and access file servers. This optimization problem has exponential computational complexity. For example to connect all clients within a LAN, all LANs within a site, and all sites within the enterprise's backbone by considering only two possible network technologies (switch and multiaccess device), we have $2^{(24 \text{ LANs} + 6 \text{ sites} + 1 \text{ backbone})} = 2^{31}$ possible infrastructures. If each infrastructure takes one second to be synthesized and evaluated for example, then it is impossible to find the optimal solution manually without lots of domain experience. On the other hand, to search for the optimal solution by a computer using brute force is also not feasible due to the enormous design space of the problem, even if obviously bad design decisions could be eliminated prior to search. For this reason we use a randomized algorithm, in particular a genetic algorithm, to search for a near-optimal solution.

i-CAD can accurately manage many more design decisions than the manual design process. These decisions include determining data management resources and allocating all files into file servers. In the previous example, there are 2^{31} possible intranet infrastructures, and each infrastructure has many possible combinations of additional design decisions posed in our problem. The *i*-CAD gives the network designers insight into the synthesized intranet and its resources that can help to estimate the performance of the intranet without an actual physical implementation. *i*-CAD enables the network designers to study and analyze the effects of different input parameters on the network design parameters. For example, if the type and amount of data traffic are changed due to clients' requests, *i*-CAD can redesign the intranet to satisfy the new traffic. This provides the network designers with a comparison between the redesign and old intranet infrastructures. *i*-CAD offers many other features such as studying and analyzing the effects of different data management system styles such as centralized or distributed.

Also, in the future, *i*-CAD will be capable of guiding network managers on how to tune or adapt the intranet resources to the application's tasks, by indicating when and where to add additional specific resources to the current intranet's infrastructure, or by restructuring the current infrastructure without additional resources. These features can be added in the future without changing the main underlying techniques or introducing large amounts of new code.

Our research is motivated by the high demand for application-specific intranets. As of 1999, intranets were being used by nearly 23 million employees worldwide and International Data Corporation (IDC) had predicted that number would grow to 180 million in the year 2000 [Ken97]. Applications supported by intranets include

- video/audio-on-demand,
- teleconferencing,
- tele-education,
- electronic transactions,
- telemedicine, and

- cinema-television animation.

Video/audio-on-demand describes an interactive television (radio) that allows people to interact with programs and control the time to watch (or listen to) them. In some cases, a client can interact with a server through a set-top-box located at the client site and all requests and replies are transmitted via high-speed networks. This application typically requires high bandwidth, an asymmetrical link and low transmission cost as the main intranet characteristics.

Teleconferencing is an information exchange system for people to conduct meetings effectively without leaving their offices. For example, users can see each other via real-time video on their multimedia workstations displays, talk and listen to all the conversation via real-time audio and watch presentations via an online electronic whiteboard. This application typically requires mobility, high bandwidth and a symmetrical link as the main intranet characteristics.

Tele-education involves a virtual learning and training campus for students and instructors to interact with each other without all being in the same classroom. In some implementations, students and instructors can see each other via real-time video on their multimedia laptops' displays, talk and listen to all discussions via real-time audio and watch lectures via an online electronic whiteboard. This application typically requires broadband transmission, mobility, low transmission cost and a symmetrical link as the main intranet characteristics.

An electronic transactions' intranet application mainly involves a financial institution that needs a secure in-house network. This application typically requires high security, reliability and connectivity as the main intranet characteristics.

Telemedicine refers often to a virtual hospital or other medical facility that provides essential services such as a rapid consultation between physicians and patients or physicians and specialists, health delivery services between hospitals and rural clinics, access to patients' records anywhere and anytime by medical personnel and a database containing the availability of organ donations. This application typically requires low transmission delay, bidirectional transmission, a symmetrical link, broadband transmission and high bandwidth as the main intranet characteristics.

An animation film studio is an online post production system for directors, writers and animators, where animated sequences of drawings as well as integrate and edit the prerecorded video, background, special-effect frames and audio samples together to produce an animated film. This application typically requires a symmetrical link, high bandwidth and broadband transmission as the main intranet characteristics.

1.5 Thesis Organization

The rest of the thesis is organized in seven chapters. Chapter 2 presents an overview of our intranet model and examples. Chapter 3 surveys the related research in the areas of network synthesis, design automation tools and multimedia systems. Chapter 4 describes a comprehensive mathematical formulation of the intranet design problem. The formulation includes a large set of network and data management design constraints and an objective function representing the total intranet integration cost. Chapter 5 describes an analytical performance model for evaluating the integrated network architecture for satisfying a given threshold delay. Also, we describe a Monte Carlo simulator for evaluating the data management system to determine how many clients' requests can be satisfied within a given threshold duration period. Chapter 6 describes the intranet computer-aided design tool, *i*-CAD, which is a suite of techniques and software that are used for automatically designing and integrating data management systems and network architectures. A genetic algorithm used by *i*-CAD for selecting and integrating the optimized set of network and data management components that minimize the total intranet integration cost, while satisfying the design and performance constraints, is described. Chapter 7 presents the results of using *i*-CAD to integrate data management systems and network architectures for several instances of the animation production studio problem. Chapter 8 contains the conclusions and contributions of our research, and future research directions in large system-level synthesis.

Chapter 2

An Overview of Intranet Design Model

2.1 Background

In the past half decade, there has been a rapid expansion in the use of networks, particularly intranets. As of 1999, intranets were being used by nearly 23 million employees worldwide and International Data Corporation (IDC) had predicted that number would grow to 180 million in the year 2000 [Ken97]. An intranet is a private network that is contained within an enterprise. It may consist of many interlinked local area networks (LAN) and also use leased lines in the wide area network that connects the LANs. The main purpose of an intranet is to share company information and computing resources among employees. An intranet can facilitate distributed groups of an enterprise's employees to work on common tasks. However, there is no uniform infrastructure that is appropriate for all intranets. The intranet's infrastructure depends on many factors, for examples the type of application (continuous media or non-continuous media), the number of nodes (clients and servers), and the physical dimensions between the clients. We view the intranets as the building blocks of the global Internet. Therefore, an intranet can be as small as a household network connecting a few components (such as PCs, printer, and smart appliances), or as large as a global enterprise network connecting offices around the world. In this thesis, we suggest a simple model that can capture both the data management and network aspects of an intranet. Our goal is to show that it is feasible to automatically synthesize a complete intranet infrastructure by using such an intranet model.

2.2 Intranet Model

We model an intranet application as a hierarchy of three tasks. The *backbone task* refers to the entire intranet application. The backbone task consists of a number of subtasks performed at physical sites, each of which is referred to as a *site task*. A site task consists of a number of distinct *group tasks*, where each group task comprises a number of distinct client tasks (performed on workstations). In order to perform all the collaborative group and site tasks within an acceptable time, clients must communicate and share data among themselves. These three tasks (backbone, site and group) can be associated with three network levels. The communication within a group task can utilize the lowest-level of network (local area network, LAN) that connects a set of clients (workstations). The site task can use the intermediate-level network that contains a set of LANs. The backbone task needs to use highest-level network that connects all sites. The physical dimension of an intranet's backbone network can be either a local or wide depending on the physical distance between sites. A local topology refers to the close physical locations of all sites. For example, when all sites are located within a university campus or studio lot, we consider such topology as local. A wide topology refers to the scattered physical locations of all sites. For example, when all sites are located across a city, state or country, we consider such topology as wide. The difference between the two topologies is in the selection of network technologies.

This thesis defines an intranet as a three-level network (backbone, site and group) and the data management system is constrained at the group level to keep the data close to the high-demand clients. Then, the intranet integration problem is to configure simultaneously a data management system and three-level network architecture for the given application's tasks, in order to perform all tasks in a certain order and within a time bound, while minimizing the total intranet integration cost. Our intranet model is one of many intranet model possibilities that can be explored in the future by increasing or decreasing the number of network levels or placing the data management system at different network levels, for example.

2.3 Example: Animation Production Studio

An animation production studio is an online post production system for directors, writers and animators that can create, integrate and edit the live-action frames, background frames, special-effect frames, animation frames and audio samples together to produce an animation film. According to Weinberg [Wei95], digital media production has rapidly become a highly distributed collaborative activity involving teams of people and digital resources in different locations.

A typical animation film studio's activity consists of multi-collaborative site tasks such as live-action, audio, background, special-effect, management and drawing, where each site task is composed of many distinct group tasks. Thus, a studio needs a data management system and a network architecture to enable all its sites to communicate with each other and access the same file servers efficiently. Such an application has certain network and data management requirements, such as high communication bandwidth, high-transfer rate, massive data storage and low delay bounds. For example, the film *Toy Story 2* has 122,699 frames of up to 4 gigabytes per frame [Sla99]. This data reflects the finished film, which means that an enormous quantity of data is created within all tasks to develop the finished film. Budget limitations can disallow the choice of the fastest possible networking hardware for the entire installation, forcing heterogeneous solutions with components that vary in cost and performance across the network. Literally millions of possible network architectures could be used for a given animation studio intranet, and this number is magnified by possible variations in the number, type, locations and capacity of the file servers. It would be impossible for a human network designer to examine all possibilities for typical large installations. This makes the animation production studio a good realistic intranet example to be integrated. Plus, studios expect their intranets to be upgraded periodically so that their products (films) reach the market on time.

To clarify the presentation of the animation's tasks, we model the group tasks and their communications as a task flow graph (TFG), where a node represents a group task and an edge represents the communication between two group tasks as shown in Figure 2.1. The graph shows an example of a full task flow graph for the animation film studio's group tasks. This graph has two attributes: it is hierarchical and is a hyper-graph. It is a *hierarchical* graph, since each node (group task) contains a set of distinct client tasks, where each client task performs part of the group task. A collection of related group tasks forms a site task that represents a task performed at a physical site location. Then, all the site tasks constitute a backbone task, which represents the entire intranet's application. It is a *hyper-graph*, since each edge represents the communication among an arbitrary subset of clients of the two group tasks.

The full example animation task flow graph has 14 group tasks (nodes in the graph), which are involved in creating, managing, integrating and editing the animation film's shots [SC95]; moreover, the graph shows the data flow order per shot between the 14 group tasks. These 14 groups are clustered into six sites and a total of 150 client tasks (performed on 150 workstations) are used to perform all group tasks. The first eight groups tasks (GT_1 to GT_8) perform the creation of the skeleton shot, which contains all video frames, audio samples, background frames, and special-effect frames except the animated drawing frames, as shown in Figure 2.2. In the partial animation task flow graph, the eight group tasks are clustered into four site tasks and a total of 65 client tasks (performed on 65 workstations) are used to perform the eight tasks. The full and partial animation task flow graphs are

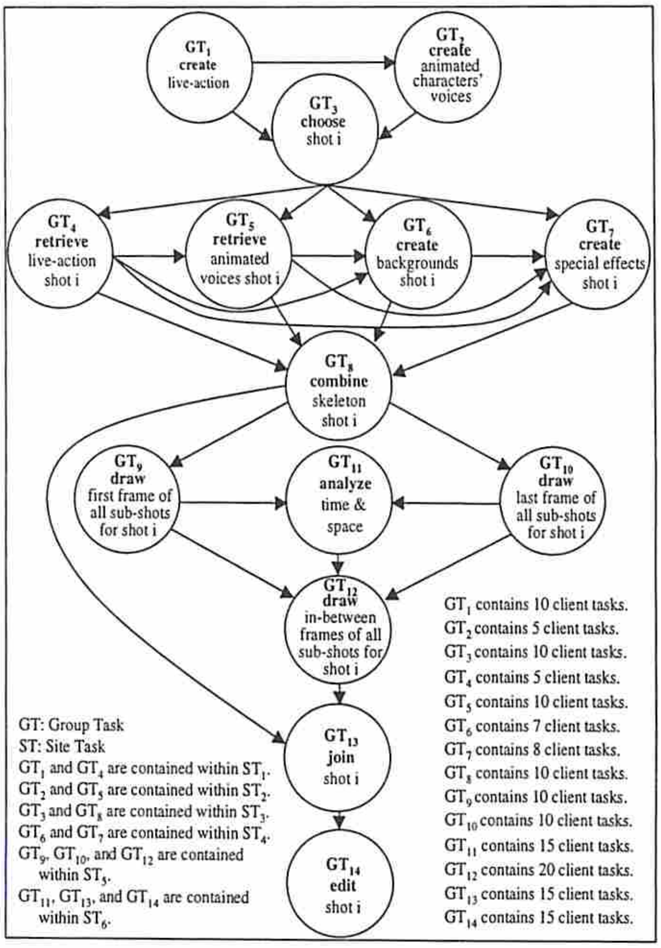

Figure 2.1: Full task flow graph for an example animation film studio.

used as our examples to integrate application-specific intranets. In the future, we intend to use the task flow graph as an input to provide additional time-dependent information to be used during intranet design. However, to simplify the problem currently as an input to *i*-CAD we simply describe the tasks' information within the task flow graph by a matrix and two tables, omitting the ordering of tasks:

- A client traffic matrix (CTM) represents the average traffic flow requirements between each pair of clients in term of bits per second,

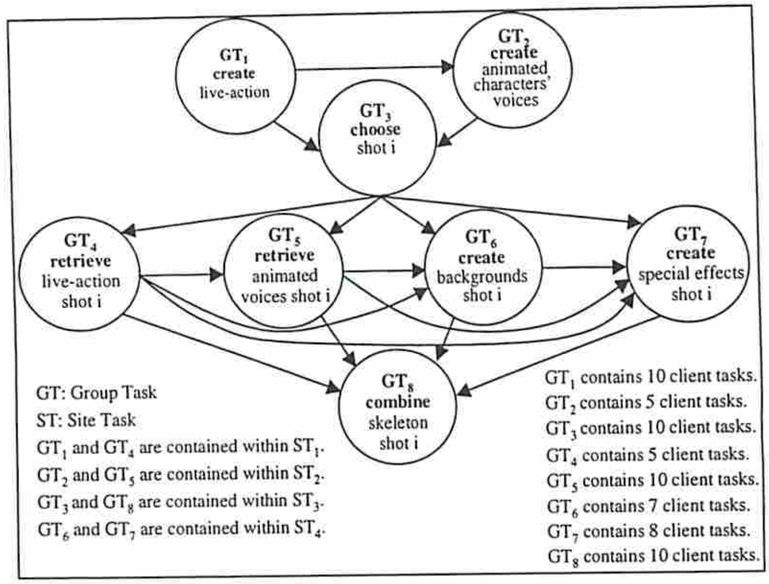

Figure 2.2: Partial task flow graph for an example animation film studio.

- A client location table (CLT) represents the physical location of each client within the intranet and its allocation to a group task and a site task, and
- A data request table (DRT) represents the access rate of each file by all clients.

The client traffic matrix and task flow graph are *not* compatible representations of the application's tasks. The client traffic matrix provides a non-hierarchical information about the application's tasks (focused on the client to client relationship), where the task flow graph provides a hierarchical information about all three levels (group, site and backbone), along with data-precedence relationships.

Chapter 3

Related Research

3.1 Background

The intranet integration problem is a multidisciplinary problem with related research in three broad categories: *network synthesis*, *design automation tools*, and *multimedia systems*. In this chapter, we examine each category and outline the fundamental concepts and relevant work related to our research.

3.2 Network Synthesis

Network synthesis is a broad expression that is used by many researchers in many different fields. In this thesis, we refer to the process of designing the hardware comprising a computer network as network synthesis. Research in network synthesis can be divided into three areas: classical network synthesis, teleprocessing network synthesis and combined network synthesis with file allocation. Next, we review the research efforts in these areas.

3.2.1 Classical Network Synthesis

In this section, we present some of the early and recent research efforts in network synthesis and analysis. The classical network synthesis problem is to determine an unconstrained[1] physical network topology and a link capacity requirement.

The early works on network analysis [EFS56, FF56, DF56] were performed in the late 1950s. In the analysis problem, the physical network topology and the link capacity matrix (LCM) are given and the objective is to find the maximum possible flow between nodes, which is the node capacity matrix. The maximum flow analysis is based on finding the minimum value among all *simple cut-sets*. A *cut-set* is a set of links such that when removed from the network, then the network falls into two or more unconnected subnetworks. A simple cut-set means a cut-set such that if any link is removed it is no longer a cut-set.

The automatic synthesis of communication networks is not a new problem; it has been researched since the early 1960s. A systematic synthesis method [Chi60] and realization conditions [May60] were developed to synthesize a communication network from its node capacity matrix (NCM), where each entry in the NCM represents the maximum possible communication capacity between two nodes in the network. The outcome is an unconstrained physical topology with a minimum weighted sum of all links' capacity. However, this synthesis method gives a non-unique topology and sometimes it is impossible to realize a topology from a nonrealizable node capacity matrix.

These early efforts in network synthesis and analysis serve as a foundation for our problem that consists of similar basic problems such as finding a constrained physical network topology, allocating network capacity and analyzing network performance. The rest of the classical network synthesis papers are divided into two sets based on the solution approach. The papers in the first set provide abstract solutions to the network synthesis problem. An abstract solution means determining only a set

[1]Nodes are connected together in an arbitrary pattern.

of links and their capacity without specifying the type of network technology. The papers in the second set provide concrete solutions to the network synthesis problem. A concrete solution means that at least one type of network technology is used to synthesize a network architecture. Next, we review the abstract and the concrete approaches for synthesizing a computer network.

3.2.1.1 Abstract Network Solution Approach

An abstract network solution means determining only a set of links and their capacities to connect a set of nodes without specifying the type of network technology. The following papers [GK77, Sak89, PK95, KTC+97, BMM+, TH, PL98] describe several abstract approaches to synthesize a computer network. In contrast to our problem and approach, the techniques described in these papers are either limited to designing a logical network topology on top of a pre-existing physical network topology, limit the number of network levels to one or two, or use rigid design styles.

Gerla and Kleinrock [GK77] classify the topological design of distributed computer networks into four general optimization problems, which are the link capacity assignment problem, the routing problem, the capacity and flow assignment problem and the topological design problem.

In the link capacity assignment problem, the objective function to be minimized is the communication cost, subject to the capacity constraint and the total average delay constraint. Given are a topology, a traffic requirement matrix and a routing policy. The variable to be determined is the link capacity.

In the routing problem, the objective function to be minimized is the average delay, subject to the link flow constraint and the capacity constraint. Given are a topology, a traffic requirement matrix and link capacities. The unknown variable is the traffic flow on each link.

In the capacity and flow assignment problem, the objective function to be minimized is the communication cost, subject to the link flow constraint, the capacity constraint and the total average delay constraint. Given are a topology, a traffic requirement matrix and a link cost per unit capacity. The unknown variables are the link capacity and traffic flow.

In the topological design problem, the objective function to be minimized is the communication cost, subject to the link flow constraint, the capacity constraint, the total average delay constraint and the k-connected reliability constraint. A traffic requirement matrix is given. The unknown variables are the set of links and their capacity. Our network design problem is similar to the fourth problem, the topological design problem. However, we extend their problem by simultaneously designing a hierarchical heterogeneous network infrastructure and mapping heterogeneous network technologies to each level of the network's infrastructure. Their problem is to determine a nonhierarchical topology design. Their solution approach is to come up with an abstract topology without considering any type of network technology that can implement such an abstract solution.

Saksena [Sak89] describes a heuristic algorithm to determine the number of trunks[2] for connecting a set of classified nodes in a two-level hierarchical mesh topology. Each node is classified either as a low or a high, where a high node forms a cluster of a set of low nodes. The objective function to be minimized is the total trunk network cost, subject to a delay constraint, a path[3] length constraint and the number of paths in a route[4] constraint. The variables to be determined are the set of links and their capacity. The author developed a heuristic algorithm that initially creates a network with all traffic routed on direct paths. In each iteration, the algorithm performs the following steps: identifying the utilized and underutilized trunks, eliminating the underutilized trunks, and re-constructing the network while satisfying all constraints. The algorithm keeps iterating until a certain cost is achieved. The paper presents a problem and an algorithm for a classical network

[2] A group of trunks comprises one link, where each trunk has a fixed bandwidth.
[3] A path is a set of one or more concatenated links connecting node pairs.
[4] A route is a set of one or more paths, not necessarily disjoint, between node pairs.

problem, which is to determine only a set of links. Our problem deals with more network levels and our tool specifies specific network hardware resources to connect all nodes.

Palmer and Kershenbaum [PK95] describe a methodology based on a genetic algorithm for finding a minimum-cost logical spanning tree network. Given are a complete graph, a traffic requirement matrix and a link cost per unit capacity. The authors focused on showing the effectiveness of genetic algorithm in minimizing the weighted sum of all the shortest paths between all pairs of nodes. The authors tried several encoding chromosomes to represent the spanning tree such as characteristic vector, predecessors, prüfer numbers and bias node/edge representation. This methodology assumes that the network consists of one level and this assumption does not reflect today networks.

A paper by a group of researchers from Hong Kong [KTC+97] describes a methodology based on a genetic algorithm for designing a mesh communication network topology, while minimizing the topology cost. The problem is given as a 10-node network with the traffic requirements among the 10 nodes, a cost structure proportional to the distance among nodes, and a maximum allowable packet delay. The authors used a binary string to represent the mesh network topology and an M/M/1 queue as their delay model. This paper provides a design technique for a specific problem, where their technique may not scale for a large problem with a multi-level network and a large number of nodes.

A paper by a group of researchers from Australia [BMM+] describes a methodology based on combining a genetic algorithm and linear programming (GA-LP) for finding a minimum-cost mesh network topology. Given are a node-to-node cost matrix, traffic requirement matrix, maximum link and node capacity matrix, and node minimum and maximum degree vectors. The authors used linear programming to determine the fitness function within the genetic algorithm and a binary string to represent the mesh topology. Their methodology cannot handle a large population, since linear programming consumes many CPU cycles. With a small population, the genetic algorithm cannot insure finding a good solution due to the small population and its lack of diversity.

The x-bone project is currently in progress at USC/Information Sciences Institute [TH]. x-bone is a software tool for a rapid, automated deployment and management of overlay networks. An overlay network is another name for a small scale virtual private network, where a pre-existing physical network topology is used to virtually configure and manage a number of overlay networks for restricted purposes. This project is not involved in any physical network design. Unlike x-bone, our proposed tool does not assume that a physical network topology is given. Therefore, our short-term objective is to design an application-specific intranet (three-level network infrastructure and data management system) and the long-term objective is to automatically manage the intranet's resources after they are synthesized.

Pierre and Legault [PL98] describe an optimization problem for the topological design of distributed networks. The inputs of the problem are node locations, node-to-node traffic demands, link capacity options with their cost, maximum average delay and degree of node connectivity. The objective function to be minimized is the link communication cost for a backbone k-connectivity network, subject to delay and reliability constraints. The cost of a link comprises two components: a permanent cost related to the capacity of the link and a variable cost related to the physical length of the link. The average delay is computed by summing all the links' delays, where a link delay is modeled as an M/M/1 queue. The reliability is measured in terms of k-connectivity. A network that remains functional despite one link or node breakdown is said to be 2-connected. The variables to be determined are the set of links and their capacity. This optimization problem is known to be NP-complete; therefore, the authors used a genetic algorithm to search for good backbone topologies. Their solutions are encoded in the form of chromosomes made up of a sequence of 1s and 0s that symbolize the existence or nonexistence of a link. The length of a chromosome depends on the number of nodes in the network. Thus, a network composed of N nodes is represented by chromosome of length $N(N-1)/2$. The initial population is generated by selecting a link whose Euclidean distance between nodes is the shortest, until all nodes have at least k incident links. For their computational experiments, they used the following parameter values: 1000 bits as an average packet size, 5 packets per second as a uniform traffic flow, 3 as a degree of connectivity, 80 chromosomes as a population size, 0.95 as a crossover probability, 0.12 as a mutation probability and 40 as a number of generations. According to their experiments, the genetic algorithm appears to work better on the average for networks of 15 nodes or more, and takes 40 seconds of CPU time to find a solution for a 25 node network, for example. This paper shows us a strong evidence that the topological design problem can be solved by a genetic algorithm, even through our problem deals with more network levels than just a backbone level. Table 3.1 summarizes all papers related to the abstract network solution approach.

Table 3.1: Summary of abstract approach papers.

Reference	Authors	Brief Description
[GK77]	M. Gerla and L. Kleinrock	The topological network design is classified into 4 general problems: link capacity assignment, routing assignment, capacity and flow assignment, and topology design; moreover, a survey of mathematical programming and heuristic approaches is presented.
[Sak89]	V. Saksena	A heuristic algorithm to determine the number of trunks for connecting a set of classified nodes in a two-level hierarchical mesh topology is described.
[PK95]	C. Plamer and A. Kershenbaum	A methodology based on a genetic algorithm for finding a minimum-cost logical spanning tree network within a given complete graph is described.
[KTC+97]	K. Ko, K. Tang, C. Chan, K. Man and S. Kwong	A methodology based on a genetic algorithm for designing a 10-node mesh network topology, while minimizing the topology cost, is described.
[BMM+]	L. Berry, B. Murtagh, G. McMahon, S. Sugden and L. Welling	A methodology based on combining a genetic algorithm and linear programming (GA-LP) for finding a minimum-cost mesh network topology is described.
[TH]	J. Touch and S. Hotz	A software tool, X-bone, is presented and its goal is to automatically deploy and manage overlay networks over pre-existing physical networks.
[PL98]	S. Pierre and G. Legault	An optimization problem for backbone topological network design is described and a genetic algorithm is used to search for good backbone topologies.

3.2.1.2 Concrete Network Solution Approach

We use the term *concrete solution* to convey that at least one type of network technology is used to synthesize a network topology. The following papers [GW90, EP93, CDSW95, FD95, ES96, DDH95, DFlH+97, MMR98] describe several non-abstract approaches to synthesize a computer network. In contrast to our problem and approach, the techniques described in these papers are either limited to designing a logical network topology on top of a pre-existing physical network topology, use one specific network technology, limit the number of network levels to one or two, or use rigid design styles.

A paper by researchers from GTE Laboratories [GW90] presents a network design model based on a mixed integer-linear programming (MILP) formulation that combines the topological design problem and facility selection problem. The facility selection problem is to determine the type of network technology for each link in the topology. Each facility type (fiber-optic, T1 carrier, copper, microwave, etc.) is represented by a different link cost function. Their goal is to design a mesh network topology that minimizes the total network cost while selecting facility types, allocating capacity and routing traffic to accommodate demand and performance requirements. The researchers focused on a flat network (one level) and their MILP formulation is only valid for a small network design problem.

Ersoy and Panwar [EP93] describe a methodology for designing logical spanning tree topologies to interconnect LAN/MAN networks, while minimizing the average network delay. The givens are a topology, a traffic requirement matrix, a LAN capacity and a bridge capacity. The overall LAN/MAN topology is decomposed by the researchers into a set of clusters and a backbone MAN in order to reduce the problem complexity. A cluster contains a number of distinct LANs; moreover, all the LANs are pre-connected in a physical topology. The topology is modeled as a graph, where a node represents a LAN and an edge represents a bridge connecting two LANs. The MAN's backbone is modeled as a central node and each cluster is connected to the central node by one LAN/MAN bridge. The design methodology, which is based on simulated annealing, has two phases. The first phase finds a minimum-delay logical spanning tree topology for each cluster and then calculates the *cluster access delay* for the found logical spanning tree topology. The cluster access delay is the maximum delay between any LAN in the cluster and the MAN in either direction; moreover, the delay model is based on an M/M/1 queue with batch Poisson arrivals. If the cluster access delay exceeds the given threshold delay, the second phase proceeds by splitting that cluster into two subtrees, allowing each subtree to have a LAN/MAN bridge and repeating the first phase. Otherwise, the methodology proceeds to the next cluster. In contrast, we design each LAN and we don't limit the type of network technology to Ethernet with bridge as in the paper by Ersoy. Also, we use a non-geometric search (genetic algorithm) for selecting solutions. This will avoid most of the local minima that may be selected by a geometric search (simulated annealing).

A paper by a group of researchers from Bellcore [CDSW95] presents a SONET Toolkit, which is decision support software to design robust fiber-optic backbone networks that protect services against the consequences of a cable cut (link) or an equipment failure (node). The SONET toolkit takes the following inputs: the physical network topology, its capacity, the available equipment, the customer demands and the protection requirements for the services. It produces SONET self-healing rings on the physical network topology. The SONET Toolkit is based on a divide-and-conquer approach, where an experienced network planner decomposes the mapping of the customer's demands on the physical network into a sequence of subproblems, such as checking the feasibility of the demands, assigning the demands as possible to the pre-existing capacities, determining the overall ring and self-healing ring, determining the cost and generating reports. The Toolkit is only available to Bellcore client companies. In contrast to our proposed tool, we synthesize a three-level physical network topology and use more than one network technology.

Fahmy and Dougligeris [FD95] present END[5], which is a rule-based expert system combined with a commercial network simulation tool, OPNET, to configure and simulate computer networks. This tool, END, interacts with the user by asking several questions about the network to be built, such as the number of network sites, type of interconnectivity between the sites, the number of buildings in each site, the number of floors in each building, type of applications, and the number of workstations and servers in each LAN. The traffic demand is not required as an input by END, since it can establish the traffic pattern from the type of application for which the network will be used. The rule-based expert system has two limitations: The first limitation is that the design can be biased toward a specific network technology, since the design rules may reflect the personal opinions of the network designers. The second limitation is the heuristic design rules, which need revision from time to time.

Elbaum and Sidi [ES96] describe a methodology based on a genetic algorithm for finding a minimum-average-delay topological design of a local area network (LAN). The problem assumes that a local area network is partitioned into a number of segments (clusters), and the upper bound on the number of segments is given by the network designer. The unknown variables are the number of LAN segments, the allocation of the users to the segments and the interconnection among the segments as a spanning tree. The authors estimate the average delay by summing the delays of all segments and bridges; furthermore, they modeled the average delay based on an M/M/1 queue. The authors used a Huffman tree structure to represent the entire LAN chromosome. In contrast to our problem, the paper is limited to the design of one LAN and one type of network technology (Ethernet with bridges).

Two papers by group of researchers from AT&T [DDH95, DFlH+97] present an Integrated Network Design Tool (INDT). The goal of the INDT is to design integrated multimedia networks on a variety of network platforms. The network

[5]END stands for Expert Network Designer.

platforms considered are mesh networks, interconnected SONET ring networks and hybrid mesh/ring networks. The first paper [DDH95] describes a network design algorithm that searches for an optimized network cost for a two-level mesh topology. The inputs to the algorithm are node locations, node-to-node traffic demands, and cost structure for links as well as nodes. The network design algorithm consists of four steps. In the first step, the algorithm begins by selecting an initial set of nodes, serving nodes (SNs), that will comprise the backbone network. The selection is based on the high traffic demands as well as span of the geographical locations between all nodes. In the second step, the algorithm assigns the rest of the nodes, access nodes (ANs), to the serving nodes. Each AN is assigned to only one SN. After it assigns all ANs, the network is divided into a set of local networks AN-SNs and one backbone network SN-SN. In the third step, the algorithm selects a set of links and their capacity to meet the backbone network traffic demand. Also, it optimizes the number of backbone links by deleting the underutilized ones and rerouting the traffic carried on them on the remaining links. Therefore, the objective of the first three steps is to come up with a good initial design. In the fourth step, a simulated annealing algorithm is used to improve the selection of SNs and repeat the entire process, until the *best* selection of SNs is achieved. The capability of INDT is extended to SONET ring network design [DFlH+97], where a ring design algorithm is developed to determine an optimal flow through a network of rings while satisfying a capacity constraint. In this extension, the researchers have divided the SONET ring design problem into many subproblems and developed innovative heuristic algorithms for each problem. As described in these two papers, the INDT consists of a suite of programs, where each program is intended for the design of a specific network infrastructure based on the AT&T network technology. Also, the INDT is focused on a large-scale backbone network, where our tool is focused on a hierarchical heterogeneous application-specific intranet.

A paper by a group of researchers from Bell Labs [MMR98] presents a VPN DESIGNER, which is a software tool for the design of virtual private networks on a service provider's infrastructure. This tool is intended to be used by internet service providers (ISP) to allocate and manage virtual private connections to outsourcing enterprises. The VPN design problem is modeled as a nonlinear optimization problem to maximize the weighted aggregate measure of carried bandwidth over the provider's infrastructure, subject to the optimal allocating and routing of all customers' traffic. The VPN DESIGNER employs an iterative algorithm, where each iteration requires a reallocation of each link's bandwidth to VPN. This reallocation is based on a linearization of the total network bandwidth and the linearized capacity costs. After each reallocation, the optimal routing problem is solved for each of the newly resized VPNs. This tool maps customers' demand on a given network, where there is no physical network design involved. Also, their tool is concentrated on a backbone logical network design, where our tool is focused on designing local and backbone physical networks. Table 3.2 summarizes all papers related to the concrete network solution approach.

Table 3.2: Summary of concrete approach papers.

Reference	Authors	Brief Description
[GW90]	A. Gresht and R. Weihmayer	A network design model based on a MILP formulation is presented. The model combines the topological design problem and facility selection (fiber-optic, T1 carrier, copper, microwave) problem.
[EP93]	C. Ersoy and S. Panwar	A methodology for designing logical spanning tree topologies to interconnect LAN/MAN networks, while minimizing the average network delay, is described. A simulated annealing is used to search the design space.
[CDSW95]	S. Cosares, D. Deutsch, I Saniee, and O Wasem	The paper presents a SONET Toolkit, which is decision support software to design robust fiber-optic backbone networks that protect services against the consequences of a cable cut (link) or an equipment failure (node).
[FD95]	H. Fahmy and C. Douligeris	A rule-based expert system, END, is combined with a commercial network simulation tool, OPNET, to configure and simulate computer networks.
[ES96]	R. Elbaum and M. Sidi	A methodology based on a genetic algorithm for finding a minimum average delay topological design of an Ethernet LAN is described.
[DDH95]	B. Doshi, S. Dravida and P. Harshavardhana	An Integrated Network Design Tool (INDT) contains a network design algorithm searching for an optimized network cost for a two-level mesh topology.
[DFlH+97]	B. Doshi, C. Funka-Lea, P. Harshavardhana, J. Gong, R. Nagarajan, S	The capability of INDT is extended to SONET ring network design, where a ring design algorithm is developed to determine an optimal flow through a network of rings while satisfying a capacity constraint.
[MMR98]	D. Mitra, J. Morrison and K. Ramakrishnan	A software tool, VPN DESIGNER, is used for the design of virtual private networks on an internet service provider's (ISP) infrastructure. This tool is intended to be used by ISP to allocate and manage virtual private connections to outsourcing enterprises.

3.2.2 Teleprocessing Network Synthesis

We have found in the literature a problem similar to our problem, which combines network design with data management. The problem, teleprocessing network synthesis, is to find an optimal topological network design for a set of clients' locations, traffic magnitudes between these clients and a single common service center. In other words, the synthesis of a teleprocessing network problem assumes that the number of the service centers is given as one, where in our problem the number of service centers is a decision variable. Also, we can synthesize two types of data management systems depending on the application requirements: centralized server with proxies or distributed servers. We cite the following papers [EW66, RG71, TWB78, KB83], which show us some ideas on how to design a network with classified nodes, such as clients and servers.

The earliest work on designing a teleprocessing network was performed by Esau and Williams [EW66], where they proposed an iterative method to connect low-speed terminals at great distances from the computing center. The method starts by connecting all terminals to the computing center in a point-to-point network, then it tries to reduce the direct unshared links from the computing center to some terminals by creating multipoint linkages between some terminals. Thus, it transforms a star topology into a tree. Their iterative method is limited by the network technology selection and it does not consider a distributed network with multiple service centers, where we consider all of that in our problem.

Rothfarb and Goldstein [RG71] consider a network synthesis problem with a nonlinear cost function that is neither concave nor convex, but piecewise linear. They solve a network problem that arises in the context of leasing long-distance telephone facilities from common carriers, where the lessee has certain voice and data communication needs. This problem is known as the TELPAK problem and its design is limited to an unconstrained logical circuit switch channel topology. This method does not consider the design of the physical network topology.

Tang, Woo and Bahl [TWB78] describe a method for finding an optimal number of concentrators within a teleprocessing network. The paper is concerned with finding the optimal number and locations of the concentrators and the optimal assignment of terminals to a given set of concentrators. The authors developed a heuristic matching algorithm to connect terminals to concentrators, while minimizing the installing cost of concentrators and the communication link cost between terminals and the installed concentrators. However, the authors did not consider data traffic requirements and link capacity when they developed their algorithm. The network hardware option is limited to concentrators only, where in our tool we consider many options, such as bridges and routers.

Designing a centralized teleprocessing network as a minimum spanning tree was performed by Kershenbaum and Boorstyn [KB83]. Their approach is based on branch and bound techniques where they develop two algorithms. The first one is based on generating subproblems by restricting nodes and the second one is based on generating subproblems by restricting arcs. This paper concentrates on finding a spanning tree topology for a classical network synthesis problem.

3.2.3 Combined File Allocation and Network Synthesis

The file allocation problem (FAP) was introduced by Chu [Chu69] in 1969. The problem is given a number of computers that process common files and allocate the files to the computers so that the allocation yields minimum storage and transmission costs, subject to constraints. Constraints are the following: the expected time to access each file is less than a given bound and the amount of storage needed at each computer does not exceed the available storage capacity. The idea of combining the file allocation problem with network synthesis problem is not done, except for some early research efforts by Professor Keki Irani and his students Whitney and Khabbaz from the University of Michigan [Whi70, IK82]. They focused on combining the network synthesis problem with the file allocation problem. The thesis of

Whitney [Whi70] addresses two problems: determine the number and locations of file sites and determine a number of links and their capacity to construct a spanning tree. Then, Khabbaz [IK82] expanded on Whitney's work and he did not restrict himself to a tree network topology. He used maximally connected network topologies with minimum diameter, which is a special case of an unconstrained topology with limit on the path length. Our problem is different from the above works because we identify the type of the file storage locations (server or proxy) and determine the amount of their storage space. Also, our network design is not constrained to a specific network technology. This reflects a realistic computer network that uses off-the-shelf components, where a network can contain a combination of technologies. Their techniques may not work for today network design process, because today a network design problem is more complex and it has many possible infrastructures and network technology options.

3.3 Design Automation Tools

The design automation tools relevant to this work consist of techniques and software tools to automatically design and analyze better computational structures faster, cheaper and more reliably than human designers. We are interested in tools for network architecture and data management system design and analysis.[6] However, most of the research and commercial network tools are focused on network analysis because automatic network and data management synthesis is a complex problem due to the large design space, and the inflexibility of design techniques.

The design automation field has several levels, where a problem can be tackled. Table 3.3 compares all levels based on components involved in each level. Our application-specific intranet hardware infrastructure problem lies in the distributed-level of the design automation hierarchy. At this level, we are dealing with the

[6]The network and data management design and analysis tools can also be called capacity planning tools.

data management and network for possibly a set of geographically distributed sites. Research on synthesis methodologies for the distributed level was not reached a mature state.

Table 3.3: The design automation hierarchy.

Abstraction	*Library Element*		
	Process	*Storage*	*Input/Output*
Distributed	client, server, bridge, router	file, disk, proxy	Ethernet, ATM, FDDI, leased lines
System	CPU, MMU, MPEG, software module	RAM, ROM, disk	bus, point-to-point, mesh
High	adder, multiplier, ALU	register	bus, mux
Logic	AND, OR, NOT	flip-flop, latch	wire
Physical	transistors	capacitance	metal, ploy

3.3.1 Synthesis Tools for the System Level

From a system-level synthesis point of view, there have been several published papers in the past several years and we cite the following two papers [PP92, TGP96] as examples. These papers presents three synthesis tools for a multiprocessor/computer system, where the goal is to synthesize a multiprocessor/computer hardware system to perform a number of tasks, while minimizing the system cost. The system is specified in terms of a number of processors and the interconnections between them. The interconnection can be in the form of a point-to-point or a bus connection. None of these synthesis tools deal with designing network architecture or data management system.

The first tool by Prakash and Parker [PP92] describes SOS[7], which is a synthesis tool for application-specific heterogeneous deterministic multiprocessor systems. Given are a task flow graph, a processor library and some cost and performance constraints. The task flow graph represents the problem executed by the multiprocessor. The library consists of general and special-purpose processors. The authors developed a formal model of multiprocessor synthesis using mixed integer linear programming (MILP). By solving the MILP formulation, SOS synthesizes non-inferior designs, which satisfy the timing and sequencing constraints defined on the task flow graph, while minimizing the system cost. The synthesis results of SOS include selecting the number and types of processors which best handle the given tasks, and synthesizing a multiprocessor architecture by determining the interconnection style. SOS schedules tasks in the task flow graph on the selected processors as well as the data transfer activities among processors. Also, SOS computes the amount of local memory, which is used as a storage for the code and temporary computation result for each processor in the synthesized multiprocessor system.

The second tool by Tirat-Gefen and Parker [TGP96, TGSP97] describes an extension to SOS which is called MEGA to synthesize heterogeneous multiprocessor systems with task-level pipelining. A genetic programming paradigm was used in MEGA to search for good solutions. The authors considered two other computing models in addition to the traditional deterministic computing model: a probabilistic and an imprecise model. In the probabilistic model, the execution time of a task on a given processor is treated as a random variable rather than a constant. In the imprecise model, the execution time of a task is divided into two parts: a mandatory part and an optional part.

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[7]SOS stands for Synthesis Of Systems.

3.3.2 Evolutionary Computations as Optimization Techniques

Evolutionary computations, based on genetic algorithms, are becoming important techniques for solving many hard optimization problems, such as optimization of functions with linear and nonlinear constraints, the traveling salesman problem, and problems of scheduling, partitioning, and control [Mic94]. The concept of genetic algorithms is based on the natural evolution of Darwin (survival of the fittest) [For93]. Professor John Holland at the University of Michigan first proposed genetic algorithms as heuristic search techniques in the early 1970s [SP94]. Theoretical foundations of genetic algorithms have been developed as shown by the following papers [BD93, BV93, AC93, Fog94, Rud94].

Genetic algorithms emulate a design process that is suited for the intranet integration problem by alternating between design and optimization processes. This is how a data management system and network architecture are designed in reality. For example, a designer places one server in a certain location and if it yields a good client-server performance, then there is no need to relocate the server. Otherwise, the designer either places a new server in a different location or relocates the old server to improve the client-server performance. As another example, a designer selects one type of a network hub in an *ad hoc* manner. If the selection yields a good network design, then there is no need to modify the network hub. Otherwise, the designer selects another choice, until a good design is produced. Use of genetic algorithms in network synthesis has already begun with promising results [PK95, KTC+97, ES96, BMM+, PL98].

3.4 Multimedia Systems

Development of multimedia systems has attracted a great deal of academic and commercial interest in past few years. Most of the published papers focus on a specific area of multimedia systems, such as server and client characteristics [BC95, CBC95], memory management for multimedia applications [DSST95, RV91, Pan97], network protocol with resource reservation [DSST95, MCKA95, ZDE+93], multimedia file systems [RV91], operating systems for multimedia environments [RVG+95], multimedia synchronization [LG90, All83], data compression [Fox91] and data caching [Koz97, KWW97, OCAV97, HRP97, HPRdSJ97].

3.4.1 Data Caching

The problem most relevant to this research is data caching, which is related to the server/proxy placement problem and the file allocation problem, where data (file) is needed to be stored closer to the users so that the network services are reduced/eliminated. The placement problem is to determine the number, type locations, process and storage requirements of all needed servers/proxies, as well as the type of binding between the placed proxies and the pre-existing servers. The recent work by Kozuck [KWW97, Koz97] presents a distributed algorithm for determining locations in a tree-network topology where cached copies of video documents should be placed. The authors modified the file allocation problem into a branch library allocation problem. The branch library is a special proxy that only maintains copies of documents from a single server (one-to-one binding), where a regular proxy maintains copies from several servers (one-to-many binding) which is a harder problem to solve for. In our problem, we are dealing with a regular proxy that can bind with several servers. This way a proxy can forward a request to a number of servers for faster reply. One-to-many binding generates more traffic on the network than one-to-one binding.

A soft caching management technique for image files over a slow link is described in [OCAV97], where a proxy maintains low resolution image files that can be delivered to users faster. If the users want to render the high resolution image file, then the proxy retrieves the rest of the file from the server. A soft cache assumes that the data management structure (server, proxy and their storage space) is already pre-placed. In our problem, we synthesize the data management system by determining the number, locations, and storage space of the file servers/proxies.

We considered the problem of caching multimedia web documents to clients in *real time* while placing the least demands on network resources such as network bandwidth and intermediate storage [HRP97]. We proposed two hierarchical models to specify the multimedia web document presentation requirements. In the first model, an object flow can be modeled as an *object flow graph* (OFG). A node represents an object type and an edge represents a data flow. Each node is associated with four different operations: *fetch* performs the retrieving of the requested object within the server storage hierarchies, *transmit* performs the transmission of the requested object from a server to client(s) via a network, *process* performs any pre-rendering services on the object such as decoding, and *render* performs the display of the object. All these operations must be done in sequence with respect to each node in OFG. These operations may be performed at different locations. In the second more detailed model, an *extended object flow graph* (EOFG) contains the four operations embedded within each node in the OFG. The goal of an is to illustrate the dependencies associated with the object flow and the operations.

We expanded on [HRP97] by developing a multimedia object scheduler that can schedule multimedia system resources for optimal or near optimal performance. The scheduler takes the execution time of each operation and the presentation time constraints as inputs. It produces a timing diagram as an output, illustrating the time of each operation occurrence. We modeled the synchronization of multimedia objects into two levels of abstraction. At the higher level (OFG), media objects are related according to their client timing requirements. At the lower level (EOFG), the operations can be modeled as a system of difference constraints, which is a special case of linear programming. Our scheduler used the Bellman-Ford algorithm, *single-source shortest-path*, to find a solution for the system of difference constraints [HPRdSJ97].

Chapter 4

The Design Problem Model

4.1 Background

The intranet integration design problem consists of the underlying three-level network architecture design problem and data management system design problem. The two design problems are not independent and good solutions are not guaranteed when these two problems are solved separately. The design decisions of the three-level network design problem involve the numbers, types, locations and capacities of network resources for each level. The design decisions of the data management system design problem involve the numbers, locations, processing capacities and storage capacities of file servers, and the storage allocation for files.

To achieve good solutions for these problems, we have formulated them as one combined optimization problem. We have used informal mixed integer non-linear programming notation to represent the intranet integration problem. This model gives us a clear picture and easy way to verify or change some aspects of the problem. This model also gives us a precise and comprehensive set of design rules that *i*-CAD must check when performing mutation and crossover. These rules have informally been incorporated into the *i*-CAD code. However, we are not using any mathematical programming techniques to search for the optimal solutions due to the complexity and the large design space of the problem. Instead, we are using a genetic algorithm to search for good solutions.

The research methodology we followed was to create the network design model and network design software first. Solving this simplified model allowed us to test our network design strategy independently of our data management design strategy. We followed a similar methodology for data management, testing the data management model and software independently. Then, the software was combined, and a comprehensive solution for data management and network design produced for several examples. The model description here is decomposed into two sets of constraints and two objective functions, one for data management, as shown in Figure 4.1, and one for network, as shown in Figure 4.2. This decomposition mirrors our methodology. In order to further simplify presentation of the model, design constraints are presented in this chapter, while performance constraints are presented later, in Chapter 5.

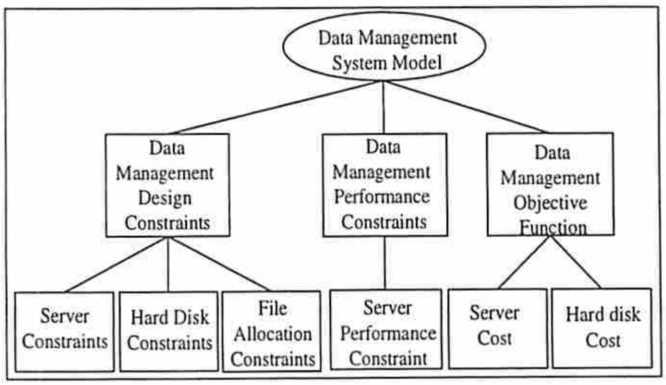


Figure 4.1: An overview of the data management model.

The rest of this chapter is organized into five sections. Section 4.2 describes the formulation of the three-level network design constraints. Section 4.3 describes the network design objective function. Section 4.4 describes the formulation of the data

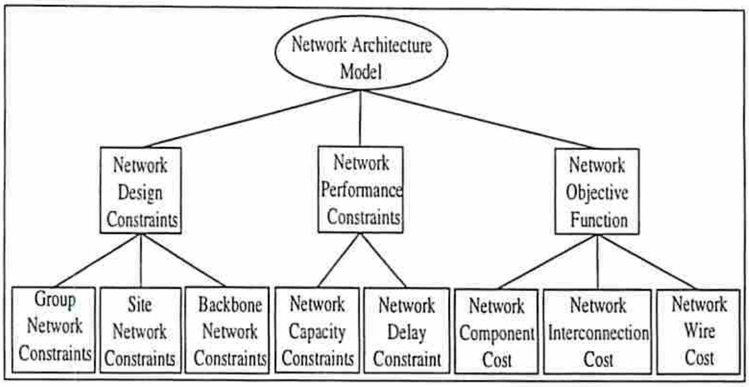


Figure 4.2: An overview of the network model.

management system design constraints. Section 4.5 describes data management system design objective function. Section 4.6 describes the overall intranet integration objective function.

4.2 Network Design Constraints

The network design constraints consist of three sets: group network constraints, site network constraints and backbone network constraints. Our goals for the group, site and backbone design constraints are to guide *i*-CAD to synthesize a correct and complete three-level network architecture, provide a model for simultaneous synthesis of all network levels, and form a model for the network synthesis problem. This model can then be scaled or adapted with respect to a given problem or the future availability of new network technology. To describe the constraints and objective function mathematically, we need to define the input parameters, the design parameters, and the binary variables that are related to the network design problem. The main *input parameter*, a client location table, is input by the network planners to *i*-CAD to specify in detail the physical locations of all clients and their allocation with respect to group tasks and site tasks. Other input parameters related to performance (client traffic matrix, data request table, threshold network delay, and threshold data management performance) are not included in this model since they don't relate to structure.

- The *client location table* (CLT) is a $D \times 5$ matrix, where D indicates the total number of client tasks. Each row indicates a client task's (workstation) physical location information. The first column (CT) represents all the client tasks in the intranet's application, ranging from 1 to D. The second, third and fourth columns indicate the client's fixed location in X, Y, Z space, which represents the physical width, height and depth of a building respectively. The coordinates are measured in feet (or meters). The fourth and fifth columns indicate the allocation of a client task (CT) within a group task (GT) and a site task (ST) respectively. A client task is located within one group task; moreover, a group task is located within one site task. Table 4.1 shows an example of a client location table.

Table 4.1: A client location table (CLT).

CT	*X*	*Y*	*Z*	*GT*	*ST*
1	10	20	1	2	1
2	8	45	15	1	2
3	30	5	30	6	1
.	.	.	.	.	.
.	.	.	.	.	.
D	40	10	1	4	10

The *Design parameters* represent the outputs of *i*-CAD: the numbers, types, locations, and capacities of network hardware resources, such as switches, multiaccess devices, routers, bridges, leased lines, SONET and virtual private connections.

The *Binary variables* are 0-1 variables that represent the implementation decisions regarding the network design problem (use = 1, don't use = 0). There are three types of binary variables defined:

- *Allocation variables*: The variables of this type specify the network hardware resources that are being included in the intranet infrastructure. The list of all network allocation variables includes the following (definitions and use of these variables are explained in later sections in this chapter):

  1. group network-connector Υ_o,
  2. site network-connector Ψ_u,
  3. site router $\mathcal{X}_t$,
  4. site-group bridge Φ_r,
  5. backbone network-connector Γ_z,
  6. backbone router Δ_y,
  7. backbone leased line $\mathcal{L}_h$,
  8. backbone optical line $\mathcal{O}_k$,
  9. backbone virtual private line $\mathcal{V}_q$, and
  10. backbone-site bridge Λ_w.

- *Binding variables*: The variables of this type assign the allocated network hardware resources to the application's tasks. These variables are used mostly to bind a network connector to a group, site, or backbone, for example. The list of all network binding variables includes the following (definitions and use of these variables are explained in later sections in this chapter):

  1. client task (workstation) to group task $\kappa_{d,e}$,
  2. group task to site task $G_{e,f}$,
  3. site task to backbone task $\upsilon_{f,BT}$,
  4. group network-connector to group task $\phi_{o,e}$,
  5. site network-connector to site task $\sigma_{u,f}$,

6. site router to site task $\tau_{t,f}$,
7. backbone network-connector to backbone task $\gamma_{z,BT}$,
8. backbone router to backbone task $\omega_{y,BT}$,
9. backbone leased line to backbone tree's link $\epsilon_{h,i}$,
10. backbone optical line to backbone tree's link $\alpha_{k,i}$, and
11. backbone virtual private line to backbone tree's link $\delta_{q,i}$.

- *Connection variables*: The variables of this type indicate a physical connection between the hardware resources. These variables are used to show a connection between a workstation and a network connector's port, for example. The list of all network connection variables includes the following (definitions and use of these variables are explained in later sections in this chapter):

  1. device (workstation, server) to group network $\varphi_{dt,di,gnt,gnpi}$,
  2. group network to site network $\nu_{gnt,gnpi,snt,snpi}$,
  3. bridge interface between group network and site network $\iota_{r,gnt,gnpi,snt,snpi}$,
  4. site network to backbone local network $\pi_{snt,snpi,bnt,bnpi}$,
  5. site network to backbone wide network $\rho_{snt,snpi,blt,bli}$, and
  6. bridge interface between site network and backbone network $\eta_{w,snt,snpi,bnt,bnpi}$.

In this model, we separate the problem of allocating and binding of network hardware resources into two smaller problems only for the initial design generation so that the problem becomes more understandable. Also, this decomposition could facilitate a separate solution to the allocation and binding problems, allowing them to be solved at separate stages in the design process. It allows the *i*-CAD software to explore many different possible bindings without changing the resources allocated.

4.2.1 Group Network Constraints

The group network constraints insure that all the client tasks (workstations) within a group task can communicate with each other efficiently so that they can carry out the group task. Each client task is bound to one workstation and vice versa. The design decision here is to select one network component, which can be either a switch or multiaccess device. A switch protocol is based on a virtual circuit setup, where a multiaccess device protocol is based on either randomly sharing a single media (such as Ethernet) or perfectedly scheduled access (such as Token Ring). The selected group network connector must handle all group task's design and performance requirements.

The reason we limit each group task to one switch or multiaccess device is to reduce the infrastructure cost and simplify the problem. Client tasks with significantly different communication requirements should be placed in different groups ideally. In our future research, we will select multiple group network connectors to connect all the workstations within a group task. Next, we describe three group network constraints:

1. group-network-connector (GNC_o) selection constraint: only one group network connector GNC_o can be allocated and bound to a group task GT_e, as shown in Figure 4.3. Thus, for each group task GT_e, the following must be satisfied:

$$\sum_{\forall GNC_o} \Upsilon_o \times \phi_{o,e} = 1, \text{ For each } GT_e \tag{4.1}$$

   Constraint 4.1 insures that only one group network connector GNC_o is allocated (Υ_o) and bound ($\phi_{o,e}$) to a group task GT_e. GNC_o is a design parameter and the index o indicates the group network connector number. GT_e is a group task, which is an input parameter, and the index e indicates the group task number. Υ_o is an allocation variable; $\Upsilon_o = 1$ indicates that a group network connector GNC_o is being included in the synthesized intranet infrastructure.

$\phi_{o,e}$ is a binding variable; $\phi_{o,e} = 1$ indicates that an allocated group network connector GNC_o is bound to a group task GT_e.

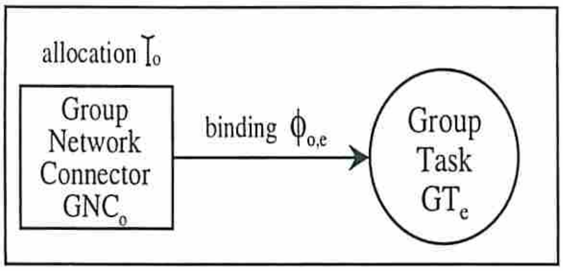


Figure 4.3: Group network allocation and binding variables.

2. group-network-connector-port constraint: a group network connector GNC_o must not connect more workstations W_d than its maximum number of available ports NP_{GNC_o}. Thus, for each allocated group network connector GNC_o, the following must be satisfied:

$$\sum_{W_d \in GT_e} \kappa_{d,e} \leq (NP_{GNC_o} - \mathcal{G}) \tag{4.2}$$

Constraint 4.2 insures that the total number of all workstations W_d (client tasks) within a group task GT_e must not exceed the maximum number of ports of its allocated and bound group network connector GNC_o. $\kappa_{d,e}$ is a binding variable; $\kappa_{d,e} = 1$ indicates that a workstation W_d is located in (bound to) group task GT_e. NP_{GNC_o} is an integer value that refers to the maximum number of available ports within the group network connector GNC_o. This value is given in the network connector design library. $\mathcal{G}$ is an integer variable which is subtracted from the right-hand-side of 4.2 and indicates one or more ports may be dedicated to a site network and server. $\mathcal{G}$ is defined by another constraint given later.

3. workstation to group-network connection constraint: a workstation W_d must be connected to a group network connector GNC_o, where W_d and GNC_o are bound to the same group task GT_e. Thus, for each workstation W_d within GT_e, the following must be satisfied:

$$\sum_{\forall gnpi \in gnt} \varphi_{dt,di,gnt,gnpi} = 1 \text{ For dt } = W_d \in GT_e \text{ and } di = d \qquad (4.3)$$

Constraint 4.3 insures that a workstation is connected to one and only one port of the allocated and bound group network connector. $\varphi_{dt,di,gnt,gnpi}$ is a connection variable. *dt* is the device type (workstation, server), *di* is the device identification (in the case of a workstation, *di* has a range of values between 1 to D, where D refers to the total number of workstations within the intranet)[1], *gnt* is the group network type (Ethernet, ATM), and *gnpi* is the group network port identification (1 to NP_{GNC_o}). NP_{GNC_o} represents the maximum number of available ports within a group network connector GNC_o.

4.2.2 Site Network Constraints

The site network constraints insure that all the group tasks within a site can communicate among themselves efficiently so that they can carry out the site task. The design decision here is to select one network component, which can be either a switch, multiaccess device, or router. The constraints are provided to resolve the inter-group routing problem, since a site network is a complex problem because each site interfaces between a set of group LANs and the backbone. The complexity is due to the heterogeneity of the network technologies used within each group, where each technology might use a different communication protocol. A group network connector can be either a switch or multiaccess device. On the other hand, a site

[1]In the case of a server, the range of *di* is given in Section 4.4, Data Management Design Constraints.

can contain either a router, switch or multiaccess device. A router is used to connect two or more network connectors that may or may not be similar. A router employs the Internet Protocol (IP) to move the packets through the network. Based on the selected site and group network components, the intranet integration cost may incur an interconnection cost. This cost reflects the installing of a protocol translator so that both site and group network components can communicate with each other.

The reason we limit each site task to either one switch, one multiaccess device or one router is to reduce the cost and simplify the problem. In our future research, we will select multiple routers or site network connectors to connect all the group tasks within a site task. The next four constraints are formulated to insure a correct heterogeneous network design between a site and its groups.

1. site network selection constraint: only one site router SR_t or one site network connector SNC_u can be allocated and bound to a site task ST_f, as shown in Figure 4.4. Thus, for each site task ST_f, the following must be satisfied:

$$\sum_{\forall SNC_u} (\Psi_u \times \sigma_{u,f}) + (1 - \Psi_u) \sum_{\forall SR_t} (\mathcal{X}_t \times \tau_{t,f}) = 1 \tag{4.4}$$

Constraint 4.4 limits the allocation and binding of either one site network connector or one site router per site task. This forces a star topology on a site network, where the centralized hub represents a site network connector (site router); moreover, the nodes represent all group network connectors and backbone network connections. ST_f is a site task, which is an input parameter, and the index f indicates the site task number. SNC_u is a site network connector, which is a design parameter, and the index u indicates the site network connector number. Ψ_u is an allocation variable; $\Psi_u = 1$ indicates that a site network connector SNC_u is being included in the synthesized intranet infrastructure. $\sigma_{u,f}$ is a binding variable; $\sigma_{u,f} = 1$ indicates that an allocated site network connector SNC_u is bound to a site task ST_f. The type selection constraint of a site network connector will be determined as part of our future work. SR_t is a site router, which is a design parameter, and the index t indicates the site router number. $\mathcal{X}_t$ is an allocation variable; $\mathcal{X}_t = 1$ indicates that a site router SR_t is being included in the synthesized intranet infrastructure. $\tau_{t,f}$ is a binding variable; $\tau_{t,f} = 1$ indicates that an allocated site router SR_t is bound to a site task ST_f.

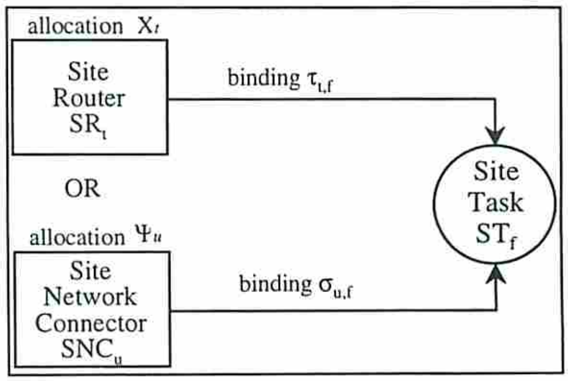


Figure 4.4: Site network allocation and binding variables. Only one allocation and binding will be selected per site task.

2. site port constraint: a site router SR_t or a site network connector SNC_u must not connect more group network connectors than its maximum number of available ports NP_{SR_t/SNC_u}. Thus, for each site router SR_t, the following must be satisfied:

$$\sum_{\forall GT_e \in ST_f} G_{e,f} \leq (NP_{SR_t} - S) \tag{4.5}$$

Constraint 4.5 insures that the total number of all group tasks within a site task ST_f must not exceed the maximum number of ports of its allocated and bound site router SR_t. $G_{e,f}$ is a binding variable; $G_{e,f} = 1$ indicates that a group

4. site-bridge constraint: if both the group and site network connectors are based on multiaccess network technology, then a site bridge (SB_r) must be installed between them. A bridge performs the moving and routing of addressed packets from a group network connector to a site network connector and vice versa, when both site and group networks use an identical transmission medium and access control. A bridge operates at the data-link layer of the Open System Interconnection (OSI) model. The constraint below insures that a bridge is used as an interface between a group network connector and a site network connector, in the case when both the group and site networks are based on multiaccess network technology (such as an Ethernet).

$$\sum_{\forall SB_r} \sum_{\forall gnpi \in gnt} \sum_{\forall snpi \in snt} (\Phi_r \times \iota_{r,gnt,gnpi,snt,snpi}) = 1 \qquad (4.7)$$

Constraint 4.7 insures that an allocated and bound group network connector GNC_o and an allocated and bound site network connector SNC_u are connected by an allocated (Φ_r) site bridge SB_r. Φ_r is an allocation variable; $\Phi_r = 1$ indicates that a site bridge SB_r is being included in the synthesized intranet infrastructure. The index r represents the bridge identification. $\iota_{r,gnt,gnpi,snt,snpi}$ is a connection variable. *gnt* is the group network type (Ethernet), *gnpi* is the group network port identification (1-NP_{GNC_o}), *snt* is the site network type (Ethernet), and *snpi* is the site network port identification (1-NP_{SNC_u}).

4.2.3 Backbone Network Constraints

The backbone network constraints insure that all the site tasks within the backbone can communicate among themselves efficiently so that they can carry out the enterprise's application. The design decision here is to determine the type of backbone topology and to select a network technology. The physical dimension of an enterprise's backbone network is a factor in selecting a network technology to connect all the sites, since all sites may be located either across a campus, city, state or country. The constraints are provided to determine the backbone topology, select the network technology, and resolve the inter-site routing problem, which is very similar to the inter-group routing problem within a site.

The backbone topology can be either a local star topology or a wide tree topology. A local star topology is selected when the physical locations of all site tasks are located very close to each other, for example when all site tasks are located within a university campus. On the other hand, a wide tree topology is selected when the physical locations of all site tasks are located across a city, state or country. The network technology options that are considered for a backbone network design are: private leased lines (T-carrier systems), optical leased lines (SONET), virtual private connections (internet service provider (ISP) connections), IP routers, and network connectors (switch or multiaccess device). Each technology offers different characteristics such as protocol, installation cost, monthly cost and capacity. The first three options: T-carrier systems, SONET and VPC connections are used when the sites are geographically located across a city, state or country. In this case, the backbone network is configured as a wide tree topology. The reason we select a tree topology is to reduce the backbone network cost, since a tree uses a minimum number of links to connect all its nodes. When one of the last two options (IP routers and network connector) is selected, the backbone is configured as a local star topology. The reason we select a star topology is to reduce the cost and simplify the problem by selecting either one router or one network connector to connect all the sites. In the future other backbone topologies will be considered.

Base on the selected backbone and site network components, the intranet integration cost may include an interconnection cost. This cost reflects the installing of a protocol translator so that both backbone and site network components can communicate with each other. The next five constraints are formulated to govern the backbone network design.

1. backbone topology constraint: a backbone topology can be either a local star topology or a wide tree topology. If the center of mass between all site tasks within the backbone is less than or equal to a backbone distance threshold (BDT), then the backbone is considered as a local star topology. Otherwise, the backbone topology is considered a wide tree topology, T(N,L). BDT is a real number given as an input and it is set to equal one mile (5,200 feet). N and L represent site-task ST_f nodes and backbone links BL_i respectively. f and i indicate the identifications of site task and backbone link respectively.

2. backbone network technology selection constraint: only one network technology is allocated and bound for the backbone network. The option is either backbone leased lines (BLL_h), backbone optical leased lines ($BOLL_k$), backbone virtual private connections ($BVPC_q$), a backbone router (BR_y) or a backbone network connector (BNC_z), as shown in Figure 4.5. We separate the backbone network selection into five constraints for presentation clarity only, but only **one** of them must be satisfied depending on which backbone technology is chosen.

$$\sum_{\forall i \in L} \mathcal{L}_h \times \epsilon_{h,i} = \sum_{\forall ST_f \in BT} v_{f,BT} - 1 \tag{4.8}$$

For each Backbone Leased Line BLL_h

Constraint 4.8 limits the number of allocated and bound backbone leased lines to the total number of site tasks in the backbone network, subtracted by one. This forces a tree topology on the backbone network. BLL_h is a backbone leased line, which is a design parameter, and the index h indicates the backbone leased line number. $\mathcal{L}_h$ is an allocation variable; $\mathcal{L}_h = 1$ indicates that a backbone leased line BLL_h is being included in the synthesized intranet configuration. $\epsilon_{h,i}$ is a binding variable; $\epsilon_{h,i} = 1$ indicates that an allocated backbone leased line BLL_h is bound to a link i within the synthesized backbone tree.

$v_{f,BT}$ is a binding variable; $v_{f,BT} = 1$ indicates that a site task ST_f is bound to the backbone task BT. The next four constraints present the other options for

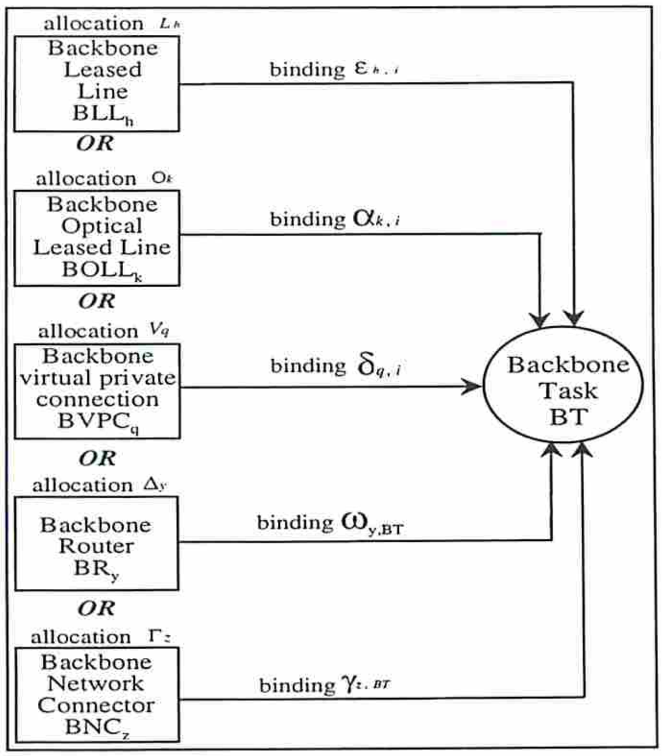


Figure 4.5: Backbone network allocation and binding variables. Only one option will be selected for the backbone task.

the backbone network design. Constraint 4.8a limits the number of allocated and bound backbone optical leased lines (SONET) to the total number of site tasks in the backbone network, subtracted by one. This forces a tree topology on the backbone network. $BOLL_k$ is a backbone optical leased line, which is a design parameter, and the index k indicates the backbone optical leased line number. O_k is an allocation variable; $O_k = 1$ indicates that a backbone optical leased line $BOLL_k$ is being included in the synthesized intranet configuration.

$\alpha_{k,i}$ is a binding variable; $\alpha_{k,i} = 1$ indicates that an allocated backbone optical leased line $BOLL_k$ is bound to a link i within the synthesized backbone tree.

$$\sum_{\forall i \in L} \mathcal{O}_k \times \alpha_{k,i} = \sum_{\forall ST_f \in BT} \upsilon_{f,BT} - 1 \tag{4.8a}$$

For each SONET $BOLL_k$

Constraint 4.8b limits the number of allocated and bound backbone virtual private connections to the total number of site tasks (F) in the backbone network, subtracted by one. This forces a tree topology on the backbone network. $BVPC_l$ is a backbone virtual private connection, which is a design parameter, and the index l indicates the backbone virtual private connection number. $\mathcal{V}_l$ is an allocation variable; $\mathcal{V}_l = 1$ indicates that a backbone virtual private connection $BVPC_l$ is being included in the synthesized intranet configuration. $\delta_{l,i}$ is a binding variable; $\delta_{l,i} = 1$ indicates that an allocated backbone virtual private connection $BVPC_l$ is bound to a link within the synthesized backbone tree.

$$\sum_{\forall i \in L} \mathcal{V}_l \times \delta_{l,i} = \sum_{\forall ST_f \in BT} \upsilon_{f,BT} - 1 \tag{4.8b}$$

For each virtual private connection $BVPC_l$

Constraint 4.8c limits the number of allocated and bound backbone routers to one. This forces a star topology on the backbone network, where the centralized hub represents an allocated and bound backbone router; moreover, the nodes represent all site network connections. BR_y is a backbone router which is a design parameter, and the index y indicates the backbone router number. Δ_y is an allocation variable; $\Delta_y = 1$ indicates that a backbone router BR_y is being included in the synthesized intranet configuration. $\omega_{y,BT}$ is a binding variable; $\omega_{y,BT} = 1$ indicates that an allocated backbone router BR_y is bound to the backbone task (BT).

$$\sum_{\forall BR_y} \Delta_y \times \omega_{y,BT} = 1 \text{ for IP router} \tag{4.8c}$$

Constraint 4.8d limits the number of allocated and bound backbone network connector to one. This forces a star topology on the backbone network, where the centralized hub represents an allocated and bound backbone network connector; moreover, the nodes represent all site network connections. BNC_z is a backbone network connector, which is a design parameter, and the index z indicates the backbone network connector number. Γ_z is an allocation variable; $\Gamma_z = 1$ indicates that a backbone network connector BNC_z is being included in the synthesized intranet configuration. $\gamma_{z,BT}$ is a binding variable; $\gamma_{z,BT} = 1$ indicates that an allocated backbone network connector BNC_z is bound to the backbone task (BT).

$$\sum_{\forall BNC_z} \Gamma_z \times \gamma_{z,BT} = 1 \text{ for backbone network connector} \tag{4.8d}$$

3. backbone port constraint: a backbone router BR_y (or a backbone network connector BNC_z) must not connect more site network connections than its maximum number of ports NP_{BR_y/BNC_z}. Thus, for a backbone router BR_y, the following must be satisfied:

$$\sum_{\forall ST_f \in BT} \upsilon_{f,BT} \leq NP_{BR_y} \tag{4.9}$$

Constraint 4.9 insures that the total number of site tasks within the backbone task must not exceed the maximum number of available ports within its allocated and bound backbone router BR_y. $\upsilon_{f,BT}$ is a binding variable; $\upsilon_{f,BT} = 1$

indicates that a site task is bound within the backbone task (BT). NP_{BR_y} is an integer value that refers to the maximum number of ports within a backbone router BR_y. This value is given in the router design library. A similar constraint for a backbone network connector is described by the constraint 4.9a, which insures that the total number of site tasks within the backbone task must not exceed the maximum number of ports of its allocated and bound backbone network connector BNC_z. NP_{BNC_z} is an integer value that refers to the maximum number of ports within a backbone network connector BNC_z. This value is given in the network connector design library.

$$\sum_{\forall ST_f \in BT} \upsilon_{f,BT} \leq NP_{BNC_z} \tag{4.9a}$$

4. site-network to backbone-local-network connection constraint: this constraint insures that each site network is connected to the backbone local network. Figure 4.6 shows all possible connections between site and backbone networks, when the backbone network is a local star topology. $\pi_{snt,snpi,bnt,bnpi}$ is a connection variable. *snt* is the site network type (Ethernet, ATM, Router), *snpi* is the site network port identification (1 to NP_{SNC_u} or NP_{SR_t}), *bnt* is the backbone network type (Ethernet, ATM, Router), and *bnpi* is the backbone network network port identification (1 to NP_{BNC_z} or NP_{BR_y}). When both site and backbone network connectors are identical (Ethernet), a backbone bridge BB_w is installed between the identical site and backbone network connectors. Λ_w is an allocation variable; $\Lambda_w = 1$ indicates that a backbone bridge is being included in the synthesized intranet configuration. $\eta_{w,snt,snpi,bnt,bnpi}$ is a connection variable. *snt* is the site network type (Ethernet), and *bnt* is the backbone local network type (Ethernet).

5. site-network to backbone-wide-network connection constraint: this constraint insures that each site network is connected within the wide backbone tree

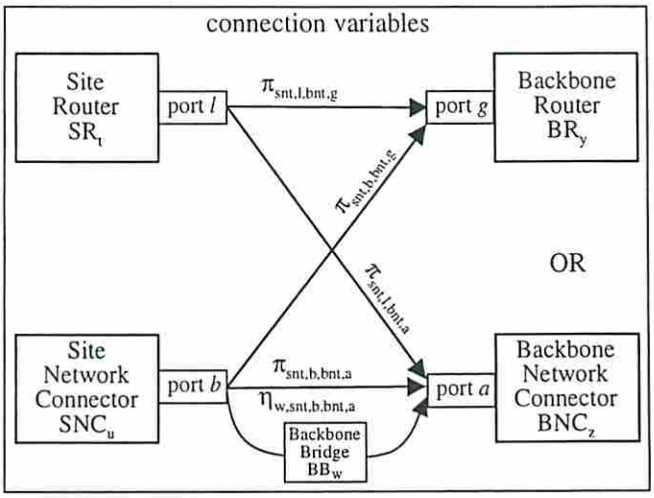


Figure 4.6: Local network interfaces between site networks and backbone networks.

topology. Figure 4.7 shows all possible connections between site and backbone networks, when the backbone network is a wide tree topology. $\rho_{snt,snpi,blt,bli}$ is a connection variable. snt is the site network type (Ethernet, ATM, Router), $snpi$ is the site network port identification (1 to NP_{SNC_u} or NP_{SR_t}), blt is the backbone link type (T-carrier, SONET, VPN), and bli is the backbone link identification (1 to (F-1)), where F is the total number of site tasks within the intranet.

4.3 Network Design Objective Function

The objective function is the network architecture cost (NAC), which consists of the summation cost of component, interconnection and wire costs as shown in Equation 4.10. The network hardware component cost (NHCC) reflects all network hardware resources needed to integrate the three-level network. The network interconnection cost (NIC) reflects the cost of protocol translators that are needed to enable distinct group and site networks to communicate with each other, and

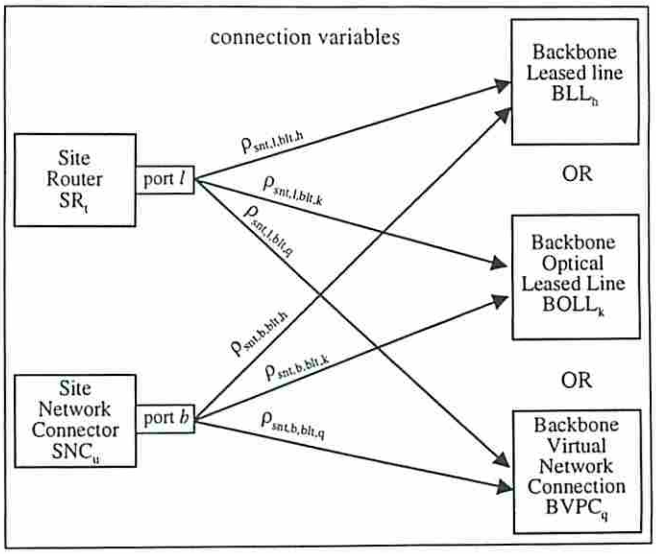


Figure 4.7: Wide network interfaces between site networks and backbone networks.

distinct site and backbone networks to communicate with each other. The network wire cost (NWC) reflects the cost of wires/cables that are needed to connect all network hardware components.

$$NAC = NHCC + NIC + NWC \tag{4.10}$$

4.3.1 Network Hardware Component Cost

The network hardware component cost (NHCC) reflects all network components that are allocated and bound for the three network levels: group, site, and backbone. The term NHCC can be expressed by summing the costs of a group network cost, a site network cost and a backbone network cost.

4.3.1.1 Group Network Cost

The group network cost can be expressed as the sum of all group network connectors, as shown in Equation 4.11.

$$\text{group network cost} = \sum_{\forall GNC_o} (\Upsilon_o \times C_o) \tag{4.11}$$

Equation 4.11 sums all group network components in the synthesized intranet. GNC_o is a design parameter and the index o indicates the group network connector identification. Υ_o is an allocation variable; $\Upsilon_o = 1$ indicates that a group network connector GNC_o is being included in the synthesized intranet infrastructure. C_o is a real number that refers to the cost of an allocated ($\Upsilon_o = 1$) group network connector GNC_o. C_o is given by the group network connector design library.

4.3.1.2 Site Network Cost

The site network cost can be expressed as the sum of all site network connectors and site routers, as shown in Equation 4.12.

$$\text{site network cost} = \sum_{\forall SNC_u} (\Psi_u \times C_u) + \sum_{\forall SR_t} (\mathcal{X}_t \times C_t) \tag{4.12}$$

Equation 4.12 sums all site network components in the synthesized intranet. SNC_u is a design parameter and the index u indicates the site network connector identification. Ψ_u is an allocation variable; $\Psi_u = 1$ indicates that a site network connector SNC_u is being included in the synthesized intranet infrastructure. C_u is real number that refers to the cost of an allocated ($\Psi_u = 1$) site network connector SNC_u. C_u is given by the site network connector design library. The other half of equation represents the site router cost. SR_t is a design parameter and the index t indicates the site router identification. $\mathcal{X}_t$ is an allocation variable; $\mathcal{X}_t = 1$ indicates that a site router SR_t is being included in the synthesized intranet infrastructure. C_t is real number that refers to the cost of an allocated ($\mathcal{X}_t = 1$) site router SR_t. C_t is given by the site router design library.

4.3.1.3 Backbone Network Cost

The backbone network cost can be expressed as the sum of either backbone leased lines, backbone optical leased lines, backbone virtual private connections, backbone router or backbone network connector, as shown in Equation 4.13.

$$\begin{aligned} \text{backbone network cost} = \; & (\Gamma_z \times C_z) + \\ & (\Delta_y \times C_y) + \\ & \sum_{\forall BLL_h} (\mathcal{L}_h \times (C_h + MSF_{BLL_h})) + \\ & \sum_{\forall BOLL_k} (\mathcal{O}_k \times (C_k + MSF_{BOLL_k})) + \\ & \sum_{\forall VPNC_q} (\mathcal{V}_q \times (C_q + MSF_{BVPC_q})) \end{aligned} \tag{4.13}$$

Equation 4.13 sums all backbone network components in the synthesized intranet. BNC_z is a design parameter and the index z indicates the backbone network connector identification. Γ_z is an allocation variable; $\Gamma_z = 1$ indicates that a backbone network connector BNC_z is being included in the synthesized intranet infrastructure. C_z is a real number that refers to the cost of an allocated ($\Gamma_z = 1$) backbone network connector BNC_z. C_z is given by the backbone network connector design library. BR_y is a design parameter and the index y indicates the backbone router identification. Δ_y is an allocation variable; $\Delta_y = 1$ indicates that a backbone router BR_y is being included in the synthesized intranet infrastructure. C_y is a real number that refers to the cost of an allocated ($\Delta_y = 1$) backbone router BR_y. C_y is given by the backbone router design library.

BLL_h is a design parameter and the index h indicates the backbone leased line identification. $\mathcal{L}_h$ is an allocation variable; $\mathcal{L}_h = 1$ indicates that a backbone leased line BLL_h is being included in the synthesized backbone tree structure. C_h is a real number that refers to the cost of an allocated ($\mathcal{L}_h = 1$) backbone leased-line BLL_h. MSF_{BLL_h} refers to the monthly subscription fee of a backbone leased line. Both C_h and MSF_{BLL_h} are given by the backbone leased line design library. $BOLL_k$ is a design parameter and the index k indicates the backbone optical leased-line identification. $\mathcal{O}_k$ is an allocation variable; $\mathcal{O}_k = 1$ indicates that a backbone optical leased-line $BOLL_k$ is being included in the synthesized backbone tree structure. C_k is a real number that refers to the cost of an allocated ($\mathcal{O}_k = 1$) backbone optical leased-line $BOLL_k$. MSF_{BOLL_k} refers to the monthly subscription fee of a backbone optical leased-line. Both C_k and MSF_{BOLL_k} are given by the backbone leased-line design library. $BVPC_q$ is a design parameter and the index q indicates the backbone virtual private connection identification. $\mathcal{V}_q$ is an allocation variable; $\mathcal{V}_q = 1$ indicates that a backbone virtual private connection $BVPC_q$ is being included in the synthesized backbone tree structure. C_q is a real number that refers to the cost of an allocated ($\mathcal{V}_q = 1$) backbone virtual private connection $BVPC_q$. MSF_{BVPC_q} refers to the monthly subscription fee of a backbone virtual private connection. Both C_q and MSF_{BVPC_q} are given by the backbone virtual private connection design library.

4.3.2 Network Interconnection Cost

The network interconnection cost (NIC) reflects the cost of protocol translators that are needed to enable distinct group and site networks to communicate with each other, and distinct site and backbone networks to communicate with each other. The network interconnection cost (NIC) can be expressed as the summation of group-site interconnection cost (GSIC) and site-backbone interconnection cost (SBIC) as shown in Equation 4.14.

$$NIC = GSIC + SBIC \tag{4.14}$$

4.3.2.1 Group Interconnection Cost

The group-site interconnection cost (GSIC) reflects all group-site interconnection cost after all network components are allocated and bound to group and site tasks.

$$GSIC = \sum_{\forall ST_f} \Big(\sum_{\forall GT_e \in ST f} IC_{e,f} \Big) \tag{4.15}$$

Equation 4.15 sums all the interconnection costs between group networks and site networks. $IC_{e,f}$ is a real number that indicates the cost to interconnect the network component within a group task GT_e to the network component within a site task ST_f. $IC_{e,f}$ is given by the interconnection table cost, which is provided by the designer to *i*-CAD.

4.3.2.2 Site Interconnection Cost

The site-backbone interconnection cost (SBIC) reflects all site-backbone interconnection cost after all network components are allocated and bound to site and backbone tasks.

$$SBIC = \sum_{\forall ST_f \in BT} IC_{f,BT} \tag{4.16}$$

Equation 4.16 sums all the interconnection costs between site networks and backbone network. $IC_{f,BT}$ is a real number that indicates the cost to interconnect the network component within a site task ST_f to the network component within the backbone task BT. $IC_{e,BT}$ is given by the interconnection table cost, which is provided by the designer to *i*-CAD.

4.3.3 Network Wire Cost

The network wire cost (NWC) reflects the cost of wires/cables that are needed to connect all client tasks within a group task, all group tasks within a site tasks and all site tasks within the backbone task. The network wire cost (NWC) can be expressed as the summation of group network wire cost (GNWC), site network wire cost (SNWC) and backbone network wire cost (BNWC) as shown in Equation 4.17.

$$NWC = GNWC + SNWC + BNWC \tag{4.17}$$

4.3.3.1 Group Wire Cost

The group network wire cost (GNWC) reflects all wire connections between client tasks to a group network connector.

$$GNWC = \sum_{\forall CT_i \in GT_e} [Distance(loc(CT_i), loc(GNC_o)) \times WCPL_{wt}] \tag{4.18}$$

Equation 4.18 sums the distance between client tasks and a group network connector and multiplies it by the wire cost per unit length $WCPL_{wt}$. *Distance()* is a function that determines the physical distance between two locations. *loc()* is a function that finds the physical location of a task. $WCPL_{wt}$ is a real number that refers to the wire cost per unit length (given by the wire design library). The index *wt* refers to the wire type that is used to connect a workstation with the group network connector. It can be either twisted pair, coaxial cable or fiber optic cable.

4.3.3.2 Site Wire Cost

The site network wire cost (SNWC) reflects all wire connections between group networks to a site network.

$$SNWC = \sum_{\forall GNC_o \in ST_f} [Distance(loc(GNC_o), loc(SNC_u/SR_t)) \times WCPL_{wt}] \tag{4.19}$$

Equation 4.19 sums the distance between group tasks and site network and multiplies it by the wire cost per unit length $WCPL_{wt}$.

4.3.3.3 Backbone Wire Cost

The backbone network wire cost (BNWC) reflects all wire connections between site networks to a backbone network, when the backbone network is a local star topology.

$$BNWC = \sum_{\forall SNC_u/SR_t \in BT} [Distance(loc(SNC_u/SR_t), loc(BNC_z/BR_y)) \times WCPL_{wt}] \tag{4.20}$$

Equation 4.20 sums the distance between site network components and backbone network component and multiplies it by the wire cost per unit length (in case of a local backbone topology). In case of a wide backbone topology, there is a monthly subscription fee that replaces the wire cost, as indicated in Equation 4.13.

4.4 Data Management Design Constraints

The design decisions of the data management system design problem are the number, locations, processing capacities and storage capacities of servers, and the storage allocation for files. A data management system can be either centralized or distributed as shown in Figure 4.8. A centralized data management system can be comprised of a single main frame server or a farm of servers, where one location within the intranet is selected to house either approach. On the other hand, a distributed data management system can be comprised of a number of distributed servers or a number of proxies attached to servers. The main different between the distributed data management system approaches is the content of servers and proxies. A server's or proxy's content refers to the number and type of files that are stored within a server's or proxy's storage space. In the distributed servers approach, the content of a server may not be a subset of other servers. In the distributed proxies attached to servers approach, the content of a proxy is a subset of its binding server(s) and also a proxy's content is directly related to its clients' requests.

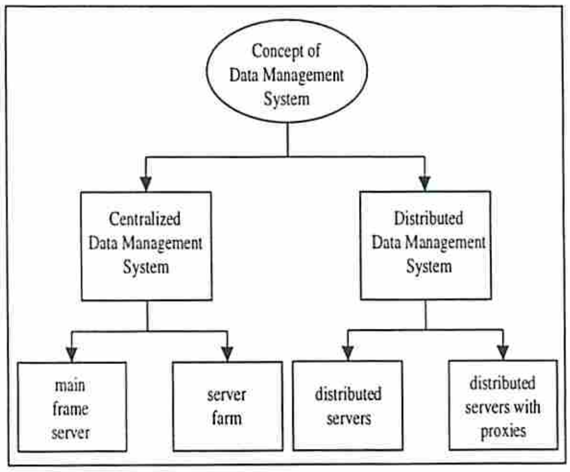


Figure 4.8: The possible data management system design structures.

The centralized or distributed data management system has its advantages and disadvantages, for example a centralized server can be easy to manage, but it may cause a network congestion since all clients' requests and the server's replys are concentrated in one spot (server location). On the other hand, distributed servers may prevent network congestion since all clients' requests and servers' replies are handled by a number of geographically distributed servers, for example. However, distributed servers can be harder to manage, especially when there are proxies attached. In this thesis, we focus on two data management systems: a centralized problem of writing files into the servers. There is no fundamental difference in the problem when writing to the server(s) in included.

Table 4.2: A data request table (DRT).

F_j	FS_j	FT_j	CT_1		.		.		CT_D	
			$FRR_{CT_1,j}$	$DB_{CT_1,j}$	.	.	.	.	$FRR_{CT_D,j}$	$DB_{CT_D,j}$
1	1	image	2	30	.	.	.	.	0	0
2	10	video	0	0	.	.	.	.	1	100
3	0.5	text	0	0	.	.	.	.	5	40
.	.		.	.	.	.	.	.	.	.
.	.		.	.	.	.	.	.	.	.
A	8	audio	1	90	.	.	.	.	0	0

The information given in the data request table is provided by the intranet user. Such information is probably approximated, and can be changed interactively, to produce a range of intranets. A sensitivity analysis can be performed by varying the information and analyzing the resulting intranet architectures and costs.

The *Design parameters* that represent the outputs of i-CAD specify in detail the number, locations, processing capacities, and storage capacities of servers.

The *Binary variables* are 0-1 variables that represent the implementation decisions regarding the data management system design problem (use = 1, don't use = 0). There are three types of binary variables defined:

- *Allocation variables*: The variables of this type specify the data management hardware resources that are being included in the intranet. The list of data management allocation variables includes the following (definitions and use of these variables are explained in later sections in this chapter):

  1. server β_n, and
  2. hard disk Ω_m.

- *Binding variables*: The variables of this type assign the allocated data management hardware resources to the application's tasks. These variables are used mostly to bind a file server to a group task, for example. The list of data management binding variables includes the following (definitions and use of these variables are explained in later sections in this chapter):

  1. server to group task $\varepsilon_{n,e}$,
  2. client task to server $\varsigma_{d,n}$,
  3. hard disk to server $\chi_{m,n}$,
  4. file to server $\psi_{j,i,n}$, and
  5. file to hard disk $\varrho_{j,i,q}$.

- *Connection variable*: This variable indicates a physical connection between a file server to a group network connector's port (definition and use of this variable is explained in later sections in this chapter).

  1. server to group network connector $\varphi_{dt,di,gnt,gnpi}$.

In this model, we separate the problem of allocating and binding of data management hardware resources into two small problems only for the initial design generation so that the problem becomes more understandable. Also, this decomposition could facilitate a separate solution to the allocation and binding problems, allowing them to be solved at separate stages in the design process. It allows the *i*-CAD software to explore many different possible bindings without changing the resources allocated.

4.4.1 Data Management Hardware Placement Constraints

The data management hardware placement constraints insure that all the client tasks within the intranet can have access to file servers. We limit the file server placement to the group tasks only, where each group task can have at most one file server. In our future research, we will place a number of application-specific servers, such as an email server, web server, video server and audio server in a given intranet; moreover, we will allocate proxies to ease the main servers' workload. Also, we will place servers at the site task and backbone task other than the group task. We formulate three data management hardware placement constraints:

1. server placement constraint: the number of possible group server GS_n placements must be bounded by the total number of group tasks in the intranet's application. Thus, for an intranet, the following must be satisfied:

   $$1 \leq \sum_{\forall GS_n} \beta_n \leq \sum_{\forall ST_f \in BT} \sum_{\forall GT_e \in ST_f} G_{e,f} \tag{4.21}$$

   Constraint 4.21 insures that there is at least one allocated (β_n) group server GS_n in the intranet and the total number of allocated group servers must not exceed the total number of group tasks GT_e in the intranet's application. GS_n is a group server, and the index n indicates the group server number. β_n is an allocation variable; $\beta_n = 1$ indicates that a group server GS_n is being included in the synthesized intranet. $G_{e,f}$ is a binding variable; $G_{e,f} = 1$ indicates that a group task GT_e is located within a site task ST_f.

2. server to group task constraint: a group task can have at most one placed server. Thus, for each group task GT_e, the following must be satisfied:

   $$\sum_{\forall n} \varepsilon_{n,e} \leq 1, \text{ For } GT_e \tag{4.22}$$

   Constraint 4.22 insures that at most one allocated server GS_n is placed within a group task GT_e. $\varepsilon_{n,e}$ is a binding variable; $\varepsilon_{n,e} = 1$ indicates that an allocated server is bound to a group task.

3. client task to server constraint: a client task is assigned to one placed server to retrieve its requests. Thus, for each client task CT_d, the following must be satisfied:

$$\sum_{\forall n} \varsigma_{d,n} = 1, \text{ For } CT_d \tag{4.23}$$

Constraint 4.23 insures that each client task is bound to one allocated server. $\varsigma_{d,n}$ is a binding variable; $\varsigma_{d,n} = 1$ indicates that a client task CT_d is bound to a server GS_n.

4. server to group-network connection constraint: an allocated group server must be connected to a group network. Thus, for a server GS_n within a group task GT_e, the following must be satisfied:

$$\sum_{\forall gnpi \in gnt} \varphi_{dt,di,gnt,gnpi} = 1, \text{ For dt } = GS_n \in GT_e \text{ and } di = n \tag{4.24}$$

Constraint 4.24 insures that an allocated group server GS_n is located and connected to one port of an allocated and bound group network connector GNC_o. $\varphi_{t,i,g,gp}$ is a connection variable. dt is the device type (server), di is the device identification (1 to $\sum_{\forall ST_f \in BT} \sum_{\forall GT_e \in ST_f} G_{e,f}$, which represents the total number of group tasks within the intranet), gnt is the group network type (Ethernet, ATM), and $gnpi$ is the group network port identification (1-NP_{GNC_o}).

5. hard disk constraint: the number of hard disks to be allocated to a placed server is constrained. Thus, for each placed server GS_n, the following must be satisfied:

$$1 \leq \sum_{\forall m} (\Omega_m \times \chi_{m,n}) \leq 10, \text{ For } GS_n \tag{4.25}$$

Constraint 4.25 insures that a placed server can have at most ten hard disks. Ω_m is an allocation variable; $\Omega_m = 1$ indicates that a hard disk HD_m is being allocated within the synthesized data management system. $\chi_{m,n}$ is a binding variable; $\chi_{m,n} = 1$ indicates that a hard disk HD_m is bound only to a group server GS_n.

6. group-server-hard-disk constraint: each allocated group server GS_n must have a storage space, where its capacity must be bounded by the size of the application's files. Thus, for each group server GS_n, the following must be satisfied:

$$max(FS_j) \leq (HDC_{GS_n} + \mathcal{S}) \leq \sum_{\forall j} FS_j \qquad (4.26)$$

Constraint 4.26 insures that the total hard disk capacity HDC_{GS_n} of a group server GS_n is bound by the maximum file size in the application and the cumulative size of all application's files. FS_j indicates the file size of the jth file and this value is an input parameter. HDC_{GS_n} is a design parameter representing the total hard disk capacity of the nth group server. $\mathcal{S}$ represent slack storage space which can be used for context switching, for example. This value is an input parameter.

4.4.2 File Allocation Constraints

The file allocation constraints insure that all files are stored in the allocated group servers, and each file must maintain its number of stored instances under an upper bound.

1. file server allocation constraint: a file F_j can allocate at most one instance within a group server GS_n. Thus, for each file F_j and group server GS_n, the following must be satisfied:

$$0 \leq \sum_{\forall i} \psi_{j,i,n} \leq 1, \text{ For } F_j \text{ and } GS_n \tag{4.27}$$

   Constraint 4.27 insures that at most one instance of a file is stored in a group server. $\psi_{j,i,n}$ is a binding variable; moreover, $\psi_{j,i,n} = 1$ indicates that an instance i of the jth file is stored in the group server GS_n.

2. file-instance constraint: the number of file instances must be bounded by the maximum number of placed servers. Thus, for each file F_j, the following must be satisfied:

$$1 \leq \sum_{\forall GS_n} \sum_{\forall i} \psi_{j,i,n} \leq \sum_{\forall ST_f \in BT} \sum_{\forall GT_e \in ST_f} G_{e,f} \tag{4.28}$$

   Constraint 4.28 insures that at least one instance of a file is stored in a group server; moreover, the total number of file instances is bound by the total number of group tasks within the intranet's application.

4.5 Data Management Design Objective Function

The data management system cost (DMSC) consists of the costs of all group servers and their hard disks.

$$DMSC = \sum_{\forall GS_n} [(\beta_n \times C_n) + \sum_{\forall HD_m \in GS_n} (\Omega_m \times C_m)] \tag{4.29}$$

Equation 4.29 sums the cost of all placed servers and their hard disks. GS_n is a group server (design parameter) and the index n indicates the group server identification. β_n is an allocation variable; $\beta_n = 1$ indicates that a group server GS_n is being included in the synthesized intranet. C_n refers to the cost of an allocated (β_n = 1) group server GS_n. C_n is given by the server design library. HD_m is a design parameter representing the hard disk and the index m indicates the hard disk identification. C_m refers to the cost of the allocated hard disk ($\Omega_m = 1$) and it is given by the hard disk design library.

4.6 Intranet Integration Objective Function

The overall objective function is to minimize the intranet integration cost (IIC), which can be expressed as the sum of the network architecture cost (NAC) and the data management system cost (DMSC), as shown in Equation 4.30. We can sum NAC and DMSC, since both are in term of dollars.

$$Minimize\ ICC,\ where\ IIC = NAC + DMSC \tag{4.30}$$

The constraints described in this chapter form the basis for the *i*-CAD code that insures that designs in the evolving population are correctly constructed.

Chapter 5

The Performance Model

5.1 Background

To determine the "goodness of fit" of each solution produced by the genetic algorithm, performance must be approximated rapidly during optimization. Therefore, the performance model consists of two methods: a quick method and a detailed method. The quick method is included during optimization, and the detailed method is run after synthesis and optimization has been completed. The detailed method provides more performance information and allows final tuning of an intranet architecture. It provides the intranet user with a greater level of confidence that the system will perform as planned. In this thesis, we present the quick performance evaluation method, and for our future work we will produce a detailed performance evaluation method or use commercial software. We used the quick performance technique to evaluate both the three-level network infrastructure and the data management system. These quick performance techniques are embedded within the *i*-CAD tool to increase the likelihood that the intranet integration solutions can satisfy the network and data management performance constraints.

The performance constraints consist of two sets: network performance constraints and data management performance constraints. To describe the performance constraints mathematically, we need to define the input parameters, and the performance variables that are related to the performance problem.

The *Input parameters*: client traffic matrix, the threshold network delay and threshold data management performance are given by the intranet planners to the i-CAD tool to specify in detail the client traffic between all pair of client tasks, the delay bound on each synthesized three-level network and the lower-bound on the data management system performance.

- The *client traffic matrix* (CTM) is a $D \times D$ matrix, where each element $t_{i,j}$ in TFM indicates the mean traffic flow from a client i to a client j in megabits per second (Mbps). The sum of all elements in a row $t_{i,1...D}$ represents the *mean client outgoing traffic* COT_i of a client i. The sum of all elements in a column $t_{1...D,i}$ represents the *mean client incoming traffic* CIT_i of a client i. Table 5.1 shows an example of a client traffic matrix.

Table 5.1: A client traffic matrix (CTM), where a CT denotes a client task.

CT/CT	1	2	3	.	.	D
1	0	20	2	1	10	0.5
2	8	0	0.1	9	15	7
3	16	0.5	0	1	0	6
.	.	.	.	0	.	.
.	.	.	.	.	0	.
D	40	10	0	1	2	0

- The *threshold network delay* (TND) is a real number given by the designer/planner and used by the i-CAD tool to bound the estimated the average network delay (AND).

- The *threshold data management performance* (TDMP) is a real number given by the designer/planner and used by the i-CAD tool to bound the estimated server performance.

5.2 Network Performance Constraints

The network performance constraints consist of two types: the network capacity constraints and the average intranet delay constraint. In the next two sections, we describe these two types.

5.2.1 Network Capacity Constraints

The network capacity constraints insure that the network capacity of each allocated and bound network hardware component is sufficient to handle all the clients' traffic. We formulate three network capacity constraints:

1. group-bandwidth constraint: The group total traffic GTT_{GT_e} must not exceed the group network connector maximum bandwidth capacity BW_{GNC_o}. GTT_{GT_e} is the summation of the group local traffic GLT_{GT_e}, group outgoing traffic GOT_{GT_e}, group incoming traffic GIT_{GT_e}, group local request (files) traffic $GLRQT_{GT_e}$, group local reply (servers) traffic $GLRPT_{GT_e}$, data management traffic for other group tasks DMT_{GT_e}, and group missing file traffic for other group tasks $GMFT_{GT_e}$. The term GLT_{GT_e} represents the summation of all group's clients local traffic within a group task GT_e. The term GOT_{GT_e} represents the summation of all group's clients outgoing traffic to other groups' clients. The term GIT_{GT_e} represents the summation of all group's clients incoming traffic from other groups' clients. All the above three terms are calculated from the client traffic matrix (CTM). The term $GLRQT_{GT_e}$ represents the summation of all clients' requests for files within a group task GT_e. The term $GLRPT_{GT_e}$ represents the summation of all servers' replies for all clients'

requests within a group task GT_e. $GLRQT_{GT_e}$ and $GLRPT_{GT_e}$ are calculated directly from the data request table (DRT) for each group task. The term DMT_{GT_e} represents the summation of all requests and replies for files within a group task GT_e to other group tasks within the intranet. The term $GMFT_{GT_e}$ represents the summation of all requests and replies for missing files within a group task GT_e to other group tasks. DMT_{GT_e} and $GMFT_{GT_e}$ can be calculated from DRT, but after all files are allocated into the placed servers. Thus, for each group task GT_e and group network connector GNC_o, the following must be satisfied:

$$GTT_{GT_e} = GLT_{GT_e} + GOT_{GT_e} + GIT_{GT_e} + GLRQT_{GT_e} + GLRPT_{GT_e} + DMT_{GT_e} + GMFT_{GT_e} \quad (5.1)$$

$$GTT_{GT_e} < BW_{GNC_o} \quad (5.2)$$

BW_{GNC_o} is an integer value that refers to the maximum network capacity of a group network connector GNC_o in term of communication bandwidth (bits per second). This value is given in the network connector design library, and varies depending on the network connector allocated to the group.

2. site-bandwidth constraint: Constraint 5.4 insures that the site total traffic STT_{ST_f} (Equation 5.4) must not exceed the site network connector maximum bandwidth capacity BW_{SNC_u}. STT_{ST_f} is the summation of the site local traffic SLT_{ST_f}, site outgoing traffic SOT_{ST_f}, site incoming traffic SIT_{ST_f}, site total data management traffic $STDMT_{ST_f}$, and site missing file traffic $SMFT_{ST_f}$. The term SLT_{ST_f} represents the summation of all site's clients local traffic within a site. The term SOT_{ST_f} represents the summation of all site's clients outgoing traffic to other sites' clients. The term SIT_{ST_f} represents the summation of all site's clients incoming traffic from other sites' clients. All the above three terms are calculated from the client traffic matrix (CTM). The

term $STDMT_{ST_f}$ represents the summation of requests and replies of files going through site task ST_f. The term $SMFT_{ST_f}$ represents the summation of all missing file traffic going through site task ST_f. $STDMT_{ST_f}$ and $SMFT_{ST_f}$ can be calculated from DRT, but after all files are allocated into the placed servers. Thus, for each site task ST_f and site network connector SNC_u, the following must be satisfied:

$$STT_{ST_f} = SLT_{ST_f} + SOT_{ST_f} + SIT_{ST_f} + STDMT_{ST_f} + SMFT_{ST_f} \quad (5.3)$$

$$STT_{ST_f} < BW_{SNC_u} \quad (5.4)$$

BW_{SNC_u} is an integer value that refers to the maximum network capacity of the site network connector SNC_u in term of communication bandwidth (bits per second). This value is given in the network connector design library.

3. backbone-bandwidth constraint: The backbone total traffic BTT must not exceed the backbone network maximum bandwidth capacity. The total traffic within the backbone is the summation of the inter-site traffic, which is called the backbone local traffic BLOT, backbone total data management traffic BT-DMT, and backbone missing file traffic BMFT. The term BLOT represents the summation of all inter-site' clients traffic which are calculated from the client traffic matrix (CTM). The term BTDMT represents the summation of requests and replies of files going through the backbone task. The term BMFT represents the summation of all missing file traffic going through the backbone task. BTDMT and BMFT can be calculated from DRT, but after all files are

allocated into the placed servers. We separate the backbone bandwidth into four constraints for presentation clarity, but only one of them must be satisfied.

$$BTT_{local} = BLOT + BTDMT + BMFT \tag{5.5}$$

$$BTT_{local} < BW_{BNC_z} \text{ for } BNC_z \tag{5.6}$$

Constraint 5.6 insures that the sum of all traffic of the backbone task BTT_{local} must not exceed the backbone network connector maximum bandwidth capacity BW_{BNC_z}. BW_{BNC_z} is an integer value that refers to the maximum network capacity of the backbone network connector BNC_z in term of communication bandwidth (bits per second). This value is given in the network connector design library. The next three constraints present the other options for the backbone tree topology performance. A wide tree topology T(N,L) consists of N site-task ST_f nodes and L backbone links BL_i, where f and i represent the identifications of site task and backbone link respectively. Constraint 5.6a insures that the client-to-client traffic and data management traffic going through a link must not exceed its allocated and bound backbone leased line maximum bandwidth capacity BW_{BLL_h}. A link traffic consists of backbone individual link traffic $BILT_{BL_i}$, backbone individual link data management traffic $BILDMT_{BL_i}$, and backbone individual link missing file traffic $BILMFT_{BL_i}$. BW_{BLL_h} is an integer value that refers to the maximum network capacity of a backbone leased line BLL_h in term of communication bandwidth (bits per second). This value is given in the leased line design library.

$$(BILT_{BL_i} + BILDMT_{BL_i} + BILMFT_{BL_i}) < BW_{BLL_h} \tag{5.6a}$$

Constraint 5.6b insures that total traffic going through a backbone link BL_i must not exceed the backbone optical leased line maximum bandwidth capacity

BW_{BOLL_k}. BW_{BOLL_k} is an integer value that refers to the maximum network capacity of the backbone optical leased line $BOLL_k$ in terms of communication bandwidth (bits per second). This value is given in the optical leased line design library.

$$(BILT_{BL_i} + BILDMT_{BL_i} + BILMFT_{BL_i}) < BW_{BOLL_k} \tag{5.6b}$$

Constraint 5.6c insures that total traffic going through a backbone BL_i must not exceed the backbone virtual private connection maximum bandwidth capacity BW_{BVPC_q}. BW_{BVPC_q} is an integer value that refers to the maximum network capacity of the backbone virtual private connection $BVPC_q$ in term of communication bandwidth (bits per second). This value is given in the virtual private connection design library.

$$(BILT_{BL_i} + BILDMT_{BL_i} + BILMFT_{BL_i}) < BW_{BVPC_q} \tag{5.6c}$$

5.2.2 Average Network Delay Constraint

The network delay estimation is based on a well-known formulation [GK77]. This formulation views the intranet as a network of M/M/1 queues, where each group, site and backbone is modeled as an M/M/1 queue. Summing all delays generated by all group tasks, site tasks and the backbone task represents the average network delay (AND). Thus, intranet's AND must satisfy the threshold configuration delay

(TCD), which is an input parameter provided by the intranet planners, as shown in Constraint 5.8.

$$AND = \sum_{\forall GT_e} GTD_{GT_e} + \sum_{\forall ST_f} STD_{ST_f} + BTD \tag{5.7}$$

$$AND < TND \tag{5.8}$$

AND consists of three terms: GTD_{GT_e}, STD_{ST_f} and BTD. The first term (GTD_{GT_e}) sums all the delays generated by all group tasks. The second term (STD_{ST_f}) sums all the delays generated by all site tasks. The third term (BTD) represents the delay generated by the backbone task. All these terms are derived in the next section.

5.3 The Network Delay Model

The average network delay (AND) model is based on formulating the intranet infrastructure as a network of M/M/1 queues. The average network delay (AND) represents the summation of all the delays generated by all the queues, which represent the group, site and backbone networks. This formulation has been used by many researchers for its simplicity and fast approximation for an average delay [GK77, BG87]. The delay of data transfer for each group task, site task and backbone task is modeled as an M/M/1 queue, where it is assumed that the inter-arrival packet times and the service times are exponentially distributed. To analyze an M/M/1 queue, we need to know only the mean arrival rate λ and the mean service rate μ. In our case, λ represents the total traffic flow while μ represents the allocated network capacity. λ is derived from the client traffic matrix (CTM), but μ is a design parameter. We can derive the average delay by using a simple M/M/1 queue model and Little's Theorem, which is stated in Equation 5.9.

$$N = \lambda \times T \tag{5.9}$$

N is the mean number of packets in a network at any point in time. λ is the packet arrival rate. T is the mean time a packet spends in a network. The state of an M/M/1 queue is given by the number of active packets in a network and it is similar to that of birth-death processes with the following correspondence:

$$\lambda_i = \lambda, \ \text{i} = 0,1,2,\ldots,\infty$$

$$\mu_i = \mu, \ \text{i} = 0,1,2,\ldots,\infty$$

The *steady-state probability* SSP_i of the ith packet being active in a network is given by Equation 5.10:

$$SSP_i = (\frac{\lambda}{\mu})^i \times SSP_0 \tag{5.10}$$

The index i is equal to 1,2,3,...,∞, and SSP_0 is the steady-state probability of no packet in the network. Since all probabilities should add to one, the probability of no packet in the network, SSP_0, is given by Equation 5.11:

$$SSP_0 = (\frac{1}{(1 + \frac{\lambda}{\mu} + (\frac{\lambda}{\mu})^2 + \cdots + (\frac{\lambda}{\mu})^i}) = 1 - (\frac{\lambda}{\mu}) \tag{5.11}$$

Then, substituting Equation 5.11 into Equation 5.10, we get the steady-state probability, SSP_i, in terms of λ and μ, as expressed in Equation 5.12:

$$SSP_i = (\frac{\lambda}{\mu})^i \times (1 - (\frac{\lambda}{\mu})), \ \text{i} = 1,2,3,\ldots,\infty \tag{5.12}$$

We derive the *group task delay* (GTD_{GT_e}) first by finding the expected number of packets E[i] in a group-level network, as given by Equation 5.13:

$$E[i] = \sum_{i=1}^{\infty} i \times SSP_i = \sum_{i=1}^{\infty} i(\frac{\lambda}{\mu})^i(1 - (\frac{\lambda}{\mu})) = \frac{(\frac{\lambda}{\mu})}{1 - (\frac{\lambda}{\mu})} \tag{5.13}$$

Then, the average packet delay (APD) is computed using Equation 5.13 and Little's Theorem, as expressed in Equation 5.14:

$$APD = \frac{E[i]}{\lambda} = \frac{\frac{(\frac{\lambda}{\mu})}{1-(\frac{\lambda}{\mu})}}{\lambda} = \frac{1}{\mu - \lambda} \tag{5.14}$$

Last, the group task data delay GTD_{GT_e} is derived by multiplying the average packet delay for a group task GT_e with the total traffic load of a group task GTT_{GT_e}, as expressed in Equation 5.15 (we substitute λ amd μ notations with GTT_{GT_e} and BW_{GNC_o} respectively.):

$$GTD_{GT_e} = \frac{1}{\mathcal{ITT}}[\frac{GTT_{GT_e}}{BW_{GNC_o} - GTT_{GT_e}}] \tag{5.15}$$

Equation 5.15 is the delay for an M/M/1 queue [GK77, BG87] at the bit level, where GTT_{GT_e} and BW_{GNC_o} are in terms of bits per second. $\mathcal{ITT}$ represents the total offered traffic within the intranet. BW_{GNC_o} represents the network maximum capacity of GNC_o. GTT_{GT_e} represents the total traffic load of GT_e. To derive the *site task delay* (STD_{ST_f}), we need to consider the delay resulting from all site routers, site network connectors and site bridges as stated in Equation 5.16.

$$\begin{aligned} STD_{ST_f} = & \frac{1}{\mathcal{ITT}}[\Psi_u(\frac{STT_{ST_f}}{BW_{SNC_u} - STT_{ST_f}}) + \\ & (1 - \Psi_u)(\frac{STT_{ST_f}}{\mathcal{SRPD}_{SR_t} - STT_{ST_f}}) + \\ & (\sum_{\forall r} \Phi_r \times \mathcal{SBLD}_{SB_r})] \end{aligned} \tag{5.16}$$

$\Psi_u = 1$ represents the allocation of a site network connector SNC_u. BW_{SNC_u} represents the site network connector maximum capacity. STT_{ST_f} represents the total traffic load of a site task ST_f. $\mathcal{X}_t = 1$ represents the allocation of a site router SR_t. $\mathcal{SRPD}_{SR_t}$ represents a site router processing delay, which is given by the router library. $\Phi_r = 1$ represents the allocation of a site bridge SB_r. $\mathcal{SBLD}_{SB_r}$

represents a site bridge lookup delay, which is given by the bridge design library. To derive the *backbone task delay* (BTD), we consider the delay resulting from either all backbone leased lines, all backbone optical leased lines, all backbone virtual private connections, a backbone router, or a backbone network connector and backbone bridges. Equations 5.17-5.18 represent the delays for local backbone topology and wide backbone topology respectively.

$$\begin{aligned} BTD_{local} = \frac{1}{\mathcal{ITT}}[\Delta_y \times (\frac{BTT_{local}}{\mathcal{BRPD}_{BR_y} - BTT_{local}}) + \\ \Gamma_z \times (\frac{BTT_{local}}{BW_{BNC_z} - BTT_{local}}) + \\ \sum_{\forall BB_w} (\Lambda_w \times \mathcal{BBLD}_{BB_w})] \end{aligned} \tag{5.17}$$

BTT_{local} represents the backbone total traffic (local star topology). $\Delta_y = 1$ represents the allocation of a backbone router BR_y. $\mathcal{BRPD}_{BR_y}$ represents a backbone router processing delay, which is given by the router design library. $\Gamma_z = 1$ represents the allocation of a backbone network connectionBNC_z. BW_{BNC_z} represents the maximum network capacity of a backbone network connector. $\Lambda_w = 1$ represents the allocation of a backbone bridge BB_w. $\mathcal{BBLD}_{BB_w}$ represents a backbone bridge lookup delay, which is given by the bridge design library. On the other hand, the backbone network delay for a wide tree topology is the summation of all links' delay.

$$BTD_{wide} = \frac{1}{ITT}[$$
$$(\mathcal{L}_h \sum_{\forall BL_i \in L} \frac{BILT_{BL_i} + BILDMT_{BL_i} + BILMFT_{BL_i}}{BW_{BLL_h} - (BILT_{BL_i} + BILDMT_{BL_i} + BILMFT_{BL_i})} + PD_{BL_i}) +$$
$$(\mathcal{O}_k \sum_{\forall BL_i \in L} \frac{BILT_{BL_i} + BILDMT_{BL_i} + BILMFT_{BL_i}}{BW_{BOLL_k} - (BILT_{BL_i} + BILDMT_{BL_i} + BILMFT_{BL_i})} + PD_{BL_i}) +$$
$$(\mathcal{V}_q \sum_{\forall BL_i \in L} \frac{BILT_{BL_i} + BILDMT_{BL_i} + BILMFT_{BL_i}}{BW_{BVPC_q} - (BILT_{BL_i} + BILDMT_{BL_i} + BILMFT_{BL_i})} + PD_{BL_i})] \tag{5.18}$$

$BILT_{BL_i}$ represents the backbone individual link traffic for a backbone link BL_i, which is one of the link constructing the backbone tree topology. $BILDMT_{BL_i}$ represents the backbone individual link data management traffic going through a backbone link BL_i. $BILMFT_{BL_i}$ represents the backbone individual link missing file traffic going through a backbone link BL_i. $\mathcal{L}_h = 1$ represents the allocation of a backbone leased line BLL_h. BW_{BLL_h} represents the maximum network capacity of a backbone leased line. PD_{BL_i} represents the propagation delay of a backbone link BL_i. $\mathcal{O}_k = 1$ represents the allocation of a backbone optical leased line $BOLL_k$. BW_{BOLL_k} represents the maximum network capacity of a backbone optical leased line. $\mathcal{V}_q = 1$ represents the allocation of a backbone virtual private connection $BVPC_q$. BW_{BVPC_q} represents the maximum network capacity of a backbone virtual private connection.

The average network delay (AND), which represents the summation of Equations 5.15 to 5.18, is stated in Equation 5.19. This value is constrained by the threshold network delay (TND). The term BTD is either equal to BTD_{local} or BTD_{wide} depending on the backbone topology type.

$$AND = (\sum_{\forall GT_e} GTD_{GT_e} + \sum_{\forall ST_f} STD_{ST_f} + BTD) \leq TND \tag{5.19}$$

5.4 Data Management Performance Constraint

The data management system performance constraint insures that all placed group servers can execute most of the clients' requests. On regular basis, a client sends a request to a server to retrieve common files shared with other clients. The number of clients exceeds the number of placed servers by several magnitudes. The placed servers try to execute as many as possible of the clients' requests during a given duration period. To evaluate the performance of a placed server, we use a quick estimation method, which is based on a quick simulation technique known as *Monte Carlo* simulation. This simulation emulates the server by trying to schedule all requests linearly within a given duration period (DP). Requests are generated at random times. Each set of requests is scheduled, and the success or failure of the schedule to meet the deadline DP is recorded. For each trial a new set of request times is generated randomly. After n trials, a probability of success (meeting all clients' requests in the duration period) is computed. DP is a real number given by the intranet planner. The simulator is embedded within the i-CAD tool. The outcome of Monte Carlo simulation is a real numerical value (SP_{GS_n}) indicating the percentage of the clients' requests that are executed during the duration period (DP). Then, SP_{GS_n} is compared with the threshold data management performance (TDMP).

$$SP_{GS_n} \geq TDMP \tag{5.20}$$

Constraint 5.20 insures that the performance of each group server GS_n in the synthesized intranet meets the minimum threshold data management performance (TDMP) parameter. SP_{GS_n} is the estimated performance for the group server GS_n. TDMP is a real number given by the intranet planners to i-CAD. In the next section, we explain the performance estimation method.

5.5 Monte Carlo Simulation

Monte Carlo simulation is based on modeling probabilistic situations that are stationary (don't change characteristics with time) [Jai91], and can be used for evaluating server performance. The arrival of each client's request to the server is *unknown* (not deterministic values) and these values can be either guessed by the intranet designer or estimated by prediction tools. In such situation, the intranet designer may be interested not only in the worst-case scenario, but the intranet designer may prefer a data management system design that meets the performance constraint with a certain probability. A worst-case scenario is when all clients' requests arrive at the same time to the server, the satisfaction of which would lead to an expensive data management system design. A probabilistic approach would trade-off a non-zero probability (SP_{GS_n}) of not satisfying all clients' requests for a less expensive design. *i*-CAD is able to produce different data management systems for different values of SP_{GS_n} that meets the threshold data management performance (TDMP), as stated in Constraint 5.20.

The algorithm that is used to perform the Monte Carlo simulation is depicted in Figure 5.1. The simulation evaluates each placed server separately. The inputs to the simulation are the server's attributes and a list of all requests intended for the evaluated server. The server's attributes are processing capacity (PC_{GS_n}) in terms of CPU clock cycle, the hard disk's seek time (SKT_{GS_n}) and the hard disk's retrieval rate (RR_{GS_n}) (bits per second). All these values are given by the server and hard disk design libraries. Each client's request contains the client's identification, client's network address, and requested file's identification.

The algorithm starts by initializing several internal parameters that are used within the simulation, including *time-line*, *counter*, and *request-counter* in lines 2-4. The time-line is a real number that keeps track of schedule requests within the server. The counter is an integer number that is used as an index to the list of clients' requests. The request-counter is an integer number which is used to count the number of executed requests by the server. The **for** loop in lines 5-8 assigns a random request time and calculates processing time and retrieval time for each client's request in the list *CR[]* of size R. The random number generator selects a real number between zero and the duration period. A sort function is called in line 9 to order the list in ascending order with respect to a randomly generated request time. The **while** loop in lines 10-28 repeatedly tries to schedule all requests within the sort list CR[] until the time-line exceeds the duration period (DP). The **if** statement in lines 12-14 insures that a scheduled request does not exceed the duration period; otherwise the simulator tries another request to schedule by incrementing the counter in line 25. Line 15 increments the request-counter when a request is scheduled for execution in the server. The **if** statement in line 16 insures that scheduling a new request does not overlap with the currently executed request. The time-line is updated in lines 17-20 when there is no overlap (the server is idle in this case). On the other hand, when the two requests overlap, the new request waits until the server finishes executing the old request and the time-line is update accordingly in lines 21-24. The server performance ratio is evaluated in line 27 by dividing the total scheduled requests over the total requests in the list CR[]. Results of performance estimates using this technique are described in Chapter 7.

Monte Carlo Simulator:

```
begin
    time-line = 0;
    counter = 1;
    request-counter = 0;
    For i = 1 to R
            CR[i].request-time = random-generation[0,DP);
            CR[i].process-time = CR[i].request-packet * $PC_{GS_n}$;
            CR[i].retrieval-time = (CR[i].file-size * $RR_{GS_n}$) + $SKT_{GS_n}$;
    SORT(CR[]);
    while (time-line ≤ DP) do
    begin
        if((CR[counter].request-time +
            CR[counter].process-time +
            CR[counter].retrieval-time) ≤ DP)
                request-counter = request-counter + 1;
                if(CR[counter].request-time ≥ time-line)
                    time-line = CR[counter].request-time +
                                CR[counter].process-time +
                                CR[counter].retrieval-time;
                else
                    time-line = time-line +
                                CR[counter].request-time +
                                CR[counter].process-time +
                                CR[counter].retrieval-time;
        counter = counter + 1;
    end
    $SP_{GS_n}$ = request-counter ÷ R;
end
```

Figure 5.1: The Monte Carlo Simulation.

Chapter 6

i-CAD: Intranet Computer-Aided Design Tool

6.1 Background

The i-CAD tool consists of three main procedures: initial intranet generation, intranet validation and evaluation, and intranet selection and optimization, as depicted in Figure 6.1. The **initial intranet generation** procedure creates a population of initial intranet designs by selecting all network and data management hardware resources randomly. This procedure executes only one time. The **intranet validation and evaluation** procedure validates and evaluates each intranet design. The **intranet selection and optimization** procedure selects the fit intranet designs, modifies some and discards the rest. The second and third procedures execute many times until the intranet designer/planner is satisfied with the intranet integration cost (IIC) and all the design and performance constraints are met.

The rest of this chapter is organized into four sections. Section 6.2 gives an overview of the genetic algorithms and presents the some of the advantages of using genetic algorithms to search for intranet integration solutions. Section 6.3 describes in detail the implementation of the i-CAD tool, such as the chromosome representation, initial population, fitness function, selection mechanism, mutation operator, crossover operator, and termination condition. Section 6.4 describes four aspects

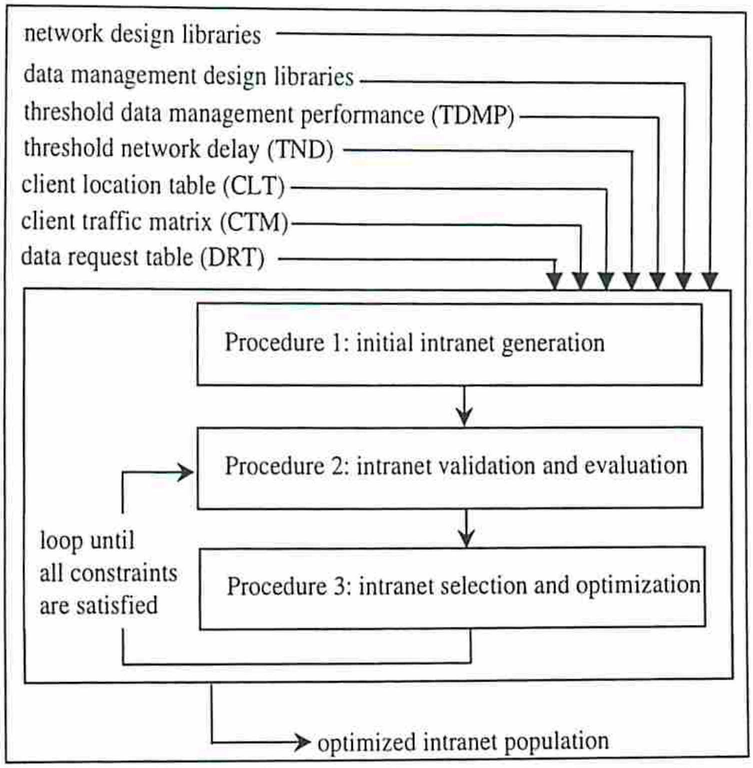


Figure 6.1: The overall structure of *i*-CAD tool.

that are considered within *i*-CAD to avoid inferior solutions while using genetic algorithms.

6.2 Overview of Genetic Algorithms

Genetic algorithms (GA) emulate the evolution process in nature [Mic94], as shown in Figure 6.2. The genetic algorithms start with an initial population **P(t=0)** of solutions encoded as *chromosomes* (line 3). An initial population is most often generated randomly but a heuristic can be used. Each chromosome is made of a sequence of *genes* and every gene controls the inheritance of specific attributes of the solution's characteristics. A fitness function in lines 4 and 11 measures the quality of the chromosome in terms of various design variables of the solution. A more fit chromosome suggests a better solution. The **while** loop in lines 5-12 represents the *evolution process*, where relatively fit designs reproduce new designs and inferior designs die. This process continues until a design with desirable fitness is found. Line 8 selects the best designs within the current generation based on their fitness values. These selected designs, known as *parents*, are used to reproduce the next generation of designs, known as *offspring*. The evolution process involves two genetic operations namely, *mutation* in line 9 and *crossover* in line 10. A mutation operator arbitrarily alters one or more genes of a randomly selected chromosome. The intuition behind the mutation operator is to introduce a missing feature in the population. A crossover operator combines features of two selected chromosomes (parents) to form two similar chromosomes (offspring) by swapping genes of the parent chromosomes. The intuition behind the crossover operator is to exchange information between different potential solutions.

```
Genetic Algorithm:
1       begin
2           t = 0;
3           initialize P(t);
4           evaluate P(t);
5           while (termination conditions are unsatisfied) do
6           begin
7               t = t + 1;
8               select P(t) from P(t-1);
9               mutate some of P(t);
10              crossover some of P(t);
11              evaluate P(t);
12          end
13      end
```

Figure 6.2: The structure of genetic algorithms.

6.2.1 Advantages of Genetic Algorithms

Genetic algorithms offer several advantages for a large design space problem such as the intranet integration problem. Genetic algorithms are very flexible, and a lot of its functions are a natural fit to our problem. These functions are the initial population generation, the selection mechanism, the crossover operator and the mutation operator, where there are many options on how to implement solutions.

Intuitively, genetic algorithms are suited to design problems since the process of evolution is similar to a real design process. In the early stage of the design process, the designer reviews a number of possible architectures and selects one that is believed to be the best (evaluation and selection), then the designer tries to improve the selected architecture by making a few changes (mutation). Also, the designer can try to design a better architecture by retaining the good characteristics of two designs (crossover).

Genetic algorithms emulate a design process that is suited for our problem by alternating between design and optimization processes. This is how a data management system and network architecture are designed in reality. For example, a designer places one server in a certain location and if it yields a good client-server performance, then there is no need to relocate the server. Otherwise, the designer either places a new server in a different location or relocates the old server in order to improve the client-server performance. As another example, a designer selects one type of a network hub in an *ad hoc* manner. If the selection yields a good network design, then there is no need to modify the network hub. Otherwise, the designer selects another choice, until a good design is produced.

Genetic algorithms can handle nonlinear constraints, while some other optimization techniques such as MILP cannot, and the constraints must be linearized. Genetic algorithms are capable of moving from one solution to another, which is significantly different from other techniques. This is called a *non-geometric* search, because it can avoid a local minima or maxima solution.

For the previous reason, many researchers would rather use genetic algorithms over simulated annealing, since the latter uses a geometric search technique. While the temperature is high, simulated annealing with a geometric search can avoid local minima or maxima. However, when the temperature is cooling down, then the search may get stuck in a local minimum or maximum. The concept of a non-geometric search can be illustrated in Figure 6.3. Genetic algorithms can avoid local minima solutions (dot-circles 1-2) and get possibly closer to global minima solution (dot-circle 3) by crossing two chromosomes from different regions of the design space. Also, genetic algorithms have been applied successfully to synthesize and optimize large design space problems like heterogeneous multiprocessor synthesis [TGP96], multi-chip system synthesis [Heo97] and others well-known problems [Mic94]. Genetic algorithms have been shown to find near-optimal solutions to these problems in shorter time than other optimal optimization techniques.

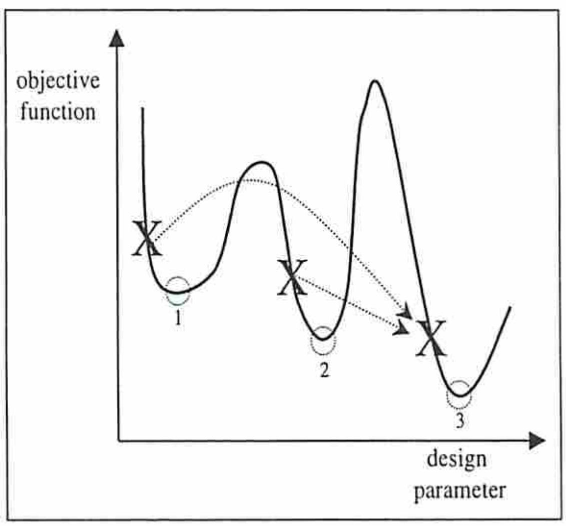


Figure 6.3: Searching the design space with genetic algorithms.

6.3 *i*-CAD Implementation

In order to apply genetic algorithms to the intranet integration optimization problem efficiently, we need to customize a genetic algorithm to work well with our problem. The overall framework of genetic algorithms is well-known; however, an improper implementation of a genetic algorithm can easily nullify its advantages. The primary difficulty comes from the complex structure (chromosome) of the intranet integration problem, which involves both data management system design and also network architecture design. The intranet chromosome encodes all application inputs, data management system design decisions and network architecture design decisions. The structural complexity of the intranet chromosome can affect the speed and the quality of the crossover and mutation outcomes.

In the next section, we detail the chromosome representation of an intranet, the initial population, the fitness of a chromosome, the selection mechanism, the mutation operator, the crossover operator, and the termination condition.

6.3.1 Chromosome Representation

Each design is represented by a single chromosome with a tree structure. Since we model an intranet application as a hierarchy of tasks, we selected a tree data structure to represent the intranet's tasks rather than classical encoding schemes such as a binary string, which requires a very long binary vector. This, in turn, generates complicated genetic mutation and crossover operators and a huge search space. The tree structure representation has three levels. The first level (root node) corresponds to the backbone task (BT). The second level corresponds to the set of site tasks (ST) within the backbone. The third level (leaf) corresponds to the set of group tasks (GT) within each site task. The tree representation is implemented in an object-oriented manner such that a tree is composed of hierarchically organized classes of objects at different abstraction levels, as depicted in Figure 6.4. This tree structure does not represent the intranet network topology.

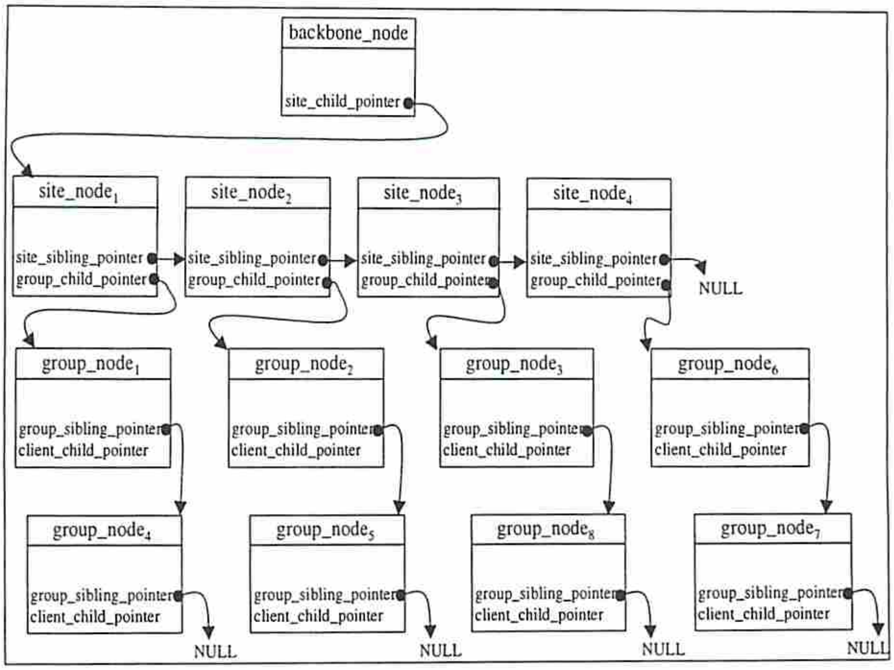


Figure 6.4: A tree representation of an intranet application in Figure 2.2.

Each node in the chromosome's tree is an instance of a class, and as shown in Figure 6.4 there are three types of classes: backbone, site and group. Each class instance contains specific input information and design decisions about the its task type. Although the genetic algorithm maintains a number of possible solutions (chromosomes) at each iteration, duplicating the chromosome's tree would not be efficient due to redundancy of similar data, such as the input information. To avoid such a costly duplication of the chromosome's tree, we use one chromosome's tree to represent the input information of all intranet's tasks, and embed a special array of pointers in each class instance to represent the data management and network design information for all candidate solutions in the population.

A backbone node contains an array of pointers to the population of backbone network designs, *b_net_pop[]*, as shown in Figure 6.5. Each entry in the array represents the backbone network of a chromosome in the population. *PS* is an integer number that is given by the designer to indicate the population size. There are four pointers in each entry of the array: *ethernet_ptr*, *atm_ptr*, *router_ptr*, and *tree_ptr* to four different instances of classes. These four pointers represents the possible network technologies that are available to connect all site networks within the backbone. Only one pointer out of the four backbone network technology pointers is valid for given candidate design, while the rest are pointing to null. A valid pointer points to a specific instance of network type, for example an *ethernet_ptr* points to an instance of an Ethernet network class which contains the attributes of the allocated Ethernet hub, as shown in Figure 6.5. This allocated Ethernet hub represents the backbone network design decision for one of the candidate solutions. Input information about the backbone is included within the backbone node. This information includes the inter-site traffic, the type of backbone (local or wide) and the data management traffic flow.

A site node contains an array of pointers to the population of site network designs, *s_net_pop[]*, as shown in Figure 6.6. Each entry in the array represents the site network of a design in the population. *PS* is an integer number that is given by the designer to indicate the population size. There are three pointers in each entry of the array: *ethernet_ptr*, *atm_ptr*, and *router_ptr* to three different instances of classes. These three pointers represent the possible network technologies that are available to connect all group networks within a site. Only one pointer out of the three site network technology pointers is valid for given candidate design, while the rest are pointing to null. A valid pointer points to a specific instance of network type, for example a *router_ptr* points to an instance of a router network class which contains the attributes of the allocated router, as shown in Figure 6.6. This allocated router represents the site network design decision for one of the candidate solutions. The

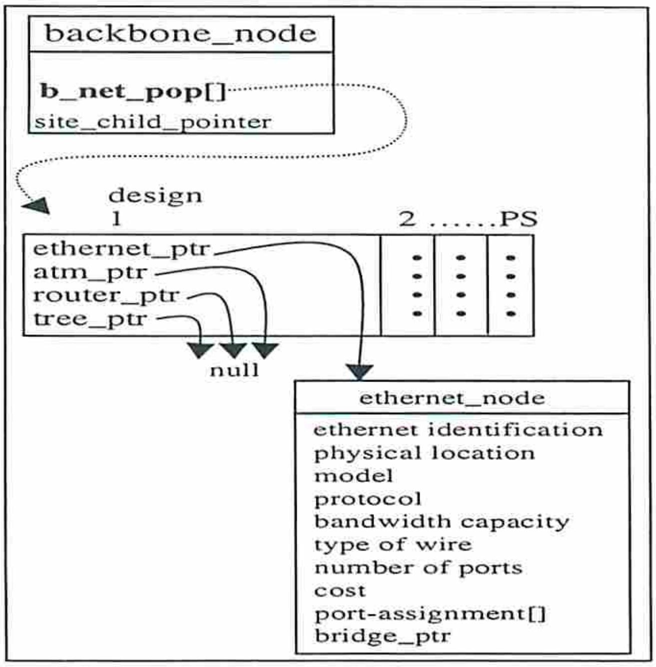


Figure 6.5: Embedded network design array for a backbone node.

site's input information is included within the site node. These inputs are the site's identification, the site traffic flow, and the data management traffic flow.

A group node contains two arrays of pointers to the population of group network designs and group data management designs: *g_net_pop[]* and *g_dm_pop[]* as shown in Figure 6.7. The array *g_net_pop[]* includes all network design decisions. Each entry in *g_net_pop[]* represents the group network of a design in the population. *PS* is an integer number that is given by the designer to indicate the population size. There are two pointers in each entry of the array: *ethernet_ptr*, and *atm_ptr* to two different instances of classes. These two pointers represents the possible network technologies that are available to connect all clients within a group. Only one pointer out of the two group network technology pointers is valid for given candidate design, while the other one is pointing to null. A valid pointer points to a specific instance of network type, for example an *atm_ptr* points to an instance of an ATM switch

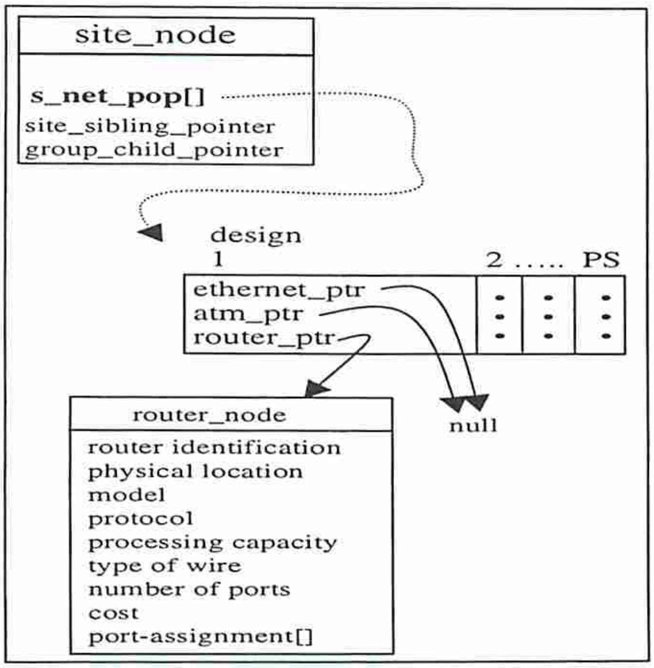


Figure 6.6: Embedded network design array for a site node.

network class which contains the attributes of the allocated ATM switch as shown in Figure 6.7. This allocated ATM switch represents the group network design decision for one of the candidate solutions. The array *g_dm_pop[]* includes all possible data management design decisions and each entry in *g_dm_pop[]* represents a design in the population. There is one pointer in each entry of the array: *server_ptr* to an instance of server class. *server_ptr* points either to a possible placement of servers for a given candidate design or null as shown in Figure 6.7. The input information for a group task includes the group's identification, the group traffic flow, the data management traffic flow, and the client linked list (pointed by *client_child_pointer*). Each node in the client linked list contains client's identification, client's location, client traffic flow, and pattern of requested files by the client.

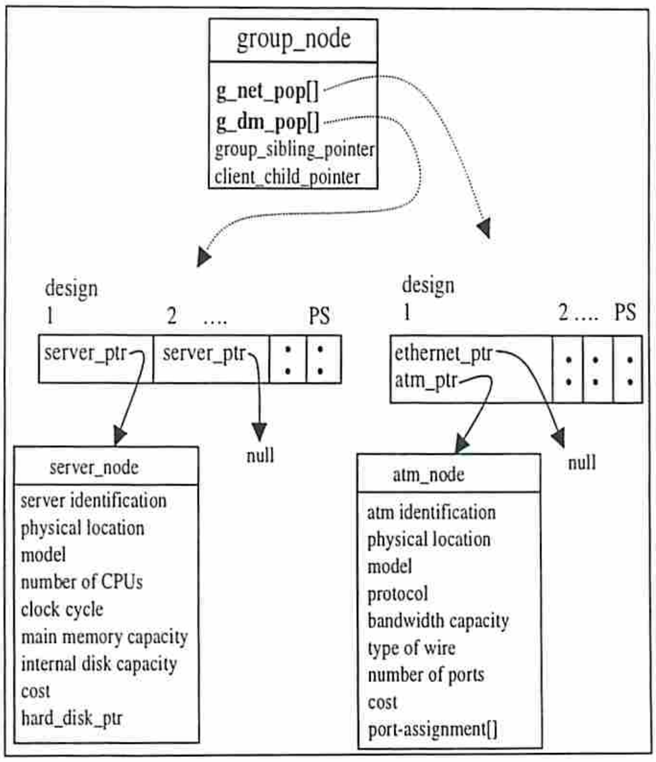


Figure 6.7: Embedded network and data management design arrays for a group node.

6.3.2 Initial Population

A genetic algorithm starts with a population of intranet infrastructures, PII(t=0) = $\{II_1^t, II_2^t, ..., II_i^t, ..., II_{PS}^t\}$. t represents the current generation number and PS represents the population size. This *initial population*, PII(t=0), represents the randomly synthesized intranet infrastructure solutions that will start the evolutionary process.

We developed a bottom-up randomized heuristic algorithm for generating valid intranet infrastructure solutions. The bottom-up algorithm consists of five procedures. The *first procedure* designs the data management system by allocating and binding data management hardware components for the group tasks in a solution. The *second procedure* designs the group network by allocating and binding a network hardware component for each group task within a design. All clients and a possible data management component within the group task are to be connected using the allocated group network connector. The *third procedure* designs the site network by allocating and binding a network hardware component for each site task within a candidate design. All group network components within a site are to be connected using either the allocated site network connector or the allocated site router. The *fourth procedure* designs either a local backbone network or a wide backbone network. For a local local backbone network, this procedure allocates and binds a network hardware component for the backbone task in a design, so that all site network components are connected to either the allocated backbone network connector or the allocated backbone router. For a wide backbone network, this procedure creates a tree topology to connect all site network components within the backbone task. The *fifth procedure* insures that the synthesized intranet infrastructure passes all design and performance constraints. Otherwise, procedures 1-4 are repeated until all the constraints of the intranet infrastructure design are met.

The bottom-up algorithm continues to run until all the initial intranet infrastructures (candidate designs) in the population are designed correctly. Also, the bottom-up algorithm insures the diversity of the initial population. For example, the bottom-up algorithm modifies Constraint 5.19 by comparing the average network delay (AND) to twice threshold network delay (TND). This creates a diverse population with high and low performance designs, which can help the genetic algorithm to converge to a good final design faster.

6.3.3 Fitness of A Chromosome

The fitness of an intranet design is measured by the intranet integration cost (IIC), as stated in Equation 4.30. The intranet integration cost (IIC) can be expressed as the sum of the network architecture cost (NAC) and the data management system cost (DMSC).

6.3.4 Selection Mechanism

The selection mechanism used in *i*-CAD is based on the *proportionate selection scheme* [Mic94]. The probability that an intranet infrastructure II_i^t will be selected for the next generation PII(t+1) has to satisfy the following constraint:

$$IIC(II_i^t) \leq \frac{\sum_{i=1}^{PS} IIC(II_i^t)}{PS} \tag{6.1}$$

Constraint 6.1 insures that the total intranet integration cost IIC() of an intranet infrastructure II_i^t to be selected has to be less than or equal to the average cost of the whole population. IIC() is the fitness function as described in Equation 4.30. II_i^t represents the identification of the ith intranet infrastructure design during the tth generation. PS is an integer number that is given by the designer to indicate the population size.

6.3.5 Mutation Operator

The mutation operator performs unary transformations by changing a single gene in the intranet infrastructure chromosome. There are six types of genes in the intranet chromosome that can be randomly selected for mutation, as shown in Figure 6.8. The flow diagram illustrates all six gene mutations: group network, site network, local backbone network, wide backbone network, group server and hard disk. The number of designs to be selected for mutation depends on the *mutation rate*, MR. This mutation rate indicates the probability of selecting chromosomes within a given population size, and it is a real number given by the designer. The mutation operator performs only one type of gene mutation during a generation, so that its effect can be examined more clearly to determine whether it improves the fitness of these candidate solutions or not.

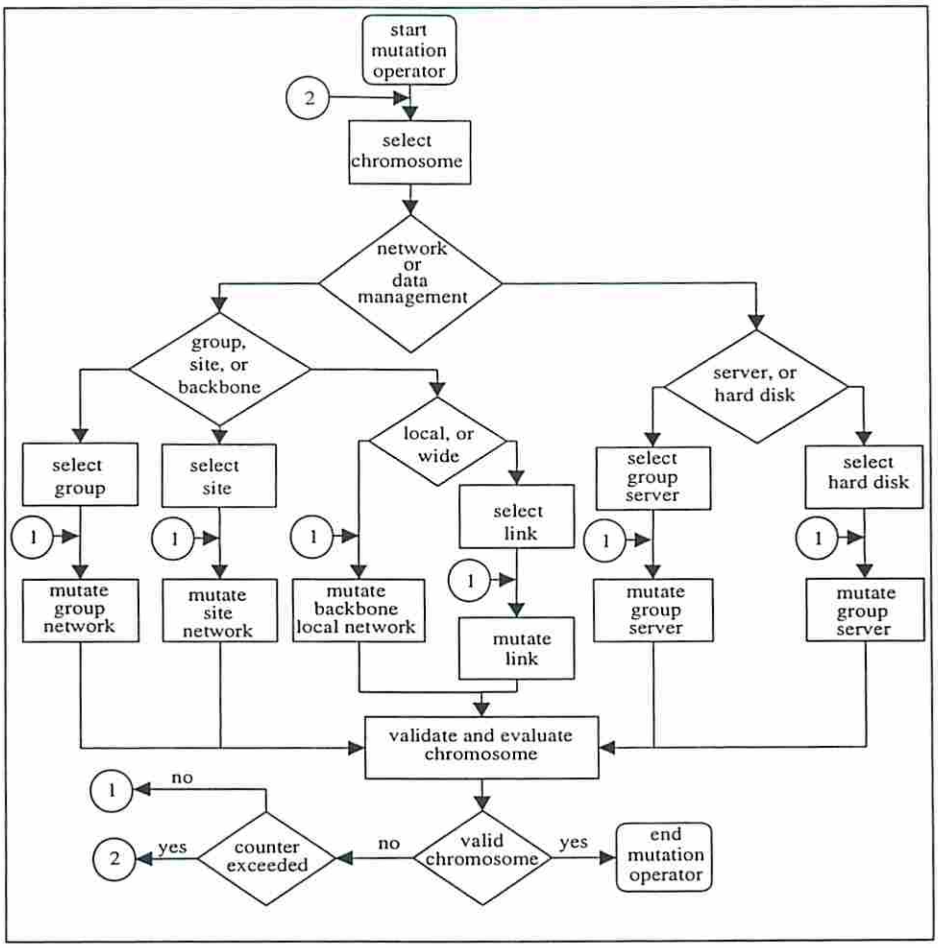


Figure 6.8: Flow diagram for the mutation operator.

The mutation operator starts by selecting a candidate design from the population randomly. During a generation, the mutation operator performs either a network mutation or a data management mutation. The case selection is determined randomly. In either case, a gene is selected and its hardware component is replaced by a new one. Then, the mutated chromosome is examined to see if it has violated any design or performance constraints. If it does violate any constraint, then the mutation operator repeats the same gene mutation, as indicated by the circled 1 in the flow diagram. The mutation operator tries to insure that the new offspring is a valid design. Otherwise, it selects another chromosome as indicated by the circled 2 in the flow diagram.

6.3.6 Crossover Operator

The crossover operator performs higher order transformations by exchanging parts from two "good" intranet solutions (parent) to replace two "bad" intranet solutions with offspring. Based on the selection mechanism and *crossover rate*, the intranet population is divided into two sets. This crossover rate indicates the probability of selecting solutions to crossover. The crossover rate is a real number given by the designer. The "good" set contains all intranet designs that satisfy all design and performance constraints. The costs of these designs are equal to or less than the average cost of the entire population as stated in Equation 6.1. The "bad" set contains all intranet designs that may satisfy all design and performance constraints but their costs are greater than the average cost of the entire population as stated in Equation 6.1.

A purely random crossover that mixes the network or data management genes from different levels (such as site and backbone, site and group or group and backbone) in an arbitrary fashion is not appropriate. For example, crossing a backbone level with a group level or vice versa leads to a lot of network and data management design violations. The network violation occurs due to the different sets of network constraints and network technology options that are defined for a backbone network, as stated in Section 4.2.3, and a group network, as stated in Section 4.2.1. The data management violation occurs due to the restriction of placing servers only at the group level, where a server is not allowed to be placed at the backbone task. Similar violations may occur when a group level is crossed with a site level or a site level is crossed with a backbone level. Because a purely random crossover violates the design constraints at each level that may generate a large number of invalid intranet designs. To repair all the invalid designs generated by a purely random crossover operator, this will be a complex task due to the large number of constraints that are involved. Also, the time to repair all invalid designs may be intolerably long. Therefore, we consider a more intelligent crossover operator that mixes the genes at the same level only, as shown in Figure 6.9.

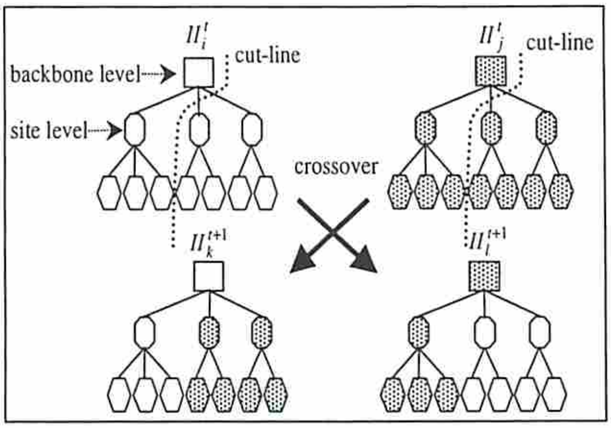


Figure 6.9: One possible example of a crossover.

Our crossover operator starts by selecting two offspring chromosomes randomly from the pool of the non-selected chromosomes, as shown in Figure 6.10. Next, two parent chromosomes are selected randomly from the pool of the selected chromosomes. To perform the crossover operation on the two parent chromosomes, two cuts are needed, one at the backbone level and one at the site level. Let II_i^t and II_j^t be the chromosome tree representations of two intranet infrastructures and let II_k^{t+1} and II_l^{t+1} be the chromosome tree representations of the new offspring intranet infrastructures. Figure 6.9 depicts one possible cut between II_i^t and II_j^t out of many possibilities.

The *first cut* depends on the type of backbone network topology: local star or wide tree. If it is a local star topology, then crossing the two backbone network components (parent) is manageable. At random, one of the parent's backbone network components is assigned to one of the offspring's backbone network component, and the other parent's backbone network component is assigned to the other offspring's

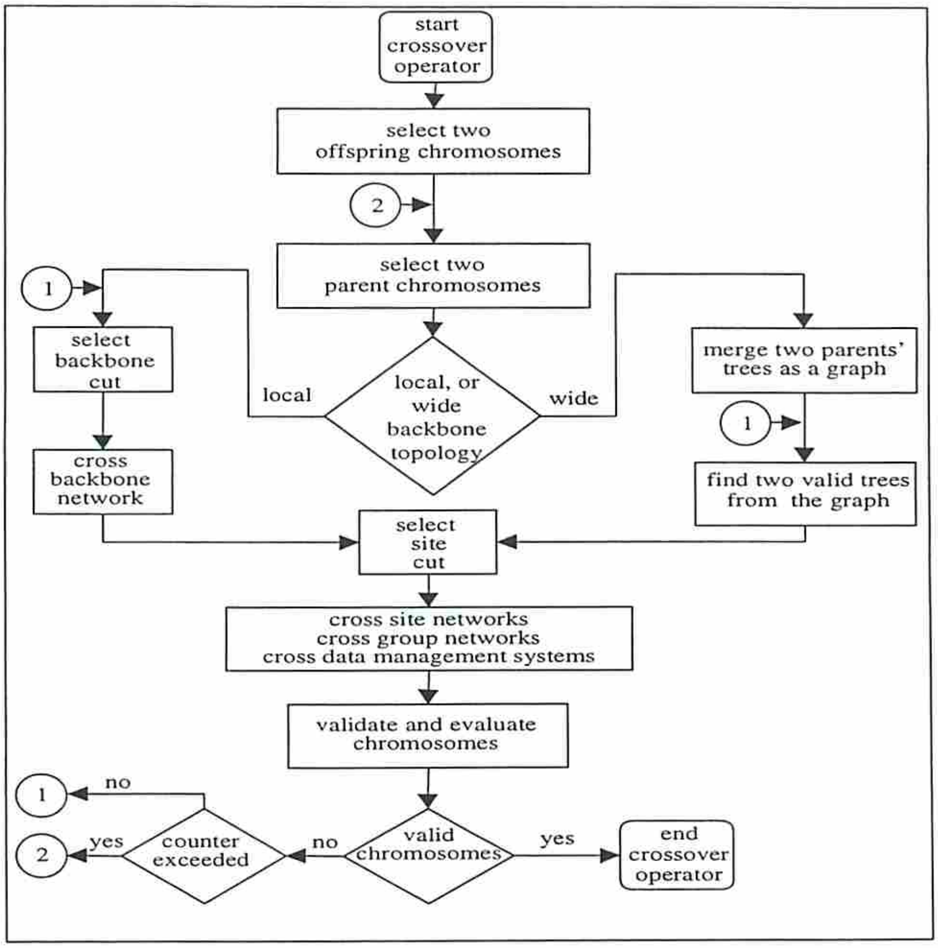


Figure 6.10: Flow diagram for the crossover operator.

backbone network component (simple swap). Otherwise, if the backbone network topology is a wide tree topology, then crossing the two backbone networks (parent) is more complicated. The problem of crossing two valid tree topologies (parent) and producing two valid tree topologies (offspring) is an open complex problem, as indicated by the following research papers [ASW94, ASW95, DAS97b, DAS97a, Che97, LLX98, ZL99, KC00]. These papers suggest several approaches in using genetic algorithm to design a tree topology network. One of these suggestions [ASW94, Che97] is not to use a crossover operator and only use a mutation operator to avoid all the repairs. The other papers suggest several crossover heuristic algorithms with several cut points, for example. In our problem, we develop a procedure to merge the two parent trees as one graph, and then find two valid trees from the graph to be considered for the offspring's backbone networks.

The *second cut* is performed at the site level. If the number of site tasks is even, then the cut happens at the middle. Otherwise, the site tasks are divided into two sets, one set is larger than the other one by one. Then, all site networks, group network and data management systems are crossed, the new offspring chromosomes are validated and evaluated. If the new offspring chromosomes satisfy all design and performance constraints, then the crossover operator stops. Otherwise, the crossover operator tries several crosses between the same parent chromosomes as indicated by the circled 1, before it selects new parent chromosomes as indicated by circled 2.

6.3.7 Termination Condition

The *maximum generation limit* is the termination condition used within *i*-CAD. This limit sets an upper bound on the number of generations (NG), given as an integer. *i*-CAD repeats the optimization loop until the generation counter reaches its upper limit.

6.4 Avoiding Sub-Optimal Solutions

To avoid converging prematurely to sub-optimal solutions, either local minima or maxima, we are aware of four aspects of genetic algorithm (GA) that can help us resolve such a problem. The first aspect is the coding of the problem. Although the overall framework of GA is well-known, an inappropriate implementation of GA for a problem can easily nullify the advantages of GA. The primary difficulty comes from the representation of the solution intranet infrastructure. The binary representation traditionally used in GA has some drawbacks when applied to multidimensional problems, since it requires a very long binary solution vector. This, in turn, generates complicated genetic operators and a huge search space. Thus, we encode each solution as a tree data structure, which gives us a better representation of the network and data management hardware infrastructure than a binary representation. The second aspect is the initial population generation. Because of the complexity of our problem, we develop techniques to create the initial population and insure its diversity. This, in turn, converges to a good solution faster. The third aspect is the selection process. We monitor the member selection process so that the population diversity is consistent for each generation and the best member of each generation is preserved. An increase in the selective pressure decreases the diversity of the population, and vice versa. This, in turn, generates an improved new generation in every iteration of GA. The fourth aspect is the number of generations. This number reflects the iteration of the selection and optimization task, which should either produce better solutions or retain the same solutions. Therefore, we try to experiment with a set of large numbers that can avoid premature convergence and at the same time reduce the number of cycles of design. Designs produced using the genetic algorithm are presented in the following chapter.

Chapter 7

Experimental Results

7.1 Background

In our experiments we considered two intranet integration problems: a **partial animation production studio** and a **full animation production studio.** *i*-CAD automatically integrated data management systems and network architectures for both these problems. Although the examples are specific to our model of a typical animation production studio, the *i*-CAD code is generic, and can design intranets in any application domain that is data intensive.

This chapter is organized into three sections. Section 7.2 contains the results of two experiments that concentrated on designing optimized network architectures for a partial animation studio intranet. Section 7.3 contains the results of two experiments involving the design of combined optimized data management systems and network architectures for the partial animation studio intranet. Section 7.4 contains the results of two experiments concerning the design of optimized data management systems and also network architectures for the full animation studio intranet.

The results of the six experiments were generated by *i*-CAD, which was implemented in C++. The software contains about 22,000 lines of code. The purpose of these experiments was first to show that automatic intranet synthesis and integration is feasible, second to observe the optimization process, and last to observe the trade-off between cost and performance.

7.2 A Partial Animation Studio: Network Design

The partial animation studio example consists of four site tasks, eight group tasks and 65 client tasks, as shown in Figure 2.2. The goal here is to design a three-level network architecture that enables all 65 client tasks (performed on 65 workstations) to perform their tasks while satisfying all design and performance constraints. Table 7.1 provides information about the clients and groups in the intranet.

Table 7.1: Client and group clustering information.

Site Task (ST)	Group Task (GT)	Client Task (CT)
1	1	1-10
	4	11-15
2	2	16-20
	5	21-30
3	6	51-57
	7	58-65
4	3	31-40
	8	41-50

The traffic flow within a group or site is summarized by three parameters: local traffic, outgoing traffic and incoming traffic, all of which are calculated from the client traffic matrix (CTM). The local traffic represents all the traffic flow within a task. The outgoing traffic represents all the traffic flow leaving a task to all other tasks. The incoming traffic represents all the traffic flow coming into a task from all other tasks. Table 7.2 shows a possible traffic flow assignment, where the traffic flow is measured in megabits per second (Mbps).

Table 7.2: Traffic flow among site and group tasks.

Task	Local Traffic (Mbps)	Outgoing Traffic (Mbps)	Incoming Traffic (Mbps)
site task 1	0.0	55.625	2.5
site task 2	0.0	15.0	21.25
site task 3	0.0	15.0	33.75
site task 4	4.2	7.5	35.625
group task 1	27.0	7.5	0.0
group task 2	2.0	2.5	2.5
group task 3	9.0	15.0	7.5
group task 4	8.0	48.125	2.5
group task 5	9.0	12.5	18.75
group task 6	4.2	7.7	16.625
group task 7	5.6	4.0	23.2
group task 8	9.0	0.0	26.25

The traffic flow within the backbone task can be summarized by one parameter (backbone local traffic, BLOT) or site traffic matrix (STM) depending on which topology is used. For a local star topology, the backbone local traffic (BLOT) represents all the traffic flow between all sites. For our example, BLOT is equal to 93.125 Mbps. For a wide tree topology, a site-to-site traffic flow is needed to determine each link's capacity. Table 7.3 shows a possible site traffic matrix (STM). Each entry in the STM, $ST_{i,j}$, represents the traffic flow from site task i to site task j. The value $ST_{i,j}$ is measured in megabits per second (Mbps). The site traffic matrix is not symmetric and is based on the data flow within the task flow graph.

7.2.1 Experiment 1: Partial Animation Studio with Local Backbone Topology

In this experiment we present the results of designing optimized three-level network architectures, where all four sites are located within a studio lot. Thus, the backbone

Table 7.3: A site traffic matrix (STM).

	site task 1	site task 2	site task 3	site task 4
site task 1	0.0	16.25	18.75	20.625
site task 2	0.0	0.0	7.5	7.5
site task 3	2.5	5.0	0.0	7.5
site task 4	0.0	0.0	7.5	0.0

network is a local star topology. The goal is to synthesize a communication network to enable all tasks to be performed in order and within a delay bound. We ran *i*-CAD with several threshold network delays (TND) ranging from five seconds to one minute. In addition, we used the following parameters: population size (PS) = 250, number of generations (NG) = 3000, mutation rate (MR) = 0.05, and crossover rate (CR) = 0.80. Figures 7.1 and 7.2 show two plots of the same three-level network design problem with two different TND values: 60.0 and 5.0 seconds respectively. The plot in Figure 7.1 depicts three curves:

1. The *average design cost curve (TND = 60.0 seconds)* represents the average 3-level network design cost of the entire network design population for one generation, where TND is equal to 60.0 seconds.

2. The *best design cost per generation curve (TND = 60.0 seconds)* represents the lowest 3-level network design cost from the entire network design population for one generation, where TND is equal to 60.0 seconds.

3. The *best design overall* represents the lowest 3-level network design cost since the beginning of the optimization process.

These three curves demonstrate the optimization process. For example the cost of the initial best 3-level network design, when TND is equal to 60.0 seconds, is \$332,430.25. During 2.24 minutes of total run time, *i*-CAD found a design costing \$78,960.13, which is four times lower in cost than the initial best design. In a second

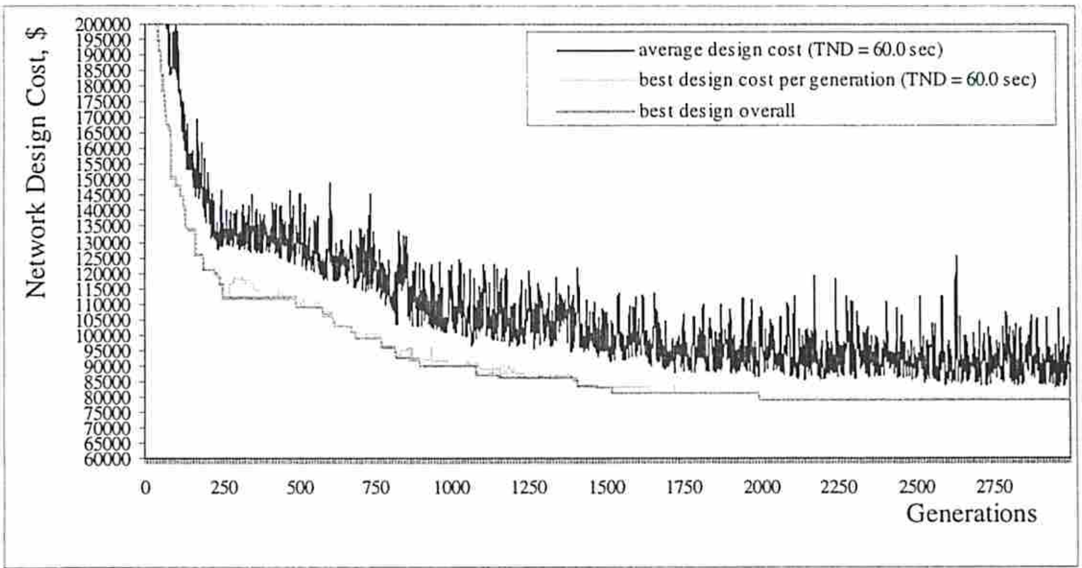


Figure 7.1: Optimization process for 3-level network design with TND = 60.0 seconds.

example as depicted by the three curves in Figure 7.2, the cost of the initial best 3-level network design, when TND is equal to 5.0 seconds, is \$533,531.13. During 2.46 minutes of total run time, *i*-CAD found a design costing \$167,815.00, which is three times lower in cost than initial best design. The three curves in Figure 7.2 represent the following:

1. The *average design cost curve (TND = 5.0 seconds)* represents the average 3-level network design cost of the entire network design population for one generation, where TND is equal to 5.0 seconds.

2. The *best design cost per generation curve (TND = 5.0 seconds)* represents the lowest 3-level network design cost from the entire network design population for one generation, where TND is equal to 5.0 seconds.

3. The *best design overall* represents the lowest 3-level network design cost since the beginning of the optimization process.

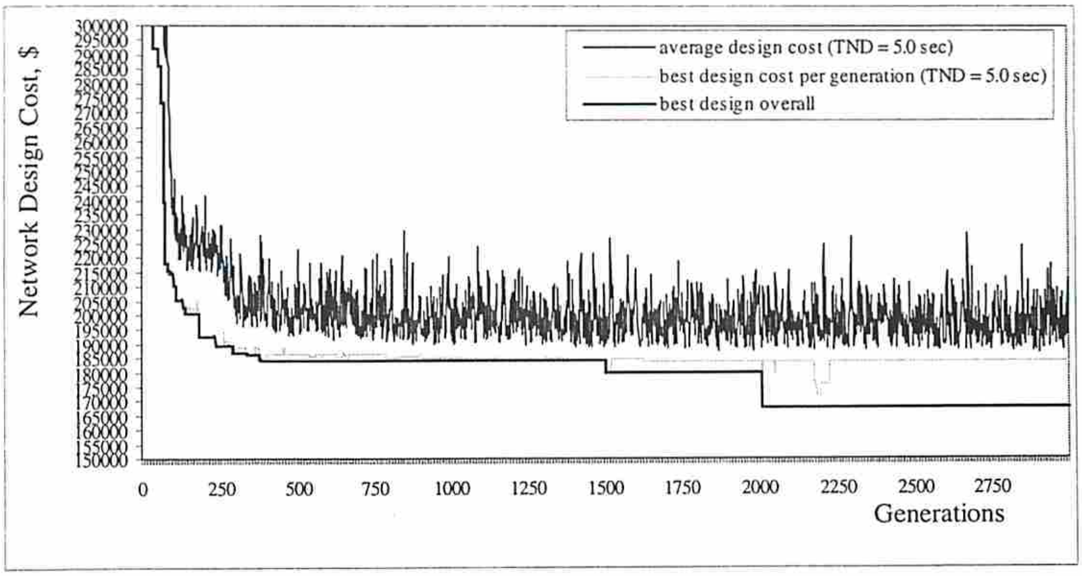


Figure 7.2: Optimization process for 3-level network design with TND = 5.0 seconds.

The different design decisions that are made by *i*-CAD for a three-level network when TND is varied from 60.0 seconds to 5.0 seconds are illustrated in Figures 7.3 and 7.4 respectively. For example, for site task one (ST_1), there are three network resources that must be allocated and bound to two group tasks (GT_1 and GT_4) and the site task (ST_1). To reduce the total network components' delay from 60.0 seconds to 5.0 seconds, different network components must be replaced. In this case all the network components are replaced so that the new TND can be satisfied. When *i*-CAD replaces a network component, it not only changes certain attributes such as bandwidth, number of ports, and cost. *i*-CAD deletes the old network component and allocates and binds a new network component.

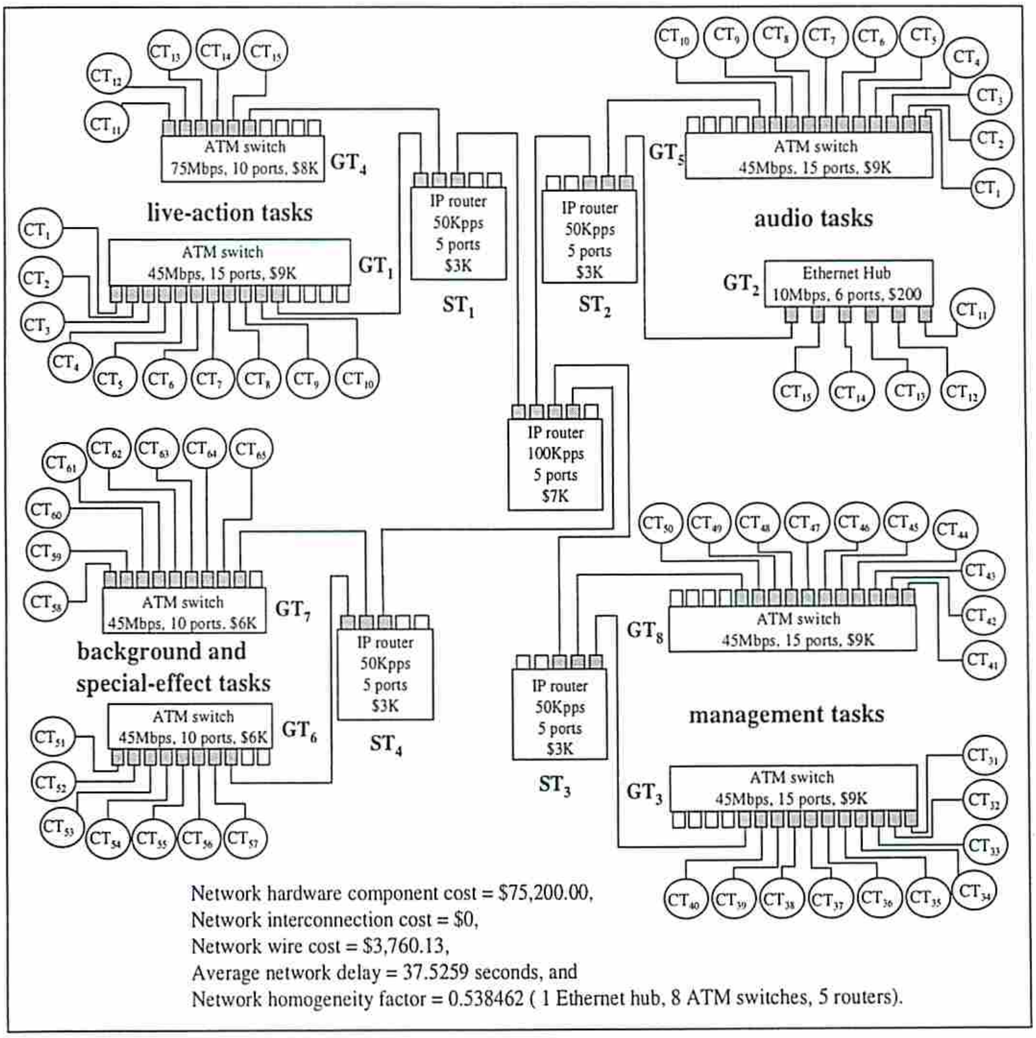


Figure 7.3: A 3-level network for partial animation studio intranet (TND = 60.0 seconds).

The network *homogeneity factor* (HF) is an output parameter in the range (0,1.0]; HF = 1.0 indicates that all the allocated network hardware components are based on the same technology. Otherwise, HF indicates the ratio of the maximum number of allocated network technology components of the same technology over the total allocated network hardware components within the intranet.

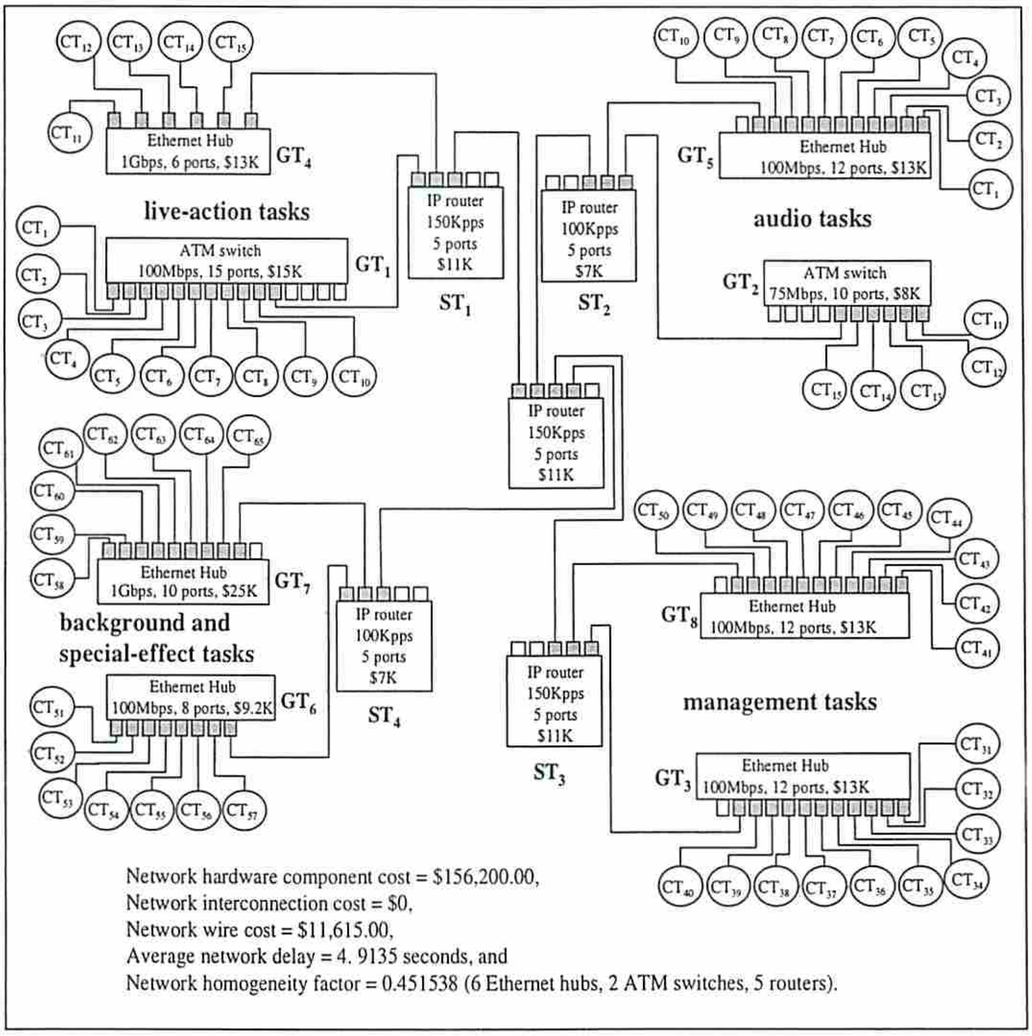


Figure 7.4: A 3-level network for partial animation studio intranet (TND = 5.0 seconds).

Comparing the outcomes of *i*-CAD for this experiment with hand-computed designs is shown in Table 7.4, where each of the 3 hand-computed designs satisfies certain constraints. The first design satisfies only the *connectivity* constraint, where all allocated and bound network components have the lowest cost and at the same time they have sufficient number of ports to connect all workstations within a group, all groups within a site and all sites within the backbone. This design costs $3400.00, but it has an infinite network delay. The second design satisfies both the *connectivity and capacity* constraints, where all allocated and bound network components have sufficient number of ports and communication bandwidth to satisfy all groups', sites' and backbone' ports and traffic flow. This design costs $75200.00 with a 37.525 seconds network delay, and was also found by *i*-CAD as the best 3-level network design when TND is set to 60.0 seconds. The third design, in Table 7.4, satisfies both the connectivity and capacity constraints, with all the allocated and bound network components having the highest communication bandwidth available in the network design libraries. Details of the design libraries are found in Appendix B.

Table 7.4: Hand-computed 3-level network designs.

Design Number	Type of Design	Component and Interconnection Costs, $	Average Network Delay, seconds
1	connectivity	3,400.00	∞
2	connectivity and capacity	75,200.00	37.525
3	connectivity with highest performance	629,000.00	0.830

The relationship between the network design cost and the threshold network delay (TND) can be shown in Figure 7.5. The seven points in the plot represent seven network designs with TND set to 5.0, 10.0, 20.0, 30.0, 40.0, 50.0 and 60.0 seconds respectively. The 3-level network design cost is reduced by more than half, from \$167,815.00 to \$78,960.10, when TND increases from 5.0 seconds to 60.0 seconds. This plot illustrates the inverse relationship between the network cost and delay. Details of the designs are found in Appendix A.

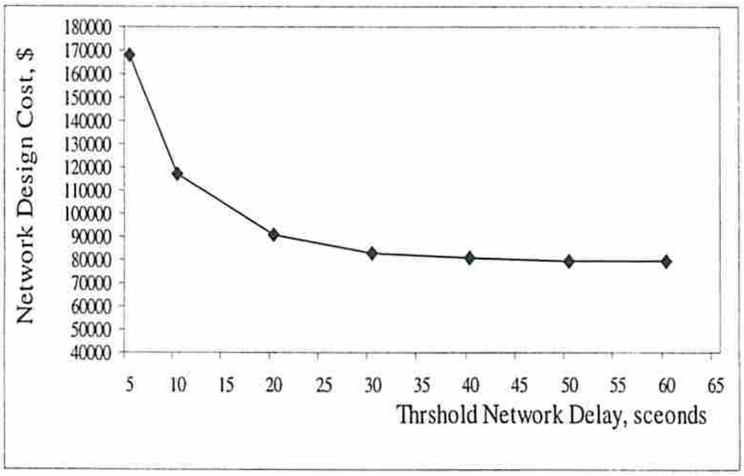


Figure 7.5: Network design cost versus threshold network delay.

The run-time of this experiment is shown in Table 7.5, when *i*-CAD is executed on a shared SUN Enterprise server E4500/E5500. The first column, *Threshold Network Delay*, is an input to the tool, and the rest of the columns are measured by *i*-CAD using the C++ library function, **clock()**. This function returns the processor time used by the program since the beginning of execution. Each row in the run-time table reflects an average of *ten* runs by *i*-CAD. The table shows the measured times to perform all the initial network designs, the crossover operation over all generations, and the mutation operation over all generations. The last column indicates the time that took *i*-CAD to design and optimize three-level network architectures for this experiment.

Table 7.5: *i*-CAD run-time for Experiment 1.

Threshold Network Delay in seconds	Initial Design Time in seconds	Crossover Operation Time in seconds	Mutation Operation Time in seconds	Total Run Time in seconds
60.0	2.59	12.50	26.96	134.54
50.0	2.54	12.49	27.16	134.93
40.0	2.56	12.42	27.39	135.05
30.0	2.56	12.45	27.96	136.33
20.0	2.57	12.54	28.56	135.54
10.0	2.96	12.55	30.78	140.03
5.0	4.29	12.69	37.47	147.84

7.2.2 Experiment 2: Partial Animation Studio with Wide Backbone Topology

In this experiment we present the results of designing optimized three-level network architectures, where all four sites are located in Southern California, United States. The first site task (live-action) is located in Burbank, the second site task (audio) is located in Pasadena, the third site task (management) is located in Hollywood and the fourth site task (background and special-effect) is located in Santa Monica. Figure 7.6 depicts a map of the Los Angeles basin and distance chart between the four sites in miles.

The objective is to synthesize a 3-level network, where the backbone network is constrained to a tree topology that must allow all site tasks to communicate with each other according to the site traffic matrix (STM) while satisfying some design and performance requirements. The tree topology has two cost functions: initial cost (IC) and monthly cost (MC). The initial cost refers to the total cost of network and interconnection components that are needed to connect all sites. This cost is considered once. The monthly cost refers to total monthly subscription fee for operating and maintaining such a tree topology network. We ran the *i*-CAD

Distance chart between the four sites in miles.

	Burbank site 1	Pasadena site 2	Hollywood site 3	Santa Monica site 4
Burbank site 1	0.0	10.0	8.0	18.0
Pasadena site 2	10.0	0.0	12.0	22.0
Hollywood site 3	8.0	12.0	0.0	10.0
Santa Monica site 4	18.0	22.0	10.0	0.0

Figure 7.6: Locations of the four site tasks within the City of Los Angeles, California, USA.

tool with several threshold network delays (TND) ranging from six seconds to one minute. In addition, we used the following parameters: population size (PS) = 250, number of generations (NG) = 3000, mutation rate (MR) = 0.05, and crossover rate (CR) = 0.80. Figures 7.7 and 7.8 show two plots of the same network design problem with two different TND values: 60.0 and 6.0 seconds respectively. The plot in Figure 7.7 depicts three curves:

1. The *average design cost curve (TND = 60.0 seconds)* represents the average 3-level network design cost of the entire network design population for one generation (including a 12-month lease for a tree topology connecting the four sites), when TND is equal to 60.0 seconds.

2. The *best design cost per generation curve (TND = 60.0 seconds)* represents the lowest 3-level network design cost from the entire network design population for one generation (including a 12-month lease for a tree topology connecting the four sites), when TND is equal to 60.0 seconds.

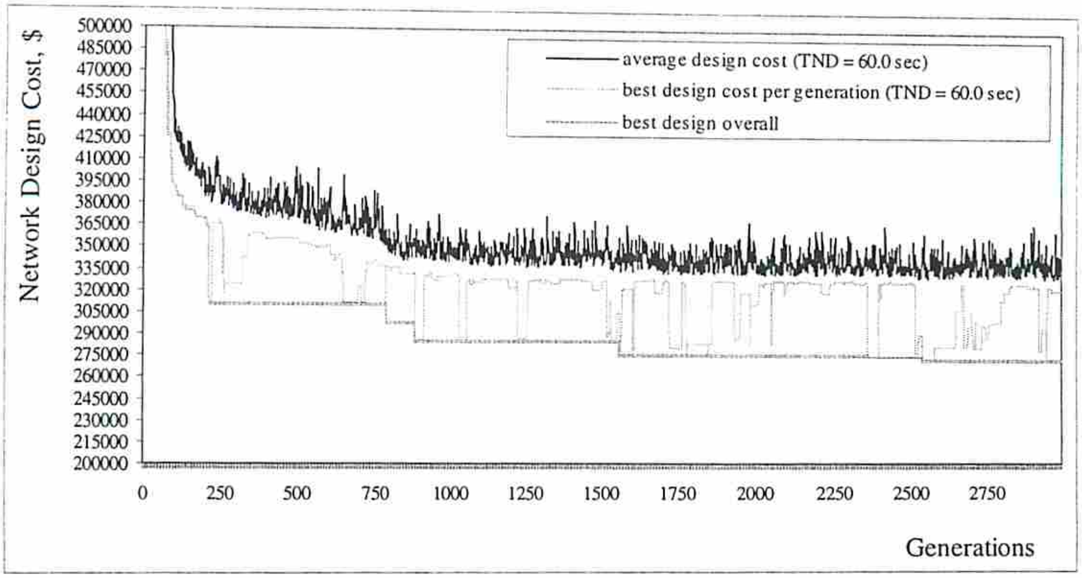


Figure 7.7: Optimization process for 3-level network design with a tree backbone topology when TDN = 60.0 seconds.

3. The *best design overall* represents the lowest 3-level network design cost with a tree backbone topology since the beginning of the optimization process.

These three curves demonstrate the optimization process. For example, the cost of the initial best 3-level network design, when TND is equal to 60.0 seconds, is \$753,702.19. During 2.50 minutes of total run time, *i*-CAD found a design costing \$272,261.31, which is about three times lower in cost than the initial best design. In the second example as depicted in Figure 7.8, the cost of the initial best 3-level network design, when TND is equal to 6.0 seconds, is \$1,406,604.63. During 3.08 minutes of total run time, *i*-CAD found a design costing \$666,357.20, which is two times lower in cost than initial best design.

1. The *average design cost curve (TND = 6.0 seconds)* represents the average 3-level network design cost of the entire network design population for one generation (including a 12-month lease for a tree topology connecting the four sites), when TND is equal to 6.0 seconds.

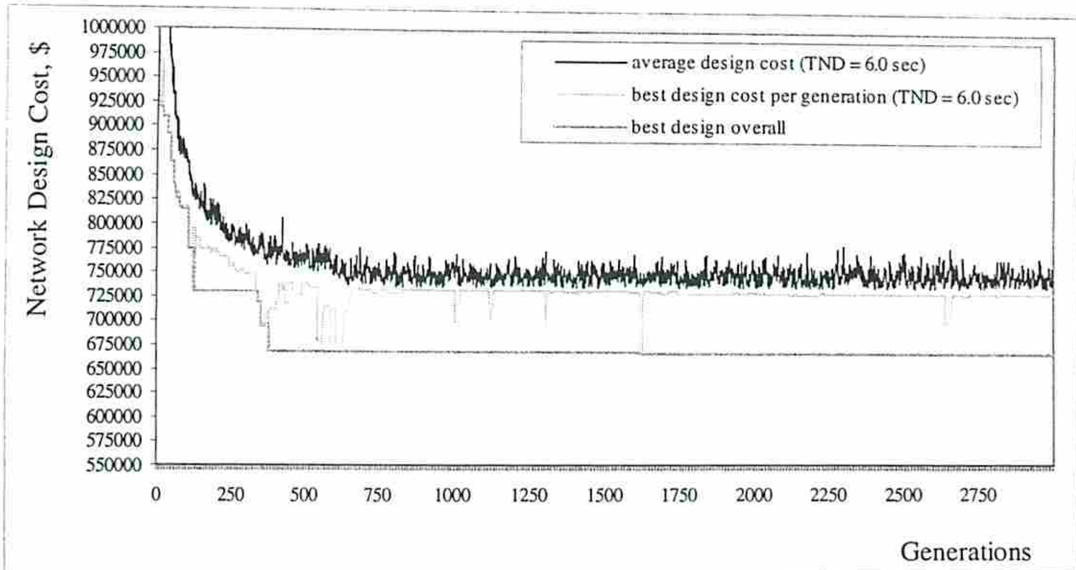


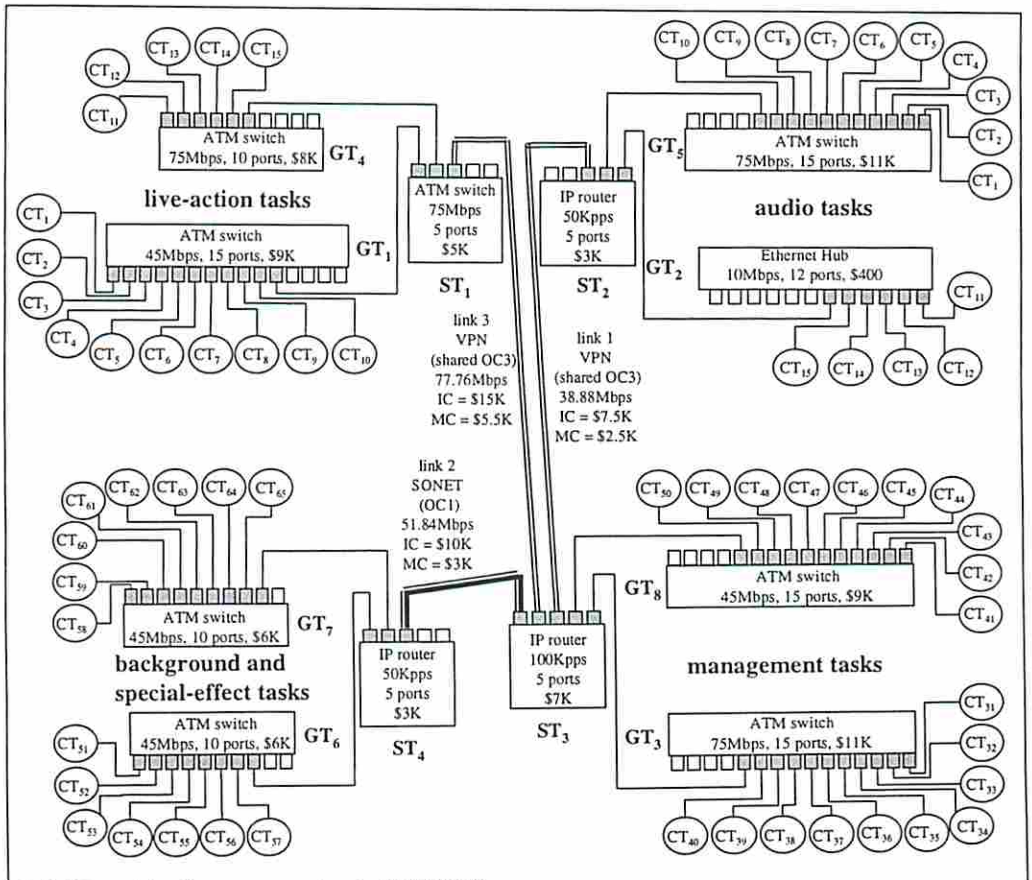
Figure 7.8: Optimization process for 3-level network design with a tree backbone topology when TDN = 6.0 seconds.

2. The *best design cost per generation curve (TND = 6.0 seconds)* represents the lowest 3-level network design cost from the entire network design population for one generation (including a 12-month lease for a tree topology connecting the four sites), when TND is equal to 6.0 seconds.

3. The *best design overall* represents the lowest 3-level network design cost with a tree backbone topology since the beginning of the optimization process.

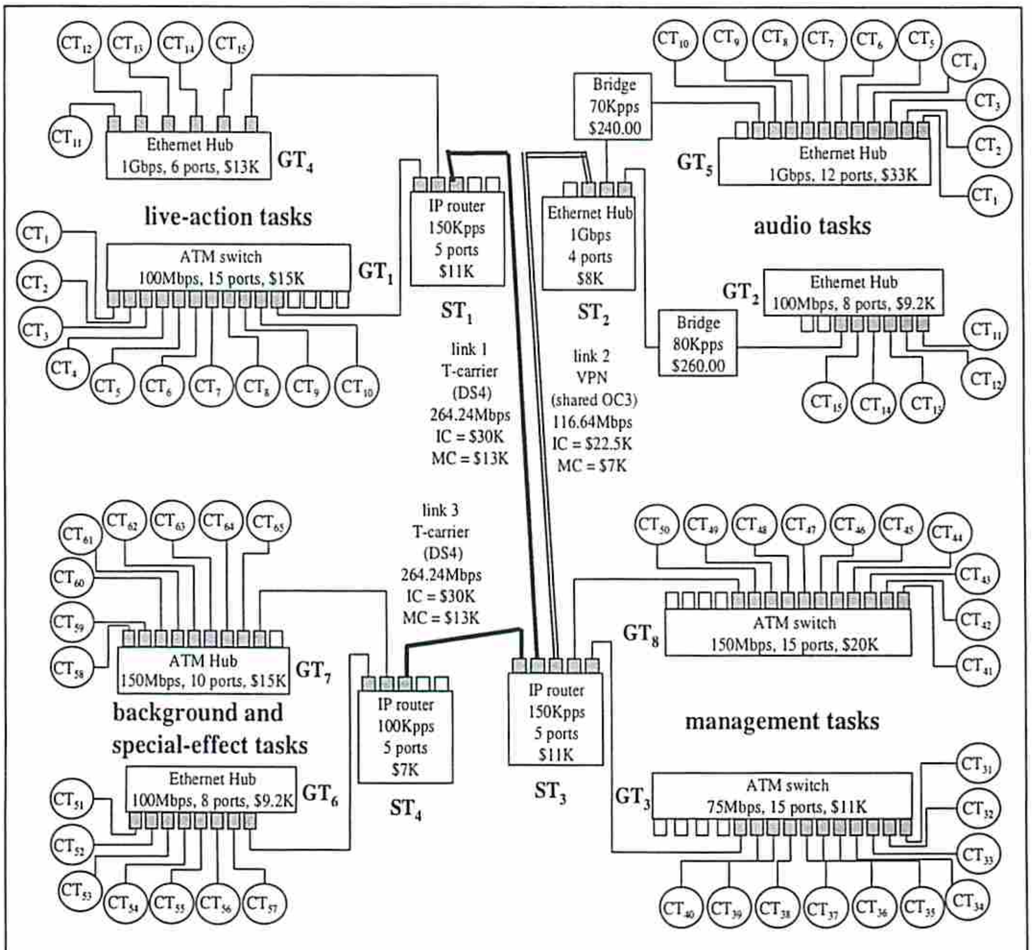
The different designs that are produced by *i*-CAD when TND is varied from 60.0 seconds to 6.0 seconds are shown in Figures 7.10 and 7.11 respectively. To connect four site tasks as a tree, there are three links that must be allocated and bound to connect all sites. To reduce the total network components' delay from 60.0 seconds to 6.0 seconds, all the link types are replaced to satisfy the new TND.

The relationship between the network design cost and the threshold network delay (TND) can be shown in Figure 7.9. The eight points in the plot represent eight network designs with TND set to 6.0, 7.5, 10.0, 20.0, 30.0, 40.0, 50.0 and 60.0



Initial Network hardware component cost = $110,900.00,
Monthly Network cost (12-month lease) = $132,200.00,
Network interconnection cost = $26,000.00,
Network wire cost = $3,561.31,
Average network delay = 48.8868 seconds, and
Network homogeneity factor = 0.53333 (1 Ethernet hub, 8 ATM switches, 3 routers, 2 VPN links, 1 SONET link).

Figure 7.10: A partial animation studio intranet (TND = 60.0 seconds).



Initial Network hardware component cost = $245,400.00,
Monthly Network cost (12-month lease) = $396, 000.00,
Network interconnection cost = $10,000.00,
Network wire cost = $14,957.20,
Average network delay = 5.98882 seconds, and
Network homogeneity factor = 0.33333 (5 Ethernet hubs, 4 ATM switches, 3 routers, 1 VPN link, 2 T-carrier links).

Figure 7.11: A partial animation studio intranet (TND = 6.0 seconds).

The run-time of this experiment is shown in Table 7.6, when *i*-CAD is executed on a shared SUN Enterprise server E4500/E5500. The first column, *Threshold Network Delay*, is an input to the tool, and the rest of the columns are measured by *i*-CAD using the C++ library function, **clock()**. Each row in the run-time table reflects an average of *ten* runs by *i*-CAD. The table shows the measured times to perform all the initial network designs, the crossover operation over all generations, and the mutation operation over all generations. The last column indicates the time that took *i*-CAD to design and optimize the three-level network architectures for this experiment.

Table 7.6: *i*-CAD run-time for Experiment 2.

Threshold Network Delay in seconds	Initial Design Time in seconds	Crossover Operation Time in seconds	Mutation Operation Time in seconds	Total Run Time in seconds
60.0	2.80	26.63	29.02	170.45
50.0	2.94	30.32	29.46	172.24
40.0	2.84	30.55	29.91	173.07
30.0	2.91	30.88	28.84	172.16
20.0	3.21	29.41	30.01	172.77
10.0	3.53	30.37	33.37	177.30
7.5	3.75	25.27	44.27	190.99
6.0	4.70	26.20	42.03	187.99

7.3 Complete Intranet Integration for A Partial Animation Studio

In this section we present the results of two experiments. The first experiment is to integrate a complete intranet infrastructure that consists of a data management system and a network architecture, where the backbone network is a **local star topology**. The second experiment is to integrate a complete intranet infrastructure that also consists of a data management system and a network architecture, but the backbone network is a **wide tree topology**. As stated in Section 7.2 the partial animation studio consists of four site tasks, eight group tasks and 65 client tasks, as shown in Figure 2.1.

The goal here is to design and integrate an optimized data management system and a three-level network architecture so that all 65 client tasks (performed on 65 workstations) can communicate with each other and access file servers while satisfying all design and performance constraints. All the input information regarding the client and group clustering information, the traffic flow among site and group tasks, and the site traffic matrix are the same as presented in Tables 7.1-7.3. The input information regarding the data management system is given by Table 7.7. The first three columns of Table 7.7 identify the file identification, the file media-type (such as text, still image, audio or video), and the file size in megabytes respectively. The fourth and fifth columns identify the group task and client task that are requesting the retrieval of such a file. The last column indicates the total number of requests per hour that are made by the client tasks. This *data request table* presents a possible pattern of requests by the 65 client tasks that execute 501 file retrieval requests during the duration period (DP) of one hour (an average of 7.7 requests per client task). The traffic generated from requesting and retrieving files in Table 7.7 is listed in Table 7.8. This table shows the data management traffic flow at a group task (column 1) when the client tasks within the group are requesting file retrieval from servers. Otherwise, there is no data management traffic flow at the group task level. The second column represents the traffic flow generated by sending all clients' requests within the group task to servers. This traffic is in addition to the traffic between clients shown in the client traffic matrix, Table 7.2. This group request traffic RQT_{GT_e} is expressed in Equation 7.1.

$$RQT_{GT_e} = \frac{TR_{GT_e} \times RQPS}{3600} \tag{7.1}$$

Table 7.7: A data request table (DRT) for the partial animation studio.

File Identification	File Type	File Size in MBytes	Group Task	Client Task	Total Requests per hour
1	image	15	1	1-5	11
			2	16-20	12
2	image	40	1	1-10	27
3	video	65	2	16-20	18
4	text	4	3	31-35	23
5	text	3	3	31-40	25
6	text	5	4	11-15	5
			5	26-30	12
			6	51-57	7
			7	58-65	12
			8	45-50	5
7	text	3	5	21-25	8
8	video	35	6	51-57	22
			7	58-65	22
9	audio	25	6	51-57	29
			7	58-65	28
10	image	15	7	60-65	28
11	video	75	8	41-50	27
12	audio	20	8	41-50	40
13	image	18	8	41-50	40
14	image	28	8	41-50	50
15	audio	20	8	41-50	50

RQT_{GT_e} represents the total request traffic flow within a group task GT_e in terms of bits per second. TR_{GT_e} represents the total request of files within a group task GT_e and TR_{GT_e} is calculated from the data request table (DRT). $RQPS$ represents the request packet size, which is an input to *i*-CAD and it is set to 512 bits for this example. The request packet includes the client network address, the server network address, the file identification and the delay retrieval bound. The third column in Table 7.8 represents the traffic flow generated by replying to all clients' requests from servers. This traffic is in addition to the traffic between clients shown

Table 7.8: Data management traffic flow within group tasks.

Group Task (GT)	Request Traffic (in bps)	Reply Traffic (in bps)
1	5.404	2.900x10^6
2	4.267	3.146x10^6
3	6.827	0.389x10^6
4	0.711	0.058x10^6
5	2.844	0.196x10^6
6	8.249	3.565x10^6
7	12.800	4.544x10^6
8	30.151	13.910x10^6

in the client traffic matrix, Table 7.2. This group reply traffic RPT_{GT_e} is expressed in Equation 7.2.

$$RPT_{GT_e} = \sum_{\forall F_i \text{ requests by } GT_e} \frac{TCR_{i,GT_e} \times FS_i}{3600} \tag{7.2}$$

RPT_{GT_e} represents the total reply traffic flow for all clients' requests within a group task GT_e in terms of bits per second. TCR_{i,GT_e} represents the total requests of file i by all the clients of a group task GT_e and TCR_{i,GT_e} is calculated from the data request table (DRT). FS_i represents the file size of the ith file (F).

The data management traffic flow within a site task or the backbone task depends on the placement of the servers and it is dynamically calculated within i-CAD after the data management system is designed. If a group task has no local server, then all its clients' request traffic RQT_{GT_e} and reply traffic RPT_{GT_e} have to flow either to its site network (case 1) or both its site network and the backbone network (case 2). The first case occurs when a server is placed within another group task in the same site and there is a binding between the server and group task (clients). The binding indicates that a particular client's files will be stored on a particular server. The second case occurs when there is no placed server within the site or there is a server placed within the site but there is no binding between the server and group task (clients).

7.3.1 Experiment 3: Partial Animation Studio with Local Backbone Topology

In this experiment we present the results of designing optimized intranet infrastructures, where all sites are located within a studio lot. Thus, the backbone network is a local star topology. The goal is to integrate a data management system and a three-level network architecture so that all 65 client tasks perform their tasks in order and within a delay bound. We ran *i*-CAD with several threshold network delays (TND) ranging from ten seconds to one minute. In addition, we used the following parameters: population size (PS) = 250, number of generations (NG) = 3000, mutation rate (MR) = 0.05, crossover rate (CR) = 0.80, initial number of servers = 4, and threshold data management performance (TDMP) = 0.30.

The optimization process of complete intranet integration is illustrated in two examples as shown in Figures 7.12 and 7.13 respectively. The first example illustrates the optimization process of an animation intranet design problem, when TND is set to 60.0 seconds and the number of servers is set to four by *i*-CAD's user. However, *i*-CAD can create intranet infrastructures with more or less than the number of servers that has been initially set by the user. This effect is due to the crossover operator. The three curves in Figure 7.12 represent the following:

1. The *average design cost curve (TND = 60.0 seconds and 4 servers)* represents the average intranet integration cost, including the 3-level network design cost and the data management system design cost, of the entire intranet design population for one generation, when TND is equal to 60.0 seconds and the number of servers is set to four.

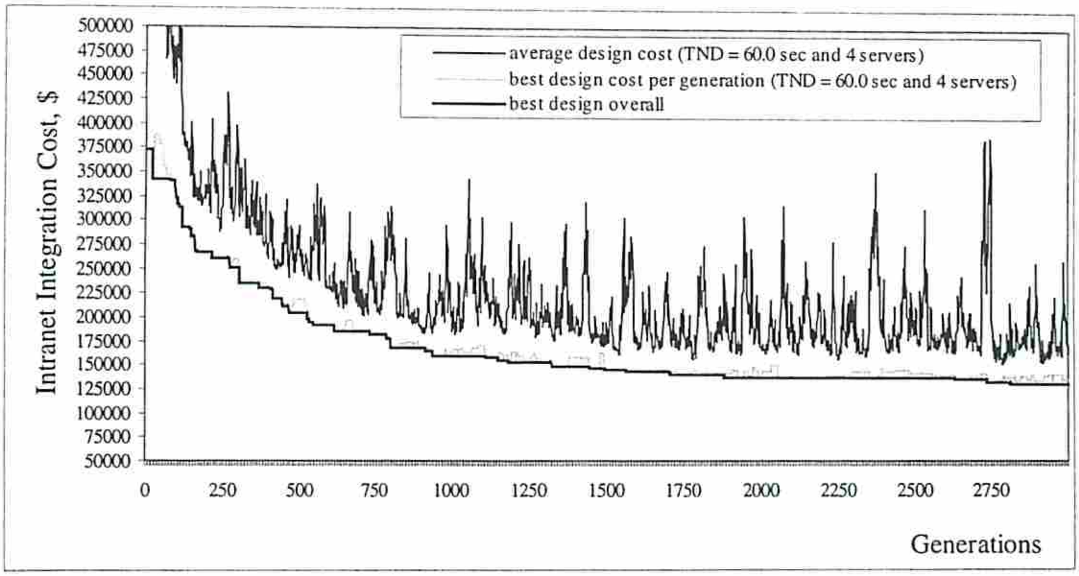


Figure 7.12: Optimization curves for the partial animation intranet with TND = 60.0 seconds and four servers.

2. The *best design cost per generation curve (TND = 60.0 seconds and 4 servers)* represents the lowest intranet integration cost, including the 3-level network design cost and the data management system design cost, of the entire intranet design population for one generation, when TND is equal to 60.0 seconds and the number of servers is set to four.

3. The *best design overall* represents the lowest intranet integration cost since the beginning of the optimization process.

These three curves demonstrate the optimization process. For example, the cost of the initial best intranet design, when TND is equal to 60.0 seconds and number of servers is set to four, is \$372,891.74 where the network architecture cost (NAC) is set to \$300,391.74 and the data management system cost (DMSC) is equal to \$72,500.00. During 3 hours of total run time on a SUN Ultra 10, *i*-CAD found a design costing \$130,836.79, which is about three times lower in cost than the initial best design. The network architecture cost (NAC) is reduced from \$300,391.74 to

$119,936.79, which is more than three times lower in cost than the initial best design. The data management system cost is reduced from $72,500.00 to $10,900.00, which is more than six times lower in cost than the initial best design. The second example illustrates the optimization process of an animation intranet design problem with a local backbone star topology, when TND is set to 20.0 seconds and the number of servers is set to four. The three curves in Figure 7.13 represent the following:

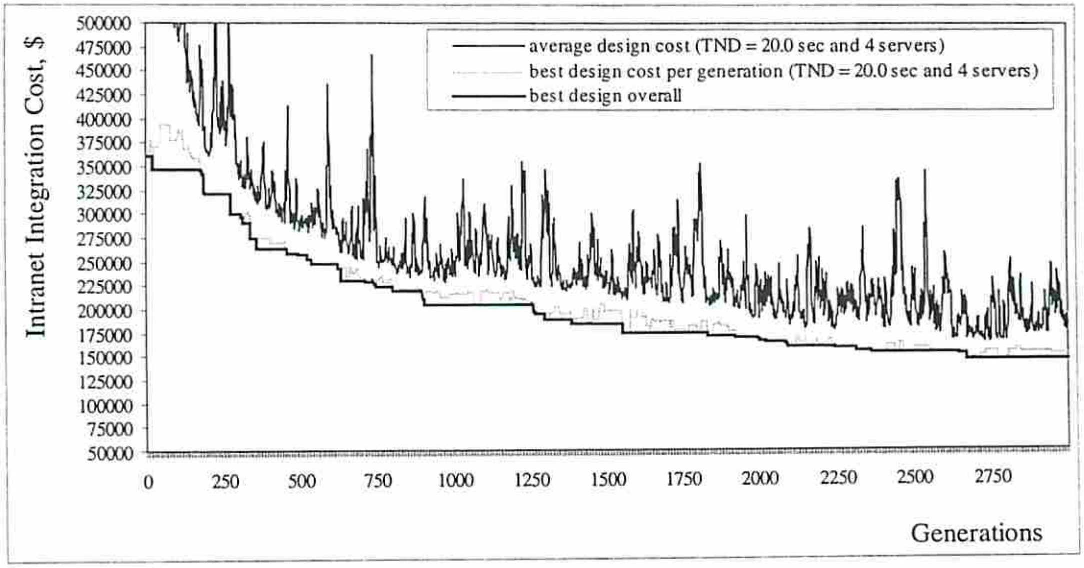


Figure 7.13: Optimization curves for the partial animation intranet with TND = 20.0 seconds and four servers.

1. The *average design cost curve (TND = 20.0 seconds and 4 servers)* represents the average intranet integration cost, including the 3-level network design cost and the data management system design cost, of the entire intranet design population for one generation, when TND is equal to 20.0 seconds and the number of servers is set to four.

2. The *best design cost per generation curve (TND = 20.0 seconds and 4 servers)* represents the lowest intranet integration cost, including the 3-level network design cost and the data management system design cost, of the entire intranet

design population for one generation, when TND is equal to 20.0 seconds and the number of servers is set to four.

3. The *best design overall* represents the lowest intranet integration cost since the beginning of the optimization process.

These three curves demonstrate the optimization process. For example, the cost of the initial best intranet design, when TND is set to 20.0 seconds and number of servers is set to four, is \$361,354.30 where the network architecture cost (NAC) is equal to \$314,354.30 and the data management system cost (DMSC) is equal to \$47,000.00. During 4.5 hours of total run time on a SUN Ultra 10, *i*-CAD found a design costing \$145,560.13, which is about two and half times lower in cost than the initial best design. The network architecture cost (NAC) is reduced from \$314,354.30 to \$125,760.13, which is two and half times lower in cost than the initial best design. The data management system cost is reduced from \$47,000.00 to \$19,800.00, which is more than two times lower in cost than the initial best design.

The different designs that are produced by *i*-CAD when TND is varied from 60.0 seconds to 20.0 seconds are illustrated in Figures 7.14 and 7.15 respectively. The relationship between the intranet integration cost and the threshold network delay (TND) can be shown in Figure 7.16. The six points in the plot represent six intranet designs with TND set to 10.0, 20.0, 30.0, 40.0, 50.0 and 60.0 seconds respectively. Details of the designs are found in Appendix A. The intranet integration cost is reduced by more than seventy five thousand dollars, from \$206,064.90 to \$130,836.79, when TND increases from 10.0 seconds to 60.0 seconds. Also, this plot illustrates the interdependent relationship between the data management system design and the network architecture design, as shown in the dot-circle. The increase in the total design cost, when the curve moves from TND = 20.0 seconds to TND = 30.0 seconds, is due to the number of servers, their locations within the intranet and their bindings with the client tasks. At TND = 20.0 seconds, *i*-CAD created an intranet with four servers which are placed at four group tasks that distribute the data management traffic over the entire intranet, as shown in Table 7.9.

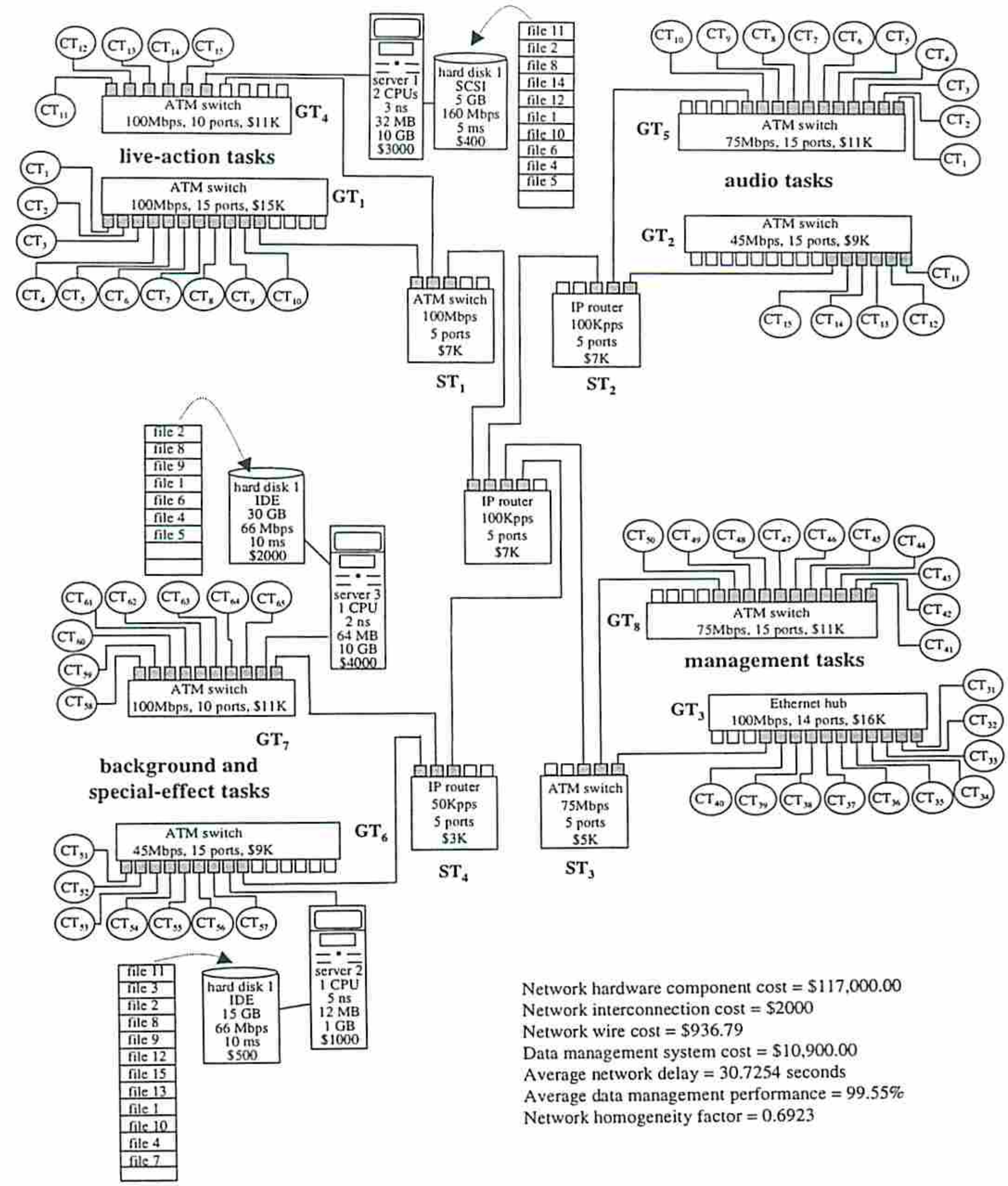


Figure 7.14: A partial animation studio intranet with TND = 60.0 seconds and four servers.

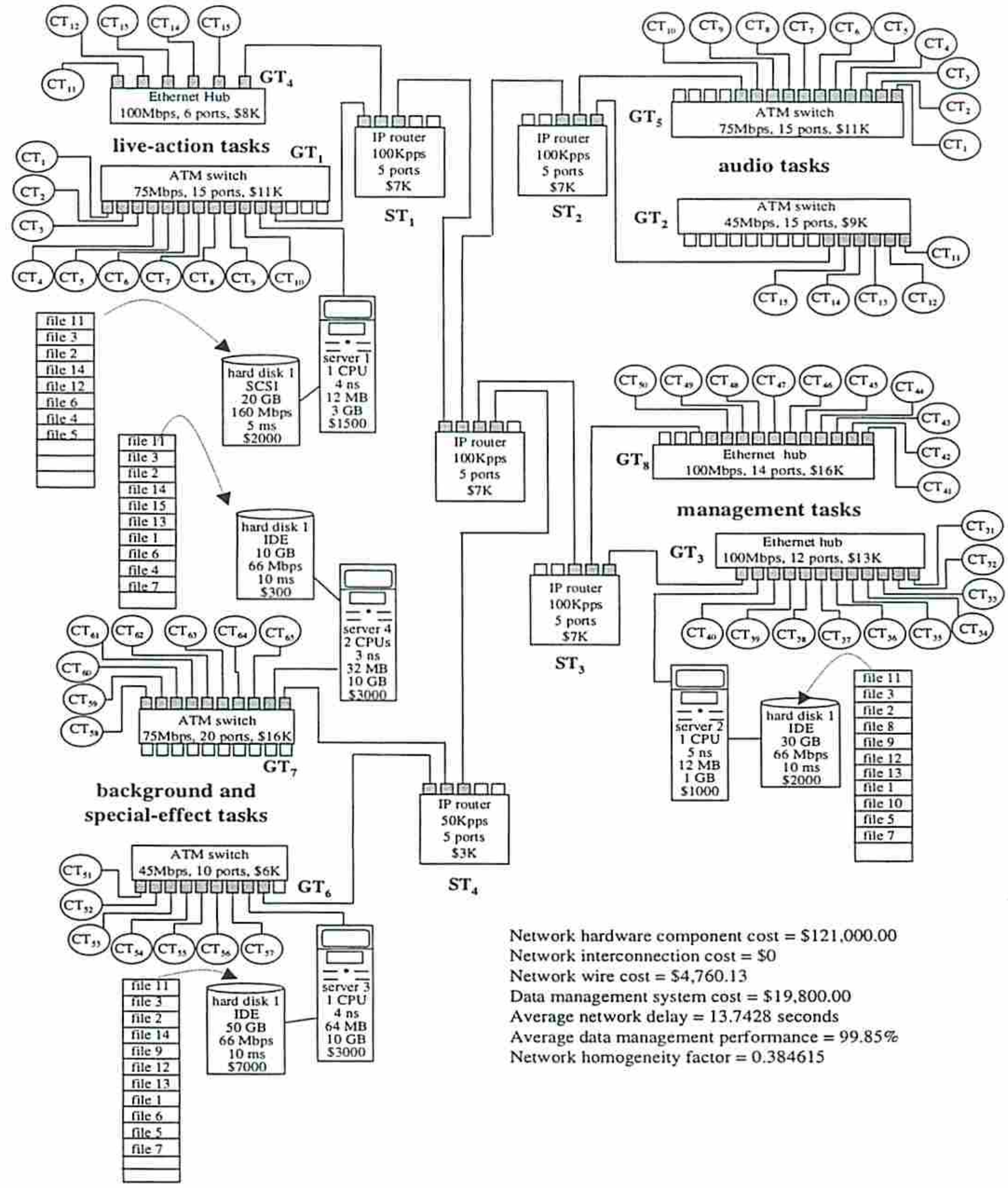


Figure 7.15: A partial animation studio intranet with TND = 20.0 seconds and four servers.

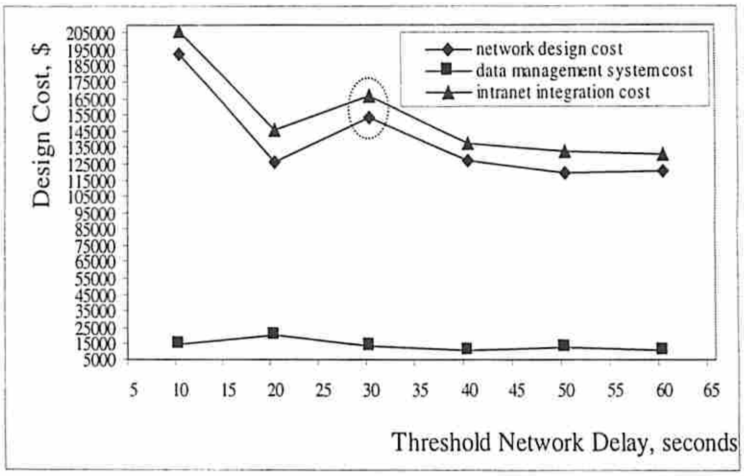


Figure 7.16: Intranet design cost versus delay.

Table 7.9: Data management system with TND = 20.0 seconds.

Server Identification	Server Location	Group Binding	Total Requests
1	group task 1	1	38
		4	5
		2	30
2	group task 3	3	48
3	group task 6	6	58
4	group task 7	7	90
		5	20
		8	212

This table shows the locations of all allocated servers (column 2) and also it shows the binding between the group tasks and placed servers (column 3). The last column shows the number of requests by each group task. Both group tasks 7 and 8 perform the most file requests to a file server (total of 291 requests per hour out of 501 requests listed the entire data request table); however, these two group tasks 7 and 8 are bound to the powerful server. This server has two CPUs with a clock cycle is equal to 3 nanoseconds per CPU and a total of 20 gigabytes of hard disk storage capacity.

On the other hand, at TND = 30.0 seconds, *i*-CAD produced an intranet with three servers even though four servers are requested at the beginning of the run time. This is a normal operation of *i*-CAD, to drop or add more servers during the optimization process than the user requested. Table 7.10 shows the placement and binding information of the three servers with the eight group task. This intranet has three placed servers in contrast to the other intranets that each intranet has four placed servers. In addition, the unbalanced group-server binding within the first server leads to an expensive intranet integration design cost.

Table 7.10: Data management system with TND = 30.0 seconds.

Server Identification	Server Location	Group Binding	Total Requests
1	group task 4	4	5
		1	38
		2	30
		6	58
		7	90
2	group task 5	5	20
		8	212
3	group task 3	3	48

7.3.2 Experiment 4: Partial Animation Studio with Wide Backbone Topology

In this experiment we present the results of designing optimized intranet infrastructures, where all four sites are located in Southern California, USA as depicted in Figure 7.6. Thus, the backbone network is a wide tree topology. The goal is to integrate a data management system and a three-level network architecture so that all 65 client tasks perform their tasks in order and within a delay bound. We ran

i-CAD with several threshold network delays (TND) ranging from ten seconds to one minute. In addition, we used the following parameters: population size (PS) = 250, number of generations (NG) = 3000, mutation rate (MR) = 0.05, crossover rate (CR) = 0.80, initial number of servers = 3, and threshold data management performance (TDMP) = 0.30.

The optimization process of a complete intranet integration is illustrated in two examples, as shown in Figures 7.17 and 7.18. The first example illustrates the optimization process of the animation intranet design problem with a wide backbone tree topology, when TND is set to 50.0 seconds and the number of servers is set to three. The three curves in Figure 7.17 represent the following:

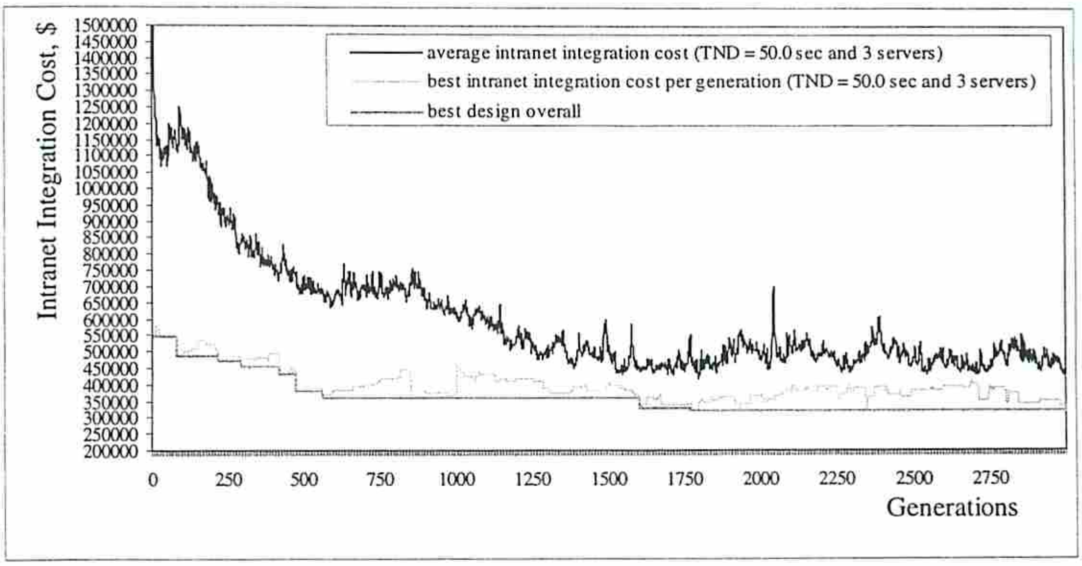


Figure 7.17: Optimization curves for the partial animation intranet with TND = 50.0 seconds and three servers.

1. The *average design cost curve (TND = 50.0 seconds and 3 servers)* represents the average intranet integration cost, including the 3-level network design cost and the data management system design cost, of the entire intranet design population for one generation (including a 1-month lease for a tree topology

connecting the four sites), when TND is equal to 50.0 seconds and the number of servers is set to three.

2. The *best design cost per generation curve (TND = 50.0 seconds and 3 servers)* represents the lowest intranet integration cost, including the 3-level network design cost and the data management system design cost (including a 1-month lease for a tree topology connecting the four sites), of the entire intranet design population for one generation, when TND is equal to 50.0 seconds and the number of servers is set to three.

3. The *best design overall* represents the lowest intranet integration cost since the beginning of the optimization process.

These three curves, in Figure 7.17, demonstrate the optimization process. For example, the cost of the initial best intranet design, when TND is set to 50.0 seconds and number of servers is set to three, is $546,190.70 where the network architecture cost (NAC), including a 1-month lease for three backbone links, is equal to $489,190.70 and the data management system cost (DMSC) is equal to $57,000.00. During 6 hours of total run time on a SUN Ultra 10, *i*-CAD found a design costing $322,091.70, which is less than the initial best intranet design by $224,099.00 (41%). The network architecture cost (NAC), including a 1-month lease for three backbone links, is reduced from $489,190.70 to $279,591.70, which is about 43% reduction in cost from the initial best network design. The data management system cost is reduced from $57,000.00 to $42,500.00, which is about 25% reduction in cost from the initial best data management system design. The second example illustrates the optimization process of an animation intranet design problem with a wide backbone tree topology, when TND is set to 10.0 seconds and the number of servers is set to three. The three curves in Figure 7.18 represent the following:

1. The *average design cost curve (TND = 10.0 seconds and 3 servers)* represents the average intranet integration cost, including the 3-level network design cost

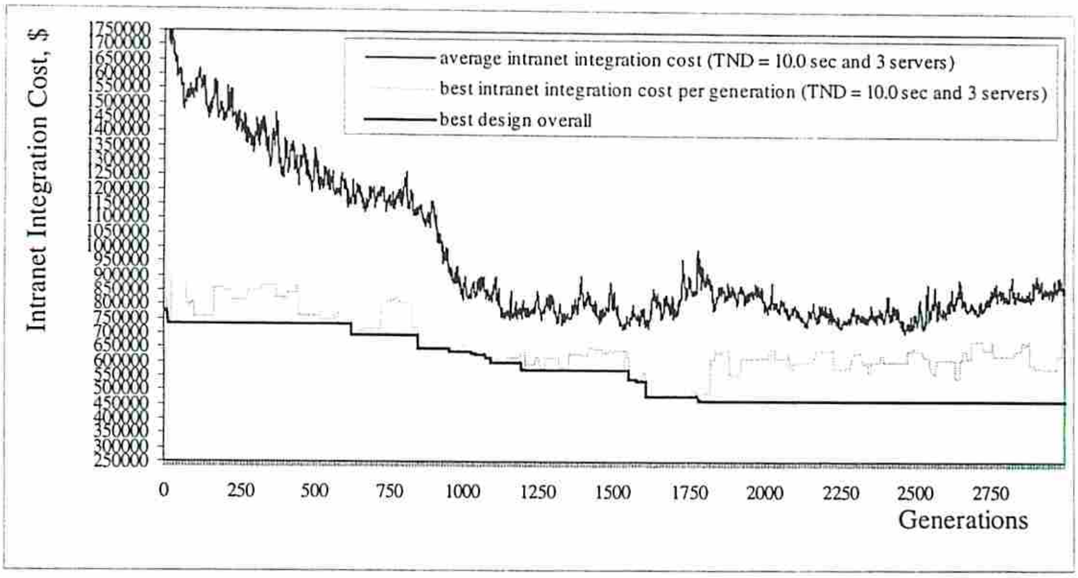


Figure 7.18: Optimization curves for the partial animation intranet with TND = 10.0 seconds and three servers.

and the data management system design cost, of the entire intranet design population for one generation (including a 1-month lease for a tree topology connecting the four sites) , when TND is equal to 10.0 seconds and the number of servers is set to three.

2. The *best design cost per generation curve (TND = 10.0 seconds and 3 servers)* represents the lowest intranet integration cost, including the 3-level network design cost and the data management system design cost, of the entire intranet design population for one generation (including a 1-month lease for a tree topology connecting the four sites), when TND is equal to 10.0 seconds and the number of servers is set to three.

3. The *best design overall* represents the lowest intranet integration cost since the beginning of the optimization process.

These three curves, in Figure 7.18, demonstrate the optimization process. For example, the cost of the initial best intranet design, when TND is set to 10.0 seconds and number of servers is set to three, is \$776,835.90 where the network architecture cost (NAC), including a 1-month lease for three backbone links, is equal to \$724,835.90 and the data management system cost (DMSC) is equal to \$75,500.00. During 6 hours of total run time on a SUN Ultra 10, *i*-CAD found a design costing \$464,076.70, which is less than the initial best intranet design by \$312,759.20 (40%). The network architecture cost (NAC), including a 1-month lease for three backbone links, is reduced from \$724,835.90 to \$388,576.70, which is about 46% reduction in cost from the initial best network design. The data management system cost is reduced from \$75,500.00 to \$52,000.00, which is about 31% reduction in cost from the initial best data management system design.

The different designs that are produced by *i*-CAD when TND is varied from 50.0 seconds to 10.0 seconds are illustrated in Figures 7.19 and 7.20 respectively. Details of the designs are found in Appendix A.

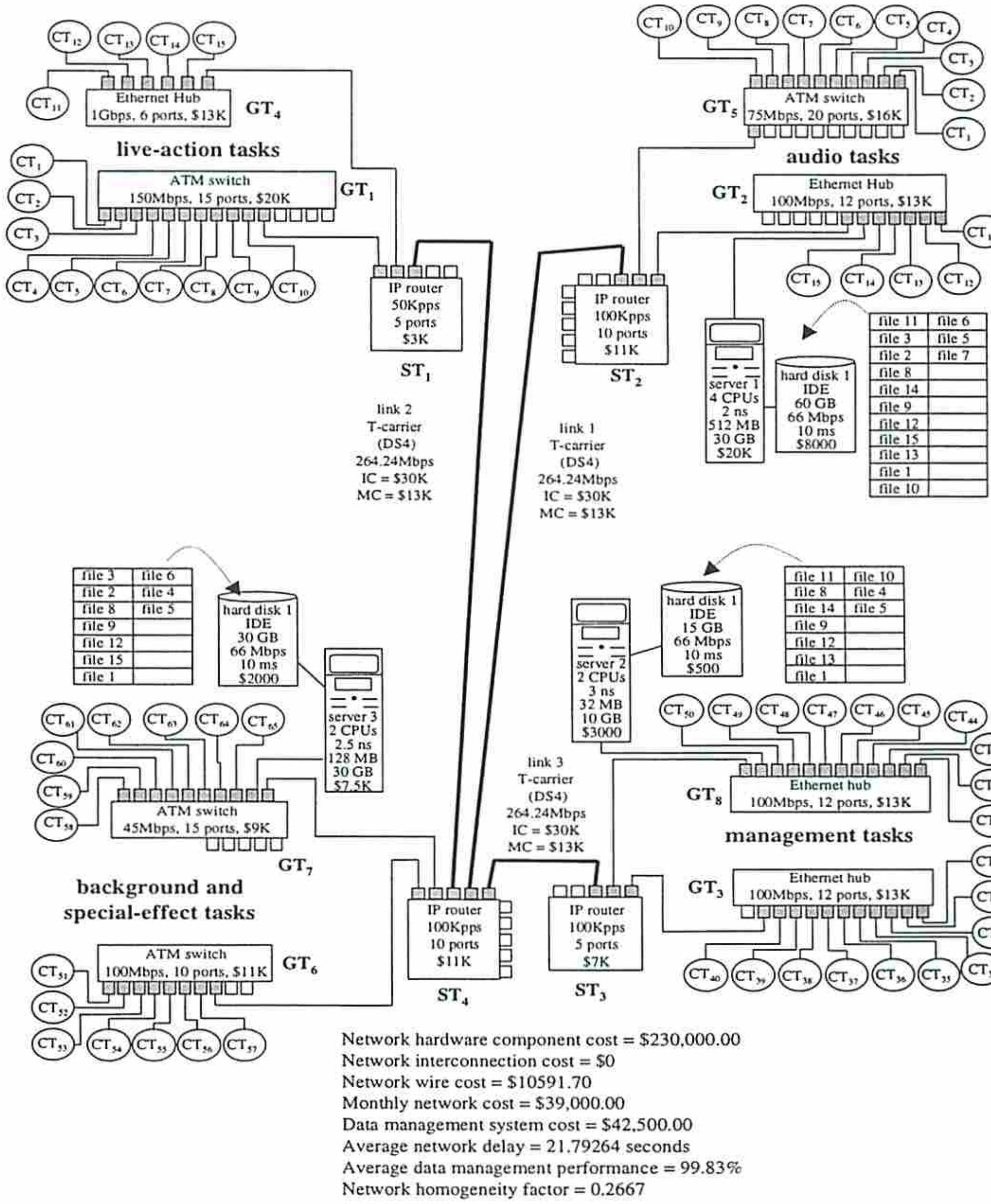


Figure 7.19: A partial animation studio intranet with TND = 50.0 seconds and three servers.

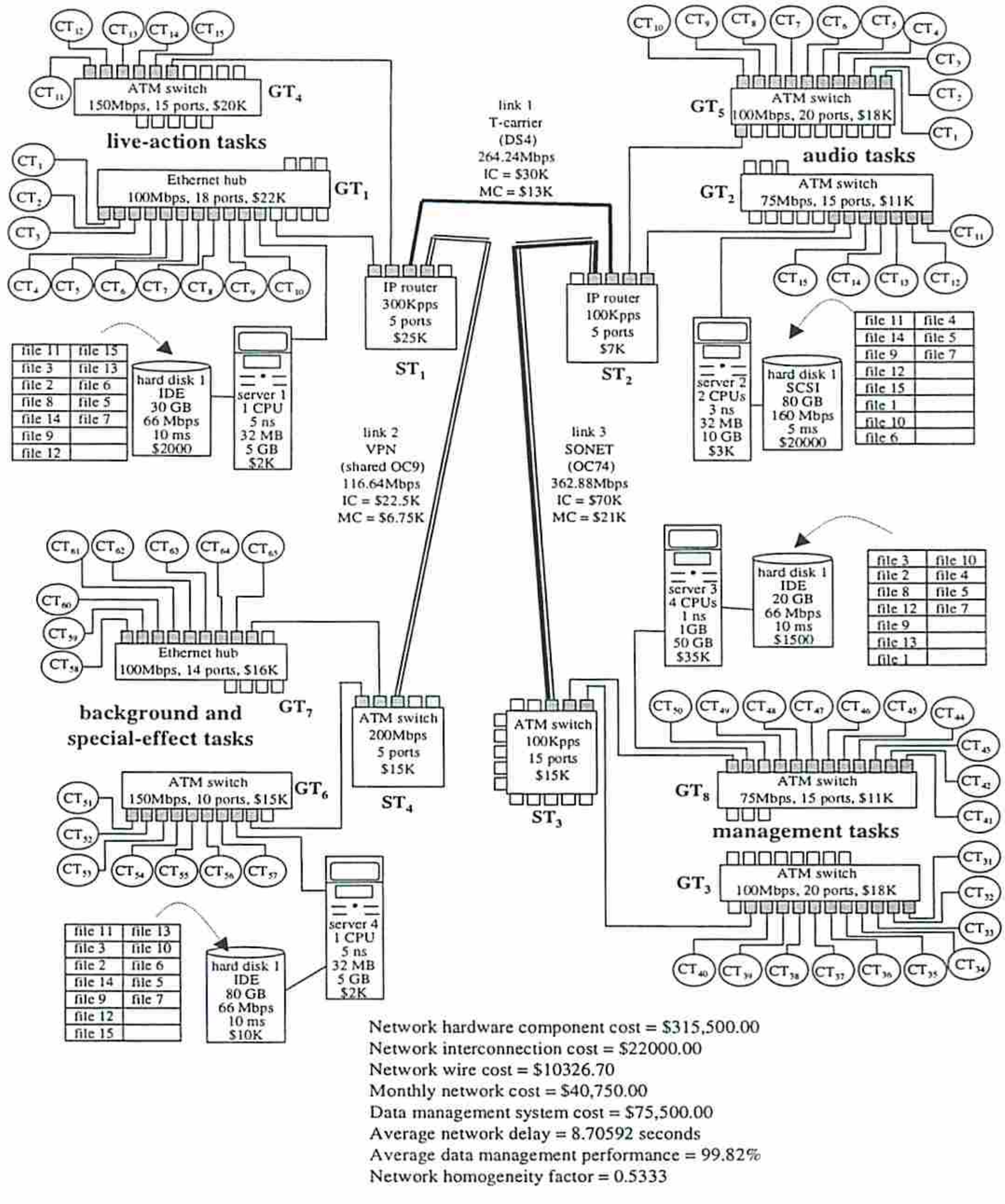


Figure 7.20: A partial animation studio intranet with TND = 10.0 seconds and three servers.

The relationship between the intranet integration cost and the threshold network delay (TND) can be shown in Figure 7.21. The six points in the plot represent six intranet designs with TND set to 10.0, 20.0, 30.0, 40.0, 50.0 and 60.0 seconds respectively. The intranet integration cost is reduced by more than eighty two thousand dollars (18%), from \$464,076.70 to \$381,598.09, when TND increases from 10.0 seconds to 60.0 seconds. The dot-circle indicates an inferior design.

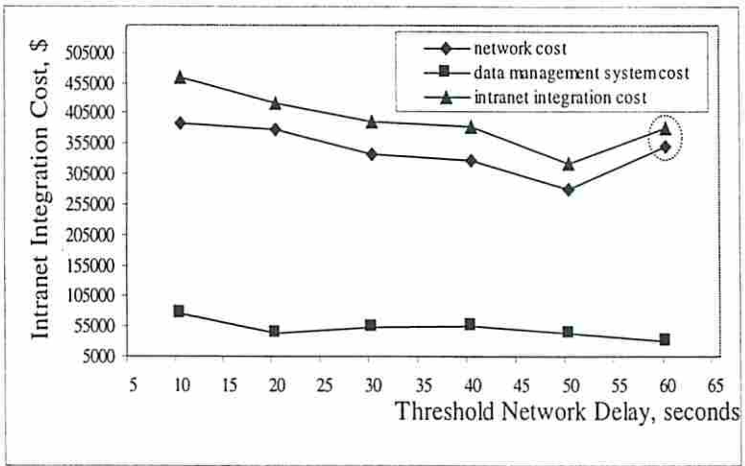


Figure 7.21: Intranet design cost versus threshold network delay.

7.4 Complete Intranet Integration for A Full Animation Studio

In this section we present the results of two experiments that involve synthesizing a full animation studio. The full animation studio consists of six site tasks, 14 group tasks and 150 client tasks as shown in Figure 2.1. The goal here is to design a data management system and a three-level network architecture that can enable all 150 client tasks (performed on 150 workstations) to perform their tasks while satisfying all design and performance constraints. Table 7.11 provides detailed information about the new clients and groups.

Table 7.11: Client and group clustering information.

Site Task (ST)	Group Task (GT)	Client Task (CT)
5	9	66-75
	10	76-85
	12	86-105
6	11	106-120
	13	121-135
	14	136-150

The clustering information regarding the first 65 client tasks is the same as in Table 7.1, while the additional 85 client tasks are divided into two site tasks (5 and 6). Site tasks 5 and 6 perform one of the essential part of the animation film production, which is involved creating, joining and editing the animated characters within the skeleton shots. The traffic flow among site task 3, 5, and 6 and group tasks 3, and 8-14 is presented in Table 7.12. The management task (site task 3) provides all the data regarding the skeleton shots for the drawing and editing tasks (site tasks 5 and 6). The traffic flow within the backbone task of the full animation studio can be summarized by one parameter (backbone local traffic, BLOT) or site traffic matrix (STM) depending on which topology is used. For a local star topology, the backbone local traffic (BLOT) represents all the traffic flow between all six sites. For our example, BLOT is equal to 209.575 Mbps. For a wide tree topology, a site-to-site traffic flow is needed to determine each link's capacity. Table 7.13 shows a possible site traffic matrix (STM). The site traffic matrix is not symmetric and is based on the data flow within the task flow graph.

The input information regarding the data management system is given by both Tables 7.7 and 7.14. The second *data request table* (shown in Table 7.14) includes

Table 7.12: Traffic flow assignment for experiments 5 and 6.

Task	Local Traffic (Mbps)	Outgoing Traffic (Mbps)	Incoming Traffic (Mbps)
site task 3	0.0	95.0	33.75
site task 5	21.0	18.95	57.5
site task 6	100.565	17.5	58.95
group task 3	9.0	15.0	7.5
group task 8	9.0	80.0	26.25
group task 9	1.98	25.0	20.0
group task 10	18.0	6.99	20.0
group task 11	4.95	31.375	43.445
group task 12	40.5	7.95	38.5
group task 13	47.31	86.69	43.875
group task 14	7.94	0.0	72.195

all the files that are requested by the additional 85 client tasks. These two tables present a possible pattern of requests by the 150 client tasks that execute 975 file retrieval requests during the duration period (DP) of one hour (an average of 6.5 requests per a client task). The traffic generated from requesting and retrieving all files is listed in Tables 7.8 and 7.15. These tables show the data management traffic flow at a group task (column 1) when the client tasks within the group are requesting file retrieval from a server. Otherwise, there is no data management traffic flow at

Table 7.13: A site traffic matrix (STM) for the full animation studio.

	site task 1	site task 2	site task 3	site task 4	site task 5	site task 6
site task 1	0.0	16.25	18.75	20.625	0.0	0.0
site task 2	0.0	0.0	7.5	7.5	0.0	0.0
site task 3	2.5	5.0	0.0	7.5	40.0	40.0
site task 4	0.0	0.0	7.5	0.0	0.0	0.0
site task 5	0.0	0.0	0.0	0.0	0.0	18.95
site task 6	0.0	0.0	0.0	0.0	17.5	0.0

the group task. The second column represents the traffic flow generated by sending all clients' requests within the group task to the server.

Table 7.14: The rest of data request table (DRT) for the full animation studio.

File Identification	File Type	File Size in MBytes	Group Task	Client Task	Total Requests per hour
16	video	250	9	66-70	5
			10	81-85	5
			13	121,123,125,127, 129,131,133	7
17	image	50	11	106-110	25
			12	91-100	20
18	image	50	11	86-90, 101-105	30
			12	116-120	20
19	text	1	11	111-115	140
20	text	1	11	111-115	140
21	text	8	12	86-90	15
22	image	280	13	122,124,126,128, 130, 132, 134	27
23	text	10	13	121-135	30
24	video	700	14	141-145	10

The group request traffic is expressed as before in Equation 7.1 and The traffic flow generated by replying to all clients' requests from a servers is expressed as before in Equation 7.2. The data management traffic flow within a site task or the backbone task depends on the placement of the servers and it is dynamically calculated within *i*-CAD after the data management system is designed.

The next two sections present the results of two experiments on designing a full animation studio. The first experiment is to integrate a complete intranet infrastructure that consists of a data management system and a network architecture, where the backbone network is a **local star topology**. The second experiment is

Table 7.15: Data management traffic flow within group tasks 9 to 14.

Group Task (GT)	Request Traffic (in bps)	Reply Traffic (in bps)
9	0.711	2.913×10^6
10	0.711	2.913×10^6
11	46.222	5.895×10^6
12	9.244	6.105×10^6
13	9.102	22.393×10^6
14	1.422	16.311×10^6

to integrate a complete intranet infrastructure that also consists of a data management system and a network architecture, but the backbone network is a **wide tree topology**.

7.4.1 Experiment 5: Full Animation Studio with Local Backbone Topology

In this experiment we present the results of designing optimized intranet infrastructures, where all six sites are located within a studio lot. Thus, the backbone network is a local star topology. The goal is to integrate a data management system and a three-level network architecture so that all 150 client tasks perform their tasks in order and within a delay bound. We ran *i*-CAD with several threshold network delays (TND) ranging from 30 seconds to three minute. In addition, we used the following parameters: population size (PS) = 250, number of generations (NG) = 5000, mutation rate (MR) = 0.05, crossover rate (CR) = 0.80, initial number of servers = 5, and threshold data management performance (TDMP) = 0.30.

The optimization process of a complete intranet integration is illustrated in two examples as shown in Figures 7.22 and 7.23 respectively. The first example illustrates the optimization process of a full animation intranet design problem, when TND is set to 180.0 seconds and the number of servers is set to five by *i*-CAD's user. The

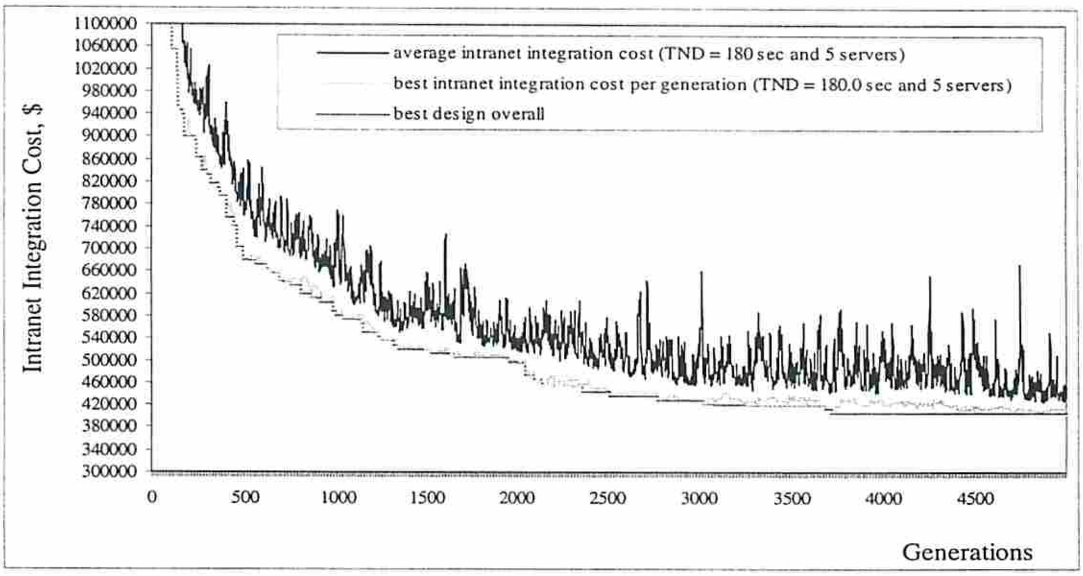


Figure 7.22: Optimization curves for the full animation intranet with TND = 180.0 seconds and five servers.

three curves in Figure 7.22 represent the following:

1. The *average design cost curve (TND = 180.0 sec and 5 servers)* represents the average intranet integration cost, including the 3-level network design cost and the data management system design cost, of the entire intranet design population for one generation, where TND is equal to 180.0 seconds and the number of servers is set to five.

2. The *best design cost per generation curve (TND = 180.0 sec and 5 servers)* represents the lowest intranet integration cost, including the 3-level network design cost and the data management system design cost, of the entire intranet design population for one generation, where TND is equal to 180.0 seconds and the number of servers is set to five.

3. The *best design overall* represents the lowest intranet integration cost since the beginning of the optimization process.

These three curves demonstrate the optimization process. For example, the cost of the initial best intranet design, when TND is equal to 180.0 seconds and number of servers is set to five, is \$1,177,823.40, where the network architecture cost (NAC) is set to \$1,103,323.40 and the data management system cost (DMSC) is equal to \$74,500.00. During 4 days of total run time on a shared (heavy loaded) SUN Enterprise server E4500/E5500, *i*-CAD found a design costing \$406,557.94, which is about three times lower in cost than the initial best design. The network architecture cost (NAC) is reduced from \$1,103,323.40 to \$373,557.94, which is about three times lower in cost than the initial best design. The data management system cost is reduced from \$74,500.00 to \$33,000.00, which is more than two times lower in cost than the initial best design. The second example illustrates the optimization process of an animation intranet design problem with a local backbone star topology, when TND is set to 30.0 seconds and the number of servers is set to five.

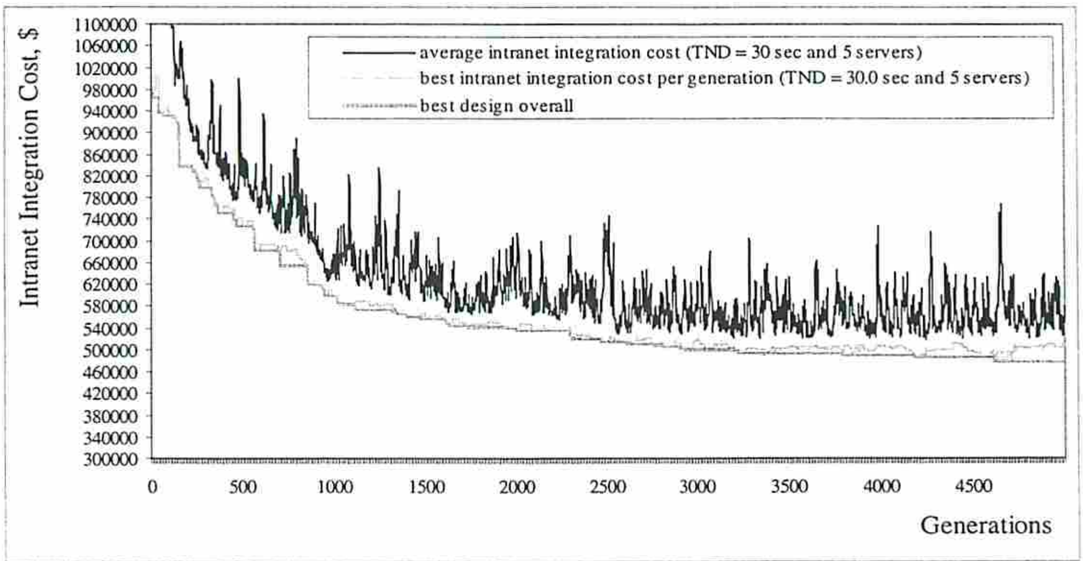


Figure 7.23: Optimization curves for the partial animation intranet with TND = 20.0 seconds and four servers.

The three curves in Figure 7.23 represent the following:

1. The *average design cost curve (TND = 30.0 sec and 5 servers)* represents the average intranet integration cost, including the 3-level network design cost and the data management system design cost, of the entire intranet design population for one generation, where TND is equal to 30.0 seconds and the number of servers is set to five.

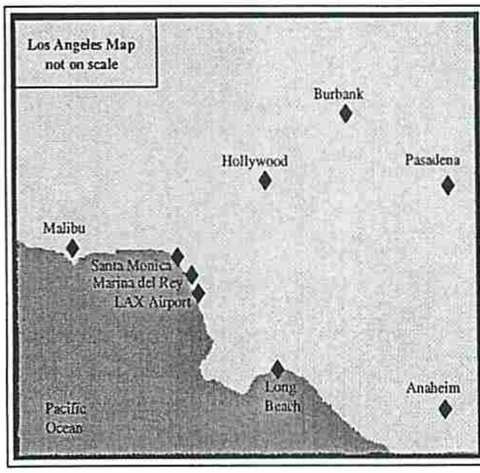
2. The *best design cost per generation curve (TND = 30.0 sec and 5 servers)* represents the lowest intranet integration cost, including the 3-level network design cost and the data management system design cost, of the entire intranet design population for one generation, where TND is equal to 30.0 seconds and the number of servers is set to five.

3. The *best design overall* represents the lowest intranet integration cost since the beginning of the optimization process.

These three curves demonstrate the optimization process. For example, the cost of the initial best intranet design, when TND is set to 20.0 seconds and number of servers is set to five, is $981,829.40 where the network architecture cost (NAC) is equal to $900,829.40 and the data management system cost (DMSC) is equal to $81,000.00. During 4 days of total run time on a shared (heavy loaded) SUN Enterprise server E4500/E5500, *i*-CAD found a design costing $477,059.10, which is about two times lower in cost than the initial best design. The network architecture cost (NAC) is reduced from $900,829.40 to $438,059.10, which is about two times lower in cost than the initial best design. The data management system cost is reduced from $81,000.00 to $39,800.00, which is more than two times lower in cost than the initial best design. The different designs that are created by *i*-CAD when TND ranges from 180.0 seconds to 30.0 seconds are found in Appendix A.

7.4.2 Experiment 6: Full Animation Studio with Wide Backbone Topology

In this experiment we present the results of designing a full animation intranet, where all six sites are located in Southern California, United States. The first site task (live-action) is located in Burbank, the second site task (audio) is located in Pasadena, the third site task (management) is located in Hollywood, the fourth site task (background and special-effect) is located in Santa Monica, the fifth task (drawing) is located in Anaheim and the sixth task (joining and editing) is located in Malibu. Figure 7.24 depicts a map of the Los Angeles basin and distance chart between the six sites in miles.



Distance chart between the six sites in miles.

	Burbank site 1	Pasadena site 2	Hollywood site 3	Santa Monica site 4	Anaheim site 5	Malibu site 6
Burbank site 1	0.0	10.0	8.0	18.0	33.0	23.0
Pasadena site 2	10.0	0.0	12.0	22.0	23.0	27.0
Hollywood site 3	8.0	12.0	0.0	10.0	35.0	15.0
Santa Monica site 4	18.0	22.0	10.0	0.0	35.0	5.0
Anaheim site 5	33.0	23.0	35.0	35.0	0.0	40.0
Malibu site 6	23.0	27.0	15.0	5.0	40.0	0.0

Figure 7.24: Locations of the six site tasks within the City of Los Angeles, California, USA.

The objective is to synthesize a data management system and a 3-level network, where the backbone network is constrained to a tree topology that must allow all site tasks to communicate with each other according to the site traffic matrix (as shown in Table 7.13) while satisfying some design and performance requirements. We ran i-CAD with two threshold network delays (TND) equal to 60 and 30 seconds. In addition, we used the following parameters: population size (PS) = 250, number of generations (NG) = 5000, mutation rate (MR) = 0.05, crossover rate (CR) = 0.80, initial number of servers = 7 and number of month lease = 12. The optimization process of a complete full animation intranet with a tree backbone topology is illustrated in Figures 7.25 and Figures 7.26. In the first example, TND is set to 60.0 seconds and the plot in Figure 7.25 depicts three cost curves:

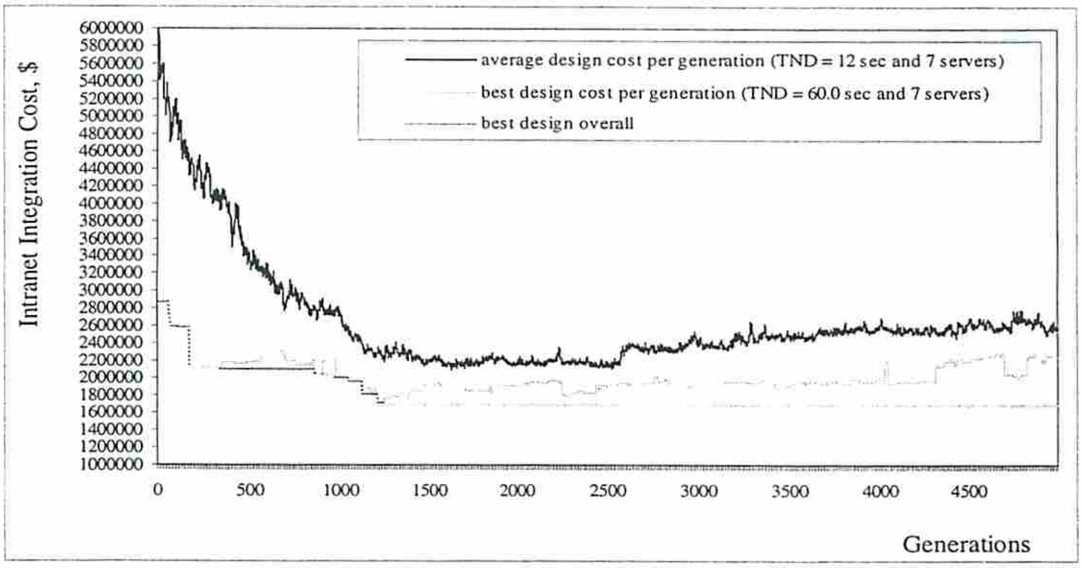


Figure 7.25: Optimization process for a full animation studio with a tree backbone topology when TDN = 60.0 seconds and 7 servers.

1. The *average design cost per generation curve (TND = 60.0 sec and 7 servers)* represents the average intranet integration cost, including the 3-level network design cost and the data management system design cost, of the entire intranet design population for one generation (including a 12-month lease for a tree topology connecting the six sites), when TND is equal to 60.0 seconds and the number of servers is set to seven.

2. The *best design cost per generation curve (TND = 60.0 sec and 7 servers)* represents the lowest intranet integration cost, including the 3-level network

design cost and the data management system design cost, of the entire intranet design population for one generation (including a 12-month lease for a tree topology connecting the six sites), when TND is equal to 60.0 seconds and the number of servers is set to seven.

3. The *best design overall* represents the lowest intranet integration cost since the beginning of the optimization process.

These three curves demonstrate the optimization process. For example, the cost of the initial best intranet design, when TND is equal to 60.0 seconds and number of servers is set to seven, is $2,872,621.10 where the network architecture cost (NAC) is set to $2,730,121.10 (including $1,263,000.00 for 12-month lease) and the data management system cost (DMSC) is equal to $142,500.00. During 1 day of total run time on a shared (light load) SUN Enterprise server E4500/E5500, *i*-CAD found a design costing $1,695,255.00, which is about 1.7 times lower in cost than the initial best design. The network architecture cost (NAC) is reduced from $2,730,121.10 to $1,617,255.00, which is about 1.7 times lower in cost than the initial best design. The data management system cost is reduced from $142,500.00 to $78,000.00, which is more than 1.8 times lower in cost than the initial best design. This design can be found in Appendix A. In the second example, TND is set to 30.0 seconds and the plot in Figure 7.26 depicts three cost curves:

1. The *average design cost per generation curve (TND = 30.0 sec and 7 servers)* represents the average intranet integration cost, including the 3-level network design cost and the data management system design cost, of the entire intranet design population for one generation (including a 12-month lease for a tree topology connecting the six sites), when TND is equal to 30.0 seconds and the number of servers is set to seven.

2. The *best design cost per generation curve (TND = 30.0 sec and 7 servers)* represents the lowest intranet integration cost, including the 3-level network

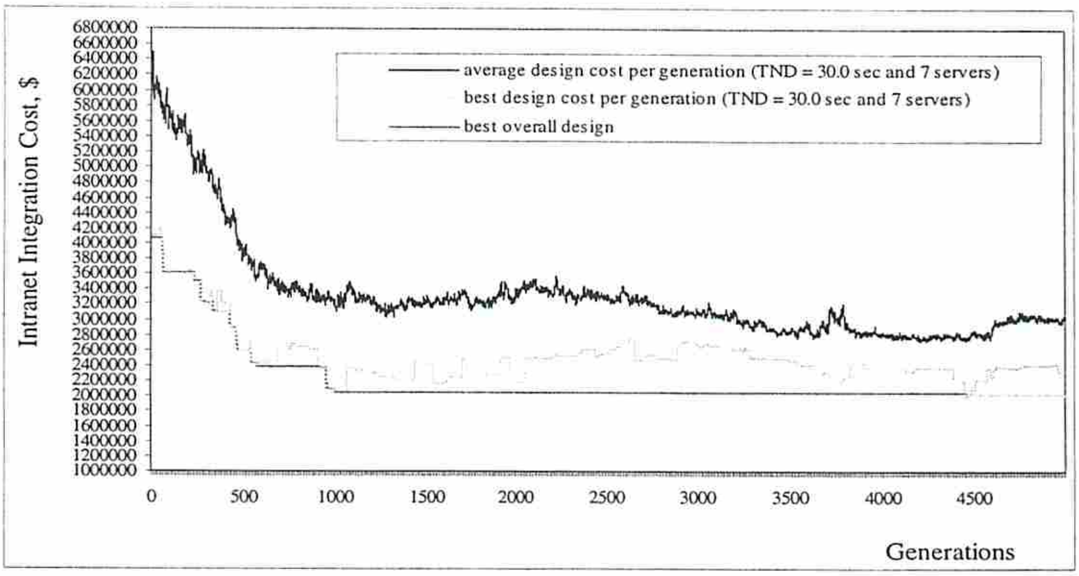


Figure 7.26: Optimization process for a full animation studio with a tree backbone topology when TDN = 30.0 seconds and 7 servers.

design cost and the data management system design cost, of the entire intranet design population for one generation (including a 12-month lease for a tree topology connecting the six sites), when TND is equal to 30.0 seconds and the number of servers is set to seven.

3. The *best design overall* represents the lowest intranet integration cost since the beginning of the optimization process.

These three curves demonstrate the optimization process. For example, the cost of the initial best intranet design, when TND is equal to 30.0 seconds and number of servers is set to seven, is \$4,060,828.80 where the network architecture cost (NAC) is set to \$3,968,828.80 (including \$1,485,000.00 for 12-month lease) and the data management system cost (DMSC) is equal to \$92,000.00. During 1 day of total run time on a shared (light load) SUN Enterprise server E4500/E5500, *i*-CAD found a design costing \$2,016,950.80, which is about two times lower in cost than the initial best design. The network architecture cost (NAC) is reduced from \$3,968,828.80 to

$1,875,950.80, which is more than two times lower in cost than the initial best design. The data management system cost is increased from $92,000.00 to $141,000.00. This design can be found in Appendix A.

Chapter 8

Conclusions and Future Work

8.1 Conclusion

We consider the design problem of an intranet integration infrastructure to minimize its hardware installation cost while satisfying the design and performance requirements. In the past half decade, there has been a rapid expansion in the use of networks, particularly intranets, to provide hardware platforms to communicate and share data among distributed multimedia applications, such as the animation production studio. We defined the intranet integration problem as a combination of two interdependent sub-problems: data management system design and network architecture design. We proposed and implemented an automated capacity planning tool, i-CAD, that attempts to optimize the intranet design cost while satisfying both design and performance constraints, but does not guarantee optimality.

An introduction to our intranet model and a description of our example, an animation production studio, were described in Chapter 2. The intranet integration problem is an interdisciplinary problem involving research in the fields of network synthesis, design automation and multimedia systems. Chapter 3 reviewed relevant related research in early and modern network synthesis and analysis, design automation tools and techniques, and multimedia systems.

The mathematical programming notation was used to formulate the combined optimization problem. Chapter 4 presented a comprehensive mathematical formulation of the intranet design problem. The formulation includes a large set of network and data management design constraints and an objective function representing the total intranet integration cost. An analytical performance model for evaluating the integrated 3-level network architecture for satisfying a given threshold delay is described in Chapter 5. Also, we described a Monte Carlo simulation for evaluating the data management system to determine how many clients' requests can be satisfied within a given threshold duration period.

The implementation of an intranet computer-aided design tool, *i*-CAD, was described in Chapter 6. *i*-CAD is a software tool that used a suite of techniques to automatically design and integrate data management systems and network architectures. A genetic algorithm used by *i*-CAD for selecting and integrating the optimized set of network and data management components that minimize the total intranet integration cost, while satisfying the design and performance constraints, was described.

The results of six experiments were presented in Chapter 7. These six experiments consist of various animation studio problems ranging from four sites, eight groups and 65 clients to six sites, 14 groups and 150 clients. The results showed that the automatic synthesis and integration of data management systems and network architectures are feasible and the run-time of *i*-CAD is in the range of a few minutes to a few days depending on the size of the problem. During the run-time, *i*-CAD was able to improve the intranet integration cost 39.20% to 76.25% from the initial best intranet cost.

8.2 Contributions

The key contributions, which resulted from research on design automation, distributed systems, network synthesis and multimedia applications, are organized in the next two sections.

8.2.1 Thesis Contributions

The research described here includes the following contributions:

1. A new direction for design automation was explored by focusing on the design of large systems that involve both data management and network architecture. This new direction moves system-level synthesis from designing a system that consists of processors, memory and input/output, which all are integrated into a single multiprocessor; into a system that consists of many geographically-distributed network nodes (clients and servers), which need a communication network and a database system in order to perform a number of cooperative periodic tasks.

2. The definition and solution of the intranet integration problem as a combination of two interdependent sub-problems, data management system design and network design, is introduced for the first time, and has not been reported in the research literature, to our knowledge. The intranet integration problem is a multidisciplinary problem and it is a complicated combinatorial optimization problem.

3. An intranet application is modeled as a hierarchy of three tasks. The *backbone task* refers to the entire intranet application. The backbone task consists of a number of subtasks performed at physical sites, each of which is referred to as a *site task*. A site task consists of a number of distinct *group tasks*, where each group task comprises a number of distinct client tasks (performed on

workstations). In order to perform all the collaborative group and site tasks within an acceptable time, clients must communicate and share data among themselves.

4. A comprehensive mathematical formulation of the intranet integration problem was developed as an optimization problem. This optimization problem includes a large set of network and data management design constraints and an objective function representing the total intranet integration cost.

5. Quick performance techniques to evaluate both the three-level network infrastructure and the data management system are embedded within the optimization problem. These quick performance techniques are used to increase the likelihood that the intranet integration solutions can satisfy both the network and data management performance constraints.

6. An automated capacity planning tool was developed to synthesize and integrate the data management system and the network architecture as an application-specific intranet. This custom-built tool, *i*-CAD, is based on an evolutionary approach and it consists of three main procedures: the initial intranet generation, the intranet validation and evaluation, and the intranet selection and optimization.

7. *i*-CAD is connected to nine design libraries (Ethernet, ATM, IP router, bridge, T-carrier, SONET, VPN, server and hard disk). Thus, the designs created by *i*-CAD are based on realistic off-the-shelf components.

8. Our results show a high feasibility of automating data management systems and network architectures for various intranet infrastructures.

8.2.2 Related Contributions

Some early contributions that started our interests in the idea of synthesizing and integration application-specific intranets, are listed below.

1. We examined different distributed file caching mechanisms. We proposed an extension protocol for the Prospero File Access Protocol (PFAP) [ANR] to handle caching prerecorded video/audio files in real time. The objective of the extension is to dynamically determine a cache block size and to store the block(s) temporarily in intermediate PFAP server(s) while the blocks are transmitted to the clients. This extension has two phases. The first phase deals with the client request by determining the nearest server from which to fetch the file and allocating temporally intermediate storage in between the nearest server and the client. The second phase deals with the server replys by determining the cache block size, the optimum number of intermediate storage sites and the block cache schedule.

2. We formulated the caching of multimedia web document as an optimization problem to minimize the retrieval cost in term of network bandwidth and memory allocation. Two hierarchical models, object flow graph (OFG) and extended object flow graph (EOFG), for representing the caching of multimedia web documents, were proposed to specify the multimedia presentation and scheduling the retrieval operations [HRP97].

3. We developed a multimedia scheduler based on OFG and EOFG, a system of difference constraints and Allen's temporal intervals. The scheduler uses the Bellman-Ford algorithm to schedule the operations in an EOFG optimally [HPRdSJ97].

8.3 Future Research

The intranet integration problem and its custom-built evolutionary program *i*-CAD can be continued in four different directions in the future. The first direction is to make the intranet model more adaptive and realistic. The second direction is to further extend and refine *i*-CAD to run faster and with more intelligence. The third direction is modify the intranet design model and *i*-CAD to handle the issue of intranet redesign. The fourth possible direction is toward integrating *i*-CAD with other design and performance analysis tools.

8.3.1 Intranet Model Enhancements

Our intranet model can be extended further to cope with new network and data management design and performance requirements. A network can have a variable number of levels, to be determined during the optimization process. Each network level (group, site or backbone) can have a number of network components connecting in a certain topology, such as a tree, ring, bus, star or mesh. This will increase the reliability of the entire intranet. As for the data management system, we can use different server placement strategies such as placing servers at various network levels (site or backbone). Another strategy is to consider a data management system hierarchy by placing proxies closer to the client tasks and binding the placed proxies with the file servers. This strategy may help in balancing the data management load and easing the network congestion.

8.3.2 i-CAD Refinement

The capability and performance of *i*-CAD can be refined by examining the behavior of the genetic algorithm, especially in improving the search for good designs within the design space, and reducing the repair time to fix invalid designs as result of the crossover operator or the mutation operator. To improve the search, for example we can alternate the order of the mutation operator and the crossover operator, and study its effect on the population. Also, we can try to find a set of values for mutation rate and crossover rate to improve the optimization process. The techniques that were used to implement the genetic operators can be improved, especially for the crossover operator since it performs exchanging network and data management components simultaneously. This is a complex operation and it produces many invalid designs that must be repaired. The size of design libraries affects the performance of i-CAD, since i-CAD accesses design libraries in a linear fashion. This incurs a high access time which affects the mutation operator.

8.3.3 Intranet Redesign

Redesigning a pre-existing network structure or data management system, where the objective is to improve the performance for example, is a valid extension to i-CAD. This extension can be considered by adding specific techniques and some code to reuse as many as possible of all pre-allocated components and add new components as little as possible so that the cost of redesign is minimized.

8.3.4 i-CAD: Complete Synthesis and Analysis Tool

This future direction is focused on embedding or interfacing synthesis and analysis tools within i-CAD. Synthesis tools, which can design application-specific computer systems or multiprocessor systems, can be combined with i-CAD to synthesize group tasks by determining the hardware or software platforms needed to perform group tasks efficiently. A detail performance analysis tool that can evaluate network structures or data management systems can be interfaced with i-CAD to give more accurate fitness values for each design.

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Appendix A

i-CAD Outputs

This appendix contains the best designs of all the six experiments in Chapter 7, which are produced by i-CAD.

A.1 Experiment 1

- The output of i-CAD for a 3-level network design for the partial animation sutdio, when TND = 5.0 seconds.

Enter the generation number from 0-2999:
2010
Intranet infrastructure(37) is the best design in generation 2010:
initial cost = $156200, monthly cost = $0, interconnection cost = $0, wire cost = $11615
average network delay = 4.9135 seconds, homogeneity factor = 0.461538
BACKBONE(1) has 4 site tasks, BLT = 93.125 Mbps
DESIGN(37): Backbone Router is located at X = 48.4892, Y = 56.7385, Z = 24.2538
router(13): ip, 150000 pps, 5 ports, $11000
ST(1) is connected to port 1
ST(2) is connected to port 2
ST(3) is connected to port 3
ST(4) is connected to port 4
SITE(1) has 2 group tasks, SLT = 0 Mbps, SOT = 55.625 Mbps, SIT = 2.5 Mbps
DESIGN(37): Site Router is located at X = 36.4, Y = 63, Z = 1.1
router(13): ip, 150000 pps, 5 ports, $11000
GT(1) is connected to port 1
GT(4) is connected to port 2
BT(1) is connected to port 3
GROUP(1) has 10 client tasks, GLT = 27 Mbps, GOT = 7.5 Mbps, GIT = 0 Mbps
DESIGN(37): GNC is located at X = 9.7, Y = 49.6, Z = 1.1
switch(18): atm, 100000000 bps, 15 ports, $15000
CT(1) is connected to port 1

⋮

CT(10) is connected to port 10
ST(1) is connected to port 11
GROUP(4) has 5 client tasks, GLT = 8 Mbps, GOT = 48.125 Mbps, GIT = 2.5 Mbps
DESIGN(37): GNC is located at X = 89.8, Y = 89.8, Z = 1.1

multiaccess(27): ethernet, 1000000000 bps, 6 ports, $13000
CT(11) is connected to port 1

⋮

CT(15) is connected to port 5
ST(1) is connected to port 6
SITE(2) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps, SIT = 21.25 Mbps
DESIGN(37): Site Router is located at X = 49.6667, Y = 56.3333, Z = 16.1
router(9): ip, 100000 pps, 5 ports, $7000
GT(2) is connected to port 1
GT(5) is connected to port 2
BT(1) is connected to port 3
GROUP(2) has 5 client tasks, GLT = 2 Mbps, GOT = 2.5 Mbps, GIT = 2.5 Mbps
DESIGN(37): GNC is located at X = 9.2, Y = 89, Z = 16.1
switch(12): atm, 75000000 bps, 10 ports, $8000
CT(16) is connected to port 1

⋮

CT(20) is connected to port 5
ST(2) is connected to port 6
GROUP(5) has 10 client tasks, GLT = 9 Mbps, GOT = 12.5 Mbps, GIT = 18.75 Mbps
DESIGN(37): GNC is located at X = 69.9, Y = 40, Z = 16.1
multiaccess(18): ethernet, 100000000 bps, 12 ports, $13000
CT(21) is connected to port 1

⋮

CT(30) is connected to port 10
ST(2) is connected to port 11
SITE(3) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps, SIT = 33.75 Mbps
DESIGN(37): Site Router is located at X = 52.45, Y = 50, Z = 32.1
router(13): ip, 150000 pps, 5 ports, $11000
GT(3) is connected to port 1
GT(8) is connected to port 2
BT(1) is connected to port 3
GROUP(3) has 10 client tasks, GLT = 9 Mbps, GOT = 15 Mbps, GIT = 7.5 Mbps
DESIGN(37): GNC is located at X = 27.5, Y = 85, Z = 32.1
multiaccess(18): ethernet, 100000000 bps, 12 ports, $13000
CT(31) is connected to port 1

⋮

CT(40) is connected to port 10
ST(3) is connected to port 11
GROUP(8) has 10 client tasks, GLT = 9 Mbps, GOT = 0 Mbps, GIT = 26.25 Mbps
DESIGN(37): GNC is located at X = 77.4, Y = 15, Z = 32.1
multiaccess(18): ethernet, 100000000 bps, 12 ports, $13000
CT(41) is connected to port 1

⋮

CT(50) is connected to port 10
ST(3) is connected to port 11
SITE(4) has 2 group tasks, SLT = 4.2 Mbps, SOT = 7.5 Mbps, SIT = 35.625 Mbps
DESIGN(37): Site Router is located at X = 54.12, Y = 59.8667, Z = 45.1
router(9): ip, 100000 pps, 5 ports, $7000

GT(6) is connected to port 1
GT(7) is connected to port 2
BT(1) is connected to port 3
GROUP(6) has 7 client tasks, GLT = 4.2 Mbps, GOT = 7.7 Mbps, GIT = 16.625 Mbps
DESIGN(37): GNC is located at X = 15.4, Y = 30.7143, Z = 45.1
multiaccess(16): ethernet, 100000000 bps, 8 ports, $9200
CT(51) is connected to port 1

⋮

CT(57) is connected to port 7
ST(4) is connected to port 8
GROUP(7) has 8 client tasks, GLT = 5.6 Mbps, GOT = 4 Mbps, GIT = 23.2 Mbps
DESIGN(37): GNC is located at X = 88, Y = 85.375, Z = 45.1
multiaccess(29): ethernet, 1000000000 bps, 10 ports, $25000
CT(58) is connected to port 1

⋮

CT(65) is connected to port 8
ST(4) is connected to port 9
Enter the generation number from 0-2999:

- The output of *i*-CAD for a 3-level network design for the partial animation sutdio, when TND = 10.0 seconds.

Enter the generation number from 0-2999:
1943
Intranet infrastructure(91) is the best design in generation 1943:
initial cost = $113400, monthly cost = $0, interconnection cost = $0, wire cost = $3760.13
average network delay = 9.90604 seconds, homogeneity Factor = 0.461538
BACKBONE(1) has 4 site tasks, BLT = 93.125 Mbps
DESIGN(91): Backbone Router is located at X = 48.4892, Y = 56.7385, Z = 24.2538
router(9): ip, 100000 pps, 5 ports, $7000
ST(1) is connected to port 1
ST(2) is connected to port 2
ST(3) is connected to port 3
ST(4) is connected to port 4
SITE(1) has 2 group tasks, SLT = 0 Mbps, SOT = 55.625 Mbps, SIT = 2.5 Mbps
DESIGN(91): Site Router is located at X = 36.4, Y = 63, Z = 1.1
router(9): ip, 100000 pps, 5 ports, $7000
GT(1) is connected to port 1
GT(4) is connected to port 2
BT(1) is connected to port 3
GROUP(1) has 10 client tasks, GLT = 27 Mbps, GOT = 7.5 Mbps, GIT = 0 Mbps
DESIGN(91): GNC is located at X = 9.7, Y = 49.6, Z = 1.1
switch(13): atm, 75000000 bps, 15 ports, $11000
CT(1) is connected to port 1

⋮

CT(10) is connected to port 10
ST(1) is connected to port 11
GROUP(4) has 5 client tasks, GLT = 8 Mbps, GOT = 48.125 Mbps, GIT = 2.5 Mbps
DESIGN(91): GNC is located at X = 89.8, Y = 89.8, Z = 1.1

multiaccess(15): ethernet, 100000000 bps, 6 ports, $8000
CT(11) is connected to port 1

⋮

CT(15) is connected to port 5
ST(1) is connected to port 6
SITE(2) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps, SIT = 21.25 Mbps
DESIGN(91): Site Router is located at X = 49.6667, Y = 56.3333, Z = 16.1
router(5): ip, 50000 pps, 5 ports, $3000
GT(2) is connected to port 1
GT(5) is connected to port 2
BT(1) is connected to port 3
GROUP(2) has 5 client tasks, GLT = 2 Mbps, GOT = 2.5 Mbps, GIT = 2.5 Mbps
DESIGN(91): GNC is located at X = 9.2, Y = 89, Z = 16.1
switch(12): atm, 75000000 bps, 10 ports, $8000
CT(16) is connected to port 1

⋮

CT(20) is connected to port 5
ST(2) is connected to port 6
GROUP(5) has 10 client tasks, GLT = 9 Mbps, GOT = 12.5 Mbps, GIT = 18.75 Mbps
DESIGN(91): GNC is located at X = 69.9, Y = 40, Z = 16.1
switch(18): atm, 100000000 bps, 15 ports, $15000
CT(21) is connected to port 1

⋮

CT(30) is connected to port 10
ST(2) is connected to port 11
SITE(3) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps, SIT = 33.75 Mbps
DESIGN(91): Site Router is located at X = 52.45, Y = 50, Z = 32.1
router(9): ip, 100000 pps, 5 ports, $7000
GT(3) is connected to port 1
GT(8) is connected to port 2
BT(1) is connected to port 3
GROUP(3) has 10 client tasks, GLT = 9 Mbps, GOT = 15 Mbps, GIT = 7.5 Mbps
DESIGN(91): GNC is located at X = 27.5, Y = 85, Z = 32.1
switch(13): atm, 75000000 bps, 15 ports, $11000
CT(31) is connected to port 1

⋮

CT(40) is connected to port 10
ST(3) is connected to port 11
GROUP(8) has 10 client tasks, GLT = 9 Mbps, GOT = 0 Mbps, GIT = 26.25 Mbps
DESIGN(91): GNC is located at X = 77.4, Y = 15, Z = 32.1
switch(13): atm, 75000000 bps, 15 ports, $11000
CT(41) is connected to port 1

⋮

CT(50) is connected to port 10
ST(3) is connected to port 11
SITE(4) has 2 group tasks, SLT = 4.2 Mbps, SOT = 7.5 Mbps, SIT = 35.625 Mbps
DESIGN(91): Site Router is located at X = 54.12, Y = 59.8667, Z = 45.1
router(9): ip, 100000 pps, 5 ports, $7000

GT(6) is connected to port 1
GT(7) is connected to port 2
BT(1) is connected to port 3
GROUP(6) has 7 client tasks, GLT = 4.2 Mbps, GOT = 7.7 Mbps, GIT = 16.625 Mbps
DESIGN(91): GNC is located at X = 15.4, Y = 30.7143, Z = 45.1
switch(12): atm, 75000000 bps, 10 ports, $8000
CT(51) is connected to port 1

⋮

ST(4) is connected to port 8
GROUP(7) has 8 client tasks, GLT = 5.6 Mbps, GOT = 4 Mbps, GIT = 23.2 Mbps
DESIGN(91): GNC is located at X = 88, Y = 85.375, Z = 45.1
multiaccess(17): ethernet, 100000000 bps, 10 ports, $10400
CT(58) is connected to port 1

⋮

ST(4) is connected to port 9
Enter the generation number from 0-2999:

- The output of *i*-CAD for a 3-level network design for the partial animation sutdio, when TND = 20.0 seconds.

Enter the generation number from 0-2999:
2209
Intranet infrastructure(158) is the best design in generation 2209:
initial cost = $87000, monthly cost = $0, interconnection cost = $0, wire cost = $3760.13
average network delay = 19.4312 seconds, homogeneity factor = 0.538462
BACKBONE(1) has 4 site tasks, BLT = 93.125 Mbps
DESIGN(158): Backbone Router is located at X = 48.4892, Y = 56.7385, Z = 24.2538
router(9): ip, 100000 pps, 5 ports, $7000
ST(1) is connected to port 1
ST(2) is connected to port 2
ST(3) is connected to port 3
ST(4) is connected to port 4
SITE(1) has 2 group tasks, SLT = 0 Mbps, SOT = 55.625 Mbps, SIT = 2.5 Mbps
DESIGN(158): Site Router is located at X = 36.4, Y = 63, Z = 1.1
router(5): ip, 50000 pps, 5 ports, $3000
GT(1) is connected to port 1
GT(4) is connected to port 2
BT(1) is connected to port 3
GROUP(1) has 10 client tasks, GLT = 27 Mbps, GOT = 7.5 Mbps, GIT = 0 Mbps
DESIGN(158): GNC is located at X = 9.7, Y = 49.6, Z = 1.1
switch(13): atm, 75000000 bps, 15 ports, $11000
CT(1) is connected to port 1

⋮

CT(10) is connected to port 10
ST(1) is connected to port 11
GROUP(4) has 5 client tasks, GLT = 8 Mbps, GOT = 48.125 Mbps, GIT = 2.5 Mbps
DESIGN(158): GNC is located at X = 89.8, Y = 89.8, Z = 1.1
multiaccess(15): ethernet, 100000000 bps, 6 ports, $8000
CT(11) is connected to port 1

⋮

CT(15) is connected to port 5
ST(1) is connected to port 6
SITE(2) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps, SIT = 21.25 Mbps
DESIGN(158): Site Router is located at X = 49.6667, Y = 56.3333, Z = 16.1
router(5): ip, 50000 pps, 5 ports, $3000
GT(2) is connected to port 1
GT(5) is connected to port 2
BT(1) is connected to port 3
GROUP(2) has 5 client tasks, GLT = 2 Mbps, GOT = 2.5 Mbps, GIT = 2.5 Mbps
DESIGN(158): GNC is located at X = 9.2, Y = 89, Z = 16.1
switch(2): atm, 25000000 bps, 10 ports, $4000
CT(16) is connected to port 1

⋮

CT(20) is connected to port 5
ST(2) is connected to port 6
GROUP(5) has 10 client tasks, GLT = 9 Mbps, GOT = 12.5 Mbps, GIT = 18.75 Mbps
DESIGN(158): GNC is located at X = 69.9, Y = 40, Z = 16.1
switch(13): atm, 75000000 bps, 15 ports, $11000
CT(21) is connected to port 1

⋮

CT(30) is connected to port 10
ST(2) is connected to port 11
SITE(3) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps, SIT = 33.75 Mbps
DESIGN(158): Site Router is located at X = 52.45, Y = 50, Z = 32.1
router(5): ip, 50000 pps, 5 ports, $3000
GT(3) is connected to port 1
GT(8) is connected to port 2
BT(1) is connected to port 3
GROUP(3) has 10 client tasks, GLT = 9 Mbps, GOT = 15 Mbps, GIT = 7.5 Mbps
DESIGN(158): GNC is located at X = 27.5, Y = 85, Z = 32.1
switch(13): atm, 75000000 bps, 15 ports, $11000
CT(31) is connected to port 1

⋮

CT(40) is connected to port 10
ST(3) is connected to port 11
GROUP(8) has 10 client tasks, GLT = 9 Mbps, GOT = 0 Mbps, GIT = 26.25 Mbps
DESIGN(158): GNC is located at X = 77.4, Y = 15, Z = 32.1
switch(13): atm, 75000000 bps, 15 ports, $11000
CT(41) is connected to port 1

⋮

CT(50) is connected to port 10
ST(3) is connected to port 11
SITE(4) has 2 group tasks, SLT = 4.2 Mbps, SOT = 7.5 Mbps, SIT = 35.625 Mbps
DESIGN(158): Site Router is located at X = 54.12, Y = 59.8667, Z = 45.1
router(5): ip, 50000 pps, 5 ports, $3000
GT(6) is connected to port 1
GT(7) is connected to port 2

BT(1) is connected to port 3
GROUP(6) has 7 client tasks, GLT = 4.2 Mbps, GOT = 7.7 Mbps, GIT = 16.625 Mbps
DESIGN(158): GNC is located at X = 15.4, Y = 30.7143, Z = 45.1
switch(7): atm, 45000000 bps, 10 ports, $6000
CT(51) is connected to port 1

⋮

CT(57) is connected to port 7
ST(4) is connected to port 8
GROUP(7) has 8 client tasks, GLT = 5.6 Mbps, GOT = 4 Mbps, GIT = 23.2 Mbps
DESIGN(158): GNC is located at X = 88, Y = 85.375, Z = 45.1
switch(7): atm, 45000000 bps, 10 ports, $6000
CT(58) is connected to port 1
...
CT(65) is connected to port 8
ST(4) is connected to port 9
Enter the generation number from 0-2999:

- The output of *i*-CAD for a 3-level network design for the partial animation sutdio, when TND = 30.0 seconds.

Enter the generation number from 0-2999:
2769
Intranet infrastructure(153) is the best design in generation 2769:
initial cost = $79320, monthly cost = $0, interconnection cost = $0, wire cost = $3760.13
average network delay = 28.7014 seconds, homogeneity factor = 0.538462
BACKBONE(1) has 4 site tasks, BLT = 93.125 Mbps
DESIGN(153): Backbone Router is located at X = 48.4892, Y = 56.7385, Z = 24.2538
router(9): ip, 100000 pps, 5 ports, $7000
ST(1) is connected to port 1
ST(2) is connected to port 2
ST(3) is connected to port 3
ST(4) is connected to port 4
SITE(1) has 2 group tasks, SLT = 0 Mbps, SOT = 55.625 Mbps, SIT = 2.5 Mbps
DESIGN(153): Site Router is located at X = 36.4, Y = 63, Z = 1.1
router(5): ip, 50000 pps, 5 ports, $3000
GT(1) is connected to port 1
GT(4) is connected to port 2
BT(1) is connected to port 3
GROUP(1) has 10 client tasks, GLT = 27 Mbps, GOT = 7.5 Mbps, GIT = 0 Mbps
DESIGN(153): GNC is located at X = 9.7, Y = 49.6, Z = 1.1
switch(8): atm, 45000000 bps, 15 ports, $9000
CT(1) is connected to port 1

⋮

CT(10) is connected to port 10
ST(1) is connected to port 11
GROUP(4) has 5 client tasks, GLT = 8 Mbps, GOT = 48.125 Mbps, GIT = 2.5 Mbps
DESIGN(153): GNC is located at X = 89.8, Y = 89.8, Z = 1.1
switch(12): atm, 75000000 bps, 10 ports, $8000
CT(11) is connected to port 1

⋮

CT(15) is connected to port 5
ST(1) is connected to port 6
SITE(2) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps, SIT = 21.25 Mbps
DESIGN(153): Site Router is located at X = 49.6667, Y = 56.3333, Z = 16.1
router(5): ip, 50000 pps, 5 ports, $3000
GT(2) is connected to port 1
GT(5) is connected to port 2
BT(1) is connected to port 3
GROUP(2) has 5 client tasks, GLT = 2 Mbps, GOT = 2.5 Mbps, GIT = 2.5 Mbps
DESIGN(153): GNC is located at X = 9.2, Y = 89, Z = 16.1
multiaccess(4): ethernet, 10000000 bps, 8 ports, $320
CT(16) is connected to port 1

⋮

CT(20) is connected to port 5
ST(2) is connected to port 6
GROUP(5) has 10 client tasks, GLT = 9 Mbps, GOT = 12.5 Mbps, GIT = 18.75 Mbps
DESIGN(153): GNC is located at X = 69.9, Y = 40, Z = 16.1
switch(13): atm, 75000000 bps, 15 ports, $11000
CT(21) is connected to port 1

⋮

CT(30) is connected to port 10
ST(2) is connected to port 11
SITE(3) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps, SIT = 33.75 Mbps
DESIGN(153): Site Router is located at X = 52.45, Y = 50, Z = 32.1
router(5): ip, 50000 pps, 5 ports, $3000
GT(3) is connected to port 1
GT(8) is connected to port 2
BT(1) is connected to port 3
GROUP(3) has 10 client tasks, GLT = 9 Mbps, GOT = 15 Mbps, GIT = 7.5 Mbps
DESIGN(153): GNC is located at X = 27.5, Y = 85, Z = 32.1
switch(13): atm, 75000000 bps, 15 ports, $11000
CT(31) is connected to port 1

⋮

CT(40) is connected to port 10
ST(3) is connected to port 11
GROUP(8) has 10 client tasks, GLT = 9 Mbps, GOT = 0 Mbps, GIT = 26.25 Mbps
DESIGN(153): GNC is located at X = 77.4, Y = 15, Z = 32.1
switch(8): atm, 45000000 bps, 15 ports, $9000
CT(41) is connected to port 1

⋮

CT(50) is connected to port 10
ST(3) is connected to port 11
SITE(4) has 2 group tasks, SLT = 4.2 Mbps, SOT = 7.5 Mbps, SIT = 35.625 Mbps
DESIGN(153): Site Router is located at X = 54.12, Y = 59.8667, Z = 45.1
router(5): ip, 50000 pps, 5 ports, $3000
GT(6) is connected to port 1
GT(7) is connected to port 2
BT(1) is connected to port 3
GROUP(6) has 7 client tasks, GLT = 4.2 Mbps, GOT = 7.7 Mbps, GIT = 16.625 Mbps

DESIGN(153): GNC is located at X = 15.4, Y = 30.7143, Z = 45.1
switch(7): atm, 45000000 bps, 10 ports, $6000
CT(51) is connected to port 1

⋮

CT(57) is connected to port 7
ST(4) is connected to port 8
GROUP(7) has 8 client tasks, GLT = 5.6 Mbps, GOT = 4 Mbps, GIT = 23.2 Mbps
DESIGN(153): GNC is located at X = 88, Y = 85.375, Z = 45.1
switch(7): atm, 45000000 bps, 10 ports, $6000
CT(58) is connected to port 1

⋮

CT(65) is connected to port 8
ST(4) is connected to port 9
Enter the generation number from 0-2999:

- The output of *i*-CAD for a 3-level network design for the partial animation sutdio, when TND = 40.0 seconds.

Enter the generation number from 0-2999:
2839
Intranet infrastructure(193) is the best design in generation 2839:
initial cost = $77200, monthly cost = $0, interconnection cost = $0, wire cost = $3760.13
average network delay = 37.6259 seconds, homogeneity factor = 0.615385
BACKBONE(1) has 4 site tasks, BLT = 93.125 Mbps
DESIGN(193): Backbone Router is located at X = 48.4892, Y = 56.7385, Z = 24.2538
router(9): ip, 100000 pps, 5 ports, $7000
ST(1) is connected to port 1
ST(2) is connected to port 2
ST(3) is connected to port 3
ST(4) is connected to port 4
SITE(1) has 2 group tasks, SLT = 0 Mbps, SOT = 55.625 Mbps, SIT = 2.5 Mbps
DESIGN(193): Site Router is located at X = 36.4, Y = 63, Z = 1.1
router(5): ip, 50000 pps, 5 ports, $3000
GT(1) is connected to port 1
GT(4) is connected to port 2
BT(1) is connected to port 3
GROUP(1) has 10 client tasks, GLT = 27 Mbps, GOT = 7.5 Mbps, GIT = 0 Mbps
DESIGN(193): GNC is located at X = 9.7, Y = 49.6, Z = 1.1
switch(8): atm, 45000000 bps, 15 ports, $9000
CT(1) is connected to port 1

⋮

CT(10) is connected to port 10
ST(1) is connected to port 11
GROUP(4) has 5 client tasks, GLT = 8 Mbps, GOT = 48.125 Mbps, GIT = 2.5 Mbps
DESIGN(193): GNC is located at X = 89.8, Y = 89.8, Z = 1.1
switch(12): atm, 75000000 bps, 10 ports, $8000
CT(11) is connected to port 1

⋮

CT(15) is connected to port 5

ST(1) is connected to port 6
SITE(2) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps, SIT = 21.25 Mbps
DESIGN(193): Site Router is located at X = 49.6667, Y = 56.3333, Z = 16.1
router(5): ip, 50000 pps, 5 ports, $3000
GT(2) is connected to port 1
GT(5) is connected to port 2
BT(1) is connected to port 3
GROUP(2) has 5 client tasks, GLT = 2 Mbps, GOT = 2.5 Mbps, GIT = 2.5 Mbps
DESIGN(193): GNC is located at X = 9.2, Y = 89, Z = 16.1
multiaccess(3): ethernet, 10000000 bps, 6 ports, $200
CT(16) is connected to port 1
⋮
CT(20) is connected to port 5
ST(2) is connected to port 6
GROUP(5) has 10 client tasks, GLT = 9 Mbps, GOT = 12.5 Mbps, GIT = 18.75 Mbps
DESIGN(193): GNC is located at X = 69.9, Y = 40, Z = 16.1
switch(8): atm, 45000000 bps, 15 ports, $9000
CT(21) is connected to port 1
⋮
CT(30) is connected to port 10
ST(2) is connected to port 11
SITE(3) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps, SIT = 33.75 Mbps
DESIGN(193): Site Switch is located at X = 52.45, Y = 50, Z = 32.1
switch(11): atm, 75000000 bps, 5 ports, $5000
GT(3) is connected to port 1
GT(8) is connected to port 2
BT(1) is connected to port 3
GROUP(3) has 10 client tasks, GLT = 9 Mbps, GOT = 15 Mbps, GIT = 7.5 Mbps
DESIGN(193): GNC is located at X = 27.5, Y = 85, Z = 32.1
switch(8): atm, 45000000 bps, 15 ports, $9000
CT(31) is connected to port 1
⋮
CT(40) is connected to port 10
ST(3) is connected to port 11
GROUP(8) has 10 client tasks, GLT = 9 Mbps, GOT = 0 Mbps, GIT = 26.25 Mbps
DESIGN(193): GNC is located at X = 77.4, Y = 15, Z = 32.1
switch(8): atm, 45000000 bps, 15 ports, $9000
CT(41) is connected to port 1
⋮
CT(50) is connected to port 10
ST(3) is connected to port 11
SITE(4) has 2 group tasks, SLT = 4.2 Mbps, SOT = 7.5 Mbps, SIT = 35.625 Mbps
DESIGN(193): Site Router is located at X = 54.12, Y = 59.8667, Z = 45.1
router(5): ip, 50000 pps, 5 ports, $3000
GT(6) is connected to port 1
GT(7) is connected to port 2
BT(1) is connected to port 3
GROUP(6) has 7 client tasks, GLT = 4.2 Mbps, GOT = 7.7 Mbps, GIT = 16.625 Mbps
DESIGN(193): GNC is located at X = 15.4, Y = 30.7143, Z = 45.1

switch(7): atm, 45000000 bps, 10 ports, $6000
CT(51) is connected to port 1

⋮

CT(57) is connected to port 7
ST(4) is connected to port 8
GROUP(7) has 8 client tasks, GLT = 5.6 Mbps, GOT = 4 Mbps, GIT = 23.2 Mbps
DESIGN(193): GNC is located at X = 88, Y = 85.375, Z = 45.1
switch(7): atm, 45000000 bps, 10 ports, $6000
CT(58) is connected to port 1

⋮

CT(65) is connected to port 8
ST(4) is connected to port 9
Enter the generation number from 0-2999:

- The output of *i*-CAD for a 3-level network design for the partial animation sutdio, when TND = 50.0 seconds.

Enter the generation number from 0-2999:
1994
Intranet infrastructure(37) is the best design in generation 1994:
initial cost = $75200, monthly cost = $0, interconnection cost = $0, wire cost = $3760.13
average network delay = 37.6259 seconds, homogeneity factor = 0.538462
BACKBONE(1) has 4 site tasks, BLT = 93.125 Mbps
DESIGN(37): Backbone Router is located at X = 48.4892, Y = 56.7385, Z = 24.2538
router(9): ip, 100000 pps, 5 ports, $7000
ST(1) is connected to port 1
ST(2) is connected to port 2
ST(3) is connected to port 3
ST(4) is connected to port 4
SITE(1) has 2 group tasks, SLT = 0 Mbps, SOT = 55.625 Mbps, SIT = 2.5 Mbps
DESIGN(37): Site Router is located at X = 36.4, Y = 63, Z = 1.1
router(5): ip, 50000 pps, 5 ports, $3000
GT(1) is connected to port 1
GT(4) is connected to port 2
BT(1) is connected to port 3
GROUP(1) has 10 client tasks, GLT = 27 Mbps, GOT = 7.5 Mbps, GIT = 0 Mbps
DESIGN(37): GNC is located at X = 9.7, Y = 49.6, Z = 1.1
switch(8): atm, 45000000 bps, 15 ports, $9000
CT(1) is connected to port 1

⋮

CT(10) is connected to port 10
ST(1) is connected to port 11
GROUP(4) has 5 client tasks, GLT = 8 Mbps, GOT = 48.125 Mbps, GIT = 2.5 Mbps
DESIGN(37): GNC is located at X = 89.8, Y = 89.8, Z = 1.1
switch(12): atm, 75000000 bps, 10 ports, $8000
CT(11) is connected to port 1

⋮

CT(15) is connected to port 5
ST(1) is connected to port 6

SITE(2) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps, SIT = 21.25 Mbps
DESIGN(37): Site Router is located at X = 49.6667, Y = 56.3333, Z = 16.1
router(5): ip, 50000 pps, 5 ports, $3000
GT(2) is connected to port 1
GT(5) is connected to port 2
BT(1) is connected to port 3
GROUP(2) has 5 client tasks, GLT = 2 Mbps, GOT = 2.5 Mbps, GIT = 2.5 Mbps
DESIGN(37): GNC is located at X = 9.2, Y = 89, Z = 16.1
multiaccess(3): ethernet, 10000000 bps, 6 ports, $200
CT(16) is connected to port 1

⋮

CT(20) is connected to port 5
ST(2) is connected to port 6
GROUP(5) has 10 client tasks, GLT = 9 Mbps, GOT = 12.5 Mbps, GIT = 18.75 Mbps
DESIGN(37): GNC is located at X = 69.9, Y = 40, Z = 16.1
switch(8): atm, 45000000 bps, 15 ports, $9000
CT(21) is connected to port 1

⋮

CT(30) is connected to port 10
ST(2) is connected to port 11
SITE(3) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps, SIT = 33.75 Mbps
DESIGN(37): Site Router is located at X = 52.45, Y = 50, Z = 32.1
router(5): ip, 50000 pps, 5 ports, $3000
GT(3) is connected to port 1
GT(8) is connected to port 2
BT(1) is connected to port 3
GROUP(3) has 10 client tasks, GLT = 9 Mbps, GOT = 15 Mbps, GIT = 7.5 Mbps
DESIGN(37): GNC is located at X = 27.5, Y = 85, Z = 32.1
switch(8): atm, 45000000 bps, 15 ports, $9000
CT(31) is connected to port 1

⋮

CT(40) is connected to port 10
ST(3) is connected to port 11
GROUP(8) has 10 client tasks, GLT = 9 Mbps, GOT = 0 Mbps, GIT = 26.25 Mbps
DESIGN(37): GNC is located at X = 77.4, Y = 15, Z = 32.1
switch(8): atm, 45000000 bps, 15 ports, $9000
CT(41) is connected to port 1

⋮

CT(50) is connected to port 10
ST(3) is connected to port 11
SITE(4) has 2 group tasks, SLT = 4.2 Mbps, SOT = 7.5 Mbps, SIT = 35.625 Mbps
DESIGN(37): Site Router is located at X = 54.12, Y = 59.8667, Z = 45.1
router(5): ip, 50000 pps, 5 ports, $3000
GT(6) is connected to port 1
GT(7) is connected to port 2
BT(1) is connected to port 3
GROUP(6) has 7 client tasks, GLT = 4.2 Mbps, GOT = 7.7 Mbps, GIT = 16.625 Mbps
DESIGN(37): GNC is located at X = 15.4, Y = 30.7143, Z = 45.1
switch(7): atm, 45000000 bps, 10 ports, $6000

CT(51) is connected to port 1

⋮

CT(57) is connected to port 7
ST(4) is connected to port 8
GROUP(7) has 8 client tasks, GLT = 5.6 Mbps, GOT = 4 Mbps, GIT = 23.2 Mbps
DESIGN(37): GNC is located at X = 88, Y = 85.375, Z = 45.1
switch(7): atm, 45000000 bps, 10 ports, $6000
CT(58) is connected to port 1

⋮

CT(65) is connected to port 8
ST(4) is connected to port 9
Enter the generation number from 0-2999:

- The output of *i*-CAD for a 3-level network design for the partial animation sutdio, when TND = 60.0 seconds.

Enter the generation number from 0-2999:
1994
Intranet infrastructure(37) is the best design in generation 1994:
initial cost = $75200, monthly cost = $0, interconnection cost = $0, wire cost = $3760.13
average network delay = 37.6259 seconds, homogeneity factor = 0.538462
BACKBONE(1) has 4 site tasks, BLT = 93.125 Mbps
DESIGN(37): Backbone Router is located at X = 48.4892, Y = 56.7385, Z = 24.2538
router(9): ip, 100000 pps, 5 ports, $7000
ST(1) is connected to port 1
ST(2) is connected to port 2
ST(3) is connected to port 3
ST(4) is connected to port 4
SITE(1) has 2 group tasks, SLT = 0 Mbps, SOT = 55.625 Mbps, SIT = 2.5 Mbps
DESIGN(37): Site Router is located at X = 36.4, Y = 63, Z = 1.1
router(5): ip, 50000 pps, 5 ports, $3000
GT(1) is connected to port 1
GT(4) is connected to port 2
BT(1) is connected to port 3
GROUP(1) has 10 client tasks, GLT = 27 Mbps, GOT = 7.5 Mbps, GIT = 0 Mbps
DESIGN(37): GNC is located at X = 9.7, Y = 49.6, Z = 1.1
switch(8): atm, 45000000 bps, 15 ports, $9000
CT(1) is connected to port 1

⋮

CT(10) is connected to port 10
ST(1) is connected to port 11
GROUP(4) has 5 client tasks, GLT = 8 Mbps , GOT = 48.125 Mbps, GIT = 2.5 Mbps
DESIGN(37): GNC is located at X = 89.8, Y = 89.8, Z = 1.1
switch(12): atm, 75000000 bps, 10 ports, $8000
CT(11) is connected to port 1

⋮

CT(15) is connected to port 5
ST(1) is connected to port 6
SITE(2) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps, SIT = 21.25 Mbps

DESIGN(37): Site Router is located at X = 49.6667, Y = 56.3333, Z = 16.1
router(5): ip, 50000 pps, 5 ports, \$3000
GT(2) is connected to port 1
GT(5) is connected to port 2
BT(1) is connected to port 3
GROUP(2) has 5 client tasks, GLT = 2 Mbps, GOT = 2.5 Mbps, GIT = 2.5 Mbps
DESIGN(37): GNC is located at X = 9.2, Y = 89, Z = 16.1
multiaccess(3): ethernet, 10000000 bps, 6 ports, \$200
CT(16) is connected to port 1
⋮
CT(20) is connected to port 5
ST(2) is connected to port 6
GROUP(5) has 10 client tasks, GLT = 9 Mbps, GOT = 12.5 Mbps, GIT = 18.75 Mbps
DESIGN(37): GNC is located at X = 69.9, Y = 40, Z = 16.1
switch(8): atm, 45000000 bps, 15 ports, \$9000
CT(21) is connected to port 1
⋮
CT(30) is connected to port 10
ST(2) is connected to port 11
SITE(3) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps, SIT = 33.75 Mbps
DESIGN(37): Site Router is located at X = 52.45, Y = 50, Z = 32.1
router(5): ip, 50000 pps, 5 ports, \$3000
GT(3) is connected to port 1
GT(8) is connected to port 2
BT(1) is connected to port 3
GROUP(3) has 10 client tasks, GLT = 9 Mbps, GOT = 15 Mbps, GIT = 7.5 Mbps
DESIGN(37): GNC is located at X = 27.5, Y = 85, Z = 32.1
switch(8): atm, 45000000 bps, 15 ports, \$9000
CT(31) is connected to port 1
⋮
CT(40) is connected to port 10
ST(3) is connected to port 11
GROUP(8) has 10 client tasks, GLT = 9 Mbps, GOT = 0 Mbps, GIT = 26.25 Mbps
DESIGN(37): GNC is located at X = 77.4, Y = 15, Z = 32.1
switch(8): atm, 45000000 bps, 15 ports, \$9000
CT(41) is connected to port 1
⋮
CT(50) is connected to port 10
ST(3) is connected to port 11
SITE(4) has 2 group tasks, SLT = 4.2 Mbps, SOT = 7.5 Mbps, SIT = 35.625 Mbps
DESIGN(37): Site Router is located at X = 54.12, Y = 59.8667, Z = 45.1
router(5): ip, 50000 pps, 5 ports, \$3000
GT(6) is connected to port 1
GT(7) is connected to port 2
BT(1) is connected to port 3
GROUP(6) has 7 client tasks, GLT = 4.2 Mbps, GOT = 7.7 Mbps, GIT = 16.625 Mbps
DESIGN(37): GNC is located at X = 15.4, Y = 30.7143, Z = 45.1
switch(7): atm, 45000000 bps, 10 ports, \$6000
CT(51) is connected to port 1

⋮

CT(57) is connected to port 7
ST(4) is connected to port 8
GROUP(7) has 8 client tasks, GLT = 5.6 Mbps, GOT = 4 Mbps, GIT = 23.2 Mbps
DESIGN(37): GNC is located at X = 88, Y = 85.375, Z = 45.1
switch(7): atm, 45000000 bps, 10 ports, $6000
CT(58) is connected to port 1

⋮

CT(65) is connected to port 8
ST(4) is connected to port 9
Enter the generation number from 0-2999:

A.2 Experiment 2

- The output of *i*-CAD for a 3-level network design, including a wide tree backbone topology, for the partial animation sutdio, when TND = 6.0 seconds.

Enter the generation number from 0-2999:
1618
Intranet infrastructure(20) is the best design in generation 1618:
initial cost = $245400, monthly cost = $396000
interconnection cost = $10000, wire cost = $14957.2
average network delay = 5.98882 seconds, homogeneity factor = 0.333333
BACKBONE(1) has 4 site tasks, BLT = 93.125 Mbps
Link(1) connects sites: 1 and 3
t-line(ds4): 264241152 bps, initial cost $30000 and monthly cost $13000
Link(2) connects sites: 3 and 2
sonet(vpc15-oc3/sonetsonet): 116640000 bps, initial cost $22500 and monthly cost $7000
Link(3) connects sites: 3 and 4
t-line(ds4): 264241152 bps, initial cost $30000 and monthly cost $13000
SITE(1) has 2 group tasks, SLT = 0 Mbps, SOT = 55.625 Mbps, SIT = 2.5 Mbps
DESIGN(20): Site Router is located at X = 83236.4, Y = 20863, Z = 1.1
router(13): ip, 150000 pps, 5 ports, $11000
GT(1) is connected to port 1
GT(4) is connected to port 2
LINK(1) is connected to port 3
GROUP(1) has 10 client tasks, GLT = 27 Mbps, GOT = 7.5 Mbps, GIT = 0 Mbps
DESIGN(20): GNC is located at X = 83209.7, Y = 20849.6, Z = 1.1
switch(18): atm, 100000000 bps, 15 ports, $15000
CT(1) is connected to port 1

⋮

CT(10) is connected to port 10
ST(1) is connected to port 11
GROUP(4) has 5 client tasks, GLT = 8 Mbps, GOT = 48.125 Mbps, GIT = 2.5 Mbps
DESIGN(20): GNC is located at X = 83289.8, Y = 20889.8, Z = 1.1
multiaccess(27): ethernet, 1000000000 bps, 6 ports, $13000
CT(11) is connected to port 1

⋮

CT(15) is connected to port 5
ST(1) is connected to port 6
SITE(2) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps, SIT = 21.25 Mbps
DESIGN(20): Site Multiaccess device is located at X = 114450, Y = 56.3333, Z = 16.1
multiaccess(26): ethernet, 1000000000 bps, 4 ports, $8000
GT(2) is connected to site task port 1 via a 2-port bridge with following attributes:
Bridge(13), has capacity 80000 frames per second and cost $260
GT(5) is connected to site task port 2 via a 2-port bridge with following attributes:
Bridge(12), has capacity 70000 frames per second and cost $240
LINK(2) is connected to port 3
GROUP(2) has 5 client tasks, GLT = 2 Mbps, GOT = 2.5 Mbps, GIT = 2.5 Mbps
DESIGN(20): GNC is located at X = 114409, Y = 89, Z = 16.1
multiaccess(16): ethernet, 100000000 bps, 8 ports, $9200
CT(16) is connected to port 1

⋮

CT(20) is connected to port 5
ST(2) is connected to port 6
GROUP(5) has 10 client tasks, GLT = 9 Mbps, GOT = 12.5 Mbps, GIT = 18.75 Mbps
DESIGN(20): GNC is located at X = 114470, Y = 40, Z = 16.1
multiaccess(30): ethernet, 1000000000 bps, 12 ports, $33000
CT(21) is connected to port 1

⋮

CT(30) is connected to port 10
ST(2) is connected to port 11
SITE(3) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps, SIT = 33.75 Mbps
DESIGN(20): Site Router is located at X = 52052.4, Y = 10450, Z = 32.1
router(13): ip, 150000 pps, 5 ports, $11000
GT(3) is connected to port 1
GT(8) is connected to port 2
LINK(1) is connected to port 3
LINK(2) is connected to port 4
LINK(3) is connected to port 5
GROUP(3) has 10 client tasks, GLT = 9 Mbps, GOT = 15 Mbps, GIT = 7.5 Mbps
DESIGN(20): GNC is located at X = 52027.5, Y = 10485, Z = 32.1
switch(13): atm, 75000000 bps, 15 ports, $11000
CT(31) is connected to port 1

⋮

CT(40) is connected to port 10
ST(3) is connected to port 11
GROUP(8) has 10 client tasks, GLT = 9 Mbps, GOT = 0 Mbps, GIT = 26.25 Mbps
DESIGN(20): GNC is located at X = 52077.4, Y = 10415, Z = 32.1
switch(23): atm, 150000000 bps, 15 ports, $20000
CT(41) is connected to port 1

⋮

CT(50) is connected to port 10
ST(3) is connected to port 11
SITE(4) has 2 group tasks, SLT = 4.2 Mbps, SOT = 7.5 Mbps, SIT = 35.625 Mbps
DESIGN(20): Site Router is located at X = 54.12, Y = 10459.9, Z = 45.1
router(9): ip, 100000 pps, 5 ports, $7000

GT(6) is connected to port 1
GT(7) is connected to port 2
LINK(3) is connected to port 3
GROUP(6) has 7 client tasks, GLT = 4.2 Mbps, GOT = 7.7 Mbps, GIT = 16.625 Mbps
DESIGN(20): GNC is located at X = 15.4, Y = 10430.7, Z = 45.1
multiaccess(16): ethernet, 100000000 bps, 8 ports, $9200
CT(51) is connected to port 1

⋮

CT(57) is connected to port 7
ST(4) is connected to port 8
GROUP(7) has 8 client tasks, GLT = 5.6 Mbps, GOT = 4 Mbps, GIT = 23.2 Mbps
DESIGN(20): GNC is located at X = 88, Y = 10485.4, Z = 45.1
switch(22): atm, 150000000 bps, 10 ports, $15000
CT(58) is connected to port 1

⋮

CT(65) is connected to port 8
ST(4) is connected to port 9
Enter the generation number from 0-2999:

- The output of *i*-CAD for a 3-level network design, including a wide tree backbone topology, for the partial animation sutdio, when TND = 7.5 seconds.

Enter the generation number from 0-2999:
2182
Intranet infrastructure(143) is the best design in generation 2182:
initial cost = $250620, monthly cost = $336000
interconnection cost = $22000, wire cost = $11751.6
average network delay = 7.42804 seconds, homogeneity factor = 0.333333
BACKBONE(1) has 4 site tasks, BLT = 93.125 Mbps
Link(1) connects sites: 1 and 3
sonet(vpc19-oc12sonetsonet): 155520000 bps, initial cost $35000 and monthly cost $9000
Link(2) connects sites: 1 and 2
t-line(ds4): 264241152 bps, initial cost $30000 and monthly cost $13000
Link(3) connects sites: 2 and 4
sonet(oc2): 103680000 bps, initial cost $20000 and monthly cost $6000
SITE(1) has 2 group tasks, SLT = 0 Mbps, SOT = 55.625 Mbps, SIT = 2.5 Mbps
DESIGN(143): Site Multiaccess device is located at X = 83236.4, Y = 20863, Z = 1.1
multiaccess(27): ethernet, 1000000000 bps, 6 ports, $13000
GT(1) is connected to site task port 1 via a 2-port bridge with following attributes:
Bridge(12), has capacity 70000 frames per second and cost $240
GT(4) is connected to site task port 2 via a 2-port bridge with following attributes:
Bridge(19), has capacity 120000 frames per second and cost $380
LINK(1) is connected to port 3
LINK(2) is connected to port 4
GROUP(1) has 10 client tasks, GLT = 27 Mbps, GOT = 7.5 Mbps, GIT = 0 Mbps
DESIGN(143): GNC is located at X = 83209.7, Y = 20849.6, Z = 1.1
multiaccess(19): ethernet, 100000000 bps, 14 ports, $16000
CT(1) is connected to port 1

⋮

CT(10) is connected to port 10
ST(1) is connected to port 11
GROUP(4) has 5 client tasks, GLT = 8 Mbps, GOT = 48.125 Mbps, GIT = 2.5 Mbps
DESIGN(143): GNC is located at X = 83289.8, Y = 20889.8, Z = 1.1
multiaccess(27): ethernet, 1000000000 bps, 6 ports, $13000
CT(11) is connected to port 1

⋮

CT(15) is connected to port 5
ST(1) is connected to port 6
SITE(2) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps, SIT = 21.25 Mbps
DESIGN(143): Site Router is located at X = 114450, Y = 56.3333, Z = 16.1
router(13): ip, 150000 pps, 5 ports, $11000
GT(2) is connected to port 1
GT(5) is connected to port 2
LINK(2) is connected to port 3
LINK(3) is connected to port 4
GROUP(2) has 5 client tasks, GLT = 2 Mbps, GOT = 2.5 Mbps, GIT = 2.5 Mbps
DESIGN(143): GNC is located at X = 114409, Y = 89, Z = 16.1
multiaccess(15): ethernet, 100000000 bps, 6 ports, $8000
CT(16) is connected to port 1

⋮

CT(20) is connected to port 5
ST(2) is connected to port 6
GROUP(5) has 10 client tasks, GLT = 9 Mbps, GOT = 12.5 Mbps, GIT = 18.75 Mbps
DESIGN(143): GNC is located at X = 114470, Y = 40, Z = 16.1
switch(23): atm, 150000000 bps, 15 ports, $20000
CT(21) is connected to port 1

⋮

CT(30) is connected to port 10
ST(2) is connected to port 11
SITE(3) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps, SIT = 33.75 Mbps
DESIGN(143): Site Router is located at X = 52052.4, Y = 10450, Z = 32.1
router(17): ip, 200000 pps, 5 ports, $19000
GT(3) is connected to port 1
GT(8) is connected to port 2
LINK(1) is connected to port 3
GROUP(3) has 10 client tasks, GLT = 9 Mbps, GOT = 15 Mbps, GIT = 7.5 Mbps
DESIGN(143): GNC is located at X = 52027.5, Y = 10485, Z = 32.1
switch(18): atm, 100000000 bps, 15 ports, $15000
CT(31) is connected to port 1

⋮

CT(40) is connected to port 10
ST(3) is connected to port 11
GROUP(8) has 10 client tasks, GLT = 9 Mbps, GOT = 0 Mbps, GIT = 26.25 Mbps
DESIGN(143): GNC is located at X = 52077.4, Y = 10415, Z = 32.1
multiaccess(18): ethernet, 100000000 bps, 12 ports, $13000
CT(41) is connected to port 1

⋮

CT(50) is connected to port 10
ST(3) is connected to port 11
SITE(4) has 2 group tasks, SLT = 4.2 Mbps, SOT = 7.5 Mbps, SIT = 35.625 Mbps
DESIGN(143): Site Switch is located at X = 54.12, Y = 10459.9, Z = 45.1
switch(16): atm, 100000000 bps, 5 ports, $7000
GT(6) is connected to port 1
GT(7) is connected to port 2
LINK(3) is connected to port 3
GROUP(6) has 7 client tasks, GLT = 4.2 Mbps, GOT = 7.7 Mbps, GIT = 16.625 Mbps
DESIGN(143): GNC is located at X = 15.4, Y = 10430.7, Z = 45.1
switch(22): atm, 150000000 bps, 10 ports, $15000
CT(51) is connected to port 1

⋮

CT(57) is connected to port 7
ST(4) is connected to port 8
GROUP(7) has 8 client tasks, GLT = 5.6 Mbps, GOT = 4 Mbps, GIT = 23.2 Mbps
DESIGN(143): GNC is located at X = 88, Y = 10485.4, Z = 45.1
switch(22): atm, 150000000 bps, 10 ports, $15000
CT(58) is connected to port 1

⋮

CT(65) is connected to port 8
ST(4) is connected to port 9
Enter the generation number from 0-2999:

- The output of *i*-CAD for a 3-level network design, including a wide tree backbone topology, for the partial animation sutdio, when TND = 10.0 seconds.

Enter the generation number from 0-2999:
1139
Intranet infrastructure(174) is the best design in generation 1139:
initial cost = $190500, monthly cost = $219000
interconnection cost = $24000, wire cost = $4028.53
average network delay = 9.86219 seconds, homogeneity factor = 0.466667
BACKBONE(1) has 4 site tasks, BLT = 93.125 Mbps
Link(1) connects sites: 3 and 1
sonet(vpc16-oc9/sonetsonet): 116640000 bps, initial cost $22500 and monthly cost $6750
Link(2) connects sites: 3 and 4
sonet(oc2): 103680000 bps, initial cost $20000 and monthly cost $6000
Link(3) connects sites: 1 and 2
sonet(vpc14-oc3/sonetsonet): 77760000 bps, initial cost $15000 and monthly cost $5500
SITE(1) has 2 group tasks, SLT = 0 Mbps, SOT = 55.625 Mbps, SIT = 2.5 Mbps
DESIGN(174): Site Router is located at X = 83236.4, Y = 20863, Z = 1.1
router(9): ip, 100000 pps, 5 ports, $7000
GT(1) is connected to port 1
GT(4) is connected to port 2
LINK(1) is connected to port 3
LINK(3) is connected to port 4
GROUP(1) has 10 client tasks, GLT = 27 Mbps, GOT = 7.5 Mbps, GIT = 0 Mbps
DESIGN(174): GNC is located at X = 83209.7, Y = 20849.6, Z = 1.1
switch(18): atm, 100000000 bps, 15 ports, $15000

CT(1) is connected to port 1

⋮

CT(10) is connected to port 10
ST(1) is connected to port 11
GROUP(4) has 5 client tasks, GLT = 8 Mbps, GOT = 48.125 Mbps, GIT = 2.5 Mbps
DESIGN(174): GNC is located at X = 83289.8, Y = 20889.8, Z = 1.1
switch(22): atm, 150000000 bps, 10 ports, $15000
CT(11) is connected to port 1

⋮

CT(15) is connected to port 5
ST(1) is connected to port 6
SITE(2) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps, SIT = 21.25 Mbps
DESIGN(174): Site Router is located at X = 114450, Y = 56.3333, Z = 16.1
router(9): ip, 100000 pps, 5 ports, $7000
GT(2) is connected to port 1
GT(5) is connected to port 2
LINK(3) is connected to port 3
GROUP(2) has 5 client tasks, GLT = 2 Mbps, GOT = 2.5 Mbps, GIT = 2.5 Mbps
DESIGN(174): GNC is located at X = 114409, Y = 89, Z = 16.1
switch(7): atm, 45000000 bps, 10 ports, $6000
CT(16) is connected to port 1

⋮

CT(20) is connected to port 5
ST(2) is connected to port 6
GROUP(5) has 10 client tasks, GLT = 9 Mbps, GOT = 12.5 Mbps, GIT = 18.75 Mbps
DESIGN(174): GNC is located at X = 114470, Y = 40, Z = 16.1
multiaccess(19): ethernet, 100000000 bps, 14 ports, $16000
CT(21) is connected to port 1

⋮

CT(30) is connected to port 10
ST(2) is connected to port 11
SITE(3) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps, SIT = 33.75 Mbps
DESIGN(174): Site Router is located at X = 52052.4, Y = 10450, Z = 32.1
router(9): ip, 100000 pps, 5 ports, $7000
GT(3) is connected to port 1
GT(8) is connected to port 2
LINK(1) is connected to port 3
LINK(2) is connected to port 4
GROUP(3) has 10 client tasks, GLT = 9 Mbps, GOT = 15 Mbps, GIT = 7.5 Mbps
DESIGN(174): GNC is located at X = 52027.5, Y = 10485, Z = 32.1
switch(18): atm, 100000000 bps, 15 ports, $15000
CT(31) is connected to port 1

⋮

CT(40) is connected to port 10
ST(3) is connected to port 11
GROUP(8) has 10 client tasks, GLT = 9 Mbps, GOT = 0 Mbps, GIT = 26.25 Mbps
DESIGN(174): GNC is located at X = 52077.4, Y = 10415, Z = 32.1
switch(18): atm, 100000000 bps, 15 ports, $15000

CT(41) is connected to port 1

⋮

CT(50) is connected to port 10
ST(3) is connected to port 11
SITE(4) has 2 group tasks, SLT = 4.2 Mbps, SOT = 7.5 Mbps, SIT = 35.625 Mbps
DESIGN(174): Site Router is located at X = 54.12, Y = 10459.9, Z = 45.1
router(13): ip, 150000 pps, 5 ports, $11000
GT(6) is connected to port 1
GT(7) is connected to port 2
LINK(2) is connected to port 3
GROUP(6) has 7 client tasks, GLT = 4.2 Mbps, GOT = 7.7 Mbps, GIT = 16.625 Mbps
DESIGN(174): GNC is located at X = 15.4, Y = 10430.7, Z = 45.1
switch(12): atm, 75000000 bps, 10 ports, $8000
CT(51) is connected to port 1

⋮

CT(57) is connected to port 7
ST(4) is connected to port 8
GROUP(7) has 8 client tasks, GLT = 5.6 Mbps, GOT = 4 Mbps, GIT = 23.2 Mbps
DESIGN(174): GNC is located at X = 88, Y = 10485.4, Z = 45.1
switch(17): atm, 100000000 bps, 10 ports, $11000
CT(58) is connected to port 1

⋮

CT(65) is connected to port 8
ST(4) is connected to port 9
Enter the generation number from 0-2999:

- The output of *i*-CAD for a 3-level network design, including a wide tree backbone topology, for the partial animation sutdio, when TND = 20.0 seconds.

Enter the generation number from 0-2999:
402
Intranet infrastructure(186) is the best design in generation 402:
initial cost = $166000, monthly cost = $180000
interconnection cost = $28000, wire cost = $5953.31
average network delay = 19.867 seconds, homogeneity factor = 0.4
BACKBONE(1) has 4 site tasks, BLT = 93.125 Mbps
Link(1) connects sites: 1 and 3
sonet(oc2): 103680000 bps, initial cost $20000 and monthly cost $6000
Link(2) connects sites: 3 and 4
sonet(oc2): 103680000 bps, initial cost $20000 and monthly cost $6000
Link(3) connects sites: 4 and 2
sonet(oc1): 51840000 bps, initial cost $10000 and monthly cost $3000
SITE(1) has 2 group tasks, SLT = 0 Mbps, SOT = 55.625 Mbps, SIT = 2.5 Mbps
DESIGN(186): Site Switch is located at X = 83236.4, Y = 20863, Z = 1.1
switch(11): atm, 75000000 bps, 5 ports, $5000
GT(1) is connected to port 1
GT(4) is connected to port 2
LINK(1) is connected to port 3
GROUP(1) has 10 client tasks, GLT = 27 Mbps, GOT = 7.5 Mbps, GIT = 0 Mbps

DESIGN(186): GNC is located at X = 83209.7, Y = 20849.6, Z = 1.1
switch(8): atm, 45000000 bps, 15 ports, $9000
CT(1) is connected to port 1
⋮
CT(10) is connected to port 10
ST(1) is connected to port 11
GROUP(4) has 5 client tasks, GLT = 8 Mbps, GOT = 48.125 Mbps, GIT = 2.5 Mbps
DESIGN(186): GNC is located at X = 83289.8, Y = 20889.8, Z = 1.1
multiaccess(15): ethernet, 100000000 bps, 6 ports, $8000
CT(11) is connected to port 1
⋮
CT(15) is connected to port 5
ST(1) is connected to port 6
SITE(2) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps, SIT = 21.25 Mbps
DESIGN(186): Site Router is located at X = 114450, Y = 56.3333, Z = 16.1
router(10): ip, 100000 pps, 10 ports, $11000
GT(2) is connected to port 1
GT(5) is connected to port 2
LINK(3) is connected to port 3
GROUP(2) has 5 client tasks, GLT = 2 Mbps, GOT = 2.5 Mbps, GIT = 2.5 Mbps
DESIGN(186): GNC is located at X = 114409, Y = 89, Z = 16.1
multiaccess(15): ethernet, 100000000 bps, 6 ports, $8000
CT(16) is connected to port 1
⋮
CT(20) is connected to port 5
ST(2) is connected to port 6
GROUP(5) has 10 client tasks, GLT = 9 Mbps, GOT = 12.5 Mbps, GIT = 18.75 Mbps
DESIGN(186): GNC is located at X = 114470, Y = 40, Z = 16.1
multiaccess(18): ethernet, 100000000 bps, 12 ports, $13000
CT(21) is connected to port 1
⋮
CT(30) is connected to port 10
ST(2) is connected to port 11
SITE(3) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps, SIT = 33.75 Mbps
DESIGN(186): Site Router is located at X = 52052.4, Y = 10450, Z = 32.1
router(10): ip, 100000 pps, 10 ports, $11000
GT(3) is connected to port 1
GT(8) is connected to port 2
LINK(1) is connected to port 3
LINK(2) is connected to port 4
GROUP(3) has 10 client tasks, GLT = 9 Mbps, GOT = 15 Mbps, GIT = 7.5 Mbps
DESIGN(186): GNC is located at X = 52027.5, Y = 10485, Z = 32.1
switch(13): atm, 75000000 bps, 15 ports, $11000
CT(31) is connected to port 1
⋮
CT(40) is connected to port 10
ST(3) is connected to port 11
GROUP(8) has 10 client tasks, GLT = 9 Mbps, GOT = 0 Mbps, GIT = 26.25 Mbps

DESIGN(186): GNC is located at X = 52077.4, Y = 10415, Z = 32.1
switch(13): atm, 75000000 bps, 15 ports, $11000
CT(31) is connected to port 1

⋮

CT(40) is connected to port 10
ST(3) is connected to port 11
GROUP(8) has 10 client tasks, GLT = 9 Mbps, GOT = 0 Mbps, GIT = 26.25 Mbps
DESIGN(186): GNC is located at X = 52077.4, Y = 10415, Z = 32.1
switch(13): atm, 75000000 bps, 15 ports, $11000
CT(41) is connected to port 1

⋮

CT(50) is connected to port 10
ST(3) is connected to port 11
SITE(4) has 2 group tasks, SLT = 4.2 Mbps, SOT = 7.5 Mbps, SIT = 35.625 Mbps
DESIGN(186): Site Router is located at X = 54.12, Y = 10459.9, Z = 45.1
router(9): ip, 100000 pps, 5 ports, $7000
GT(6) is connected to port 1
GT(7) is connected to port 2
LINK(2) is connected to port 3
LINK(3) is connected to port 4
GROUP(6) has 7 client tasks, GLT = 4.2 Mbps, GOT = 7.7 Mbps, GIT = 16.625 Mbps
DESIGN(186): GNC is located at X = 15.4, Y = 10430.7, Z = 45.1
switch(17): atm, 100000000 bps, 10 ports, $11000
CT(51) is connected to port 1

⋮

CT(57) is connected to port 7
ST(4) is connected to port 8
GROUP(7) has 8 client tasks, GLT = 5.6 Mbps, GOT = 4 Mbps, GIT = 23.2 Mbps
DESIGN(186): GNC is located at X = 88, Y = 10485.4, Z = 45.1
switch(17): atm, 100000000 bps, 10 ports, $11000
CT(58) is connected to port 1

⋮

CT(65) is connected to port 8
ST(4) is connected to port 9
Enter the generation number from 0-2999:

- The output of *i*-CAD for a 3-level network design, including a wide tree backbone topology, for the partial animation sutdio, when TND = 30.0 seconds.

Enter the generation number from 0-2999:
2930
Intranet infrastructure(169) is the best design in generation 2930:
initial cost = $119200, monthly cost = $174000
interconnection cost = $24000, wire cost = $3561.31
average network delay = 29.7443 seconds, homogeneity factor = 0.4
BACKBONE(1) has 4 site tasks, BLT = 93.125 Mbps
Link(1) connects sites: 2 and 4
sonet(oc1): 51840000 bps, initial cost $10000 and monthly cost $3000
Link(2) connects sites: 4 and 1

sonet(oc2): 103680000 bps, initial cost $20000 and monthly cost $6000
Link(3) connects sites: 1 and 3
sonet(vpc14-oc3/sonetsonet): 77760000 bps, initial cost $15000 and monthly cost $5500
SITE(1) has 2 group tasks, SLT = 0 Mbps, SOT = 55.625 Mbps, SIT = 2.5 Mbps
DESIGN(169): Site Router is located at X = 83236.4, Y = 20863, Z = 1.1
router(5): ip, 50000 pps, 5 ports, $3000
GT(1) is connected to port 1
GT(4) is connected to port 2
LINK(2) is connected to port 3
LINK(3) is connected to port 4
GROUP(1) has 10 client tasks, GLT = 27 Mbps, GOT = 7.5 Mbps, GIT = 0 Mbps
DESIGN(169): GNC is located at X = 83209.7, Y = 20849.6, Z = 1.1
switch(8): atm, 45000000 bps, 15 ports, $9000
CT(1) is connected to port 1

⋮

CT(10) is connected to port 10
ST(1) is connected to port 11
GROUP(4) has 5 client tasks, GLT = 8 Mbps, GOT = 48.125 Mbps, GIT = 2.5 Mbps
DESIGN(169): GNC is located at X = 83289.8, Y = 20889.8, Z = 1.1
multiaccess(15): ethernet, 100000000 bps, 6 ports, $8000
CT(11) is connected to port 1

⋮

CT(15) is connected to port 5
ST(1) is connected to port 6
SITE(2) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps, SIT = 21.25 Mbps
DESIGN(169): Site Router is located at X = 114450, Y = 56.3333, Z = 16.1
router(5): ip, 50000 pps, 5 ports, $3000
GT(2) is connected to port 1
GT(5) is connected to port 2
LINK(1) is connected to port 3
GROUP(2) has 5 client tasks, GLT = 2 Mbps, GOT = 2.5 Mbps, GIT = 2.5 Mbps
DESIGN(169): GNC is located at X = 114409, Y = 89, Z = 16.1
multiaccess(3): ethernet, 10000000 bps, 6 ports, $200
CT(16) is connected to port 1

⋮

CT(20) is connected to port 5
ST(2) is connected to port 6
GROUP(5) has 10 client tasks, GLT = 9 Mbps, GOT = 12.5 Mbps, GIT = 18.75 Mbps
DESIGN(169): GNC is located at X = 114470, Y = 40, Z = 16.1
switch(13): atm, 75000000 bps, 15 ports, $11000
CT(21) is connected to port 1

⋮

CT(30) is connected to port 10
ST(2) is connected to port 11
SITE(3) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps, SIT = 33.75 Mbps
DESIGN(169): Site Router is located at X = 52052.4, Y = 10450, Z = 32.1
router(5): ip, 50000 pps, 5 ports, $3000
GT(3) is connected to port 1
GT(8) is connected to port 2

LINK(3) is connected to port 3
GROUP(3) has 10 client tasks, GLT = 9 Mbps, GOT = 15 Mbps, GIT = 7.5 Mbps
DESIGN(169): GNC is located at X = 52027.5, Y = 10485, Z = 32.1
switch(8): atm, 45000000 bps, 15 ports, $9000
CT(31) is connected to port 1

⋮

CT(40) is connected to port 10
ST(3) is connected to port 11
GROUP(8) has 10 client tasks, GLT = 9 Mbps, GOT = 0 Mbps, GIT = 26.25 Mbps
DESIGN(169): GNC is located at X = 52077.4, Y = 10415, Z = 32.1
switch(13): atm, 75000000 bps, 15 ports, $11000
CT(41) is connected to port 1

⋮

CT(50) is connected to port 10
ST(3) is connected to port 11
SITE(4) has 2 group tasks, SLT = 4.2 Mbps, SOT = 7.5 Mbps, SIT = 35.625 Mbps
DESIGN(169): Site Router is located at X = 54.12, Y = 10459.9, Z = 45.1
router(5): ip, 50000 pps, 5 ports, $3000
GT(6) is connected to port 1
GT(7) is connected to port 2
LINK(1) is connected to port 3
LINK(2) is connected to port 4
GROUP(6) has 7 client tasks, GLT = 4.2 Mbps, GOT = 7.7 Mbps, GIT = 16.625 Mbps
DESIGN(169): GNC is located at X = 15.4, Y = 10430.7, Z = 45.1
switch(7): atm, 45000000 bps, 10 ports, $6000
CT(51) is connected to port 1

⋮

CT(57) is connected to port 7
ST(4) is connected to port 8
GROUP(7) has 8 client tasks, GLT = 5.6 Mbps, GOT = 4 Mbps, GIT = 23.2 Mbps
DESIGN(169): GNC is located at X = 88, Y = 10485.4, Z = 45.1
switch(12): atm, 75000000 bps, 10 ports, $8000
CT(58) is connected to port 1

⋮

CT(65) is connected to port 8
ST(4) is connected to port 9
Enter the generation number from 0-2999:

- The output of *i*-CAD for a 3-level network design, including a wide tree backbone topology, for the partial animation sutdio, when TND = 40.0 seconds.

Enter the generation number from 0-2999:
2965
Intranet infrastructure(244) is the best design in generation 2965:
initial cost = $122650, monthly cost = $180000
interconnection cost = $24000, wire cost = $3561.31
average network delay = 39.1117 seconds, homogeneity factor = 0.4
BACKBONE(1) has 4 site tasks, BLT = 93.125 Mbps
Link(1) connects sites: 3 and 2

sonet(oc2): 103680000 bps, initial cost $20000 and monthly cost $6000
Link(2) connects sites: 2 and 4
sonet(oc1): 51840000 bps, initial cost $10000 and monthly cost $3000
Link(3) connects sites: 3 and 1
sonet(oc2): 103680000 bps, initial cost $20000 and monthly cost $6000
SITE(1) has 2 group tasks, SLT = 0 Mbps, SOT = 55.625 Mbps, SIT = 2.5 Mbps
DESIGN(244): Site Router is located at X = 83236.4, Y = 20863, Z = 1.1
router(5): ip, 50000 pps, 5 ports, $3000
GT(1) is connected to port 1
GT(4) is connected to port 2
LINK(3) is connected to port 3
GROUP(1) has 10 client tasks, GLT = 27 Mbps, GOT = 7.5 Mbps, GIT = 0 Mbps
DESIGN(244): GNC is located at X = 83209.7, Y = 20849.6, Z = 1.1
switch(8): atm, 45000000 bps, 15 ports, $9000
CT(1) is connected to port 1

⋮

CT(10) is connected to port 10
ST(1) is connected to port 11
GROUP(4) has 5 client tasks, GLT = 8 Mbps, GOT = 48.125 Mbps, GIT = 2.5 Mbps
DESIGN(244): GNC is located at X = 83289.8, Y = 20889.8, Z = 1.1
multiaccess(15): ethernet, 100000000 bps, 6 ports, $8000
CT(11) is connected to port 1

⋮

CT(15) is connected to port 5
ST(1) is connected to port 6
SITE(2) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps, SIT = 21.25 Mbps
DESIGN(244): Site Router is located at X = 114450, Y = 56.3333, Z = 16.1
router(5): ip, 50000 pps, 5 ports, $3000
GT(2) is connected to port 1
GT(5) is connected to port 2
LINK(1) is connected to port 3
LINK(2) is connected to port 4
GROUP(2) has 5 client tasks, GLT = 2 Mbps, GOT = 2.5 Mbps, GIT = 2.5 Mbps
DESIGN(244): GNC is located at X = 114409, Y = 89, Z = 16.1
multiaccess(7): ethernet, 10000000 bps, 14 ports, $650
CT(16) is connected to port 1

⋮

CT(20) is connected to port 5
ST(2) is connected to port 6
GROUP(5) has 10 client tasks, GLT = 9 Mbps, GOT = 12.5 Mbps, GIT = 18.75 Mbps
DESIGN(244): GNC is located at X = 114470, Y = 40, Z = 16.1
switch(8): atm, 45000000 bps, 15 ports, $9000
CT(21) is connected to port 1

⋮

CT(30) is connected to port 10
ST(2) is connected to port 11
SITE(3) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps, SIT = 33.75 Mbps
DESIGN(244): Site Router is located at X = 52052.4, Y = 10450, Z = 32.1
router(5): ip, 50000 pps, 5 ports, $3000

GT(3) is connected to port 1
GT(8) is connected to port 2
LINK(1) is connected to port 3
LINK(3) is connected to port 4
GROUP(3) has 10 client tasks, GLT = 9 Mbps, GOT = 15 Mbps, GIT = 7.5 Mbps
DESIGN(244): GNC is located at X = 52027.5, Y = 10485, Z = 32.1
switch(8): atm, 45000000 bps, 15 ports, $9000
CT(31) is connected to port 1

⋮

CT(40) is connected to port 10
ST(3) is connected to port 11
GROUP(8) has 10 client tasks, GLT = 9 Mbps, GOT = 0 Mbps, GIT = 26.25 Mbps
DESIGN(244): GNC is located at X = 52077.4, Y = 10415, Z = 32.1
switch(13): atm, 75000000 bps, 15 ports, $11000
CT(41) is connected to port 1

⋮

CT(50) is connected to port 10
ST(3) is connected to port 11
SITE(4) has 2 group tasks, SLT = 4.2 Mbps, SOT = 7.5 Mbps, SIT = 35.625 Mbps
DESIGN(244): Site Router is located at X = 54.12, Y = 10459.9, Z = 45.1
router(5): ip, 50000 pps, 5 ports, $3000
GT(6) is connected to port 1
GT(7) is connected to port 2
LINK(2) is connected to port 3
GROUP(6) has 7 client tasks, GLT = 4.2 Mbps, GOT = 7.7 Mbps, GIT = 16.625 Mbps
DESIGN(244): GNC is located at X = 15.4, Y = 10430.7, Z = 45.1
switch(7): atm, 45000000 bps, 10 ports, $6000
CT(51) is connected to port 1

⋮

CT(57) is connected to port 7
ST(4) is connected to port 8
GROUP(7) has 8 client tasks, GLT = 5.6 Mbps, GOT = 4 Mbps, GIT = 23.2 Mbps
DESIGN(244): GNC is located at X = 88, Y = 10485.4, Z = 45.1
switch(12): atm, 75000000 bps, 10 ports, $8000
CT(58) is connected to port 1

⋮

CT(65) is connected to port 8
ST(4) is connected to port 9
Enter the generation number from 0-2999:

- The output of *i*-CAD for a 3-level network design, including a wide tree backbone topology, for the partial animation sutdio, when TND = 50.0 seconds.

Enter the generation number from 0-2999:
2135
Intranet infrastructure(53) is the best design in generation 2135:
initial cost = $123320, monthly cost = $180000
interconnection cost = $24000, wire cost = $3561.31
average network delay = 41.023 seconds, homogeneity factor = 0.4

BACKBONE(1) has 4 site tasks, BLT = 93.125 Mbps
Link(1) connects sites: 1 and 3
sonet(oc2): 103680000 bps, initial cost $20000 and monthly cost $6000
Link(2) connects sites: 3 and 2
sonet(oc2): 103680000 bps, initial cost $20000 and monthly cost $6000
Link(3) connects sites: 2 and 4
sonet(oc1): 51840000 bps, initial cost $10000 and monthly cost $3000
SITE(1) has 2 group tasks, SLT = 0 Mbps, SOT = 55.625 Mbps, SIT = 2.5 Mbps
DESIGN(53): Site Router is located at X = 83236.4, Y = 20863, Z = 1.1
router(5): ip, 50000 pps, 5 ports, $3000
GT(1) is connected to port 1
GT(4) is connected to port 2
LINK(1) is connected to port 3
GROUP(1) has 10 client tasks, GLT = 27 Mbps, GOT = 7.5 Mbps, GIT = 0 Mbps
DESIGN(53): GNC is located at X = 83209.7, Y = 20849.6, Z = 1.1
switch(8): atm, 45000000 bps, 15 ports, $9000
CT(1) is connected to port 1
⋮
CT(10) is connected to port 10
ST(1) is connected to port 11
GROUP(4) has 5 client tasks, GLT = 8 Mbps, GOT = 48.125 Mbps, GIT = 2.5 Mbps
DESIGN(53): GNC is located at X = 83289.8, Y = 20889.8, Z = 1.1
multiaccess(15): ethernet, 100000000 bps, 6 ports, $8000
CT(11) is connected to port 1
⋮
CT(15) is connected to port 5
ST(1) is connected to port 6
SITE(2) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps, SIT = 21.25 Mbps
DESIGN(53): Site Router is located at X = 114450, Y = 56.3333, Z = 16.1
router(5): ip, 50000 pps, 5 ports, $3000
GT(2) is connected to port 1
GT(5) is connected to port 2
LINK(2) is connected to port 3
LINK(3) is connected to port 4
GROUP(2) has 5 client tasks, GLT = 2 Mbps, GOT = 2.5 Mbps, GIT = 2.5 Mbps
DESIGN(53): GNC is located at X = 114409, Y = 89, Z = 16.1
multiaccess(4): ethernet, 10000000 bps, 8 ports, $320
CT(16) is connected to port 1
⋮
CT(20) is connected to port 5
ST(2) is connected to port 6
GROUP(5) has 10 client tasks, GLT = 9 Mbps, GOT = 12.5 Mbps, GIT = 18.75 Mbps
DESIGN(53): GNC is located at X = 114470, Y = 40, Z = 16.1
switch(8): atm, 45000000 bps, 15 ports, $9000
CT(21) is connected to port 1
⋮
CT(30) is connected to port 10
ST(2) is connected to port 11
SITE(3) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps, SIT = 33.75 Mbps

DESIGN(53): Site Router is located at X = 52052.4, Y = 10450, Z = 32.1
router(5): ip, 50000 pps, 5 ports, $3000
GT(3) is connected to port 1
GT(8) is connected to port 2
LINK(1) is connected to port 3
LINK(2) is connected to port 4
GROUP(3) has 10 client tasks, GLT = 9 Mbps, GOT = 15 Mbps, GIT = 7.5 Mbps
DESIGN(53): GNC is located at X = 52027.5, Y = 10485, Z = 32.1
switch(8): atm, 45000000 bps, 15 ports, $9000
CT(31) is connected to port 1

⋮

CT(40) is connected to port 10
ST(3) is connected to port 11
GROUP(8) has 10 client tasks, GLT = 9 Mbps, GOT = 0 Mbps, GIT = 26.25 Mbps
DESIGN(53): GNC is located at X = 52077.4, Y = 10415, Z = 32.1
switch(13): atm, 75000000 bps, 15 ports, $11000
CT(41) is connected to port 1

⋮

CT(50) is connected to port 10
ST(3) is connected to port 11
SITE(4) has 2 group tasks, SLT = 4.2 Mbps, SOT = 7.5 Mbps, SIT = 35.625 Mbps
DESIGN(53): Site Router is located at X = 54.12, Y = 10459.9, Z = 45.1
router(6): ip, 50000 pps, 10 ports, $6000
GT(6) is connected to port 1
GT(7) is connected to port 2
LINK(3) is connected to port 3
GROUP(6) has 7 client tasks, GLT = 4.2 Mbps, GOT = 7.7 Mbps, GIT = 16.625 Mbps
DESIGN(53): GNC is located at X = 15.4, Y = 10430.7, Z = 45.1
switch(7): atm, 45000000 bps, 10 ports, $6000
CT(51) is connected to port 1

⋮

CT(57) is connected to port 7
ST(4) is connected to port 8
GROUP(7) has 8 client tasks, GLT = 5.6 Mbps, GOT = 4 Mbps, GIT = 23.2 Mbps
DESIGN(53): GNC is located at X = 88, Y = 10485.4, Z = 45.1
switch(7): atm, 45000000 bps, 10 ports, $6000
CT(58) is connected to port 1

⋮

CT(65) is connected to port 8
ST(4) is connected to port 9
Enter the generation number from 0-2999:

- The output of *i*-CAD for a 3-level network design, including a wide tree backbone topology, for the partial animation sutdio, when TND = 60.0 seconds.

Enter the generation number from 0-2999:
2540
Intranet infrastructure(172) is the best design in generation 2540:
initial cost = $110900, monthly cost = $132000

interconnection cost = \$26000, wire cost = \$3561.31
average network delay = 48.8868 seconds, homogeneity factor = 0.533333
BACKBONE(1) has 4 site tasks, BLT = 93.125 Mbps
Link(1) connects sites: 3 and 2
sonet(vpc13-oc3/sonetsonet): 38880000 bps, initial cost \$7500 and monthly cost \$2500
Link(2) connects sites: 3 and 4
sonet(oc1): 51840000 bps, initial cost \$10000 and monthly cost \$3000
Link(3) connects sites: 3 and 1
sonet(vpc14-oc3/sonetsonet): 77760000 bps, initial cost \$15000 and monthly cost \$5500
SITE(1) has 2 group tasks, SLT = 0 Mbps, SOT = 55.625 Mbps, SIT = 2.5 Mbps
DESIGN(172): Site Switch is located at X = 83236.4, Y = 20863, Z = 1.1
switch(11): atm, 75000000 bps, 5 ports, \$5000
GT(1) is connected to port 1
GT(4) is connected to port 2
LINK(3) is connected to port 3
GROUP(1) has 10 client tasks, GLT = 27 Mbps, GOT = 7.5 Mbps, GIT = 0 Mbps
DESIGN(172): GNC is located at X = 83209.7, Y = 20849.6, Z = 1.1
switch(8): atm, 45000000 bps, 15 ports, \$9000
CT(1) is connected to port 1

⋮

CT(10) is connected to port 10
ST(1) is connected to port 11
GROUP(4) has 5 client tasks, GLT = 8 Mbps, GOT = 48.125 Mbps, GIT = 2.5 Mbps
DESIGN(172): GNC is located at X = 83289.8, Y = 20889.8, Z = 1.1
switch(12): atm, 75000000 bps, 10 ports, \$8000
CT(11) is connected to port 1

⋮

CT(15) is connected to port 5
ST(1) is connected to port 6
SITE(2) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps, SIT = 21.25 Mbps
DESIGN(172): Site Router is located at X = 114450, Y = 56.3333, Z = 16.1
router(5): ip, 50000 pps, 5 ports, \$3000
GT(2) is connected to port 1
GT(5) is connected to port 2
LINK(1) is connected to port 3
GROUP(2) has 5 client tasks, GLT = 2 Mbps, GOT = 2.5 Mbps, GIT = 2.5 Mbps
DESIGN(172): GNC is located at X = 114409, Y = 89, Z = 16.1
multiaccess(6): ethernet, 10000000 bps, 12 ports, \$400
CT(16) is connected to port 1

⋮

CT(20) is connected to port 5
ST(2) is connected to port 6
GROUP(5) has 10 client tasks, GLT = 9 Mbps, GOT = 12.5 Mbps, GIT = 18.75 Mbps
DESIGN(172): GNC is located at X = 114470, Y = 40, Z = 16.1
switch(13): atm, 75000000 bps, 15 ports, \$11000
CT(21) is connected to port 1

⋮

CT(30) is connected to port 10
ST(2) is connected to port 11

SITE(3) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps, SIT = 33.75 Mbps
DESIGN(172): Site Router is located at X = 52052.4, Y = 10450, Z = 32.1
router(9): ip, 100000 pps, 5 ports, $7000
GT(3) is connected to port 1
GT(8) is connected to port 2
LINK(1) is connected to port 3
LINK(2) is connected to port 4
LINK(3) is connected to port 5
GROUP(3) has 10 client tasks, GLT = 9 Mbps, GOT = 15 Mbps, GIT = 7.5 Mbps
DESIGN(172): GNC is located at X = 52027.5, Y = 10485, Z = 32.1
switch(13): atm, 75000000 bps, 15 ports, $11000
CT(31) is connected to port 1

⋮

CT(40) is connected to port 10
ST(3) is connected to port 11
GROUP(8) has 10 client tasks, GLT = 9 Mbps, GOT = 0 Mbps, GIT = 26.25 Mbps
DESIGN(172): GNC is located at X = 52077.4, Y = 10415, Z = 32.1
switch(8): atm, 45000000 bps, 15 ports, $9000
CT(41) is connected to port 1

⋮

CT(50) is connected to port 10
ST(3) is connected to port 11
SITE(4) has 2 group tasks, SLT = 4.2 Mbps, SOT = 7.5 Mbps, SIT = 35.625 Mbps
DESIGN(172): Site Router is located at X = 54.12, Y = 10459.9, Z = 45.1
router(5): ip, 50000 pps, 5 ports, $3000
GT(6) is connected to port 1
GT(7) is connected to port 2
LINK(2) is connected to port 3
GROUP(6) has 7 client tasks, GLT = 4.2 Mbps, GOT = 7.7 Mbps, GIT = 16.625 Mbps
DESIGN(172): GNC is located at X = 15.4, Y = 10430.7, Z = 45.1
switch(7): atm, 45000000 bps, 10 ports, $6000
CT(51) is connected to port 1

⋮

CT(57) is connected to port 7
ST(4) is connected to port 8
GROUP(7) has 8 client tasks, GLT = 5.6 Mbps, GOT = 4 Mbps, GIT = 23.2 Mbps
DESIGN(172): GNC is located at X = 88, Y = 10485.4, Z = 45.1
switch(7): atm, 45000000 bps, 10 ports, $6000
CT(58) is connected to port 1

⋮

CT(65) is connected to port 8
ST(4) is connected to port 9
Enter the generation number from 0-2999:

A.3 Experiment 3

- The output of *i*-CAD for a complete intranet integration for the partial animation sutdio, when TND = 10.0 seconds and the initial number of servers = 4.

Enter the generation number from 0-2999:
2745
Intranet infrastructure(3) is the best design in generation 2745
initial network cost = $177700, monthly network cost = $0
interconnection cost = $4000, wire cost = $10064.9
initial data management system cost = $14300, data management performance = 99.8118%
average network delay = 9.89861 seconds, homogeneity factor = 0.384615
BACKBONE(1) has 4 site tasks, BLT = 93.125 Mbps and MDT = 1.86507e+07 bps
DESIGN(3): Backbone Router is located at X = 48.4892, Y = 56.7385, Z = 24.2538
router(25): ip, 500000 pps, 5 ports, $30000
ST(1) is connected to port 1
ST(2) is connected to port 2
ST(3) is connected to port 3
ST(4) is connected to port 4
SITE(1) has 2 group tasks, SLT = 0 Mbps, SOT = 55.625 Mbps,
SIT = 2.5 Mbps and DMT = 253992 bps
DESIGN(3): Site Router is located at X = 36.4, Y = 63, Z = 1.1
router(9): ip, 100000 pps, 5 ports, $7000
GT(1) is connected to port 1
GT(4) is connected to port 2
BT(1) is connected to port 3
GROUP(1) has 10 client tasks, GLT = 27 Mbps, GOT = 7.5 Mbps,
GIT = 0 Mbps and DMT = 253992 bps
DESIGN(3): GNC is located at X = 9.7, Y = 49.6, Z = 1.1
switch(23): atm, 150000000 bps, 15 ports, $20000
CT(1) is connected to port 1
⋮
CT(10) is connected to port 10
GS(1) is connected to port 11
server(3) has the following attributes:
number of CPUs = 1, CPU clock cycle = 5 ns
main memory capacity = 32000000 bytes, internal hard disk capacity = 5e+09 bytes
cost = $2000
max performance = 100%, average performance = 100%, min performance = 100%
hard disk(4) has the following attributes:
type = SCSI, capacity = 1e+10 bytes, average seek time = 5 ms, transfer rate = 1.6e+08 bps
cost = $500
stored files: 2, 8, 14, 9, 15, 1, 10, 4.
ST(1) is connected to port 12
GROUP(4) has 5 client tasks, GLT = 8 Mbps, GOT = 48.125 Mbps,
GIT = 2.5 Mbps and DMT = 0 bps
DESIGN(3): GNC is located at X = 89.8, Y = 89.8, Z = 1.1
multiaccess(27): ethernet, 1000000000 bps, 6 ports, $13000
CT(11) is connected to port 1

⋮

CT(15) is connected to port 5
ST(1) is connected to port 6
SITE(2) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps,
SIT = 21.25 Mbps and DMT = 1.86507e+07 bps
DESIGN(3): Site Multiaccess device is located at X = 49.6667, Y = 56.3333, Z = 16.1
multiaccess(14): ethernet, 100000000 bps, 4 ports, $6000
GT(2) is connected to site task port 1 via a 2-port bridge with following attributes:
Bridge(15), has capacity 100000 frames per second and cost $300
GT(5) is connected to port 2
BT(1) is connected to port 3
GROUP(2) has 5 client tasks, GLT = 2 Mbps, GOT = 2.5 Mbps,
GIT = 2.5 Mbps and DMT = 1.8455e+07 bps
DESIGN(3): GNC is located at X = 9.2, Y = 89, Z = 16.1
multiaccess(19): ethernet, 100000000 bps, 14 ports, $16000
CT(16) is connected to port 1

⋮

CT(20) is connected to port 5
GS(2) is connected to port 6
server(6) has the following attributes:
number of CPUs = 1, CPU clock cycle = 2 ns
main memory capacity = 64000000 bytes, internal hard disk capacity = 1e+10 bytes
cost = $4000
max performance = 100%, average performance = 99.5918%, min performance = 98.9796%
hard disk(7) has the following attributes:
type = IDE, capacity = 2e+10 bytes, average seek time = 10 ms, transfer rate = 6.6e+07 bps
cost = $1500
stored files: 11, 2, 8, 9, 15, 13, 1, 6, 4, 5.
ST(2) is connected to port 7
GROUP(5) has 10 client tasks, GLT = 9 Mbps, GOT = 12.5 Mbps,
GIT = 18.75 Mbps and DMT = 0 bps
DESIGN(3): GNC is located at X = 69.9, Y = 40, Z = 16.1
switch(18): atm, 100000000 bps, 15 ports, $15000
CT(21) is connected to port 1

⋮

CT(30) is connected to port 10
ST(2) is connected to port 11
SITE(3) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps,
SIT = 33.75 Mbps and DMT = 1.39111e+07 bps
DESIGN(3): Site Router is located at X = 52.45, Y = 50, Z = 32.1
router(13): ip, 150000 pps, 5 ports, $11000
GT(3) is connected to port 1
GT(8) is connected to port 2
BT(1) is connected to port 3
GROUP(3) has 10 client tasks, GLT = 9 Mbps, GOT = 15 Mbps,
GIT = 7.5 Mbps and DMT = 0 bps
DESIGN(3): GNC is located at X = 27.5, Y = 85, Z = 32.1
switch(14): atm, 75000000 bps, 20 ports, $16000
CT(31) is connected to port 1

⋮
CT(40) is connected to port 10
GS(3) is connected to port 11
server(1) has the following attributes:
number of CPUs = 1, CPU clock cycle = 5 ns
main memory capacity = 12000000 bytes, internal hard disk capacity = 1e+09 bytes
cost = $1000
max performance = 100%, average performance = 100%, min performance = 100%
hard disk(11) has the following attributes:
type = IDE, capacity = 4e+10 bytes, average seek time = 10 ms, transfer rate = 6.6e+07 bps
cost = $4000
stored files: 2, 8, 14, 9, 12, 13, 1, 10, 6, 4, 5.
ST(3) is connected to port 12
GROUP(8) has 10 client tasks, GLT = 9 Mbps, GOT = 0 Mbps,
GIT = 26.25 Mbps and DMT = 0 bps
DESIGN(3): GNC is located at X = 77.4, Y = 15, Z = 32.1
switch(13): atm, 75000000 bps, 15 ports, $11000
CT(41) is connected to port 1
⋮
CT(50) is connected to port 10
ST(3) is connected to port 11
SITE(4) has 2 group tasks, SLT = 4.2 Mbps, SOT = 7.5 Mbps,
SIT = 35.625 Mbps and DMT = 4.54384e+06 bps
DESIGN(3): Site Router is located at X = 54.12, Y = 59.8667, Z = 45.1
router(10): ip, 100000 pps, 10 ports, $11000
GT(6) is connected to port 1
GT(7) is connected to port 2
BT(1) is connected to port 3
GROUP(6) has 7 client tasks, GLT = 4.2 Mbps, GOT = 7.7 Mbps,
GIT = 16.625 Mbps and DMT = 0 bps
DESIGN(3): GNC is located at X = 15.4, Y = 30.7143, Z = 45.1
switch(13): atm, 75000000 bps, 15 ports, $11000
CT(51) is connected to port 1
⋮
CT(57) is connected to port 7
GS(4) is connected to port 8
server(1) has the following attributes:
number of CPUs = 1, CPU clock cycle = 5 ns
main memory capacity = 12000000 bytes, internal hard disk capacity = 1e+09 bytes
cost = $1000
max performance = 100%, average performance = 99.6552%, min performance = 98.2759%
hard disk(3) has the following attributes:
type = IDE, capacity = 1e+10 bytes, average seek time = 10 ms, transfer rate = 6.6e+07 bps
cost = $300
stored files: 11, 3, 2, 8, 14, 9, 12, 15, 13, 6, 7.
ST(4) is connected to port 9
GROUP(7) has 8 client tasks, GLT = 5.6 Mbps, GOT = 4 Mbps,
GIT = 23.2 Mbps and DMT = 0 bps
DESIGN(3): GNC is located at X = 88, Y = 85.375, Z = 45.1
multiaccess(17): ethernet, 100000000 bps, 10 ports, $10400

CT(58) is connected to port 1

⋮

CT(65) is connected to port 8
ST(4) is connected to port 9
Enter the generation number from 0-2999:

- The output of *i*-CAD for a complete intranet integration for the partial animation sutdio, when TND = 20.0 seconds and the initial number of servers = 4.

Enter the generation number from 0-2999:
2770
Intranet infrastructure(7) is the best design in generation 2770
initial network cost = $121000, monthly network cost = $0
interconnection cost = $0, wire cost = $4760.13
initial data management system cost = $19800, data management performance = 99.8529%
average network delay = 13.7428 seconds, homogeneity factor = 0.384615
BACKBONE(1) has 4 site tasks, BLT = 93.125 Mbps and MDT = 1.72526e+07 bps
DESIGN(7): Backbone Router is located at X = 48.4892, Y = 56.7385, Z = 24.2538
router(9): ip, 100000 pps, 5 ports, $7000
ST(1) is connected to port 1
ST(2) is connected to port 2
ST(3) is connected to port 3
ST(4) is connected to port 4
SITE(1) has 2 group tasks, SLT = 0 Mbps, SOT = 55.625 Mbps,
SIT = 2.5 Mbps and DMT = 3.20399e+06 bps
DESIGN(7): Site Router is located at X = 36.4, Y = 63, Z = 1.1
router(9): ip, 100000 pps, 5 ports, $7000
GT(1) is connected to port 1
GT(4) is connected to port 2
BT(1) is connected to port 3
GROUP(1) has 10 client tasks, GLT = 27 Mbps, GOT = 7.5 Mbps,
GIT = 0 Mbps and DMT = 3.20399e+06 bps
DESIGN(7): GNC is located at X = 9.7, Y = 49.6, Z = 1.1
switch(13): atm, 75000000 bps, 15 ports, $11000
CT(1) is connected to port 1

⋮

CT(10) is connected to port 10
GS(1) is connected to port 11
server(2) has the following attributes:
number of CPUs = 1, CPU clock cycle = 4 ns
main memory capacity = 12000000 bytes, internal hard disk capacity = 3e+09 bytes
cost = $1500
max performance = 100%, average performance = 100%, min performance = 100%
hard disk(8) has the following attributes:
type = SCSI, capacity = 2e+10 bytes, average seek time = 5 ms, transfer rate = 1.6e+08 bps
cost = $2000
stored files: 11, 3, 2, 14, 12, 6, 4, 5.
ST(1) is connected to port 12
GROUP(4) has 5 client tasks, GLT = 8 Mbps, GOT = 48.125 Mbps,

GIT = 2.5 Mbps and DMT = 0 bps
DESIGN(7): GNC is located at X = 89.8, Y = 89.8, Z = 1.1
multiaccess(15): ethernet, 100000000 bps, 6 ports, $8000
CT(11) is connected to port 1

⋮

CT(15) is connected to port 5
ST(1) is connected to port 6
SITE(2) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps,
SIT = 21.25 Mbps and DMT = 3.34147e+06 bps
DESIGN(7): Site Router is located at X = 49.6667, Y = 56.3333, Z = 16.1
router(9): ip, 100000 pps, 5 ports, $7000
GT(2) is connected to port 1
GT(5) is connected to port 2
BT(1) is connected to port 3
GROUP(2) has 5 client tasks, GLT = 2 Mbps, GOT = 2.5 Mbps,
GIT = 2.5 Mbps and DMT = 0 bps
DESIGN(7): GNC is located at X = 9.2, Y = 89, Z = 16.1
switch(8): atm, 45000000 bps, 15 ports, $9000
CT(16) is connected to port 1

⋮

CT(20) is connected to port 5
ST(2) is connected to port 6
GROUP(5) has 10 client tasks, GLT = 9 Mbps, GOT = 12.5 Mbps,
GIT = 18.75 Mbps and DMT = 0 bps
DESIGN(7): GNC is located at X = 69.9, Y = 40, Z = 16.1
switch(13): atm, 75000000 bps, 15 ports, $11000
CT(21) is connected to port 1

⋮

CT(30) is connected to port 10
ST(2) is connected to port 11
SITE(3) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps,
SIT = 33.75 Mbps and DMT = 1.39111e+07 bps
DESIGN(7): Site Router is located at X = 52.45, Y = 50, Z = 32.1
router(9): ip, 100000 pps, 5 ports, $7000
GT(3) is connected to port 1
GT(8) is connected to port 2
BT(1) is connected to port 3
GROUP(3) has 10 client tasks, GLT = 9 Mbps, GOT = 15 Mbps,
GIT = 7.5 Mbps and DMT = 0 bps
DESIGN(7): GNC is located at X = 27.5, Y = 85, Z = 32.1
multiaccess(18): ethernet, 100000000 bps, 12 ports, $13000
CT(31) is connected to port 1

⋮

CT(40) is connected to port 10
GS(2) is connected to port 11
server(1) has the following attributes:
number of CPUs = 1, CPU clock cycle = 5 ns
main memory capacity = 12000000 bytes, internal hard disk capacity = 1e+09 bytes
cost = $1000

max performance = 100%, average performance = 100%, min performance = 100%
hard disk(9) has the following attributes:
type = IDE, capacity = 3e+10, average seek time = 10 ms, transfer rate = 6.6e+07 bps
cost = $2000
stored files: 11, 3, 2, 8, 9, 12, 13, 1, 10, 5, 7.
ST(3) is connected to port 12
GROUP(8) has 10 client tasks, GLT = 9 Mbps, GOT = 0 Mbps,
GIT = 26.25 Mbps and DMT = 0 bps
DESIGN(7): GNC is located at X = 77.4, Y = 15, Z = 32.1
multiaccess(19): ethernet, 100000000 bps, 14 ports, $16000
CT(41) is connected to port 1

⋮

CT(50) is connected to port 10
ST(3) is connected to port 11
SITE(4) has 2 group tasks, SLT = 4.2 Mbps, SOT = 7.5 Mbps,
SIT = 35.625 Mbps and DMT = 1.41069e+07 bps
DESIGN(7): Site Router is located at X = 54.12, Y = 59.8667, Z = 45.1
router(5): ip, 50000 pps, 5 ports, $3000
GT(6) is connected to port 1
GT(7) is connected to port 2
BT(1) is connected to port 3
GROUP(6) has 7 client tasks, GLT = 4.2 Mbps, GOT = 7.7 Mbps,
GIT = 16.625 Mbps and DMT = 0 bps
DESIGN(7): GNC is located at X = 15.4, Y = 30.7143, Z = 45.1
switch(7): atm, 45000000 bps, 10 ports, $6000
CT(51) is connected to port 1

⋮

CT(57) is connected to port 7
GS(3) is connected to port 8
server(5) has the following attributes:
number of CPUs = 1, CPU clock cycle = 4 ns
main memory capacity = 64000000 bytes, internal hard disk capacity = 1e+10 bytes
cost = $3000
max performance = 100%, average performance = 100%, min performance = 100%
hard disk(13) has the following attributes:
type = IDE, capacity = 5e+10 bytes, average seek time = 10 ms, transfer rate = 6.6e+07 bps
cost = $7000
stored files: 11, 3, 2, 14, 9, 12, 13, 1, 6, 5, 7.
ST(4) is connected to port 9
GROUP(7) has 8 client tasks, GLT = 5.6 Mbps, GOT = 4 Mbps,
GIT = 23.2 Mbps and DMT = 1.41069e+07 bps
DESIGN(7): GNC is located at X = 88, Y = 85.375, Z = 45.1
switch(14): atm, 75000000 bps, 20 ports, $16000
CT(58) is connected to port 1

⋮

CT(65) is connected to port 8
GS(4) is connected to port 9
server(7) has the following attributes:
number of CPUs = 2, CPU clock cycle = 3 ns

main memory capacity = 32000000 bytes, internal hard disk capacity = 1e+10 bytes
cost = $3000
max performance = 100%, average performance = 99.4118%, min performance = 98.5294%
hard disk(3) has the following attributes:
type = IDE, capacity = 1e+10 bytes, average seek time = 10 ms, transfer rate = 6.6e+07 bps
cost = $300
stored files: 11, 3, 2, 14, 15, 13, 1, 6, 4, 7.
ST(4) is connected to port 10
Enter the generation number from 0-2999:

- The output of *i*-CAD for a complete intranet integration for the partial animation sutdio, when TND = 30.0 seconds and the initial number of servers = 4.

Enter the generation number from 0-2999:
2899
Intranet infrastructure(20) is the best design in generation 2899
initial network cost = $139620, monthly network cost = $0
interconnection cost = $8000, wire cost = $5629.73
initial data management system cost = $13500, data management performance = 99.5293%
average network delay = 24.6313 seconds, homogeneity factor = 0.538462
BACKBONE(1) has 4 site tasks, BLT = 93.125 Mbps and MDT = 2.51659e+07 bps
DESIGN(20): Backbone Router is located at X = 48.4892, Y = 56.7385, Z = 24.2538
router(10): ip, 100000 pps, 10 ports, $11000
ST(1) is connected to port 1
ST(2) is connected to port 2
ST(3) is connected to port 3
ST(4) is connected to port 4
SITE(1) has 2 group tasks, SLT = 0 Mbps, SOT = 55.625 Mbps,
SIT = 2.5 Mbps and DMT = 1.41558e+07 bps
DESIGN(20): Site Switch is located at X = 36.4, Y = 63, Z = 1.1
switch(17): atm, 100000000 bps, 10 ports, $11000
GT(1) is connected to port 1
GT(4) is connected to port 2
BT(1) is connected to port 3
GROUP(1) has 10 client tasks, GLT = 27 Mbps, GOT = 7.5 Mbps,
GIT = 0 Mbps and DMT = 0 bps
DESIGN(20): GNC is located at X = 9.7, Y = 49.6, Z = 1.1
switch(13): atm, 75000000 bps, 15 ports, $11000
CT(1) is connected to port 1
⋮
CT(10) is connected to port 10
ST(1) is connected to port 11
GROUP(4) has 5 client tasks, GLT = 8 Mbps, GOT = 48.125 Mbps,
GIT = 2.5 Mbps and DMT = 1.41558e+07 bps
DESIGN(20): GNC is located at X = 89.8, Y = 89.8, Z = 1.1
switch(18): atm, 100000000 bps, 15 ports, $15000
CT(11) is connected to port 1
⋮
CT(15) is connected to port 5

GS(1) is connected to port 6
server(5) has the following attributes:
number of CPUs = 1, CPU clock cycle = 4 ns
main memory capacity = 64000000 bytes, internal hard disk capacity = 1e+10 bytes
cost = $3000
max performance = 99.5475%, average performance = 98.914%, min performance = 98.19%
hard disk(5) has the following attributes:
type = IDE, capacity = 1.5e+10 bytes, average seek time = 10 ms, transfer rate = 6.6e+07 bps
cost = $500
stored files: 3, 2, 8, 14, 9, 12, 13, 1, 10, 6, 5, 7.
ST(1) is connected to port 7
SITE(2) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps,
SIT = 21.25 Mbps and DMT = 1.70569e+07 bps
DESIGN(20): Site Multiaccess device is located at X = 49.6667, Y = 56.3333, Z = 16.1
multiaccess(14): ethernet, 100000000 bps, 4 ports, $6000
GT(2) is connected to site task port 1 via a 2-port bridge with following attributes:
Bridge(13), has capacity 80000 packets per second and cost $260
GT(5) is connected to port 2
BT(1) is connected to port 3
GROUP(2) has 5 client tasks, GLT = 2 Mbps, GOT = 2.5 Mbps,
GIT = 2.5 Mbps and DMT = 0 bps
DESIGN(20): GNC is located at X = 9.2, Y = 89, Z = 16.1
multiaccess(15): ethernet, 100000000 bps, 6 ports, $8000
CT(16) is connected to port 1

⋮

CT(20) is connected to port 5
ST(2) is connected to port 6
GROUP(5) has 10 client tasks, GLT = 9 Mbps, GOT = 12.5 Mbps,
GIT = 18.75 Mbps and DMT = 1.39111e+07 bps
DESIGN(20): GNC is located at X = 69.9, Y = 40, Z = 16.1
switch(13): atm, 75000000 bps, 15 ports, $11000
CT(21) is connected to port 1

⋮

CT(30) is connected to port 10
GS(2) is connected to port 11
server(9) has the following attributes:
number of CPUs = 2, CPU clock cycle = 2.5 ns
main memory capacity = 128000000 bytes, internal hard disk capacity = 3e+10 bytes
cost = $7500
max performance = 100%, average performance = 99.6739%, min performance = 98.913%
hard disk(1) has the following attributes:
type = IDE, capacity = 5e+09 bytes, average seek time = 10 ms, transfer rate = 6.6e+07 bps
cost = $200
stored files: 11, 3, 2, 8, 14, 12, 15, 1, 10, 6, 5.
ST(2) is connected to port 12
SITE(3) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps,
SIT = 33.75 Mbps and DMT = 1.39111e+07 bps
DESIGN(20): Site Multiaccess device is located at X = 52.45, Y = 50, Z = 32.1
multiaccess(15): ethernet, 100000000 bps, 6 ports, $8000
GT(3) is connected to port 1

GT(8) is connected to site task port 2 via a 2-port bridge with following attributes:
Bridge(18), has capacity 115000 frames per second and cost $360
BT(1) is connected to port 3
GROUP(3) has 10 client tasks, GLT = 9 Mbps, GOT = 15 Mbps,
GIT = 7.5 Mbps and DMT = 0 bps
DESIGN(20): GNC is located at X = 27.5, Y = 85, Z = 32.1
switch(14): atm, 75000000 bps, 20 ports, $16000
CT(31) is connected to port 1
⋮
CT(40) is connected to port 10
GS(3) is connected to port 11
server(3) has the following attributes:
number of CPUs = 1, CPU clock cycle = 5 ns
main memory capacity = 32000000 bytes, internal hard disk capacity = 5e+09 bytes
cost = $2000
max performance = 100%, average performance = 100%, min performance = 100%
hard disk(3) has the following attributes:
type = IDE, capacity = 1e+10 bytes, average seek time = 10 ms, transfer rate = 6.6e+07 bps
cost = $300
stored files: 3, 2, 8, 12, 15, 10, 4, 5, 7.
ST(3) is connected to port 12
GROUP(8) has 10 client tasks, GLT = 9 Mbps, GOT = 0 Mbps,
GIT = 26.25 Mbps and DMT = 0 bps
DESIGN(20): GNC is located at X = 77.4, Y = 15, Z = 32.1
multiaccess(18): ethernet, 100000000 bps, 12 ports, $13000
CT(41) is connected to port 1
⋮
CT(50) is connected to port 10
ST(3) is connected to port 11
SITE(4) has 2 group tasks, SLT = 4.2 Mbps, SOT = 7.5 Mbps,
SIT = 35.625 Mbps and DMT = 8.10901e+06 bps
DESIGN(20): Site Router is located at X = 54.12, Y = 59.8667, Z = 45.1
router(5): ip, 50000 pps, 5 ports, $3000
GT(6) is connected to port 1
GT(7) is connected to port 2
BT(1) is connected to port 3
GROUP(6) has 7 client tasks, GLT = 4.2 Mbps, GOT = 7.7 Mbps,
GIT = 16.625 Mbps and DMT = 0 bps
DESIGN(20): GNC is located at X = 15.4, Y = 30.7143, Z = 45.1
switch(18): atm, 100000000 bps, 15 ports, $15000
CT(51) is connected to port 1
⋮
CT(57) is connected to port 7
ST(4) is connected to port 8
GROUP(7) has 8 client tasks, GLT = 5.6 Mbps, GOT = 4 Mbps,
GIT = 23.2 Mbps and DMT = 0 bps
DESIGN(20): GNC is located at X = 88, Y = 85.375, Z = 45.1
switch(17): atm, 100000000 bps, 10 ports, $11000
CT(58) is connected to port 1

⋮

CT(65) is connected to port 8
ST(4) is connected to port 9
Enter the generation number from 0-2999:

- The output of *i*-CAD for a complete intranet integration for the partial animation sutdio, when TND = 40.0 seconds and the initial number of servers = 4.

Enter the generation number from 0-2999:
2656
Intranet infrastructure(13) is the best design in generation 2656
initial network cost = $123400, monthly network cost = $0
interconnection cost = $2000, wire cost = $1269.59
initial data management system cost = $10500, data management performance = 99.7009%
average network delay = 27.3268 seconds, homogeneity factor = 0.692308
BACKBONE(1) has 4 site tasks, BLT = 93.125 Mbps and MDT = 8.69389e+06 bps
DESIGN(13): Backbone Router is located at X = 23.6308, Y = 14.2, Z = 24.2538
router(9): ip, 100000 pps, 5 ports, $7000
ST(1) is connected to port 1
ST(2) is connected to port 2
ST(3) is connected to port 3
ST(4) is connected to port 4
SITE(1) has 2 group tasks, SLT = 0 Mbps, SOT = 55.625 Mbps,
SIT = 2.5 Mbps and DMT = 643137 bps
DESIGN(13): Site Switch is located at X = 4.4, Y = 43.3333, Z = 1.1
switch(12): atm, 75000000 bps, 10 ports, $8000
GT(1) is connected to port 1
GT(4) is connected to port 2
BT(1) is connected to port 3
GROUP(1) has 10 client tasks, GLT = 27 Mbps, GOT = 7.5 Mbps,
GIT = 0 Mbps and DMT = 643137 bps
DESIGN(13): GNC is located at X = 3.9, Y = 43.6, Z = 1.1
switch(19): atm, 100000000 bps, 20 ports, $18000
CT(1) is connected to port 1

⋮

CT(10) is connected to port 10
GS(1) is connected to port 11
server(1) has the following attributes:
number of CPUs = 1, CPU clock cycle = 5 ns
main memory capacity = 12000000 bytes, internal hard disk capacity = 1e+09 bytes
cost = $1000
max performance = 100%, average performance = 100%, min performance = 100%
hard disk(5) has the following attributes:
type = IDE, capacity = 1.5e+10 bytes, average seek time = 10 ms, transfer rate = 6.6e+07 bps
cost = $500
stored files: 11, 2, 8, 9, 12, 15, 13, 10, 6, 5, 7.
ST(1) is connected to port 12
GROUP(4) has 5 client tasks, GLT = 8 Mbps, GOT = 48.125 Mbps,
GIT = 2.5 Mbps and DMT = 0 bps

DESIGN(13): GNC is located at X = 5.4, Y = 42.8, Z = 1.1
multiaccess(17): ethernet, 100000000 bps, 10 ports, $10400
CT(11) is connected to port 1

⋮

CT(15) is connected to port 5
ST(1) is connected to port 6
SITE(2) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps,
SIT = 21.25 Mbps and DMT = 3.7609e+06 bps
DESIGN(13): Site Switch is located at X = 45.0667, Y = 5, Z = 16.1
switch(11): atm, 75000000 bps, 5 ports, $5000
GT(2) is connected to port 1
GT(5) is connected to port 2
BT(1) is connected to port 3
GROUP(2) has 5 client tasks, GLT = 2 Mbps, GOT = 2.5 Mbps,
GIT = 2.5 Mbps and DMT = 3.56517e+06 bps
DESIGN(13): GNC is located at X = 48.4, Y = 5, Z = 16.1
switch(12): atm, 75000000 bps, 10 ports, $8000
CT(16) is connected to port 1

⋮

CT(20) is connected to port 5
GS(2) is connected to port 6
server(3) has the following attributes:
number of CPUs = 1, CPU clock cycle = 5 ns
main memory capacity = 32000000 bytes, internal hard disk capacity = 5e+09 bytes
cost = $2000
max performance = 100%, average performance = 99.6825%, min performance = 98.4127%
hard disk(9) has the following attributes:
type = IDE, capacity = 3e+10 bytes, average seek time = 10 ms, transfer rate = 6.6e+07 bps
cost = $2000
stored files: 11, 2, 8, 14, 9, 12, 15, 13, 1, 10, 4, 5, 7.
ST(2) is connected to port 7
GROUP(5) has 10 client tasks, GLT = 9 Mbps, GOT = 12.5 Mbps,
GIT = 18.75 Mbps and DMT = 0 bps
DESIGN(13): GNC is located at X = 43.4, Y = 5, Z = 16.1
switch(13): atm, 75000000 bps, 15 ports, $11000
CT(21) is connected to port 1

⋮

CT(30) is connected to port 10
ST(2) is connected to port 11
SITE(3) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps,
SIT = 33.75 Mbps and DMT = 4.93299e+06 bps
DESIGN(13): Site Router is located at X = 4.9, Y = 6.15, Z = 32.1
router(9): ip, 100000 pps, 5 ports, $7000
GT(3) is connected to port 1
GT(8) is connected to port 2
BT(1) is connected to port 3
GROUP(3) has 10 client tasks, GLT = 9 Mbps, GOT = 15 Mbps,
GIT = 7.5 Mbps and DMT = 0 bps
DESIGN(13): GNC is located at X = 3.4, Y = 7.3, Z = 32.1

switch(14): atm, 75000000 bps, 20 ports, $16000
CT(31) is connected to port 1

⋮

CT(40) is connected to port 10
ST(3) is connected to port 11
GROUP(8) has 10 client tasks, GLT = 9 Mbps, GOT = 0 Mbps,
GIT = 26.25 Mbps and DMT = 4.54384e+06 bps
DESIGN(13): GNC is located at X = 6.4, Y = 5, Z = 32.1
switch(13): atm, 75000000 bps, 15 ports, $11000
CT(41) is connected to port 1

⋮

CT(50) is connected to port 10
GS(3) is connected to port 11
server(5) has the following attributes:
number of CPUs = 1, CPU clock cycle = 4 ns
main memory capacity = 64000000 bytes, internal hard disk capacity = 1e+10 bytes
cost = $3000
max performance = 100%, average performance = 99.4203%, min performance = 99.0338%
hard disk(9) has the following attributes:
type = IDE, capacity = 3e+10 bytes, average seek time = 10 ms, transfer rate = 6.6e+07 bps
cost = $2000
stored files: 3, 2, 8, 14, 9, 12, 15, 6, 4, 5, 7.
ST(3) is connected to port 12
SITE(4) has 2 group tasks, SLT = 4.2 Mbps, SOT = 7.5 Mbps,
SIT = 35.625 Mbps and DMT = 8.10901e+06 bps
DESIGN(13): Site Router is located at X = 46.4, Y = 5, Z = 45.1
router(6): ip, 50000 pps, 10 ports, $6000
GT(6) is connected to port 1
GT(7) is connected to port 2
BT(1) is connected to port 3
GROUP(6) has 7 client tasks, GLT = 4.2 Mbps, GOT = 7.7 Mbps,
GIT = 16.625 Mbps and DMT = 0 bps
DESIGN(13): GNC is located at X = 47.8286, Y = 4.14286, Z = 45.1
switch(12): atm, 75000000 bps, 10 ports, $8000
CT(51) is connected to port 1

⋮

CT(57) is connected to port 7
ST(4) is connected to port 8
GROUP(7) has 8 client tasks, GLT = 5.6 Mbps, GOT = 4 Mbps,
GIT = 23.2 Mbps and DMT = 0 bps
DESIGN(13): GNC is located at X = 45.15, Y = 5.75, Z = 45.1
switch(12): atm, 75000000 bps, 10 ports, $8000
CT(58) is connected to port 1

⋮

CT(65) is connected to port 8
ST(4) is connected to port 9
Enter the generation number from 0-2999:

- The output of *i*-CAD for a complete intranet integration for the partial animation sutdio, when TND = 50.0 seconds and the initial number of servers = 4.

Enter the generation number from 0-2999:
2440
Intranet infrastructure(7) is the best design in generation 2440
initial network cost = \$112000, monthly network cost = \$0
interconnection cost = \$0, wire cost = \$7340.93
initial data management system cost = \$12800, data management performance = 99.8125
average network delay = 20.701 seconds, homogeneity factor = 0.538462
BACKBONE(1) has 4 site tasks, BLT = 93.125 Mbps and MDT = 1.45543e+07 bps
DESIGN(7): Backbone Router is located at X = 48.4892, Y = 56.7385, Z = 24.2538
router(9): ip, 100000 pps, 5 ports, \$7000
ST(1) is connected to port 1
ST(2) is connected to port 2
ST(3) is connected to port 3
ST(4) is connected to port 4
SITE(1) has 2 group tasks, SLT = 0 Mbps, SOT = 55.625 Mbps,
SIT = 2.5 Mbps and DMT = 1.45543e+07 bps
DESIGN(7): Site Router is located at X = 36.4, Y = 63, Z = 1.1
router(9): ip, 100000 pps, 5 ports, \$7000
GT(1) is connected to port 1
GT(4) is connected to port 2
BT(1) is connected to port 3
GROUP(1) has 10 client tasks, GLT = 27 Mbps, GOT = 7.5 Mbps,
GIT = 0 Mbps and DMT = 1.4496e+07 bps
DESIGN(7): GNC is located at X = 9.7, Y = 49.6, Z = 1.1
multiaccess(18): ethernet, 100000000 bps, 12 ports, \$13000
CT(1) is connected to port 1
⋮
CT(10) is connected to port 10
GS(1) is connected to port 11
server(3) has the following attributes:
number of CPUs = 1, CPU clock cycle = 5 ns
main memory capacity = 32000000 bytes, internal hard disk capacity = 5e+09 bytes
cost = \$2000
max performance = 100%, average performance = 99.5726%, min performance = 99.1453%
hard disk(8) has the following attributes:
type = SCSI, capacity = 2e+10 bytes, average seek time = 5 ms, transfer rate = 1.6e+08 bps
cost = \$2000
stored files: 11, 2, 8, 9, 12, 15, 13, 10, 6, 5, 7.
ST(1) is connected to port 12
GROUP(4) has 5 client tasks, GLT = 8 Mbps, GOT = 48.125 Mbps,
GIT = 2.5 Mbps and DMT = 0 bps
DESIGN(7): GNC is located at X = 89.8, Y = 89.8, Z = 1.1
multiaccess(15): ethernet, 100000000 bps, 6 ports, \$8000
CT(11) is connected to port 1
⋮
CT(15) is connected to port 5

ST(1) is connected to port 6
SITE(2) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps,
SIT = 21.25 Mbps and DMT = 195737 bps
DESIGN(7): Site Switch is located at X = 49.6667, Y = 56.3333, Z = 16.1
switch(11): atm, 75000000 bps, 5 ports, $5000
GT(2) is connected to port 1
GT(5) is connected to port 2
BT(1) is connected to port 3
GROUP(2) has 5 client tasks, GLT = 2 Mbps, GOT = 2.5 Mbps,
GIT = 2.5 Mbps and DMT = 0 bps
DESIGN(7): GNC is located at X = 9.2, Y = 89, Z = 16.1
switch(7): atm, 45000000 bps, 10 ports, $6000
CT(16) is connected to port 1

⋮

CT(20) is connected to port 5
GS(2) is connected to port 6
server(7) has the following attributes:
number of CPUs = 2, CPU clock cycle = 3 ns
main memory capacity = 32000000 bytes, internal hard disk capacity = 1e+10 bytes
cost = $3000
max performance = 100%, average performance = 100%, min performance = 100%
hard disk(6) has the following attributes:
type = SCSI, capacity = 1.5e+10 bytes, average seek time = 5 ms, transfer rate = 1.6e+08 bps
cost = $1000
stored files: 11, 2, 8, 14, 9, 12, 15, 13, 1, 10, 4, 5, 7.
ST(2) is connected to port 7
GROUP(5) has 10 client tasks, GLT = 9 Mbps, GOT = 12.5 Mbps,
GIT = 18.75 Mbps and DMT = 0 bps
DESIGN(7): GNC is located at X = 69.9, Y = 40, Z = 16.1
switch(9): atm, 45000000 bps, 20 ports, $13000
CT(21) is connected to port 1

⋮

CT(30) is connected to port 10
ST(2) is connected to port 11
SITE(3) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps,
SIT = 33.75 Mbps and DMT = 1.43003e+07 bps
DESIGN(7): Site Router is located at X = 52.45, Y = 50, Z = 32.1
router(5): ip, 50000 pps, 5 ports, $3000
GT(3) is connected to port 1
GT(8) is connected to port 2
BT(1) is connected to port 3
GROUP(3) has 10 client tasks, GLT = 9 Mbps, GOT = 15 Mbps,
GIT = 7.5 Mbps and DMT = 0 bps
DESIGN(7): GNC is located at X = 27.5, Y = 85, Z = 32.1
switch(18): atm, 100000000 bps, 15 ports, $15000
CT(31) is connected to port 1

⋮

CT(40) is connected to port 10
ST(3) is connected to port 11

GROUP(8) has 10 client tasks, GLT = 9 Mbps, GOT = 0 Mbps,
GIT = 26.25 Mbps and DMT = 0 bps
DESIGN(7): GNC is located at X = 77.4, Y = 15, Z = 32.1
switch(18): atm, 100000000 bps, 15 ports, $15000
CT(41) is connected to port 1

⋮

CT(50) is connected to port 10
ST(3) is connected to port 11
SITE(4) has 2 group tasks, SLT = 4.2 Mbps, SOT = 7.5 Mbps,
SIT = 35.625 Mbps and DMT = 58254.9 bps
DESIGN(7): Site Router is located at X = 54.12, Y = 59.8667, Z = 45.1
router(6): ip, 50000 pps, 10 ports, $6000
GT(6) is connected to port 1
GT(7) is connected to port 2
BT(1) is connected to port 3
GROUP(6) has 7 client tasks, GLT = 4.2 Mbps, GOT = 7.7 Mbps,
GIT = 16.625 Mbps and DMT = 58254.9 bps
DESIGN(7): GNC is located at X = 15.4, Y = 30.7143, Z = 45.1
switch(12): atm, 75000000 bps, 10 ports, $8000
CT(51) is connected to port 1

⋮

CT(57) is connected to port 7
GS(3) is connected to port 8
server(4) has the following attributes:
number of CPUs = 1, CPU clock cycle = 4 ns
main memory capacity = 32000000 bytes, internal hard disk capacity = 5e+09 bytes
cost = $2500
max performance = 100%, average performance = 100%, min performance = 100%
hard disk(3) has the following attributes:
type = IDE, capacity = 1e+10 bytes, average seek time = 10 ms, transfer rate = 6.6e+07 bps
cost = $300
stored files: 3, 2, 14, 12, 15, 13, 10, 6, 7.
ST(4) is connected to port 9
GROUP(7) has 8 client tasks, GLT = 5.6 Mbps, GOT = 4 Mbps,
GIT = 23.2 Mbps and DMT = 0 bps
DESIGN(7): GNC is located at X = 88, Y = 85.375, Z = 45.1
switch(7): atm, 45000000 bps, 10 ports, $6000
CT(58) is connected to port 1

⋮

CT(65) is connected to port 8
GS(4) is connected to port 9
server(1) has the following attributes:
number of CPUs = 1, CPU clock cycle = 5 ns
main memory capacity = 12000000 bytes, internal hard disk capacity = 1e+09 bytes
cost = $1000
max performance = 100%, average performance = 99.6774%, min performance = 98.3871%
hard disk(6) has the following attributes:
type = SCSI, capacity = 1.5e+10 bytes, average seek time = 5 ms, transfer rate = 1.6e+08 bps
cost = $1000

stored files: 3, 2, 8, 14, 9, 12, 13, 6, 4, 5, 7.
ST(4) is connected to port 10
Enter the generation number from 0-2999:

- The output of *i*-CAD for a complete intranet integration for the partial animation sutdio, when TND = 60.0 seconds and the initial number of servers = 4.

Enter the generation number from 0-2999:
2813
Intranet infrastructure(16) is the best design in generation 2813
initial network cost = $117000, monthly network cost = $0
interconnection cost = $2000, wire cost = $936.786
initial data management system cost = $10900, data management performance = 99.5534%
average network delay = 30.7254 seconds, homogeneity factor = 0.692308
BACKBONE(1) has 4 site tasks, BLT = 93.125 Mbps and MDT = 1.76418e+07 bps
DESIGN(16): Backbone Router is located at X = 23.6308, Y = 14.2, Z = 24.2538
router(9): ip, 100000 pps, 5 ports, $7000
ST(1) is connected to port 1
ST(2) is connected to port 2
ST(3) is connected to port 3
ST(4) is connected to port 4
SITE(1) has 2 group tasks, SLT = 0 Mbps, SOT = 55.625 Mbps,
SIT = 2.5 Mbps and DMT = 2.03471e+07 bps
DESIGN(16): Site Switch is located at X = 4.4, Y = 43.3333, Z = 1.1
switch(16): atm, 100000000 bps, 5 ports, $7000
GT(1) is connected to port 1
GT(4) is connected to port 2
BT(1) is connected to port 3
GROUP(1) has 10 client tasks, GLT = 27 Mbps, GOT = 7.5 Mbps,
GIT = 0 Mbps and DMT = 0 bps
DESIGN(16): GNC is located at X = 3.9, Y = 43.6, Z = 1.1
switch(18): atm, 100000000 bps, 15 ports, $15000
CT(1) is connected to port 1
⋮
CT(10) is connected to port 10
ST(1) is connected to port 11
GROUP(4) has 5 client tasks, GLT = 8 Mbps, GOT = 48.125 Mbps,
GIT = 2.5 Mbps and DMT = 2.03471e+07 bps
DESIGN(16): GNC is located at X = 5.4, Y = 42.8, Z = 1.1
switch(17): atm, 100000000 bps, 10 ports, $11000
CT(11) is connected to port 1
⋮
CT(15) is connected to port 5
GS(1) is connected to port 6
server(7) has the following attributes:
number of CPUs = 2, CPU clock cycle = 3 ns
main memory capacity = 32000000 bytes, internal hard disk capacity = 1e+10 bytes
cost = $3000
max performance = 100%, average performance = 99.6444%, min performance = 99.5556%

hard disk(2) has the following attributes:
type = SCSI, capacity = 5e+09, average seek time = 5 ms, transfer rate = 1.6e+08 bps
cost = $400
stored files: 11, 2, 8, 14, 12, 1, 10, 6, 4, 5.
ST(1) is connected to port 7
SITE(2) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps,
SIT = 21.25 Mbps and DMT = 3.34147e+06 bps
DESIGN(16): Site Router is located at X = 45.0667, Y = 5, Z = 16.1
router(9): ip, 100000 pps, 5 ports, $7000
GT(2) is connected to port 1
GT(5) is connected to port 2
BT(1) is connected to port 3
GROUP(2) has 5 client tasks, GLT = 2 Mbps, GOT = 2.5 Mbps,
GIT = 2.5 Mbps and DMT = 0 bps
DESIGN(16): GNC is located at X = 48.4, Y = 5, Z = 16.1
switch(2): atm, 25000000 bps, 10 ports, $4000
CT(16) is connected to port 1

⋮

CT(20) is connected to port 5
ST(2) is connected to port 6
GROUP(5) has 10 client tasks, GLT = 9 Mbps, GOT = 12.5 Mbps,
GIT = 18.75 Mbps and DMT = 0 bps
DESIGN(16): GNC is located at X = 43.4, Y = 5, Z = 16.1
switch(13): atm, 75000000 bps, 15 ports, $11000
CT(21) is connected to port 1

⋮

CT(30) is connected to port 10
ST(2) is connected to port 11
SITE(3) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps,
SIT = 33.75 Mbps and DMT = 1.43003e+07 bps
DESIGN(16): Site Switch is located at X = 4.9, Y = 6.15, Z = 32.1
switch(11): atm, 75000000 bps, 5 ports, $5000
GT(3) is connected to port 1
GT(8) is connected to port 2
BT(1) is connected to port 3
GROUP(3) has 10 client tasks, GLT = 9 Mbps, GOT = 15 Mbps,
GIT = 7.5 Mbps and DMT = 0 bps
DESIGN(16): GNC is located at X = 3.4, Y = 7.3, Z = 32.1
multiaccess(19): ethernet, 100000000 bps, 14 ports, $16000
CT(31) is connected to port 1

⋮

CT(40) is connected to port 10
ST(3) is connected to port 11
GROUP(8) has 10 client tasks, GLT = 9 Mbps, GOT = 0 Mbps,
GIT = 26.25 Mbps and DMT = 0 bps
DESIGN(16): GNC is located at X = 6.4, Y = 5, Z = 32.1
switch(13): atm, 75000000 bps, 15 ports, $11000
CT(41) is connected to port 1

⋮

CT(50) is connected to port 10
ST(3) is connected to port 11
SITE(4) has 2 group tasks, SLT = 4.2 Mbps, SOT = 7.5 Mbps,
SIT = 35.625 Mbps and DMT = 195737 bps
DESIGN(16): Site Router is located at X = 46.4, Y = 5, Z = 45.1
router(5): ip, 50000 pps, 5 ports, $3000
GT(6) is connected to port 1
GT(7) is connected to port 2
BT(1) is connected to port 3
GROUP(6) has 7 client tasks, GLT = 4.2 Mbps, GOT = 7.7 Mbps,
GIT = 16.625 Mbps and DMT = 195737 bps
DESIGN(16): GNC is located at X = 47.8286, Y = 4.14286, Z = 45.1
switch(8): atm, 45000000 bps, 15 ports, $9000
CT(51) is connected to port 1

⋮

CT(57) is connected to port 7
GS(2) is connected to port 8
server(1) has the following attributes:
number of CPUs = 1, CPU clock cycle = 5 ns
main memory capacity = 12000000 bytes, internal hard disk capacity = 1e+09 bytes
cost = $1000
max performance = 100% average performance = 99.661%, min performance = 98.3051%
hard disk(5) has the following attributes:
type = IDE, capacity = 1.5e+10 bytes, average seek time = 10 ms, transfer rate = 6.6e+07 bps
cost = $500
stored files: 11, 3, 2, 8, 9, 12, 15, 13, 1, 10, 4, 7.
ST(4) is connected to port 9
GROUP(7) has 8 client tasks, GLT = 5.6 Mbps, GOT = 4 Mbps,
GIT = 23.2 Mbps and DMT = 0 bps
DESIGN(16): GNC is located at X = 45.15, Y = 5.75, Z = 45.1
switch(17): atm, 100000000 bps, 10 ports, $11000
CT(58) is connected to port 1

⋮

CT(65) is connected to port 8
GS(3) is connected to port 9
server(6) has the following attributes:
number of CPUs = 1, CPU clock cycle = 2 ns
main memory capacity = 64000000 bytes, internal hard disk capacity = 1e+10 bytes
cost = $4000
max performance = 100%, average performance = 99.3548%, min performance = 98.3871%
hard disk(9) has the following attributes:
type = IDE, capacity = 3e+10 bytes, average seek time = 10 ms, transfer rate = 6.6e+07 bps
cost = $2000
stored files: 2, 8, 9, 1, 6, 4, 5.
ST(4) is connected to port 10
Enter the generation number from 0-2999:

⋮

CT(40) is connected to port 10
ST(3) is connected to port 11
GROUP(8) has 10 client tasks, GLT = 9 Mbps, GOT = 0 Mbps,
GIT = 26.25 Mbps and DMT = 0 bps
DESIGN(18): GNC is located at X = 52077.4, Y = 10415, Z = 32.1
switch(13): atm, 75000000 bps, 15 ports, $11000
CT(41) is connected to port 1

⋮

CT(50) is connected to port 10
GS(3) is connected to port 11
server(15) has the following attributes:
number of CPUs = 4, CPU clock cycle = 1 ns
main memory capacity = 1024000000 bytes, internal hard disk capacity = 5e+10 bytes
cost = $35000
max performance = 100%, average performance = 99.7778%, min performance = 98.8889%
hard disk(7) has the following attributes:
type = IDE, capacity = 2e+10 bytes, average seek time = 10 ms, transfer rate = 6.6e+07 bps
cost = $1500
stored files: 3, 2, 8, 14, 9, 13, 1, 10, 4, 5, 7.
ST(3) is connected to port 12
SITE(4) has 2 group tasks, SLT = 4.2 Mbps, SOT = 7.5 Mbps,
SIT = 35.625 Mbps and DMT = 4.54384e+06 bps
DESIGN(18): Site Switch is located at X = 54.12, Y = 10459.9, Z = 45.1
switch(26): atm, 200000000 bps, 5 ports, $15000
GT(6) is connected to port 1
GT(7) is connected to port 2
LINK(2) is connected to port 3
GROUP(6) has 7 client tasks, GLT = 4.2 Mbps, GOT = 7.7 Mbps,
GIT = 16.625 Mbps and DMT = 0 bps
DESIGN(18): GNC is located at X = 15.4, Y = 10430.7, Z = 45.1
switch(22): atm, 150000000 bps, 10 ports, $15000
CT(51) is connected to port 1

⋮

CT(57) is connected to port 7
GS(4) is connected to port 8
server(3) has the following attributes:
number of CPUs = 1, CPU clock cycle = 5 ns
main memory capacity = 32000000 bytes, internal hard disk capacity = 5e+09 bytes
cost = $2000
max performance = 100%, average performance = 100%, min performance = 100%
hard disk(19) has the following attributes:
type = IDE, capacity = 8e+10 bytes, verage seek time = 10 ms, transfer rate = 6.6e+07 bps
cost = $10000
stored files: 11, 3, 2, 14, 9, 12, 15, 13, 10, 6, 5, 7.
ST(4) is connected to port 9
GROUP(7) has 8 client tasks, GLT = 5.6 Mbps, GOT = 4 Mbps,
GIT = 23.2 Mbps and DMT = 0 bps
DESIGN(18): GNC is located at X = 88, Y = 10485.4, Z = 45.1
multiaccess(19): ethernet, 100000000 bps, 14 ports, $16000

CT(58) is connected to port 1

⋮

CT(65) is connected to port 8
ST(4) is connected to port 9
Enter the generation number from 0-2999:

- The output of *i*-CAD for a complete intranet integration for the partial animation sutdio, including a wide tree backbone topology, when TND = 20.0 seconds and the initial number of servers = 3.

Enter the generation number from 0-2999:
2347
Intranet infrastructure(33) is the best design in generation 2347
initial network cost = $300800, monthly network cost = $53000
interconnection cost = $16000, wire cost = $7976.86
initial data management system cost = $42500, data management performance = 99.5909%
average network delay = 16.8058 seconds, homogeneity factor = 0.533333
BACKBONE(1) has 4 site tasks, BLT = 93.125 Mbps and MDT = 1.16439e+07 bps
Link(1) connects sites: 2 and 4
t-line(ds4): 264241152 bps, initial cost $30000 and monthly cost $13000
Link(2) connects sites: 4 and 1
sonet(oc9): 466560000 bps, initial cost $90000 and monthly cost $27000
Link(3) connects sites: 4 and 3
t-line(ds4): 264241152 bps, initial cost $30000 and monthly cost $13000
SITE(1) has 2 group tasks, SLT = 0 Mbps, SOT = 55.625 Mbps,
SIT = 2.5 Mbps and DMT = 1.05906e+07 bps
DESIGN(33): Site Switch is located at X = 83236.4, Y = 20863, Z = 1.1
switch(23): atm, 150000000 bps, 15 ports, $20000
GT(1) is connected to port 1
GT(4) is connected to port 2
LINK(1) is connected to port 3
GROUP(1) has 10 client tasks, GLT = 27 Mbps, GOT = 7.5 Mbps,
GIT = 0 Mbps and DMT = 0 bps
DESIGN(33): GNC is located at X = 83209.7, Y = 20849.6, Z = 1.1
multiaccess(19): ethernet, 100000000 bps, 14 ports, $16000
CT(1) is connected to port 1

⋮

CT(10) is connected to port 10
ST(1) is connected to port 11
GROUP(4) has 5 client tasks, GLT = 8 Mbps, GOT = 48.125 Mbps,
GIT = 2.5 Mbps and DMT = 1.05906e+07 bps
DESIGN(33): GNC is located at X = 83289.8, Y = 20889.8, Z = 1.1
multiaccess(17): ethernet, 100000000 bps, 10 ports, $10400
CT(11) is connected to port 1

⋮

CT(15) is connected to port 5
GS(1) is connected to port 6
server(4) has the following attributes:
number of CPUs = 1, CPU clock cycle = 4 ns

main memory capacity = 32000000 bytes, internal hard disk capacity = 5e+09 bytes
cost = $2500
max performance = 100%, average performance = 99.6296%, min performance = 99.0741%
hard disk(16) has the following attributes:
type = SCSI, capacity = 6e+10 bytes, average seek time = 5 ms, transfer rate = 1.6e+08 bps
cost = $11000
stored files: 11, 3, 8, 14, 12, 1, 10, 6, 5, 7.
ST(1) is connected to port 7
SITE(2) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps,
SIT = 21.25 Mbps and DMT = 7.10004e+06 bps
DESIGN(33): Site Router is located at X = 114450, Y = 56.3333, Z = 16.1
router(5): ip, 50000 pps, 5 ports, $3000
GT(2) is connected to port 1
GT(5) is connected to port 2
LINK(1) is connected to port 3
GROUP(2) has 5 client tasks, GLT = 2 Mbps, GOT = 2.5 Mbps,
GIT = 2.5 Mbps and DMT = 0 bps
DESIGN(33): GNC is located at X = 114409, Y = 89, Z = 16.1
switch(2): atm, 25000000 bps, 10 ports, $4000
CT(16) is connected to port 1

⋮

CT(20) is connected to port 5
ST(2) is connected to port 6
GROUP(5) has 10 client tasks, GLT = 9 Mbps, GOT = 12.5 Mbps,
GIT = 18.75 Mbps and DMT = 3.95431e+06 bps
DESIGN(33): GNC is located at X = 114470, Y = 40, Z = 16.1
multiaccess(19): ethernet, 100000000 bps, 14 ports, $16000
CT(21) is connected to port 1

⋮

CT(30) is connected to port 10
GS(2) is connected to port 11
server(8) has the following attributes:
number of CPUs = 2, CPU clock cycle = 3 ns
main memory capacity = 64000000 bytes, internal hard disk capacity = 1.5e+10 bytes
cost = $5000
max performance = 100%, average performance = 99.5294%, min performance = 98.8235%
hard disk(19) has the following attributes:
type = IDE, capacity = 8e+10 bytes, average seek time = 10 ms, transfer rate = 6.6e+07 bps
cost = $10000
stored files: 11, 14, 9, 12, 15, 13, 1, 10, 4, 5, 7.
ST(2) is connected to port 12
SITE(3) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps,
SIT = 33.75 Mbps and DMT = 389145 bps
DESIGN(33): Site Multiaccess device is located at X = 52052.4, Y = 10450, Z = 32.1
multiaccess(14): ethernet, 100000000 bps, 4 ports, $6000
GT(3) is connected to site task port 1 via a 2-port bridge with following attributes:
Bridge(23), has capacity 500000 frames per second and cost $4000
GT(8) is connected to site task port 2 via a 2-port bridge with following attributes:
Bridge(23), has capacity 500000 frames per second and cost $4000
LINK(1) is connected to port 3

GROUP(3) has 10 client tasks, GLT = 9 Mbps, GOT = 15 Mbps,
GIT = 7.5 Mbps and DMT = 0 bps
DESIGN(33): GNC is located at X = 52027.5, Y = 10485, Z = 32.1
multiaccess(18): ethernet, 100000000 bps, 12 ports, $13000
CT(31) is connected to port 1

⋮

CT(40) is connected to port 10
ST(3) is connected to port 11
GROUP(8) has 10 client tasks, GLT = 9 Mbps, GOT = 0 Mbps,
GIT = 26.25 Mbps and DMT = 0 bps
DESIGN(33): GNC is located at X = 52077.4, Y = 10415, Z = 32.1
multiaccess(19): ethernet, 100000000 bps, 14 ports, $16000
CT(41) is connected to port 1

⋮

CT(50) is connected to port 10
GS(3) is connected to port 11
server(7) has the following attributes:
number of CPUs = 2, CPU clock cycle = 3 ns
main memory capacity = 32000000 bytes, internal hard disk capacity = 1e+10 bytes
cost = $3000
max performance = 100%, average performance = 99.6135%, min performance = 99.5169%
hard disk(16) has the following attributes:
type = SCSI, capacity = 6e+10 bytes, average seek time = 5 ms, transfer rate = 1.6e+08 bps
cost = $11000
stored files: 11, 3, 2, 8, 14, 9, 12, 15, 13, 10, 5, 7.
ST(3) is connected to port 12
SITE(4) has 2 group tasks, SLT = 4.2 Mbps, SOT = 7.5 Mbps,
SIT = 35.625 Mbps and DMT = 8.10901e+06 bps
DESIGN(33): Site Router is located at X = 54.12, Y = 10459.9, Z = 45.1
router(5): ip, 50000 pps, 5 ports, $3000
GT(6) is connected to port 1
GT(7) is connected to port 2
LINK(1) is connected to port 3
GROUP(6) has 7 client tasks, GLT = 4.2 Mbps, GOT = 7.7 Mbps,
GIT = 16.625 Mbps and DMT = 0 bps
DESIGN(33): GNC is located at X = 15.4, Y = 10430.7, Z = 45.1
multiaccess(17): ethernet, 100000000 bps, 10 ports, $10400
CT(51) is connected to port 1

⋮

CT(57) is connected to port 7
ST(4) is connected to port 8
GROUP(7) has 8 client tasks, GLT = 5.6 Mbps, GOT = 4 Mbps,
GIT = 23.2 Mbps and DMT = 0 bps
DESIGN(33): GNC is located at X = 88, Y = 10485.4, Z = 45.1
multiaccess(29): ethernet, 1000000000 bps, 10 ports, $25000
CT(58) is connected to port 1

⋮

CT(65) is connected to port 8
ST(4) is connected to port 9

Enter the generation number from 0-2999:

- The output of *i*-CAD for a complete intranet integration for the partial animation sutdio, including a wide tree backbone topology, when TND = 30.0 seconds and the initial number of servers = 3.

Enter the generation number from 0-2999:
2682
Intranet infrastructure(16) is the best design in generation 2682
initial network cost = $267000, monthly network cost = $47000
interconnection cost = $14000, wire cost $10428.5
initial data management system cost = $52500, data management performance = 99.8201
average network delay = 24.5864 seconds, homogeneity factor = 0.333333
BACKBONE(1) has 4 site tasks, BLT = 93.125 Mbps and MDT = 1.75043e+07 bps
Link(1) connects sites: 3 and 4
t-line(ds4): 264241152 bps, initial cost $30000 and monthly cost $13000
Link(2) connects sites: 4 and 2
t-line(ds4): 264241152 bps, initial cost $30000 and monthly cost $13000
Link(3) connects sites: 4 and 1
sonet(oc7): 362880000 bps, initial cost $70000 and monthly cost $21000
SITE(1) has 2 group tasks, SLT = 0 Mbps, SOT = 55.625 Mbps,
SIT = 2.5 Mbps and DMT = 1.71151e+07 bps
DESIGN(16): Site Multiaccess device is located at X = 83236.4, Y = 20863, Z = 1.1
multiaccess(14): ethernet, 100000000 bps, 4 ports, $6000
GT(1) is connected to site task port 1 via a 2-port bridge with following attributes:
Bridge(22), has capacity 300000 frames per second and cost $2000
GT(4) is connected to site task port 2 via a 2-port bridge with following attributes:
Bridge(22), has capacity 300000 frames per second and cost $2000
LINK(3) is connected to port 3
GROUP(1) has 10 client tasks, GLT = 27 Mbps, GOT = 7.5 Mbps,
GIT = 0 Mbps and DMT = 1.70569e+07 bps
DESIGN(16): GNC is located at X = 83209.7, Y = 20849.6, Z = 1.1
multiaccess(22): ethernet, 100000000 bps, 20 ports, $25000
CT(1) is connected to port 1

⋮

CT(10) is connected to port 10
GS(1) is connected to port 11
server(11) has the following attributes:
number of CPUs = 4, CPU clock cycle = 2.5 ns
main memory capacity = 256000000 bytes, internal hard disk capacity = 2e+10 bytes
cost = $12000
max performance = 100%, average performance = 99.9034%, min performance = 99.5169%
hard disk(16) has the following attributes:
type = SCSI, capacity = 6e+10 bytes, average seek time = 5 ms, transfer rate = 1.6e+08 bps
cost = $11000
stored files: 11, 2, 8, 9, 12, 15, 13, 1, 4, 5, 7
ST(1) is connected to port 12
GROUP(4) has 5 client tasks, GLT = 8 Mbps, GOT = 48.125 Mbps,
GIT = 2.5 Mbps and DMT = 0 bps
DESIGN(16): GNC is located at X = 83289.8, Y = 20889.8, Z = 1.1

multiaccess(15): ethernet, 100000000 bps, 6 ports, $8000
CT(11) is connected to port 1

⋮

CT(15) is connected to port 5
ST(1) is connected to port 6
SITE(2) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps,
SIT = 21.25 Mbps and DMT = 3.14573e+06 bps
DESIGN(16): Site Router is located at X = 114450, Y = 56.3333, Z = 16.1
router(6): ip, 50000 pps, 10 ports, $6000
GT(2) is connected to port 1
GT(5) is connected to port 2
LINK(2) is connected to port 3
GROUP(2) has 5 client tasks, GLT = 2 Mbps, GOT = 2.5 Mbps.
GIT = 2.5 Mbps and DMT = 0 bps
DESIGN(16): GNC is located at X = 114409, Y = 89, Z = 16.1
switch(22): atm, 150000000 bps, 10 ports, $15000
CT(16) is connected to port 1

⋮

CT(20) is connected to port 5
ST(2) is connected to port 6
GROUP(5) has 10 client tasks, GLT = 9 Mbps, GOT = 12.5 Mbps,
GIT = 18.75 Mbps and DMT = 0 bps
DESIGN(16): GNC is located at X = 114470, Y = 40, Z = 16.1
switch(13): atm, 75000000 bps, 15 ports, $11000
CT(21) is connected to port 1

⋮

CT(30) is connected to port 10
GS(2) is connected to port 11
server(2) has the following attributes:
number of CPUs = 1, CPU clock cycle = 4 ns
main memory capacity = 12000000 bytes, internal hard disk capacity = 3e+09 bytes
cost = $1500
max performance = 100%, average performance = 100%, min performance = 100%
hard disk(15) has the following attributes:
type = IDE, capacity = 6e+10 bytes, average seek time = 10 ms, transfer rate = 6.6e+07 bps
cost = $8000
stored files: 11, 3, 2, 14, 9, 12, 15, 1, 10, 6, 4, 5.
ST(2) is connected to port 12
SITE(3) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps.
SIT = 33.75 Mbps and DMT = 1.43003e+07 bps
DESIGN(16): Site Switch is located at X = 52052.4, Y = 10450, Z = 32.1
switch(11): atm, 75000000 bps, 5 ports, $5000
GT(3) is connected to port 1
GT(8) is connected to port 2
LINK(1) is connected to port 3
GROUP(3) has 10 client tasks, GLT = 9 Mbps, GOT = 15 Mbps.
GIT = 7.5 Mbps and DMT = 0 bps
DESIGN(16): GNC is located at X = 52027.5, Y = 10485, Z = 32.1
switch(8): atm, 45000000 bps, 15 ports, $9000

CT(31) is connected to port 1

⋮

CT(40) is connected to port 10
ST(3) is connected to port 11
GROUP(8) has 10 client tasks, GLT = 9 Mbps, GOT = 0 Mbps,
GIT = 26.25 Mbps and DMT = 0 bps
DESIGN(16): GNC is located at X = 52077.4, Y = 10415, Z = 32.1
multiaccess(18): ethernet, 100000000 bps, 12 ports, $13000
CT(41) is connected to port 1

⋮

CT(50) is connected to port 10
ST(3) is connected to port 11
SITE(4) has 2 group tasks, SLT = 4.2 Mbps, SOT = 7.5 Mbps.
SIT = 35.625 Mbps and DMT = 447400 bps
DESIGN(16): Site Router is located at X = 54.12, Y = 10459.9, Z = 45.1
router(9): ip, 100000 pps, 5 ports, $7000
GT(6) is connected to port 1
GT(7) is connected to port 2
LINK(1) is connected to port 3
LINK(2) is connected to port 4
LINK(3) is connected to port 5
GROUP(6) has 7 client tasks, GLT = 4.2 Mbps, GOT = 7.7 Mbps,
GIT = 16.625 Mbps and DMT = 389145 bps
DESIGN(16): GNC is located at X = 15.4, Y = 10430.7, Z = 45.1
multiaccess(18): ethernet, 100000000 bps, 12 ports, $13000
CT(51) is connected to port 1

⋮

CT(57) is connected to port 7
GS(3) is connected to port 8
server(8) has the following attributes:
number of CPUs = 2, CPU clock cycle = 3 ns
main memory capacity = 64000000 bytes, internal hard disk capacity = 1.5e+10 bytes
cost = $5000
max performance = 100%, average performance = 99.798%, min performance = 98.9899%
hard disk(8) has the following attributes:
type = SCSI, capacity = 2e+10 bytes, average seek time = 5 ms, transfer rate = 1.6e+08 bps
cost = $2000
stored files: 11, 3, 8, 14, 9, 12, 13, 10, 4, 5, 7.
ST(4) is connected to port 9
GROUP(7) has 8 client tasks, GLT = 5.6 Mbps, GOT = 4 Mbps,
GIT = 23.2 Mbps and DMT = 58254.9 bps
DESIGN(16): GNC is located at X = 88, Y = 10485.4, Z = 45.1
switch(18): atm, 100000000 bps, 15 ports, $15000
CT(58) is connected to port 1

⋮

CT(65) is connected to port 8
GS(4) is connected to port 9
server(8) has the following attributes:
number of CPUs = 2, CPU clock cycle = 3 ns

main memory capacity = 64000000 bytes, internal hard disk capacity = 1.5e+10 bytes
cost = $5000
max performance = 100%, average performance = 99.5789%, min performance = 98.9474%
hard disk(15) has the following attributes:
type = IDE, capacity = 6e+10 bytes, average seek time = 10 ms, transfer rate = 6.6e+07 bps
cost = $8000
stored files: 11, 3, 2, 8, 14, 9, 12, 15, 13, 1, 10, 6, 4, 5, 7.
ST(4) is connected to port 10
Enter the generation number from 0-2999:

- The output of *i*-CAD for a complete intranet integration for the partial animation sutdio, including a wide tree backbone topology, when TND = 40.0 seconds and the initial number of servers = 3.

Enter the generation number from 0-2999:
1340
Intranet infrastructure(1) is the best design in generation 1340
initial network cost = $267400, monthly network cost = $32000
interconnection cost = $22000, wire cost = $6094.88
initial data management system cost = $55500, data management performance = 99.7034%
average network delay = 35.8453 seconds, homogeneity factor = 0.4
BACKBONE(1) has 4 site tasks, BLT = 93.125 Mbps and MDT = 7.89231e+06 bps
Link(1) connects sites: 1 and 2
t-line(ds4): 264241152 bps, initial cost $30000 and monthly cost $13000
Link(2) connects sites: 2 and 4
sonet(oc2): 103680000 bps, initial cost $20000 and monthly cost $6000
Link(3) connects sites: 1 and 3
t-line(ds4): 264241152 bps, initial cost $30000 and monthly cost $13000
SITE(1) has 2 group tasks, SLT = 0 Mbps, SOT = 55.625 Mbps,
SIT = 2.5 Mbps and DMT = 2.95932e+06 bps
DESIGN(1): Site Router is located at X = 83236.4, Y = 20863, Z = 1.1
router(6): ip, 50000 pps, 10 ports, $6000
GT(1) is connected to port 1
GT(4) is connected to port 2
LINK(1) is connected to port 3
LINK(3) is connected to port 4
GROUP(1) has 10 client tasks, GLT = 27 Mbps, GOT = 7.5 Mbps,
GIT = 0 Mbps and DMT = 0 bps
DESIGN(1): GNC is located at X = 83209.7, Y = 20849.6, Z = 1.1
switch(8): atm, 45000000 bps, 15 ports, $9000
CT(1) is connected to port 1

⋮

CT(10) is connected to port 10
ST(1) is connected to port 11
GROUP(4) has 5 client tasks, GLT = 8 Mbps, GOT = 48.125 Mbps,
GIT = 2.5 Mbps and DMT = 0 bps
DESIGN(1): GNC is located at X = 83289.8, Y = 20889.8, Z = 1.1
switch(13): atm, 75000000 bps, 15 ports, $11000
CT(11) is connected to port 1

⋮

CT(15) is connected to port 5
ST(1) is connected to port 6
SITE(2) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps,
SIT = 21.25 Mbps and DMT = 7.68957e+06 bps
DESIGN(1): Site Switch is located at X = 114450, Y = 56.3333, Z = 16.1
switch(25): atm, 150000000 bps, 32 ports, $38000
GT(2) is connected to port 1
GT(5) is connected to port 2
LINK(1) is connected to port 3
LINK(2) is connected to port 4
GROUP(2) has 5 client tasks, GLT = 2 Mbps, GOT = 2.5 Mbps,
GIT = 2.5 Mbps and DMT = 0 bps
DESIGN(1): GNC is located at X = 114409, Y = 89, Z = 16.1
multiaccess(19): ethernet, 100000000 bps, 14 ports, $16000
CT(16) is connected to port 1

⋮

CT(20) is connected to port 5
ST(2) is connected to port 6
GROUP(5) has 10 client tasks, GLT = 9 Mbps, GOT = 12.5 Mbps,
GIT = 18.75 Mbps and DMT = 7.68957e+06 bps
DESIGN(1): GNC is located at X = 114470, Y = 40, Z = 16.1
multiaccess(19): ethernet, 100000000 bps, 14 ports, $16000
CT(21) is connected to port 1

⋮

CT(30) is connected to port 10
GS(1) is connected to port 11
server(4) has the following attributes:
number of CPUs = 1, CPU clock cycle = 4 ns
main memory capacity = 32000000 bytes, internal hard disk capacity = 5e+09 bytes
cost = $2500
max performance = 100%, average performance = 99.8039%, min performance = 99.0196%
hard disk(20) has the following attributes:
type = SCSI, capacity = 8e+10 bytes, average seek time = 5 ms, transfer rate = 1.6e+08 bps
cost = $20000
stored files: 2, 8, 14, 9, 12, 15, 13, 10, 6, 4, 5.
ST(2) is connected to port 12
SITE(3) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps,
SIT = 33.75 Mbps and DMT = 3.29021e+06 bps
DESIGN(1): Site Router is located at X = 52052.4, Y = 10450, Z = 32.1
router(10): ip, 100000 pps, 10 ports, $11000
GT(3) is connected to port 1
GT(8) is connected to port 2
LINK(3) is connected to port 3
GROUP(3) has 10 client tasks, GLT = 9 Mbps, GOT = 15 Mbps.
GIT = 7.5 Mbps and DMT = 0 bps
DESIGN(1): GNC is located at X = 52027.5, Y = 10485, Z = 32.1
switch(8): atm, 45000000 bps, 15 ports, $9000
CT(31) is connected to port 1

⋮

CT(40) is connected to port 10
ST(3) is connected to port 11
GROUP(8) has 10 client tasks, GLT = 9 Mbps, GOT = 0 Mbps,
GIT = 26.25 Mbps and DMT = 2.90107e+06 bps
DESIGN(1): GNC is located at X = 52077.4, Y = 10415, Z = 32.1
switch(24): atm, 150000000 bps, 20 ports, $28000
CT(41) is connected to port 1

⋮

CT(50) is connected to port 10
GS(2) is connected to port 11
server(3) has the following attributes:
number of CPUs = 1, CPU clock cycle = 5 ns
main memory capacity = 32000000 bytes, internal hard disk capacity = 5e+09 bytes
cost = $2000
max performance = 99.422%, average performance = 99.3064%, min performance = 98.8439%
hard disk(14) has the following attributes:
type = SCSI, capacity = 5e+10 bytes, average seek time = 5 ms, transfer rate = 1.6e+08 bps
cost = $9000
stored files: 3, 2, 8, 14, 9, 12, 13, 1, 10, 6, 4, 5, 7.
ST(3) is connected to port 12
SITE(4) has 2 group tasks, SLT = 4.2 Mbps, SOT = 7.5 Mbps,
SIT = 35.625 Mbps and DMT = 4.99124e+06 bps
DESIGN(1): Site Multiaccess device is located at X = 54.12, Y = 10459.9, Z = 45.1
multiaccess(15): ethernet, 100000000 bps, 6 ports, $8000
GT(6) is connected to port 1
GT(7) is connected to site task port 2 via a 2-port bridge with following attributes:
Bridge(20), has capacity 125000 packets per second and cost $400
LINK(2) is connected to port 3
GROUP(6) has 7 client tasks, GLT = 4.2 Mbps, GOT = 7.7 Mbps,
GIT = 16.625 Mbps and DMT = 447400 bps
DESIGN(1): GNC is located at X = 15.4, Y = 10430.7, Z = 45.1
switch(14): atm, 75000000 bps, 20 ports, $16000
CT(51) is connected to port 1

⋮

CT(57) is connected to port 7
GS(3) is connected to port 8
server(11) has the following attributes:
number of CPUs = 4, CPU clock cycle = 2.5 ns
main memory capacity = 256000000 bytes, internal hard disk capacity = 2e+10 bytes
cost = $12000
max performance = 100%, average performance = 100%, min performance = 100%
hard disk(19) has the following attributes:
type = IDE, capacity = 8e+10 bytes, average seek time = 10 ms, transfer rate = 6.6e+07 bps
cost = $10000
stored files: 11, 3, 2, 8, 14, 12, 13, 1, 6, 4, 7.
ST(4) is connected to port 9
GROUP(7) has 8 client tasks, GLT = 5.6 Mbps, GOT = 4 Mbps,
GIT = 23.2 Mbps and DMT = 0 bps
DESIGN(1): GNC is located at X = 88, Y = 10485.4, Z = 45.1
multiaccess(20): ethernet, 100000000 bps, 16 ports, $19000

CT(58) is connected to port 1

⋮

CT(65) is connected to port 8
ST(4) is connected to port 9
Enter the generation number from 0-2999:

- The output of *i*-CAD for a complete intranet integration for the partial animation sutdio, including a wide tree backbone topology, when TND = 50.0 seconds and the initial number of servers = 3.

Enter the generation number from 0-2999:
1775
Intranet infrastructure(46) is the best design in generation 1775
initial network cost = $230000, monthly network cost = $39000
interconnection cost = $0, wire cost = $10591.7
initial data management system cost = $42500, data management ratio = 99.8316%
average network delay = 21.7926 seconds, homogeneity factor = 0.266667
BACKBONE(1) has 4 site tasks, BLT = 93.125 Mbps and MDT = 6.91363e+06 bps
Link(1) connects sites: 2 and 4
t-line(ds4): 264241152 bps, initial cost $30000 and monthly cost $13000
Link(2) connects sites: 4 and 1
t-line(ds4): 264241152 bps, initial cost $30000 and monthly cost $13000
Link(3) connects sites: 4 and 3
t-line(ds4): 264241152 bps, initial cost $30000 and monthly cost $13000
SITE(1) has 2 group tasks, SLT = 0 Mbps, SOT = 55.625 Mbps,
SIT = 2.5 Mbps and DMT = 2.95932e+06 bps
DESIGN(46): Site Router is located at X = 83236.4, Y = 20863, Z = 1.1
router(5): ip, 50000 pps, 5 ports, $3000
GT(1) is connected to port 1
GT(4) is connected to port 2
LINK(2) is connected to port 3
GROUP(1) has 10 client tasks, GLT = 27 Mbps, GOT = 7.5 Mbps,
GIT = 0 Mbps and DMT = 0 bps
DESIGN(46): GNC is located at X = 83209.7, Y = 20849.6, Z = 1.1
switch(23): atm, 150000000 bps, 15 ports, $20000
CT(1) is connected to port 1

⋮

CT(10) is connected to port 10
ST(1) is connected to port 11
GROUP(4) has 5 client tasks, GLT = 8 Mbps, GOT = 48.125 Mbps,
GIT = 2.5 Mbps and DMT = 0 bps
DESIGN(46): GNC is located at X = 83289.8, Y = 20889.8, Z = 1.1
multiaccess(27): ethernet, 1000000000 bps, 6 ports, $13000
CT(11) is connected to port 1

⋮

CT(15) is connected to port 5
ST(1) is connected to port 6
SITE(2) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps,
SIT = 21.25 Mbps and DMT = 3.0968e+06 bps

DESIGN(46): Site Router is located at X = 114450, Y = 56.3333, Z = 16.1
router(10): ip, 100000 pps, 10 ports, $11000
GT(2) is connected to port 1
GT(5) is connected to port 2
LINK(1) is connected to port 3
GROUP(2) has 5 client tasks, GLT = 2 Mbps, GOT = 2.5 Mbps,
GIT = 2.5 Mbps and DMT = 3.0968e+06 bps
DESIGN(46): GNC is located at X = 114409, Y = 89, Z = 16.1
multiaccess(18): ethernet, 100000000 bps, 12 ports, $13000
CT(16) is connected to port 1

⋮

CT(20) is connected to port 5
GS(1) is connected to port 6
server(13) has the following attributes:
number of CPUs = 4, CPU clock cycle = 2 ns
main memory capacity = 512000000 bytes, internal hard disk capacity = 3e+10 bytes
cost = $20000
max performance = 100%, average performance = 99.7727%, min performance = 98.8636%
hard disk(15) has the following attributes:
type = IDE, capacity = 6e+10, average seek time = 10 ms, transfer rate = 6.6e+07 bps
cost = $8000 stored files: 11, 3, 2, 8, 14, 9, 12, 15, 13, 1, 10, 6, 5, 7.
ST(2) is connected to port 7
GROUP(5) has 10 client tasks, GLT = 9 Mbps, GOT = 12.5 Mbps,
GIT = 18.75 Mbps and DMT = 0 bps
DESIGN(46): GNC is located at X = 114470, Y = 40, Z = 16.1
switch(14): atm, 75000000 bps, 20 ports, $16000
CT(21) is connected to port 1

⋮

CT(30) is connected to port 10
ST(2) is connected to port 11
SITE(3) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps,
SIT = 33.75 Mbps and DMT = 4.01257e+06 bps
DESIGN(46): Site Router is located at X = 52052.4, Y = 10450, Z = 32.1
router(9): ip, 100000 pps, 5 ports, $7000
GT(3) is connected to port 1
GT(8) is connected to port 2
LINK(3) is connected to port 3
GROUP(3) has 10 client tasks, GLT = 9 Mbps, GOT = 15 Mbps,
GIT = 7.5 Mbps and DMT = 0 bps
DESIGN(46): GNC is located at X = 52027.5, Y = 10485, Z = 32.1
multiaccess(18): ethernet, 100000000 bps, 12 ports, $13000
CT(31) is connected to port 1

⋮

CT(40) is connected to port 10
ST(3) is connected to port 11
GROUP(8) has 10 client tasks, GLT = 9 Mbps, GOT = 0 Mbps,
GIT = 26.25 Mbps and DMT = 3.62342e+06 bps
DESIGN(46): GNC is located at X = 52077.4, Y = 10415, Z = 32.1
multiaccess(18): ethernet, 100000000 bps, 12 ports, $13000

CT(41) is connected to port 1

⋮

CT(50) is connected to port 10
GS(2) is connected to port 11
server(7) has the following attributes:
number of CPUs = 2, CPU clock cycle = 3 ns
main memory capacity = 32000000 bytes, internal hard disk capacity = 1e+10 bytes
cost = $3000
max performance = 100%, average performance = 99.9038%, min performance = 99.5192%
hard disk(8) has the following attributes:
type = SCSI, capacity = 2e+10 bytes, average seek time = 5 ms, transfer rate = 1.6e+08 bps
cost = $2000
stored files: 11, 8, 14, 9, 12, 13, 1, 10, 4, 5.
ST(3) is connected to port 12
SITE(4) has 2 group tasks, SLT = 4.2 Mbps, SOT = 7.5 Mbps,
SIT = 35.625 Mbps and DMT = 3.95431e+06 bps
DESIGN(46): Site Router is located at X = 54.12, Y = 10459.9, Z = 45.1
router(10): ip, 100000 pps, 10 ports, $11000
GT(6) is connected to port 1
GT(7) is connected to port 2
LINK(1) is connected to port 3
LINK(2) is connected to port 4
LINK(3) is connected to port 5
GROUP(6) has 7 client tasks, GLT = 4.2 Mbps, GOT = 7.7 Mbps.
GIT = 16.625 Mbps and DMT = 0 bps
DESIGN(46): GNC is located at X = 15.4, Y = 10430.7, Z = 45.1
switch(17): atm, 100000000 bps, 10 ports, $11000
CT(51) is connected to port 1

⋮

CT(57) is connected to port 7
ST(4) is connected to port 8
GROUP(7) has 8 client tasks, GLT = 5.6 Mbps, GOT = 4 Mbps.
GIT = 23.2 Mbps and DMT = 389145 bps
DESIGN(46): GNC is located at X = 88, Y = 10485.4, Z = 45.1
switch(8): atm, 45000000 bps, 15 ports, $9000
CT(58) is connected to port 1

⋮

CT(65) is connected to port 8
GS(3) is connected to port 9
server(9) has the following attributes:
number of CPUs = 2, CPU clock cycle = 2.5 ns
main memory capacity = 128000000 bytes, internal hard disk capacity = 3e+10 bytes
cost = $7500
max performance = 100%, average performance = 99.8182%, min performance = 99.0909%
hard disk(9) has the following attributes:
type = IDE, capacity = 3e+10 bytes, verage seek time = 10 ms, transfer rate = 6.6e+07 bps
cost = $2000
stored files: 3, 2, 8, 9, 12, 15, 1, 6, 4, 5.
ST(4) is connected to port 10

Enter the generation number from 0-2999:

- The output of i-CAD for a complete intranet integration for the partial animation sutdio, including a wide tree backbone topology, when TND = 60.0 seconds and the initial number of servers = 3.

Enter the generation number from 0-2999:
2444
Intranet infrastructure(35) is the best design in generation 2444
initial network cost = $280200, monthly network cost = $50000
interconnection cost = $14000, wire cost = $6898.09
initial data management system cost = $30500, data management performance = 99.5483%
average network delay = 30.3252 seconds, homogeneity factor = 0.533333
BACKBONE(1) has 4 site tasks, BLT = 93.125 Mbps and MDT = 1.14505e+07 bps
Link(1) connects sites: 4 and 3
t-line(ds4): 264241152 bps, initial cost $30000 and monthly cost $13000
Link(2) connects sites: 4 and 1
t-line(ds4): 264241152 bps, initial cost $30000 and monthly cost $13000
Link(3) connects sites: 4 and 2
sonet(oc8): 414720000 bps, initial cost $80000 and monthly cost $24000
SITE(1) has 2 group tasks, SLT = 0 Mbps, SOT = 55.625 Mbps,
SIT = 2.5 Mbps and DMT = 7.44491e+06 bps
DESIGN(35): Site Switch is located at X = 83236.4, Y = 20863, Z = 1.1
switch(12): atm, 75000000 bps, 10 ports, $8000
GT(1) is connected to port 1
GT(4) is connected to port 2
LINK(2) is connected to port 3
GROUP(1) has 10 client tasks, GLT = 27 Mbps, GOT = 7.5 Mbps,
GIT = 0 Mbps and DMT = 0 bps
DESIGN(35): GNC is located at X = 83209.7, Y = 20849.6, Z = 1.1
switch(13): atm, 75000000 bps, 15 ports, $11000
CT(1) is connected to port 1

⋮

CT(10) is connected to port 10
ST(1) is connected to port 11
GROUP(4) has 5 client tasks, GLT = 8 Mbps, GOT = 48.125 Mbps,
GIT = 2.5 Mbps and DMT = 7.44491e+06 bps
DESIGN(35): GNC is located at X = 83289.8, Y = 20889.8, Z = 1.1
multiaccess(16): ethernet, 100000000 bps, 8 ports, $9200
CT(11) is connected to port 1

⋮

CT(15) is connected to port 5
GS(1) is connected to port 6
server(11) has the following attributes:
number of CPUs = 4, CPU clock cycle = 2.5 ns
main memory capacity = 256000000 bytes, internal hard disk capacity = 2e+10 bytes
cost = $12000
max performance = 100%, average performance = 99.4286%, min performance = 99.0476%
hard disk(17) has the following attributes:
type = IDE, capacity = 7e+10 bytes, average seek time = 10 ms, transfer rate = 6.6e+07 bps

cost = \$9000
stored files: 3, 2, 8, 9, 12, 15, 1, 6, 5, 7.
ST(1) is connected to port 7
SITE(2) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps,
SIT = 21.25 Mbps and DMT = 3.34147e+06 bps
DESIGN(35): Site Switch is located at X = 114450, Y = 56.3333, Z = 16.1
switch(22): atm, 150000000 bps, 10 ports, \$15000
GT(2) is connected to port 1
GT(5) is connected to port 2
LINK(3) is connected to port 3
GROUP(2) has 5 client tasks, GLT = 2 Mbps, GOT = 2.5 Mbps,
GIT = 2.5 Mbps and DMT = 0 bps
DESIGN(35): GNC is located at X = 114409, Y = 89, Z = 16.1
switch(2): atm, 25000000 bps, 10 ports, \$4000
CT(16) is connected to port 1
⋮
CT(20) is connected to port 5
ST(2) is connected to port 6
GROUP(5) has 10 client tasks, GLT = 9 Mbps, GOT = 12.5 Mbps,
GIT = 18.75 Mbps and DMT = 0 bps
DESIGN(35): GNC is located at X = 114470, Y = 40, Z = 16.1
switch(13): atm, 75000000 bps, 15 ports, \$11000
CT(21) is connected to port 1
⋮
CT(30) is connected to port 10
ST(2) is connected to port 11
SITE(3) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps,
SIT = 33.75 Mbps and DMT = 6.90664e+06 bps
DESIGN(35): Site Router is located at X = 52052.4, Y = 10450, Z = 32.1
router(10): ip, 100000 pps, 10 ports, \$11000
GT(3) is connected to port 1
GT(8) is connected to port 2
LINK(1) is connected to port 3
GROUP(3) has 10 client tasks, GLT = 9 Mbps, GOT = 15 Mbps,
GIT = 7.5 Mbps and DMT = 3.34147e+06 bps
DESIGN(35): GNC is located at X = 52027.5, Y = 10485, Z = 32.1
switch(19): atm, 100000000 bps, 20 ports, \$18000
CT(31) is connected to port 1
⋮
CT(40) is connected to port 10
GS(2) is connected to port 11
server(4) has the following attributes:
number of CPUs = 1, CPU clock cycle = 4 ns
main memory capacity = 32000000 bytes, internal hard disk capacity = 5e+09 bytes
cost = \$2500
max performance = 100%, average performance = 99.6491%, min performance = 98.2456%
hard disk(9) has the following attributes:
type = IDE, capacity = 3e+10 bytes, average seek time = 10 ms, transfer rate = 6.6e+07 bps
cost = \$2000

stored files: 11, 2, 14, 9, 12, 15, 13, 1, 6, 5, 7.
ST(3) is connected to port 12
GROUP(8) has 10 client tasks, GLT = 9 Mbps, GOT = 0 Mbps,
GIT = 26.25 Mbps and DMT = 3.56517e+06 bps
DESIGN(35): GNC is located at X = 52077.4, Y = 10415, Z = 32.1
multiaccess(20): ethernet, 100000000 bps, 16 ports, $19000
CT(41) is connected to port 1

⋮

CT(50) is connected to port 10
GS(3) is connected to port 11
server(5) has the following attributes:
number of CPUs = 1, CPU clock cycle = 4 ns
main memory capacity = 64000000 bytes, internal hard disk capacity = 1e+10 bytes
cost = $3000
max performance = 100%, average performance = 99.5671%, min performance = 99.1342%
hard disk(8) has the following attributes:
type = SCSI, capacity = 2e+10 bytes, average seek time = 5 ms, transfer rate = 1.6e+08 bps
cost = $2000
stored files: 3, 8, 14, 9, 12, 15, 13, 1, 10, 4, 7.
ST(3) is connected to port 12
SITE(4) has 2 group tasks, SLT = 4.2 Mbps, SOT = 7.5 Mbps,
SIT = 35.625 Mbps and DMT = 8.10901e+06 bps
DESIGN(35): Site Router is located at X = 54.12, Y = 10459.9, Z = 45.1
router(7): ip, 50000 pps, 15 ports, $20000
GT(6) is connected to port 1
GT(7) is connected to port 2
LINK(1) is connected to port 3
LINK(2) is connected to port 4
LINK(3) is connected to port 5
GROUP(6) has 7 client tasks, GLT = 4.2 Mbps, GOT = 7.7 Mbps,
GIT = 16.625 Mbps and DMT = 0 bps
DESIGN(35): GNC is located at X = 15.4, Y = 10430.7, Z = 45.1
switch(7): atm, 45000000 bps, 10 ports, $6000
CT(51) is connected to port 1

⋮

CT(57) is connected to port 7
ST(4) is connected to port 8
GROUP(7) has 8 client tasks, GLT = 5.6 Mbps, GOT = 4 Mbps,
GIT = 23.2 Mbps and DMT = 0 bps
DESIGN(35): GNC is located at X = 88, Y = 10485.4, Z = 45.1
switch(12): atm, 75000000 bps, 10 ports, $8000
CT(58) is connected to port 1

⋮

CT(65) is connected to port 8
ST(4) is connected to port 9
Enter the generation number from 0-2999:

A.5 Experiment 5

- The output of *i*-CAD for a complete intranet integration for the full animation sutdio, when TND = 30.0 seconds and the initial number of servers = 5.

Enter the generation number from 0-4999:
4627
Intranet infrastructure(32) is the best design in generation 4627
initial network cost = $417440, monthly network cost = $0
interconnection cost = $8000, wire cost = $12619.1
initial data management system cost = $39000, data management performance = 99.6508%
average network delay = 25.0348 seconds, homogeneity factor = 0.619048
BACKBONE(1) has 6 site tasks, BLT = 209.575 Mbps and MDT = 5.87576e+07 bps
DESIGN(32): Backbone Router is located at X = 24.3733, Y = 14.1867, Z = 49.3
router(22): ip, 300000 pps, 10 ports, $40000
ST(1) is connected to port 1
⋮
ST(6) is connected to port 6
SITE(1) has 2 group tasks, SLT = 0 Mbps, SOT = 55.625 Mbps,
SIT = 2.5 Mbps and DMT = 2.95932e+06 bps
DESIGN(32): Site Router is located at X = 4.4, Y = 43.3333, Z = 1.1
router(9): ip, 100000 pps, 5 ports, $7000
GT(1) is connected to port 1
GT(4) is connected to port 2
BT(1) is connected to port 3
GROUP(1) has 10 client tasks, GLT = 27 Mbps, GOT = 7.5 Mbps,
GIT = 0 Mbps and DMT = 0 bps
DESIGN(32): GNC is located at X = 3.9, Y = 43.6, Z = 1.1
switch(19): atm, 100000000 bps, 20 ports, $18000
CT(1) is connected to port 1
⋮
CT(10) is connected to port 10
ST(1) is connected to port 11
GROUP(4) has 5 client tasks, GLT = 8 Mbps, GOT = 48.125 Mbps,
GIT = 2.5 Mbps and DMT = 0 bps
DESIGN(32): GNC is located at X = 5.4, Y = 42.8, Z = 1.1
multiaccess(17): ethernet, 100000000 bps, 10 ports, $10400
CT(11) is connected to port 1
⋮
CT(15) is connected to port 5
ST(1) is connected to port 6
SITE(2) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps,
SIT = 21.25 Mbps and DMT = 1.71525e+07 bps
DESIGN(32): Site Multiaccess device is located at X = 45.0667, Y = 5, Z = 16.1
multiaccess(26): ethernet, 1000000000 bps, 4 ports, $8000
GT(2) is connected to site task port 1 via a 2-port bridge with following attributes:
Bridge(16), has capacity 105000 frames per second and cost $320
GT(5) is connected to site task port 2 via a 2-port bridge with following attributes:
Bridge(18), has capacity 115000 frames per second and cost $360

BT(1) is connected to port 3
GROUP(2) has 5 client tasks, GLT = 2 Mbps, GOT = 2.5 Mbps,
GIT = 2.5 Mbps and DMT = 1.69567e+07 bps
DESIGN(32): GNC is located at X = 48.4, Y = 5, Z = 16.1
multiaccess(17): ethernet, 100000000 bps, 10 ports, $10400
CT(16) is connected to port 1

⋮

CT(20) is connected to port 5
GS(1) is connected to port 6
server(1) has the following attributes:
number of CPUs = 1, CPU clock cycle = 5 ns
main memory capacity = 12000000 bytes, internal hard disk capacity = 1e+09 bytes
cost = $1000
max performance = 100%, average performance = 99.3277%, min performance = 98.7395%
hard disk(15) has the following attributes:
type = IDE, capacity = 6e+10 bytes, average seek time = 10 ms, transfer rate = 6.6e+07 bps
cost = $8000
stored files: 11, 3, 9, 12, 13, 1, 21, 5, 7, 19.
ST(2) is connected to port 7
GROUP(5) has 10 client tasks, GLT = 9 Mbps, GOT = 12.5 Mbps,
GIT = 18.75 Mbps and DMT = 0 bps
DESIGN(32): GNC is located at X = 43.4, Y = 5, Z = 16.1
multiaccess(18): ethernet, 100000000 bps, 12 ports, $13000
CT(21) is connected to port 1

⋮

CT(30) is connected to port 10
ST(2) is connected to port 11
SITE(3) has 2 group tasks, SLT = 0 Mbps, SOT = 95 Mbps,
SIT = 33.75 Mbps and DMT = 2.29778e+07 bps
DESIGN(32): Site Router is located at X = 4.9, Y = 6.15, Z = 32.1
router(14): ip, 150000 pps, 10 ports, $20000
GT(3) is connected to port 1
GT(8) is connected to port 2
BT(1) is connected to port 3
GROUP(3) has 10 client tasks, GLT = 9 Mbps, GOT = 15 Mbps,
GIT = 7.5 Mbps and DMT = 0 bps
DESIGN(32): GNC is located at X = 3.4, Y = 7.3, Z = 32.1
multiaccess(18): ethernet, 100000000 bps, 12 ports, $13000
CT(31) is connected to port 1

⋮

CT(40) is connected to port 10
ST(3) is connected to port 11
GROUP(8) has 10 client tasks, GLT = 9 Mbps, GOT = 80 Mbps.
GIT = 26.25 Mbps and DMT = 2.25887e+07 bps
DESIGN(32): GNC is located at X = 6.4, Y = 5, Z = 32.1
multiaccess(30): ethernet, 1000000000 bps, 12 ports, $33000
CT(41) is connected to port 1

⋮

CT(50) is connected to port 10

GS(2) is connected to port 11
server(3) has the following attributes:
number of CPUs = 1, CPU clock cycle = 5 ns
main memory capacity = 32000000 bytes, internal hard disk capacity = 5e+09 bytes
cost = $2000
max performance = 99.3289%, average performance = 98.9262%, min performance = 97.3154%
hard disk(10) has the following attributes:
type = SCSI, capacity = 3e+10 bytes, average seek time = 5 ms, transfer rate = 1.6e+08 bps
cost = $3000
stored files: 22, 3, 17, 8, 12, 13, 1, 10, 23, 6, 5, 19.
ST(3) is connected to port 12
SITE(4) has 2 group tasks, SLT = 4.2 Mbps, SOT = 7.5 Mbps,
SIT = 35.625 Mbps and DMT = 2.08201e+07 bps
DESIGN(32): Site Multiaccess device is located at X = 46.4, Y = 5, Z = 45.1
multiaccess(14): ethernet, 100000000 bps, 4 ports, $6000
GT(6) is connected to site task port 1 via a 2-port bridge with following attributes:
Bridge(16), has capacity 105000 frames per second and cost $320
GT(7) is connected to port 2
BT(1) is connected to port 3
GROUP(6) has 7 client tasks, GLT = 4.2 Mbps, GOT = 7.7 Mbps,
GIT = 16.625 Mbps and DMT = 1.63112e+07 bps
DESIGN(32): GNC is located at X = 47.8286, Y = 4.14286, Z = 45.1
multiaccess(17): ethernet, 100000000 bps, 10 ports, $10400
CT(51) is connected to port 1

⋮

CT(57) is connected to port 7
GS(3) is connected to port 8
server(1) has the following attributes:
number of CPUs = 1, CPU clock cycle = 5 ns
main memory capacity = 12000000 bytes, internal hard disk capacity = 1e+09 bytes
cost = $1000
max performance = 100%, average performance = 100%, min performance = 100%
hard disk(7) has the following attributes:
type = IDE, capacity = 2e+10 bytes, average seek time = 10 ms, transfer rate = 6.6e+07 bps
cost = $1500
stored files: 22, 16, 3, 17, 18, 2, 8, 14, 15, 10, 23, 21, 6, 5, 7, 19.
ST(4) is connected to port 9
GROUP(7) has 8 client tasks, GLT = 5.6 Mbps, GOT = 4 Mbps,
GIT = 23.2 Mbps and DMT = 0 bps
DESIGN(32): GNC is located at X = 45.15, Y = 5.75, Z = 45.1
switch(14): atm, 75000000 bps, 20 ports, $16000
CT(58) is connected to port 1

⋮

CT(65) is connected to port 8
ST(4) is connected to port 9
SITE(5) has 3 group tasks, SLT = 21 Mbps, SOT = 18.95 Mbps,
SIT = 57.5 Mbps and DMT = 9.00612e+06 bps
DESIGN(32): Site Multiaccess device is located at X = 12.5, Y = 13.25, Z = 62.1
multiaccess(26): ethernet, 1000000000 bps, 4 ports, $8000
GT(9) is connected to site task port 1 via a 2-port bridge with following attributes

Bridge(12), has capacity 70000 frames per second and cost \$240
GT(10) is connected to site task port 2 via a 2-port bridge with following attributes:
Bridge(21), has capacity 200000 frames per second and cost \$1000
GT(12) is connected to port 3
BT(1) is connected to port 4
GROUP(9) has 10 client tasks, GLT = 1.98 Mbps, GOT = 25 Mbps,
GIT = 20 Mbps and DMT = 0 bps
DESIGN(32): GNC is located at X = 20, Y = 5, Z = 62.1
multiaccess(20): ethernet, 100000000 bps, 16 ports, \$19000
CT(66) is connected to port 1

⋮

CT(75) is connected to port 10
GS(4) is connected to port 11
server(3) has the following attributes:
number of CPUs = 1, CPU clock cycle = 5 ns
main memory capacity = 32000000 bytes, internal hard disk capacity = 5e+09 bytes
cost = \$2000
max performance = 100%, average performance = 100%, min performance = 100%
hard disk(17) has the following attributes:
type = IDE, capacity = 7e+10 bytes, average seek time = 10 ms, transfer rate = 6.6e+07 bps
cost = \$9000 bytes
stored files: 22, 17, 2, 14, 15, 1, 6, 5, 7, 19, 20.
ST(5) is connected to port 12
GROUP(10) has 10 client tasks, GLT = 18 Mbps, GOT = 6.99999 Mbps,
GIT = 20 Mbps and DMT = 2.90107e+06 bps
DESIGN(32): GNC is located at X = 10, Y = 10, Z = 62.1
multiaccess(19): ethernet, 100000000 bps, 14 ports, \$16000
CT(76) is connected to port 1

⋮

CT(85) is connected to port 10
GS(5) is connected to port 11
server(2) has the following attributes:
number of CPUs = 1, CPU clock cycle = 4 ns
main memory capacity = 12000000 bytes, internal hard disk capacity = 3e+09 bytes
cost = \$1500
max performance = 100%, average performance = 100%, min performance = 100%
hard disk(19) has the following attributes:
type = IDE, capacity = 8e+10 bytes, average seek time = 10 ms, transfer rate = 6.6e+07 bps
cost = \$10000
stored files: 24, 22, 16, 11, 3, 2, 8, 14, 15, 21, 6, 4, 5, 7, 19, 20.
ST(5) is connected to port 12
GROUP(12) has 20 client tasks, GLT = 40.5 Mbps, GOT = 7.95002 Mbps.
GIT = 38.5 Mbps and DMT = 0 bps
DESIGN(32): GNC is located at X = 10, Y = 19, Z = 62.1
switch(25): atm, 150000000 bps, 32 ports, \$38000
CT(86) is connected to port 1

⋮

CT(105) is connected to port 20
ST(5) is connected to port 21

SITE(6) has 3 group tasks, SLT = 100.565 Mbps, SOT = 17.5002 Mbps,
SIT = 58.9502 Mbps and DMT = 4.45995e+07 bps
DESIGN(32): Site Router is located at X = 36, Y = 15, Z = 74.1
router(21): ip, 300000 pps, 5 ports, $25000
GT(11) is connected to port 1
GT(13) is connected to port 2
GT(14) is connected to port 3
BT(1) is connected to port 4
GROUP(11) has 15 client tasks, GLT = 4.95 Mbps, GOT = 31.375 Mbps,
GIT = 43.445 Mbps and DMT = 0 bps
DESIGN(32): GNC is located at X = 26, Y = 14, Z = 74.1
multiaccess(20): ethernet, 100000000 bps, 16 ports, $19000
CT(106) is connected to port 1

⋮

CT(120) is connected to port 15
ST(6) is connected to port 16
GROUP(13) has 15 client tasks, GLT = 47.31 Mbps, GOT = 86.69 Mbps,
GIT = 43.875 Mbps and DMT = 0 bps
DESIGN(32): GNC is located at X = 36, Y = 15, Z = 74.1
multiaccess(32): ethernet, 1000000000 bps, 16 ports, $45000
CT(121) is connected to port 1

⋮

CT(135) is connected to port 15
ST(6) is connected to port 16
GROUP(14) has 15 client tasks, GLT = 7.94 Mbps, GOT = 0 Mbps,
GIT = 72.195 Mbps and DMT = 0 bps
DESIGN(32): GNC is located at X = 46, Y = 16, Z = 74.1
switch(29): atm, 200000000 bps, 20 ports, $40000
CT(136) is connected to port 1

⋮

CT(150) is connected to port 15
ST(6) is connected to port 16
Enter the generation number from 0-4999:

- The output of *i*-CAD for a complete intranet integration for the full animation sutdio, when TND = 180.0 seconds and the initial number of servers = 5.

Enter the generation number from 0-4999:
4701
Intranet infrastructure(4) is the best design in generation 4701
initial network cost = $363200, monthly network cost = $0
interconnection cost = $2000, wire cost = $8357.94
initial data management system cost = $33000, data management performance = 98.5227%
average network delay = 136.622 seconds, homogeneity factor = 0.52381
BACKBONE(1) has 6 site tasks, BLT = 209.575 Mbps and MDT = 3.55026e+07 bps
DESIGN(4): Backbone Router is located at X = 24.3733, Y = 14.1867, Z = 49.3
router(18): ip, 200000 pps, 10 ports, $31000
ST(1) is connected to port 1

ST(6) is connected to port 6
SITE(1) has 2 group tasks, SLT = 0 Mbps, SOT = 55.625 Mbps.
SIT = 2.5 Mbps and DMT = 1.49108e+07 bps
DESIGN(4): Site Router is located at X = 4.4, Y = 43.3333, Z = 1.1
router(9): ip, 100000 pps, 5 ports, $7000
GT(1) is connected to port 1
GT(4) is connected to port 2
BT(1) is connected to port 3
GROUP(1) has 10 client tasks, GLT = 27 Mbps, GOT = 7.5 Mbps,
GIT = 0 Mbps and DMT = 0 bps
DESIGN(4): GNC is located at X = 3.9, Y = 43.6, Z = 1.1
switch(13): atm, 75000000 bps, 15 ports, $11000
CT(1) is connected to port 1

⋮

CT(10) is connected to port 10
ST(1) is connected to port 11
GROUP(4) has 5 client tasks, GLT = 8 Mbps, GOT = 48.125 Mbps,
GIT = 2.5 Mbps and DMT = 1.49108e+07 bps
DESIGN(4): GNC is located at X = 5.4, Y = 42.8, Z = 1.1
multiaccess(16): ethernet, 100000000 bps, 8 ports, $9200
CT(11) is connected to port 1

⋮

CT(15) is connected to port 5
GS(1) is connected to port 6
server(2) has the following attributes:
number of CPUs = 1, CPU clock cycle = 4 ns
main memory capacity = 12000000 bytes, internal hard disk capacity = 3e+09 bytes
cost = $1500
max performance = 100%, average performance = 99.8206%, min performance = 99.5516%
hard disk(11) has the following attributes:
type = IDE, capacity = 4e+10 bytes, average seek time = 10 ms, transfer rate = 6.6e+07 bps
cost = $4000
stored files: 11, 18, 2, 14, 9, 15, 13, 1, 23, 6, 5, 20.
ST(1) is connected to port 7
SITE(2) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps,
SIT = 21.25 Mbps and DMT = 3.34147e+06 bps
DESIGN(4): Site Switch is located at X = 45.0667, Y = 5, Z = 16.1
switch(11): atm, 75000000 bps, 5 ports, $5000
GT(2) is connected to port 1
GT(5) is connected to port 2
BT(1) is connected to port 3
GROUP(2) has 5 client tasks, GLT = 2 Mbps, GOT = 2.5 Mbps,
GIT = 2.5 Mbps and DMT = 0 bps
DESIGN(4): GNC is located at X = 48.4, Y = 5, Z = 16.1
switch(2): atm, 25000000 bps, 10 ports, $4000
CT(16) is connected to port 1

⋮

CT(20) is connected to port 5
ST(2) is connected to port 6

GROUP(5) has 10 client tasks, GLT = 9 Mbps, GOT = 12.5 Mbps,
GIT = 18.75 Mbps and DMT = 0 bps
DESIGN(4): GNC is located at X = 43.4, Y = 5, Z = 16.1
multiaccess(18): ethernet, 100000000 bps, 12 ports, $13000
CT(21) is connected to port 1

⋮

CT(30) is connected to port 10
ST(2) is connected to port 11
SITE(3) has 2 group tasks, SLT = 0 Mbps, SOT = 95 Mbps,
SIT = 33.75 Mbps and DMT = 1.4242e+07 bps
DESIGN(4): Site Router is located at X = 4.9, Y = 6.15, Z = 32.1
router(17): ip, 200000 pps, 5 ports, $19000
GT(3) is connected to port 1
GT(8) is connected to port 2
BT(1) is connected to port 3
GROUP(3) has 10 client tasks, GLT = 9 Mbps, GOT = 15 Mbps,
GIT = 7.5 Mbps and DMT = 0 bps
DESIGN(4): GNC is located at X = 3.4, Y = 7.3, Z = 32.1
switch(9): atm, 45000000 bps, 20 ports, $13000
CT(31) is connected to port 1

⋮

CT(40) is connected to port 10
ST(3) is connected to port 11
GROUP(8) has 10 client tasks, GLT = 9 Mbps, GOT = 80 Mbps,
GIT = 26.25 Mbps and DMT = 0 bps
DESIGN(4): GNC is located at X = 6.4, Y = 5, Z = 32.1
switch(23): atm, 150000000 bps, 15 ports, $20000
CT(41) is connected to port 1

⋮

CT(50) is connected to port 10
ST(3) is connected to port 11
SITE(4) has 2 group tasks, SLT = 4.2 Mbps, SOT = 7.5 Mbps,
SIT = 35.625 Mbps and DMT = 2.34928e+07 bps
DESIGN(4): Site Router is located at X = 46.4, Y = 5, Z = 45.1
router(5): ip, 50000 pps, 5 ports, $3000
GT(6) is connected to port 1
GT(7) is connected to port 2
BT(1) is connected to port 3
GROUP(6) has 7 client tasks, GLT = 4.2 Mbps, GOT = 7.7 Mbps,
GIT = 16.625 Mbps and DMT = 389145 bps
DESIGN(4): GNC is located at X = 47.8286, Y = 4.14286, Z = 45.1
switch(18): atm, 100000000 bps, 15 ports, $15000
CT(51) is connected to port 1

⋮

CT(57) is connected to port 7
GS(2) is connected to port 8
server(7) has the following attributes:
number of CPUs = 2, CPU clock cycle = 3 ns
main memory capacity = 32000000 bytes, internal hard disk capacity = 1e+10 bytes

cost = $3000
max performance = 100%, average performance = 99.6226%, min performance = 98.1132%
hard disk(6) has the following attributes:
type = SCSI, capacity = 1.5e+10 bytes, average seek time = 5 ms, transfer rate = 1.6e+08 bps
cost = $1000
stored files: 11, 18, 8, 14, 9, 12, 15, 23, 6, 4, 5, 19, 20.
ST(4) is connected to port 9
GROUP(7) has 8 client tasks, GLT = 5.6 Mbps, GOT = 4 Mbps,
GIT = 23.2 Mbps and DMT = 2.31037e+07 bps
DESIGN(4): GNC is located at X = 45.15, Y = 5.75, Z = 45.1
switch(12): atm, 75000000 bps, 10 ports, $8000
CT(58) is connected to port 1

⋮

CT(65) is connected to port 8
GS(3) is connected to port 9
server(1) has the following attributes:
number of CPUs = 1, CPU clock cycle = 5 ns
main memory capacity = 12000000 bytes, internal hard disk capacity = 1e+09 bytes
cost = $1000
max performance = 98.7069%, average performance = 97.7586%, min performance = 95.6897%
hard disk(17) has the following attributes:
type = IDE, capacity = 7e+10 bytes, average seek time = 10 ms, transfer rate = 6.6e+07 bps
cost = $9000
stored files: 22, 11, 17, 18, 2, 8, 14, 9, 1, 10, 23, 21, 4, 5, 7, 19, 20.
ST(4) is connected to port 10
SITE(5) has 3 group tasks, SLT = 21 Mbps, SOT = 18.95 Mbps,
SIT = 57.5 Mbps and DMT = 1.20237e+07 bps
DESIGN(4): Site Router is located at X = 12.5, Y = 13.25, Z = 62.1
router(9): ip, 100000 pps, 5 ports, $7000
GT(9) is connected to port 1
GT(10) is connected to port 2
GT(12) is connected to port 3
BT(1) is connected to port 4
GROUP(9) has 10 client tasks, GLT = 1.98 Mbps, GOT = 25 Mbps,
GIT = 20 Mbps and DMT = 0 bps
DESIGN(4): GNC is located at X = 20, Y = 5, Z = 62.1
switch(19): atm, 100000000 bps, 20 ports, $18000
CT(66) is connected to port 1

⋮

CT(75) is connected to port 10
ST(5) is connected to port 11
GROUP(10) has 10 client tasks, GLT = 18 Mbps, GOT = 6.99999 Mbps,
GIT = 20 Mbps and DMT = 0 bps
DESIGN(4): GNC is located at X = 10, Y = 10, Z = 62.1
switch(18): atm, 100000000 bps, 15 ports, $15000
CT(76) is connected to port 1

⋮

CT(85) is connected to port 10
ST(5) is connected to port 11

GROUP(12) has 20 client tasks, GLT = 40.5 Mbps, GOT = 7.95002 Mbps,
GIT = 38.5 Mbps and DMT = 0 bps
DESIGN(4): GNC is located at X = 10, Y = 19, Z = 62.1
switch(20): atm, 100000000 bps, 32 ports, $28000
CT(86) is connected to port 1

⋮

CT(105) is connected to port 20
ST(5) is connected to port 21
SITE(6) has 3 group tasks, SLT = 100.565 Mbps, SOT = 17.5002 Mbps,
SIT = 58.9502 Mbps and DMT = 5.89537e+06 bps
DESIGN(4): Site Router is located at X = 36, Y = 15, Z = 74.1
router(17): ip, 200000 pps, 5 ports, $19000
GT(11) is connected to port 1
GT(13) is connected to port 2
GT(14) is connected to port 3
BT(1) is connected to port 4
GROUP(11) has 15 client tasks, GLT = 4.95 Mbps, GOT = 31.375 Mbps,
GIT = 43.445 Mbps and DMT = 0 bps
DESIGN(4): GNC is located at X = 26, Y = 14, Z = 74.1
multiaccess(22): ethernet, 100000000 bps, 20 ports, $25000
CT(106) is connected to port 1

⋮

CT(120) is connected to port 15
ST(6) is connected to port 16
GROUP(13) has 15 client tasks, GLT = 47.31 Mbps, GOT = 86.69 Mbps,
GIT = 43.875 Mbps and DMT = 0 bps
DESIGN(4): GNC is located at X = 36, Y = 15, Z = 74.1
multiaccess(33): ethernet, 1000000000 bps, 18 ports, $65000
CT(121) is connected to port 1

⋮

CT(135) is connected to port 15
GS(4) is connected to port 16
server(1) has the following attributes:
number of CPUs = 1
CPU clock cycle = 5 ns
main memory capacity = 12000000 bytes
internal hard disk capacity = 1e+09 bytes
cost = $1000
max performance = 100%, average performance = 99.4118%, min performance = 97.0588%
hard disk(10) has the following attributes:
type = SCSI, capacity = 3e+10 bytes, average seek time = 5 ms, transfer rate = 1.6e+08 bps
cost = $3000 byes
stored files: 24, 22, 16, 11, 18, 2, 14, 13, 21, 6, 4, 5, 7, 19, 20.
ST(6) is connected to port 17
GROUP(14) has 15 client tasks, GLT = 7.94 Mbps, GOT = 0 Mbps,
GIT = 72.195 Mbps and DMT = 0 bps
DESIGN(4): GNC is located at X = 46, Y = 16, Z = 74.1
switch(24): atm, 150000000 bps, 20 ports, $28000
CT(136) is connected to port 1

⋮

CT(150) is connected to port 15
GS(5) is connected to port 16
server(4) has the following attributes:
number of CPUs = 1, CPU clock cycle = 4 ns
main memory capacity = 32000000 bytes, internal hard disk capacity = 5e+09 bytes
cost = $2500
max performance = 100%, average performance = 96%, min performance = 90%
hard disk(12) has the following attributes:
type = SCSI, capacity = 4e+10 bytes, average seek time = 5 ms, transfer rate = 1.6e+08 bps
cost = $7000
stored files: 24, 16, 3, 18, 14, 15, 13, 1, 23, 21, 4, 5, 7, 19, 20.
ST(6) is connected to port 17
Enter the generation number from 0-4999:

A.6 Experiment 6

- The output of *i*-CAD for a complete intranet integration for the full animation sutdio, including a wide tree backbone topology, when TND = 60.0 seconds and the initial number of servers = 7.

Enter the generation number from 0-4999:
1376
Intranet infrastructure(15) is the best design in generation 1376
initial network cost $741700, monthly network cost $68500
interconnection cost $24000, wire cost $29555
initial data management system cost $78000, data management ratio = 99.5419%
average network delay = 46.8228 seconds, homogeneity factor = 0.32
BACKBONE(1) has 6 site tasks, BLT = 209.575 Mbps and MDT = 4.86237e+07 bps
Link(1) connects sites: 4 and 6
t-line(ds4): 264241152 bps, initial cost $30000 and monthly cost $13000
Link(2) connects sites: 4 and 1
t-line(vpc12-ds4/t-line): 198144000 bps, initial cost $8250 and monthly cost $9750
Link(3) connects sites: 4 and 2
sonet(oc7): 362880000 bps, initial cost $70000 and monthly cost $21000
Link(4) connects sites: 1 and 5
t-line(vpc12-ds4/t-line): 198144000 bps, initial cost $8250 and monthly cost $9750
Link(5) connects sites: 2 and 3
sonet(oc5): 259200000 bps, initial cost $50000 and monthly cost $15000
SITE(1) has 2 group tasks, SLT = 0 Mbps, SOT = 55.625 Mbps,
SIT = 2.5 Mbps and DMT = 2.95932e+06 bps
DESIGN(15): Site Switch is located at X = 36440, Y = 135233, Z = 1.1
switch(22): atm, 150000000 bps, 10 ports, $15000
GT(1) is connected to port 1
GT(4) is connected to port 2
LINK(2) is connected to port 3
LINK(4) is connected to port 4
GROUP(1) has 10 client tasks, GLT = 27 Mbps, GOT = 7.5 Mbps,
GIT = 0 Mbps and DMT = 0 bps

DESIGN(15): GNC is located at X = 36427.5, Y = 135200, Z = 1.1
switch(15): atm, 75000000 bps, 32 ports, $26000
CT(1) is connected to port 1

⋮

CT(10) is connected to port 10
ST(1) is connected to port 11
GROUP(4) has 5 client tasks, GLT = 8 Mbps, GOT = 48.125 Mbps,
GIT = 2.5 Mbps and DMT = 0 bps
DESIGN(15): GNC is located at X = 36465, Y = 135300, Z = 1.1
multiaccess(19): ethernet, 100000000 bps, 14 ports, $16000
CT(11) is connected to port 1

⋮

CT(15) is connected to port 5
ST(1) is connected to port 6
SITE(2) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps,
SIT = 21.25 Mbps and DMT = 1.00011e+07 bps
DESIGN(15): Site Router is located at X = 11, Y = 119643, Z = 16.1
router(14): ip, 150000 pps, 10 ports, $20000
GT(2) is connected to port 1
GT(5) is connected to port 2
LINK(3) is connected to port 3
LINK(5) is connected to port 4
GROUP(2) has 5 client tasks, GLT = 2 Mbps, GOT = 2.5 Mbps,
GIT = 2.5 Mbps and DMT = 0 bps
DESIGN(15): GNC is located at X = 11, Y = 119624, Z = 16.1
switch(3): atm, 25000000 bps, 15 ports, $7000
CT(16) is connected to port 1

⋮

CT(20) is connected to port 5
ST(2) is connected to port 6
GROUP(5) has 10 client tasks, GLT = 9 Mbps, GOT = 12.5 Mbps,
GIT = 18.75 Mbps and DMT = 1.00011e+07 bps
DESIGN(15): GNC is located at X = 11, Y = 119652, Z = 16.1
multiaccess(18): ethernet, 100000000 bps, 12 ports, $13000
CT(21) is connected to port 1

⋮

CT(30) is connected to port 10
GS(1) is connected to port 11
server(4) has the following attributes:
number of CPUs = 1, CPU clock cycle = 4 ns
main memory capacity = 32000000 bytes, internal hard disk capacity = 5e+09 bytes
cost = $2500
max performance = 100%, average performance = 100%, min performance = 100%
hard disk(18) has the following attributes:
type = SCSI, capacity = 7e+10 bytes, average seek time = 5 ms, transfer rate = 1.6e+08 bps
cost = $15000
stored files: 11, 3, 18, 2, 8, 9, 12, 15, 13, 23, 21, 4, 5, 19, 20.
ST(2) is connected to port 12
SITE(3) has 2 group tasks, SLT = 0 Mbps, SOT = 95 Mbps,

SIT = 33.75 Mbps and DMT = 1.67586e+07 bps
DESIGN(15): Site Router is located at X = 62452.4, Y = 119450, Z = 32.1
router(29): ip, 1000000 pps, 5 ports, $40000
GT(3) is connected to port 1
GT(8) is connected to port 2
LINK(5) is connected to port 3
GROUP(3) has 10 client tasks, GLT = 9 Mbps, GOT = 15 Mbps,
GIT = 7.5 Mbps and DMT = 0 bps
DESIGN(15): GNC is located at X = 62427.5, Y = 119485, Z = 32.1
multiaccess(19): ethernet, 100000000 bps, 14 ports, $16000
CT(31) is connected to port 1
⋮
CT(40) is connected to port 10
ST(3) is connected to port 11
GROUP(8) has 10 client tasks, GLT = 9 Mbps, GOT = 80 Mbps,
GIT = 26.25 Mbps and DMT = 1.63694e+07 bps
DESIGN(15): GNC is located at X = 62477.4, Y = 119415, Z = 32.1
multiaccess(30): ethernet, 1000000000 bps, 12 ports, $33000
CT(41) is connected to port 1
⋮
CT(50) is connected to port 10
GS(2) is connected to port 11
server(8) has the following attributes:
number of CPUs = 2, CPU clock cycle = 3 ns
main memory capacity = 64000000 bytes, internal hard disk capacity = 1.5e+10 bytes
cost = $5000
max performance = 100%, average performance = 98.9535%, min performance = 97.093%
hard disk(9) has the following attributes:
type = IDE, capacity = 3e+10 bytes, average seek time = 10 ms, transfer rate = 6.6e+07 bps
cost = $2000
stored files: 24, 16, 11, 3, 18, 8, 9, 12, 15, 13, 6, 7, 19, 20.
ST(3) is connected to port 12
SITE(4) has 2 group tasks, SLT = 4.2 Mbps, SOT = 7.5 Mbps,
SIT = 35.625 Mbps and DMT = 6.57109e+06 bps
DESIGN(15): Site Router is located at X = 88454.1, Y = 93459.7, Z = 45.1
router(17): ip, 200000 pps, 5 ports, $19000
GT(6) is connected to port 1
GT(7) is connected to port 2
LINK(1) is connected to port 3
LINK(2) is connected to port 4
LINK(3) is connected to port 5
GROUP(6) has 7 client tasks, GLT = 4.2 Mbps, GOT = 7.7 Mbps,
GIT = 16.625 Mbps and DMT = 0 bps
DESIGN(15): GNC is located at X = 88415.4, Y = 93430.7, Z = 45.1
multiaccess(16): ethernet, 100000000 bps, 8 ports, $9200
CT(51) is connected to port 1
⋮
CT(57) is connected to port 7
ST(4) is connected to port 8

GROUP(7) has 8 client tasks, GLT = 5.6 Mbps, GOT = 4 Mbps,
GIT = 23.2 Mbps and DMT = 3.00592e+06 bps
DESIGN(15): GNC is located at X = 88488, Y = 93485.1, Z = 45.1
switch(14): atm, 75000000 bps, 20 ports, $16000
CT(58) is connected to port 1

⋮

CT(65) is connected to port 8
GS(3) is connected to port 9
server(12) has the following attributes:
number of CPUs = 4, CPU clock cycle = 2 ns
main memory capacity = 512000000 bytes, internal hard disk capacity = 2.5e+10 bytes
cost = $15000
max performance = 100%, average performance = 99.5181%, min performance = 98.7952%
hard disk(15) has the following attributes:
type = IDE, capacity = 6e+10 bytes, average seek time = 10 ms, transfer rate = 6.6e+07 bps
cost = $8000
stored files: 16, 3, 17, 2, 8, 14, 9, 12, 15, 13, 10, 21, 5, 7, 19.
ST(4) is connected to port 10
SITE(5) has 3 group tasks, SLT = 21 Mbps, SOT = 18.95 Mbps,
SIT = 57.5 Mbps and DMT = 3.15039e+07 bps
DESIGN(15): Site Switch is located at X = 57.475, Y = 15.25, Z = 34.6
switch(21): atm, 150000000 bps, 5 ports, $11000
GT(9) is connected to port 1
GT(10) is connected to port 2
GT(12) is connected to port 3
LINK(4) is connected to port 4
GROUP(9) has 10 client tasks, GLT = 1.98 Mbps, GOT = 25 Mbps,
GIT = 20 Mbps and DMT = 0 bps
DESIGN(15): GNC is located at X = 32.5, Y = 5, Z = 12.1
switch(24): atm, 150000000 bps, 20 ports, $28000
CT(66) is connected to port 1

⋮

CT(75) is connected to port 10
ST(5) is connected to port 11
GROUP(10) has 10 client tasks, GLT = 18 Mbps, GOT = 6.99999 Mbps,
GIT = 20 Mbps and DMT = 2.8498e+07 bps
DESIGN(15): GNC is located at X = 109.9, Y = 15, Z = 62.1
switch(35): atm, 400000000 bps, 20 ports, $75000
CT(76) is connected to port 1

⋮

CT(85) is connected to port 10
GS(4) is connected to port 11
server(10) has the following attributes:
number of CPUs = 2, CPU clock cycle = 2.5 ns,
main memory capacity = 256000000 bytes, internal hard disk capacity = 3e+10 bytes
cost = $9500
max performance = 100%, average performance = 99.4805%, min performance = 98.7013%
hard disk(19) has the following attributes:
type = IDE, capacity = 8e+10 bytes, average seek time = 10 ms, transfer rate = 6.6e+07 bps

cost = $10000
stored files: 16, 3, 17, 18, 2, 8, 9, 15, 1, 21, 4, 7, 19.
ST(5) is connected to port 12
GROUP(12) has 20 client tasks, GLT = 40.5 Mbps, GOT = 7.95002 Mbps,
GIT = 38.5 Mbps and DMT = 0 bps
DESIGN(15): GNC is located at X = 43.75, Y = 20.5, Z = 32.1
switch(30): atm, 200000000 bps, 32 ports, $60000
CT(86) is connected to port 1

⋮

CT(105) is connected to port 20
ST(5) is connected to port 21
SITE(6) has 3 group tasks, SLT = 100.565 Mbps, SOT = 17.5002 Mbps,
SIT = 58.9502 Mbps and DMT = 3.87041e+07 bps
DESIGN(15): Site Router is located at X = 114238, Y = 93322.3, Z = 54.1
router(17): ip, 200000 pps, 5 ports, $19000
GT(11) is connected to port 1
GT(13) is connected to port 2
GT(14) is connected to port 3
LINK(1) is connected to port 4
GROUP(11) has 15 client tasks, GLT = 4.95 Mbps, GOT = 31.375 Mbps,
GIT = 43.445 Mbps and DMT = 0 bps
DESIGN(15): GNC is located at X = 114232, Y = 93336, Z = 74.1
multiaccess(21): ethernet, 100000000 bps, 18 ports, $22000
CT(106) is connected to port 1

⋮

CT(120) is connected to port 15
GS(5) is connected to port 16
server(1) has the following attributes:
number of CPUs = 1, CPU clock cycle = 5 ns
main memory capacity = 12000000 bytes, internal hard disk capacity = 1e+09 bytes
cost = $1000
max performance = 100%, average performance = 99.7576%, min performance = 99.3939%
hard disk(19) has the following attributes:
type = IDE, capacity = 8e+10 bytes, average seek time = 10 ms, transfer rate = 6.6e+07 bps
cost = $10000
stored files: 22, 16, 11, 17, 2, 8, 14, 9, 13, 4, 7, 19.
ST(6) is connected to port 17
GROUP(13) has 15 client tasks, GLT = 47.31 Mbps, GOT = 86.69 Mbps,
GIT = 43.875 Mbps and DMT = 0 bps
DESIGN(15): GNC is located at X = 114336, Y = 93415, Z = 54.1
multiaccess(33): ethernet, 1000000000 bps, 18 ports, $65000
CT(121) is connected to port 1

⋮

CT(135) is connected to port 15
ST(6) is connected to port 16
GROUP(14) has 15 client tasks, GLT = 7.94 Mbps, GOT = 0 Mbps,
GIT = 72.195 Mbps and DMT = 0 bps
DESIGN(15): GNC is located at X = 114146, Y = 93216, Z = 34.1
multiaccess(33): ethernet, 1000000000 bps, 18 ports, $65000

CT(136) is connected to port 1

⋮

CT(150) is connected to port 15
ST(6) is connected to port 16
Enter the generation number from 0-4999:

- The output of *i*-CAD for a complete intranet integration for the full animation sutdio, including a wide tree backbone topology, when TND = 30.0 seconds and the initial number of servers = 7.

Enter the generation number from 0-4999:
4456
Intranet infrastructure(16) is the best design in generation 4456
initial network cost $868000, monthly network cost $74000
interconnection cost $70000, wire cost $49950.8
initial data management system cost $141000, data management ratio = 99.3986%
average network delay = 22.2633 seconds, homogeneity factor = 0.44
BACKBONE(1) has 6 site tasks, BLT = 209.575 Mbps and MDT = 1.57543e+07 bps
Link(1) connects sites: 5 and 3
t-line(ds4): 264241152 bps, initial cost $30000 and monthly cost $13000
Link(2) connects sites: 3 and 4
sonet(oc9): 466560000 bps, initial cost $90000 and monthly cost $27000
Link(3) connects sites: 3 and 1
sonet(oc3): 155520000 bps, initial cost $30000 and monthly cost $9000
Link(4) connects sites: 5 and 2
sonet(oc4): 207360000 bps, initial cost $40000 and monthly cost $12000
Link(5) connects sites: 5 and 6
t-line(ds4): 264241152 bps, initial cost $30000 and monthly cost $13000
SITE(1) has 2 group tasks, SLT = 0 Mbps, SOT = 55.625 Mbps,
SIT = 2.5 Mbps and DMT = 1.86554e+07 bps
DESIGN(16): Site Switch is located at X = 36440, Y = 135233, Z = 1.1
switch(26): atm, 200000000 bps, 5 ports, $15000
GT(1) is connected to port 1
GT(4) is connected to port 2
LINK(3) is connected to port 3
GROUP(1) has 10 client tasks, GLT = 27 Mbps, GOT = 7.5 Mbps,
GIT = 0 Mbps and DMT = 0 bps
DESIGN(16): GNC is located at X = 36427.5, Y = 135200, Z = 1.1
multiaccess(20): ethernet, 100000000 bps, 16 ports, $19000
CT(1) is connected to port 1

⋮

CT(10) is connected to port 10
ST(1) is connected to port 11
GROUP(4) has 5 client tasks, GLT = 8 Mbps, GOT = 48.125 Mbps,
GIT = 2.5 Mbps and DMT = 1.86554e+07 bps
DESIGN(16): GNC is located at X = 36465, Y = 135300, Z = 1.1
multiaccess(30): ethernet, 1000000000 bps, 12 ports, $33000
CT(11) is connected to port 1

⋮

CT(15) is connected to port 5
GS(1) is connected to port 6
server(1) has the following attributes:
number of CPUs = 1, CPU clock cycle = 5 ns
main memory capacity = 12000000 bytes, internal hard disk capacity = 1e+09 bytes
cost = $1000
max performance = 100%, average performance = 100%, min performance = 100%
hard disk(18) has the following attributes:
type = SCSI, capacity = 7e+10 bytes, average seek time = 5 ms, transfer rate = 1.6e+08 bps
cost = $15000
stored files: 24, 22, 16, 11, 3, 17, 8, 14, 9, 15, 10, 7, 19.
ST(1) is connected to port 7
SITE(2) has 2 group tasks, SLT = 0 Mbps, SOT = 15 Mbps,
SIT = 21.25 Mbps and DMT = 3.34147e+06 bps
DESIGN(16): Site Multiaccess device is located at X = 11, Y = 119643, Z = 16.1
multiaccess(18): ethernet, 100000000 bps, 12 ports, $13000
GT(2) is connected to port 1
GT(5) is connected to port 2
LINK(1) is connected to port 3
GROUP(2) has 5 client tasks, GLT = 2 Mbps, GOT = 2.5 Mbps,
GIT = 2.5 Mbps and DMT = 0 bps
DESIGN(16): GNC is located at X = 11, Y = 119624, Z = 16.1
switch(29): atm, 200000000 bps, 20 ports, $40000
CT(16) is connected to port 1

⋮

ST(2) is connected to port 6
GROUP(5) has 10 client tasks, GLT = 9 Mbps, GOT = 12.5 Mbps,
GIT = 18.75 Mbps and DMT = 0 bps
DESIGN(16): GNC is located at X = 11, Y = 119652, Z = 16.1
switch(13): atm, 75000000 bps, 15 ports, $11000
CT(21) is connected to port 1

⋮

CT(30) is connected to port 10
ST(2) is connected to port 11
SITE(3) has 2 group tasks, SLT = 0 Mbps, SOT = 95 Mbps,
SIT = 33.75 Mbps and DMT = 389145 bps
DESIGN(16): Site Switch is located at X = 62452.4, Y = 119450, Z = 32.1
switch(31): atm, 400000000 bps, 5 ports, $20000
GT(3) is connected to port 1
GT(8) is connected to port 2
LINK(1) is connected to port 3
LINK(2) is connected to port 4
LINK(3) is connected to port 5
GROUP(3) has 10 client tasks, GLT = 9 Mbps, GOT = 15 Mbps,
GIT = 7.5 Mbps and DMT = 0 bps
DESIGN(16): GNC is located at X = 62427.5, Y = 119485, Z = 32.1
switch(20): atm, 100000000 bps, 32 ports, $28000
CT(31) is connected to port 1

⋮

CT(40) is connected to port 10
ST(3) is connected to port 11
GROUP(8) has 10 client tasks, GLT = 9 Mbps, GOT = 80 Mbps,
GIT = 26.25 Mbps and DMT = 0 bps
DESIGN(16): GNC is located at X = 62477.4, Y = 119415, Z = 32.1
multiaccess(30): ethernet, 1000000000 bps, 12 ports, $33000
CT(41) is connected to port 1

⋮

CT(50) is connected to port 10
GS(2) is connected to port 11
server(10) has the following attributes:
number of CPUs = 2, CPU clock cycle = 2.5 ns
main memory capacity = 256000000 bytes, internal hard disk capacity = 3e+10 bytes
cost = $9500
max performance = 100%, average performance = 99.2208%, min performance = 97.4026%
hard disk(15) has the following attributes:
type = IDE, capacity = 6e+10 bytes, average seek time = 10 ms, transfer rate = 6.6e+07 bps
cost = $8000
stored files: 24, 22, 16, 11, 3, 17, 18, 2, 8, 14, 9, 1, 10, 4, 7, 19, 20.
ST(3) is connected to port 12
SITE(4) has 2 group tasks, SLT = 4.2 Mbps, SOT = 7.5 Mbps.
SIT = 35.625 Mbps and DMT = 0 bps
DESIGN(16): Site Switch is located at X = 88454.1, Y = 93459.7, Z = 45.1
switch(18): atm, 100000000 bps, 15 ports, $15000
GT(6) is connected to port 1
GT(7) is connected to port 2
LINK(1) is connected to port 3
GROUP(6) has 7 client tasks, GLT = 4.2 Mbps, GOT = 7.7 Mbps.
GIT = 16.625 Mbps and DMT = 0 bps
DESIGN(16): GNC is located at X = 88415.4, Y = 93430.7, Z = 45.1
switch(23): atm, 150000000 bps, 15 ports, $20000
CT(51) is connected to port 1

⋮

CT(57) is connected to port 7
GS(3) is connected to port 8
server(8) has the following attributes:
number of CPUs = 2, CPU clock cycle = 3 ns
main memory capacity = 64000000 bytes, internal hard disk capacity = 1.5e+10 bytes
cost = $5000
max performance = 100%, average performance = 99.3103%, min performance = 96.5517%
hard disk(15) has the following attributes:
type = IDE, capacity = 6e+10 bytes, average seek time = 10 ms, transfer rate = 6.6e+07 bps
cost = $8000
stored files: 24, 22, 11, 3, 18, 2, 8, 14, 12, 15, 13, 23, 21, 6, 19
ST(4) is connected to port 9
GROUP(7) has 8 client tasks, GLT = 5.6 Mbps, GOT = 4 Mbps.
GIT = 23.2 Mbps and DMT = 0 bps
DESIGN(16): GNC is located at X = 88488, Y = 93485.1, Z = 45.1
switch(24): atm, 150000000 bps, 20 ports, $28000
CT(58) is connected to port 1

⋮

CT(65) is connected to port 8
GS(4) is connected to port 9
server(8) has the following attributes:
number of CPUs = 2, CPU clock cycle = 3 ns
main memory capacity = 64000000 bytes, internal hard disk capacity = 1.5e+10 bytes
cost = $5000
max performance = 100%, average performance = 100%, min performance = 100%
hard disk(16) has the following attributes:
type = SCSI, capacity = 6e+10 bytes, average seek time = 5 ms, transfer rate = 1.6e+08 bps
cost = $11000
stored files: 22, 16, 18, 8, 14, 12, 15, 23, 21, 6, 4, 19, 20.
ST(4) is connected to port 10
SITE(5) has 3 group tasks, SLT = 21 Mbps, SOT = 18.95 Mbps,
SIT = 57.5 Mbps and DMT = 1.20237e+07 bps
DESIGN(16): Site Multiaccess device is located at X = 57.475, Y = 15.25, Z = 34.6
multiaccess(27): ethernet, 1000000000 bps, 6 ports, $13000
GT(9) is connected to site task port 1 via a 2-port bridge with following attributes:
Bridge(28), has capacity 5000000 frames per second and cost $14000
GT(10) is connected to port 2
GT(12) is connected to port 3
LINK(1) is connected to port 4
LINK(4) is connected to port 5
LINK(5) is connected to port 6
GROUP(9) has 10 client tasks, GLT = 1.98 Mbps, GOT = 25 Mbps,
GIT = 20 Mbps and DMT = 0 bps
DESIGN(16): GNC is located at X = 32.5, Y = 5, Z = 12.1
multiaccess(19): ethernet, 100000000 bps, 14 ports, $16000
CT(66) is connected to port 1

⋮

CT(75) is connected to port 10
ST(5) is connected to port 11
GROUP(10) has 10 client tasks, GLT = 18 Mbps, GOT = 6.99999 Mbps,
GIT = 20 Mbps and DMT = 0 bps
DESIGN(16): GNC is located at X = 109.9, Y = 15, Z = 62.1
switch(33): atm, 400000000 bps, 15 ports, $55000
CT(76) is connected to port 1

⋮

CT(85) is connected to port 10
ST(5) is connected to port 11
GROUP(12) has 20 client tasks, GLT = 40.5 Mbps, GOT = 7.95002 Mbps,
GIT = 38.5 Mbps and DMT = 0 bps
DESIGN(16): GNC is located at X = 43.75, Y = 20.5, Z = 32.1
switch(30): atm, 200000000 bps, 32 ports, $60000
CT(86) is connected to port 1

⋮

CT(105) is connected to port 20
ST(5) is connected to port 21
SITE(6) has 3 group tasks, SLT = 100.565 Mbps, SOT = 17.5002 Mbps,

SIT = 58.9502 Mbps and DMT = 0 bps
DESIGN(16): Site Multiaccess device is located at X = 114238, Y = 93322.3, Z = 54.1
multiaccess(28): ethernet, 1000000000 bps, 8 ports, $20000
GT(11) is connected to site task port 1 via a 2-port bridge with following attributes:
Bridge(21), has capacity 200000 frames per second and cost $1000
GT(13) is connected to site task port 2 via a 2-port bridge with following attributes:
Bridge(23), has capacity 500000 frames per second and cost $4000
GT(14) is connected to port 3
LINK(5) is connected to port 4
GROUP(11) has 15 client tasks, GLT = 4.95 Mbps, GOT = 31.375 Mbps,
GIT = 43.445 Mbps and DMT = 0 bps
DESIGN(16): GNC is located at X = 114232, Y = 93336, Z = 74.1
multiaccess(33): ethernet, 1000000000 bps, 18 ports, $65000
CT(106) is connected to port 1

⋮

CT(120) is connected to port 15
GS(5) is connected to port 16
server(15) has the following attributes:
number of CPUs = 4, CPU clock cycle = 1 ns
main memory capacity = 1024000000 bytes, internal hard disk capacity = 5e+10 bytes
cost = $35000
max performance = 100%, average performance = 100%, min performance = 100%
hard disk(20) has the following attributes:
type = SCSI, capacity = 8e+10 bytes, average seek time = 5 ms, transfer rate = 1.6e+08 bps
cost = $20000
stored files: 24, 22, 16, 11, 17, 18, 8, 9, 15, 13, 1, 10, 23, 21, 4, 5, 19.
ST(6) is connected to port 17
GROUP(13) has 15 client tasks, GLT = 47.31 Mbps, GOT = 86.69 Mbps,
GIT = 43.875 Mbps and DMT = 0 bps
DESIGN(16): GNC is located at X = 114336, Y = 93415, Z = 54.1
multiaccess(33): ethernet, 1000000000 bps, 18 ports, $65000
CT(121) is connected to port 1

⋮

CT(135) is connected to port 15
GS(6) is connected to port 16
server(1) has the following attributes:
number of CPUs = 1, CPU clock cycle = 5 ns
main memory capacity = 12000000 bytes, internal hard disk capacity = 1e+09 bytes
cost = $1000
max performance = 100%, average performance = 99.2593%, min performance = 96.2963%
hard disk(14) has the following attributes:
type = SCSI, capacity = 5e+10 bytes, average seek time = 5 ms, transfer rate = 1.6e+08 bps
cost = $9000
stored Files: 24, 22, 11, 18, 2, 12, 15, 13, 21, 6, 19.
ST(6) is connected to port 17
GROUP(14) has 15 client tasks, GLT = 7.94 Mbps, GOT = 0 Mbps.
GIT = 72.195 Mbps and DMT = 0 bps
DESIGN(16): GNC is located at X = 114146, Y = 93216, Z = 34.1
switch(30): atm, 200000000 bps, 32 ports, $60000
CT(136) is connected to port 1

⋮

CT(150) is connected to port 15
GS(7) is connected to port 16
server(10) has the following attributes:
number of CPUs = 2, CPU clock cycle = 2.5 ns
main memory capacity = 256000000 bytes, internal hard disk capacity = 3e+10 bytes
cost = $9500
max performance = 100%, average performance = 98%, min performance = 90%
hard disk(11) has the following attributes:
type = IDE, capacity = 4e+10 bytes, average seek time = 10 ms, transfer rate = 6.6e+07 bps
cost = $4000
stored files: 24, 22, 17, 18, 8, 9, 12, 13, 10, 23, 21, 4, 5, 7, 19.
ST(6) is connected to port 17
Enter the generation number from 0-4999:

Appendix B

The Design Libraries

The design libraries for Ethernet hubs, ATM switches, IP routers, bridges, T-carrier leasedlines, SONET leasedlines, VPN leasedlines, servers, hard disks, wires/cables and interconnection network used by *i*-CAD experiments are given here.

Table B.1: Server library.

Device Identification	Number of CPUs	Main Memory Capacity	CPU Clock Cycle	Internal Hard Disk Capacity	Device Cost in Dollars
1	1	12Mbytes	5.0 ns	1Gbytes	1000.00
2	1	12Mbbytes	4.0 ns	3Gbytes	1500.00
3	1	32Mbytes	5.0 ns	5Gbytes	2000.00
4	1	32Mbytes	4.0 ns	5Gbytes	2500.00
5	1	64Mbytes	4.0 ns	10Gbytes	3000.00
6	1	64Mbytes	2.0 ns	10Gbytes	4000.00
7	2	32Mbytes	3.0 ns	10Gbytes	3000.00
8	2	64Mbytes	3.0 ns	15Gbytes	5000.00
9	2	128Mbytes	2.5 ns	30Gbytes	7500.00
10	2	256Mbytes	2.5 ns	30Gbytes	9500.00
11	4	256Mbytes	2.0 ns	20Gbytes	12000.00
12	4	512Mbytes	2.0 ns	25Gbytes	15000.00
13	4	512Mbytes	2.0 ns	30Gbytes	20000.00
14	4	512Mbytes	2.0 ns	40Gbytes	25000.00
15	4	1024Mbytes	1.0 ns	50Gbytes	35000.00

Table B.2: Hard Disk library.

Device Identification	Hard Disk Type	Total Capacity	Average Seek Time	Transfer Rate	Device Cost in Dollars
1	IDE	5Gbytes	10.0 ms	66Mbps	200.00
2	SCSI	5Gbytes	5.0 ms	160Mbps	400.00
3	IDE	10Gbytes	10.0 ms	66Mbps	300.00
4	SCSI	10Gbytes	5.0 ms	160Mbps	500.00
5	IDE	15Gbytes	10.0 ms	66Mbps	500.00
6	SCSI	15Gbytes	5.0 ms	160Mbps	1000.00
7	IDE	20Gbytes	10.0 ms	66Mbps	1500.00
8	SCSI	20Gbytes	5.0 ms	160Mbps	2000.00
9	IDE	30Gbytes	10.0 ms	66Mbps	2000.00
10	SCSI	30Gbytes	5.0 ms	160Mbps	3000.00
11	IDE	40Gbytes	10.0 ms	66Mbps	4000.00
12	SCSI	40Gbytes	5.0 ms	160Mbps	7000.00
13	IDE	50Gbytes	10.0 ms	66Mbps	7000.00
14	SCSI	50Gbytes	5.0 ms	160Mbps	9000.00
15	IDE	60Gbytes	10.0 ms	66Mbps	8000.00
16	SCSI	60Gbytes	5.0 ms	160Mbps	11000.00
17	IDE	70Gbytes	10.0 ms	66Mbps	9000.00
18	SCSI	70Gbytes	5.0 ms	160Mbps	15000.00
19	IDE	80Gbytes	10.0 ms	66Mbps	10000.00
20	SCSI	80Gbytes	5.0 ms	160Mbps	20000.00

Table B.3: Wire/cable library.

Wire/Cable Type	Cost (in Dollars) per Foot
Twisted Pair	2.00
Coxial Cable	10.00
Fiber Optic	20.00

Table B.4: Bridge library.

Device Identification	Capacity in Frames per Seconds	Bridge Cost in Dollars
1	1000	20.00
2	2000	40.00
3	3000	60.00
4	4000	80.00
5	5000	100.00
6	10000	120.00
7	20000	140.00
8	30000	160.00
9	40000	180.00
10	50000	200.00
11	60000	220.00
12	70000	240.00
13	80000	260.00
14	90000	280.00
15	100000	300.00
16	105000	320.00
17	110000	340.00
18	115000	360.00
19	120000	380.00
20	125000	400.00
21	200000	1000.00
22	300000	2000.00
23	500000	4000.00
24	700000	6000.00
25	900000	8000.00
26	1000000	10000.00
27	3000000	12000.00
28	5000000	14000.00
29	7000000	16000.00
30	9000000	18000.00

Table B.5: Ethernet Hub library.

Device Identification	Type of Protocol	Bandwidth (Mbps)	Number of Ports	Type of Wire	Device Cost in Dollars
1	CSMA/CD	10	2	twisted-pair	50.00
2	CSMA/CD	10	4	twisted-pair	100.00
3	CSMA/CD	10	6	twisted-pair	200.00
4	CSMA/CD	10	8	twisted-pair	320.00
5	CSMA/CD	10	10	twisted-pair	340.00
6	CSMA/CD	10	12	twisted-pair	400.00
7	CSMA/CD	10	14	twisted-pair	650.00
8	CSMA/CD	10	16	twisted-pair	900.00
9	CSMA/CD	10	18	twisted-pair	1000.00
10	CSMA/CD	10	20	twisted-pair	1500.00
11	CSMA/CD	10	25	twisted-pair	2500.00
12	CSMA/CD	10	32	twisted-pair	5000.00
13	CSMA/CD	100	2	twisted-pair	3500.00
14	CSMA/CD	100	4	coaxial cable	6000.00
15	CSMA/CD	100	6	twisted-pair	8000.00
16	CSMA/CD	100	8	coaxial cable	9200.00
17	CSMA/CD	100	10	twisted-pair	10400.00
18	CSMA/CD	100	12	coaxial cable	13000.00
19	CSMA/CD	100	14	twisted-pair	16000.00
20	CSMA/CD	100	16	coaxial cable	19000.00
21	CSMA/CD	100	18	twisted-pair	22000.00
22	CSMA/CD	100	20	coaxial cable	25000.00
23	CSMA/CD	100	25	twisted-pair	50000.00
24	CSMA/CD	100	32	coaxial cable	75000.00
25	CSMA/CD	1000	2	fiber optics	4000.00
26	CSMA/CD	1000	4	fiber optics	8000.00
27	CSMA/CD	1000	6	fiber optics	13000.00
28	CSMA/CD	1000	8	fiber optics	20000.00
29	CSMA/CD	1000	10	fiber optics	25000.00
30	CSMA/CD	1000	12	fiber optics	33000.00
31	CSMA/CD	1000	14	fiber optics	40000.00
32	CSMA/CD	1000	16	fiber optics	45000.00
33	CSMA/CD	1000	18	fiber optics	65000.00
34	CSMA/CD	1000	20	fiber optics	80000.00
35	CSMA/CD	1000	25	fiber optics	90000.00
36	CSMA/CD	1000	32	fiber optics	100000.00

Table B.6: ATM switch library.

Device Identification	Bandwidth (Mbps)	Number of Ports	Type of Wire	Device Cost in Dollars
1	25	5	twisted-pair	2000.00
2	25	10	twisted-pair	4000.00
3	25	15	twisted-pair	7000.00
4	25	20	twisted-pair	9000.00
5	25	32	twisted-pair	15000.00
6	45	5	twisted-pair	3000.00
7	45	10	twisted-pair	6000.00
8	45	15	twisted-pair	9000.00
9	45	20	twisted-pair	13000.00
10	45	32	twisted-pair	20000.00
11	75	5	twisted-pair	5000.00
12	75	10	twisted-pair	8000.00
13	75	15	twisted-pair	11000.00
14	75	20	twisted-pair	16000.00
15	75	32	twisted-pair	26000.00
16	100	5	twisted-pair	7000.00
17	100	10	twisted-pair	11000.00
18	100	15	twisted-pair	15000.00
19	100	20	coaxial cable	18000.00
20	100	32	coaxial cable	28000.00
21	150	5	coaxial cable	11000.00
22	150	10	coaxial cable	15000.00
23	150	15	coaxial cable	20000.00
24	150	20	coaxial cable	28000.00
25	150	32	coaxial cable	38000.00
26	200	5	coaxial cable	15000.00
27	200	10	coaxial cable	23000.00
28	200	15	coaxial cable	33000.00
29	200	20	coaxial cable	40000.00
30	200	32	coaxial cable	60000.00
31	400	5	fiber optics	20000.00
32	400	10	fiber optics	35000.00
33	400	15	fiber optics	55000.00
34	400	20	fiber optics	75000.00
35	400	32	fiber optics	90000.00
36	622	32	fiber optics	250000.00

Table B.7: Router library.

Device Identification	Type of Protocol	Device Capacity	Number of Ports	Type of Wire	Device Cost in Dollars
1	IP	10Kpps	5	twisted-pair	1000.00
2	IP	10Kpps	10	twisted-pair	3000.00
3	IP	10Kpps	15	twisted-pair	10000.00
4	IP	10Kpps	20	twisted-pair	15000.00
5	IP	50Kpps	5	twisted-pair	3000.00
6	IP	50Kpps	10	twisted-pair	6000.00
7	IP	50Kpps	15	twisted-pair	20000.00
8	IP	50Kpps	20	twisted-pair	25000.00
9	IP	100Kpps	5	twisted-pair	7000.00
10	IP	100Kpps	10	twisted-pair	11000.00
11	IP	100Kpps	15	twisted-pair	35000.00
12	IP	100Kpps	20	twisted-pair	45000.00
13	IP	150Kpps	5	twisted-pair	11000.00
14	IP	150Kpps	10	twisted-pair	20000.00
15	IP	150Kpps	15	twisted-pair	40000.00
16	IP	150Kpps	20	twisted-pair	55000.00
17	IP	200Kpps	5	twisted-pair	19000.00
18	IP	200Kpps	10	twisted-pair	31000.00
19	IP	200Kpps	15	twisted-pair	55000.00
20	IP	200Kpps	20	twisted-pair	70000.00
21	IP	300Kpps	5	coaxial cable	25000.00
22	IP	300Kpps	10	coaxial cable	40000.00
23	IP	300Kpps	15	coaxial cable	75000.00
24	IP	300Kpps	20	coaxial cable	90000.00
25	IP	500Kpps	5	coaxial cable	30000.00
26	IP	500Kpps	10	coaxial cable	55000.00
27	IP	500Kpps	15	coaxial cable	80000.00
28	IP	500Kpps	20	coaxial cable	100000.00
29	IP	1000Kpps	5	fiber optics	40000.00
30	IP	1000Kpps	10	fiber optics	60000.00
31	IP	1000Kpps	15	fiber optics	100000.00
32	IP	1000Kpps	20	fiber optics	150000.00
33	IP	2000Kpps	5	fiber optics	60000.00
34	IP	2000Kpps	10	fiber optics	800000.00
35	IP	2000Kpps	15	fiber optics	1500000.00
36	IP	2000Kpps	20	fiber optics	2000000.00

Table B.8: T-carrier library.

Line Identification	Line Name	Line Bandwidth	Initial Cost in Dollars	Monthly Cost in Dollars
1	DS0	64Kbps	1000.00	500.00
2	DS1	1.536Mbps	3000.00	1000.00
3	DS1c	3.072Mbps	5000.00	2000.00
4	DS2	6.144Mbps	7000.00	5000.00
5	DS3	44.032Mbps	15000.00	9000.00
6	DS4	264.192Mbps	30000.00	13000.00

Table B.9: SONET library.

Line Identification	Line Name	Line Bandwidth	Initial Cost in Dollars	Monthly Cost in Dollars
1	OC1	51.84Mbps	10000.00	3000.00
2	OC2	103.68Mbps	20000.00	6000.00
3	OC3	155.52Mbps	30000.00	9000.00
4	OC4	207.36Mbps	40000.00	12000.00
5	OC5	259.20Mbps	50000.00	15000.00
6	OC6	311.04Mbps	60000.00	18000.00
7	OC7	362.88Mbps	70000.00	21000.00
8	OC8	414.72Mbps	80000.00	24000.00
9	OC9	466.56Mbps	90000.00	27000.00
10	OC10	518.40Mbps	100000.00	30000.00
11	OC11	570.24Mbps	120000.00	33000.00
12	OC12	622.08Mbps	140000.00	36000.00
13	OC13	673.92Mbps	160000.00	39000.00
14	OC14	725.76Mbps	180000.00	42000.00
15	OC15	777.60Mbps	200000.00	45000.00
16	OC16	829.44Mbps	230000.00	48000.00
17	OC17	881.28Mbps	260000.00	51000.00
18	OC18	933.12Mbps	290000.00	54000.00
19	OC19	984.96Mbps	320000.00	57000.00
20	OC20	1036.80Mbps	350000.00	60000.00

Table B.10: Virtual Private Network (VPN) library.

Line Identification	Line Type	Precentage of Line leased	Line Bandwidth	Initial Cost in Dollars	Monthly Cost in Dollars
1	DS1	25%	384Kbps	250.00	125.00
2	DS1	50%	768Kbps	500.00	250.00
3	DS1	75%	1.152Mbps	750.00	375.00
4	DS2	25%	1.536Mbps	1750.00	1250.00
5	DS2	50%	3.072Mbps	3500.00	2500.00
6	DS2	75%	4.608Mbps	5250.00	3750.00
7	DS3	25%	11.008Mbps	2250.00	2250.00
8	DS3	50%	22.016Mbps	4500.00	4500.00
9	DS3	75%	33.024Mbps	6750.00	6750.00
10	DS4	25%	66.048Mbps	2750.00	3250.00
11	DS4	50%	132.096Mbps	5500.00	6500.00
12	DS4	75%	198.144Mbps	8250.00	9750.00
13	OC3	25%	38.880Mbps	7500.00	2500.00
14	OC3	50%	77.760Mbps	15000.00	5500.00
15	OC3	75%	116.640Mbps	22500.00	7000.00
16	OC9	25%	116.640Mbps	22500.00	6750.00
17	OC9	50%	233.280Mbps	45000.00	13500.00
18	OC9	75%	349.920Mbps	67500.00	20250.00
19	OC12	25%	155.520Mbps	35000.00	9000.00
20	OC12	50%	311.040Mbps	70000.00	18000.00
21	OC12	75%	466.560Mbps	105000.00	27000.00
22	OC15	25%	194.400Mbps	50000.00	11250.00
23	OC15	50%	388.800Mbps	100000.00	22500.00
24	OC15	75%	583.200Mbps	150000.00	33750.00
25	OC18	25%	233.280Mbps	72500.00	13500.00
26	OC18	50%	466.560Mbps	145000.00	27000.00
27	OC18	75%	699.840Mbps	217500.00	40500.00
28	OC20	25%	259.200Mbps	87500.00	15000.00
29	OC20	50%	518.400Mbps	175000.00	30000.00
30	OC20	75%	777.600Mbps	262500.00	45000.00

Table B.11: Group-site interconnection network cost matrix.

Devices	Ethernet	ATM	Router
Ethernet	0	2000	0
ATM	4000	0	0

Table B.12: Site-backbone interconnection network cost matrix.

Devices	Ethernet	ATM	Router	T-carrier	SONET	VPN
Ethernet	0	2000	0	2000	6000	2000
ATM	4000	0	0	2000	6000	2000
Router	6000	6000	0	0	4000	0