A Multiple Class Buffer Priority Algorithm for the Design of B-ISDN Networks

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ABSTRACT

This paper addresses the issue of furnishing a **multiple class selective discard** mechanism in the context of B-ISDN networks. We introduce a ***Multiple Class Buffer Priority*** **(MCBP)** algorithm for the evaluation of the loss probability per class in multimedia scenarios. The MCBP algorithm exploits the conservation property of the work-conserving queues. The MCBP algorithm is exact and it is computed in *n-1* steps where *n* is the number of classes.

I) INTRODUCTION

Broadband Integrated Services Digital Networks (B-ISDN) will carry a wide spectrum of multimedia applications with different Quality of Service (QOS) requirements [1]-[4]. Coping with diverse delay and loss requirements in a cost/effective way calls for the implementation of differential services at the cell level. An alternate approach is to provide a unique bearer service and to dimension the network resources according to the most demanding class. This solution either results in network underutilization or leads to unnecessary restriction of users' demands.

In a statistical multiplexer, whenever the incoming stream of cells exceeds the storage capacity, loss occurs. A ***multiclass selective discard mechanism*** discards cells in an overflow situation according to their priority level. Whenever a higher priority cell finds the buffer full and there is an enqueued lower priority cell, the lower priority one is discarded in order to release a buffer (at the tail of the queue) for the higher priority cell [5]. By providing different levels of service to different streams, the network can support different loss requirements that would be impossible otherwise.

Determining the appropriate number of priority levels is a difficult task. A fast and accurate computational algorithm is an essential tool. In this paper, we introduce the ***Multiple Class Buffer Priority*** **(MCBP)** algorithm. The MCBP algorithm provides exact analysis and runs in *n-1* steps where *n* is the number of classes involved in the problem.

This paper is organized as follows: section II explains the buffer priority concept, section III introduces the MCBP algorithm, section IV describes a solution for a two priority system that can be used as the MCBP elementary step, section V illustrates the MCBP algorithm and finally, some conclusions are drawn in section VI.

II) BUFFER PRIORITY MECHANISM

A queue is basically composed of two resources: the server and the waiting room. A priority mechanism establishes a scale of rights for using a queueing resource. A service priority mechanism determines which client will be served next and a buffer priority mechanism differentiates among the clients on the basis of which have the right of remaining enqueued when overflow occurs. In a priority queue with "push out" whenever there is no available space, the arrival of a higher priority client causes the drop out of a lower priority one.

A queueing scheme is considered work-conservative if no customer is refused the right of using a queueing resource when it is available, i.e., a work-conserving scheme fully utilizes the system resources (buffer + server). A work-conservative queue is one that: i) no server is left idle when the buffer is not empty, ii) customers are lost only when the buffer is full, iii) all classes of customers have the same service requirement, iv) served customers are immediately removed from the system and v) no work (i.e. service requirement) is created or destroyed by the particular employed rule. An example of work-conserving buffer organization is complete sharing. In complete sharing, a cell from any priority class is always accepted to the system when the buffer is not full. The work-conserving disciplines maximize the overall cell loss probability. An important property of the work-conserving queues is that the overall loss probability can be computed using the loss probability of each priority class, i.e. [5]:

$$\sum_{i=1}^{n} \lambda_i \Phi_i = \lambda \Phi$$

where Φ and Φ_i are the aggregate loss probability and the loss probability per class respectively and λ and λ_i are the total arrival rate and the per class arrival rate.

Service priority systems (single and multiple classes) have been studied for a long time [9] and they have also been applied in the context of B-ISDN networks [10] [11]. Buffer priority has recently gained attention with the advent of B-ISDN networks [5]-[8] [12]-[16]. Most of the studies in buffer priority systems focus on the two level case, due to the adoption of the ATM standard. To the authors' best knowledge no results have been derived for the multiple class buffer priority queue.

III) THE MCBP ALGORITHM

The main difficulty in generalizing the known 2-class solution to the multiclass case is the growth in complexity as a function of the number of classes. For example, a straightforward approach, using a multi-dimensional Markov chain, to the exact solution for a *n* class system is O (B^n) where *B* is the number of buffers and *n* the number of classes. The MCBP algorithm avoids this dramatic complexity growth. It computes the solution of a *n* priority class system by solving *n-1* two priority systems. Each of these two priority systems corresponds to a different mapping of the original *n* classes into two superclasses (aggregation of classes). The algorithm starts by mapping the highest priority class of the *n* class system into the high priority superclass of the two priority system. The other *n-1* classes are mapped into the low priority superclass. At step *g*, the highest *g* priority classes are mapped into the high priority superclass of the two priority system and the remaining *n-g* are mapped into the low priority superclass (see figure 1). The loss probabilities of the original *n* class system are computed based on the loss probabilities of the *n-1* two priority systems.

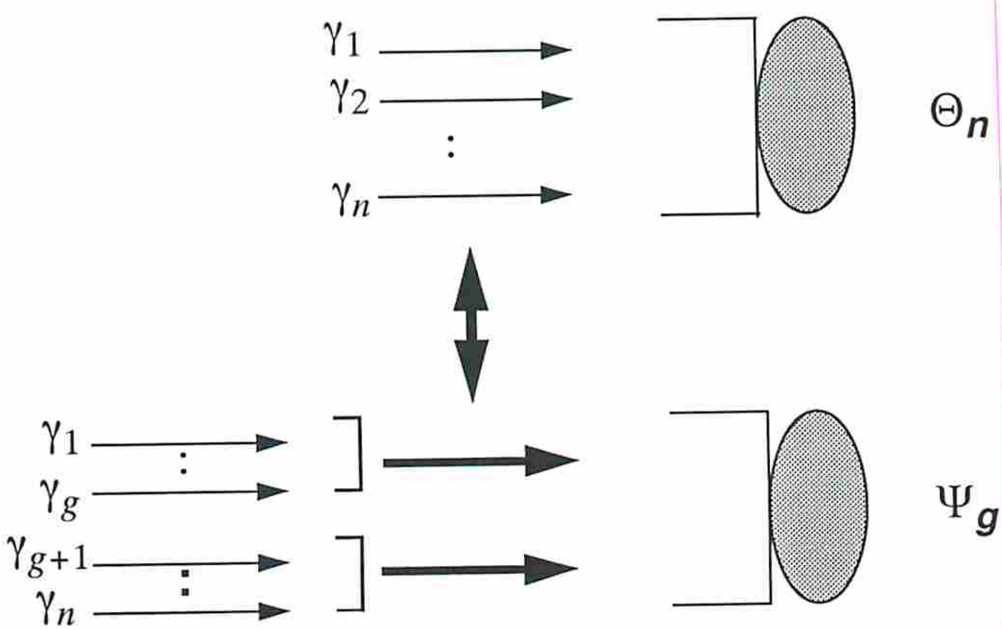

Figure 1: The MCBP mapping

Before presenting the MCBP algorithm, let us introduce some notation. Let Θ_n denote a n class system to be solved and Ψ_g a corresponding two priority system. Let the g highest classes of Θ_n be mapped into the high superclass of Ψ_g and let the lowest n - g classes of Θ_n be mapped into the low superclass of Ψ_g.

Let γ_g^h (γ_g^l) be the high (low) superclass arrival rate and Φ_g^h (Φ_g^l) the high (low) superclass loss probabilities respectively. Let us assume that the classes are ordered in decreasing order of priority, that is the highest priority class is the first class.

The Multiple Class Buffer Priority algorithm can be stated as follows:

STEP 1 - For g = 1 to n - 1

Solve Ψ_g

STEP 2- $\Phi_n = \Phi_{n-1}^l$ and $\Phi_1 = \Phi_1^h$

STEP 3 - For $j = n$ - 1 to 2 compute

$$\Phi_j = \frac{1}{\gamma_j}\left[\gamma_{j-1}^l \Phi_{j-1}^l - \sum_{z=j+1}^{n} \gamma_z \Phi_z\right]$$

Note that step 3 can be computed either in a top down fashion or in a bottom up one. Actually, each Φ_j could be computed after the j^{th} step.

Step 1 contains n-1 iterations and each iteration is essentially the solution of a two priority system, Ψ_g. Step 3 then computes the n-2 remaining loss probabilities by substitution of known values. Thus, the MCBP algorithm is computed in n-1 steps. Its complexity depends on the complexity of the elementary step Ψ_g. The MCBP algorithm does not introduce any approximation and, again, its accuracy depends only on the accuracy of the solution of the two priority model used.

We illustrate, below, the MCBP algorithm for a 5 class system:

STEP 1

	HIGH	LOW
Ψ_1	1	2,3,4,5
Ψ_2	1,2	3,4,5
Ψ_3	1,2,3	4,5
Ψ_4	1,2,3,4	5

STEP 2

$$\Phi_5 = \Phi_4^l \quad \text{and} \quad \Phi_1 = \Phi_1^h$$

STEP 3

$$\Phi_4 = \frac{1}{\gamma_4}[\gamma_3^l \Phi_3^l - \gamma_5 \Phi_5]$$

$$\Phi_3 = \frac{1}{\gamma_3}[\gamma_2^l \Phi_2^l - \gamma_5 \Phi_5 - \gamma_4 \Phi_4]$$

$$\Phi_2 = \frac{1}{\gamma_2}\left[\gamma_1^l \Phi_1^l - \gamma_5 \Phi_5 - \gamma_4 \Phi_4 - \gamma_3 \Phi_3\right]$$

IV) A SOLUTION FOR A TWO PRIORITY LEVEL SYSTEM

In this section, we describe a solution for a two level priority system that can be used in the first step of the MCBP algorithm for the computation of the equivalent two level system of a *n* priority level one.

We consider a complete buffer sharing output queue of a N x N B-ISDN switch [17]-[19]. It is assumed that the time axis is divided into time slots (discrete-time) and that all arrivals and departures are synchronized with slot boundaries. The cells that are transferred in a slot from the input lines to a specific output line form a batch whose size is trinomially distributed. We assume that the cell that is assigned for transmission in this

FIFO output queue cannot be dropped by the arriving batch. The output line is a single channel and has a limit *B* of waiting buffers. In this sense, the modeled system has a deterministic inter-batch arrival time (*D*), a trinomial batch-size distribution $[A_h, A_l]$, a single server, a deterministic service time distribution (D) and a buffer size equal to B. This queue is generally denoted by $D^{[A_h, A_l]}/D/1/B$.

We model the described system by a two dimension markov chain (MC). The MC state is defined as the number of queued high (*i*) and low priority (*j*) cells. The general way of computing a transition probability is:

Prob (transmitted cell be of a certain type)) x Prob (arriving batch has n_h and n_l cells) where n_h and n_l denote respectively the high and low priority number of arriving cells.

For example, the transition probability from state *ij* to state *ks* where $i > 0$ or $j > 0$ and $k+s<B$ is given by:

$$P_{ij,\,ks} = \frac{i}{i+j} \times \frac{N!}{(k-i+1)! \times (s-j)! \times (n-k+i-1-s+j)!}$$

$$\times$$

$$q_1^{k-i+1} \times q_2^{s-j} \times (1-q_1-q_2)^{N-k+i-1-s+j}$$

$$+$$

$$\frac{j}{i+j} \times \frac{N!}{(k-i)! \times (s-j+1)! \times (n-k+i-s+j+1)!}$$

$$\times$$

$$q_1^{k-i} \times q_2^{s-j+1} \times (1-q_1-q_2)^{N-k+i-s+j+1}$$

The total loss probability is computed as:

$$\Phi = \sum_{m} P(i,j) \times P_b(n_h, n_l)$$

where P (i,j) is the probability of state (i, j) and $P_b(n_h,n_l)$ is the probability that the arriving batch has size equal to $n_1 + n_2$; m is the set of 4-uples such that $i+j+n_1+n_2-1 > B$

The high priority loss probability is given by a similar expression, except that $i + n_1 - 1 > B$ whenever a high priority cell is transmitted in the same slot or $i + n_1 > B$ in the alternate case.

The reader is referred to the appendix for the complete definition of the Markov Chain.

V) NUMERICAL EXAMPLES

In this section, we illustrate the MCBP algorithm. We consider an output queue of a 32x32 switch. We claimed that a multiple class selective discard mechanism enhances the network flexibility in accommodating traffic scenarios with diverse loss requirements. The following examples reinforce this claim.

The first example shows a straightforward scenario that a two priority level network cannot support but which can be supported by a three priority level network. Consider the three traffic types defined in table 1 for a buffer size of B = 16. In a two priority level network, if we gather types *A* and *B* as the high priority superclass, we have a high superclass loss probability of 3×10^{-7} which does not satisfy the type *A* requirement. If we gather types *B* and *C* as the low priority superclass, we have a low superclass loss probability of 2×10^{-5} which does not support the type *B* requirement. However, the loss requirements in table 1 are fully satisfied in a three priority level network.

	A	B	C
load	0.3	0.2	0.2
loss	10^{-9}	10^{-7}	10^{-5}

Table 1: traffic scenario feasible only in a three priority level network

In table 2, each entry gives the maximum load (for a total load of 0.75) which can be transported under a specific loss requirement in a network with a certain number of priority levels (B = 16). For instance, a system with no priority (row 1) can carry a load of 0.75 with loss requirement of 10^{-5} whereas a system with two priority levels can transport at maximum a load of 0.3 with loss requirement of 10^{-9} and the remaining load (0.45) has to be transported with loss requirement of 10^{-4}. Note that as the number of priority levels increases, we gain flexibility in accommodating different loss requirements.

#class/loss	10^{-9}	10^{-8}	10^{-7}	10^{-6}	10^{-5}	10^{-4}
1					0.75	
2	0.3					0.45
3	0.3	0.05				0.4
4	0.3	0.05	0.09			0.31
5	0.3	0.05	0.09	0.07		0.24
6	0.3	0.05	0.09	0.07	0.14	0.1

Table 2: Maximum load carried with a certain loss requirement X number of priority levels

In figure 2, there are four similar traffic types (A, B, C and D). Each one contributes a load of 0.2. We show how these four traffic types can be transported in networks with 1 to 4 priority levels (B = 16). Starting with no priority, at each additional priority level, we assign a traffic type exclusively to it. The difference in the loss probability of the assigned traffic type can be viewed as the advantage of having the additional priority level.

The number of priority levels may reduce the buffer requirements for a fixed total load. Figure 3 shows the minimum buffer size necessary to transport the table 3 traffic scenario as a function of the number of priority levels provided in the network.

VI) CONCLUSIONS

In this paper, we introduced an algorithm for the computation of the per class loss probability in a multiple class queue in O (n) steps where n is the number of classes.

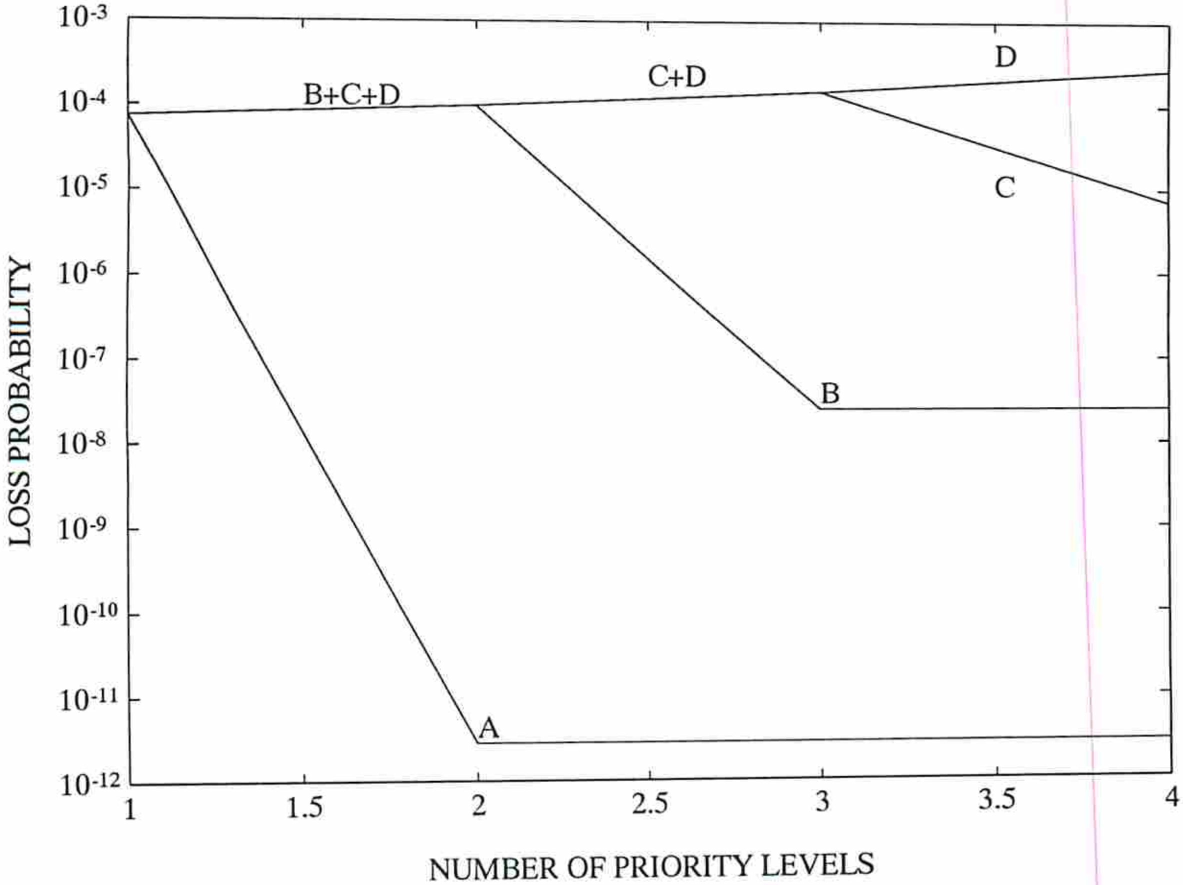

Figure 2: Loss pobablity when a traffic type is assigned an exclusive priority level

The *Multiple Class Buffer Priority* is based on the work conservation property of the complete buffer sharing queueing organization and it does not introduce any approximation. The accuracy of the final results depends basically on the accuracy of the two priority level solution used as its elementary step.

Estimating the suitable network's grade of the bearer service is an evolving task that requires the evaluation of its adequacy in relation to different projected traffic scenarios and its long term growth. It is a critical decision that has to be evaluated together with others network design decisions.

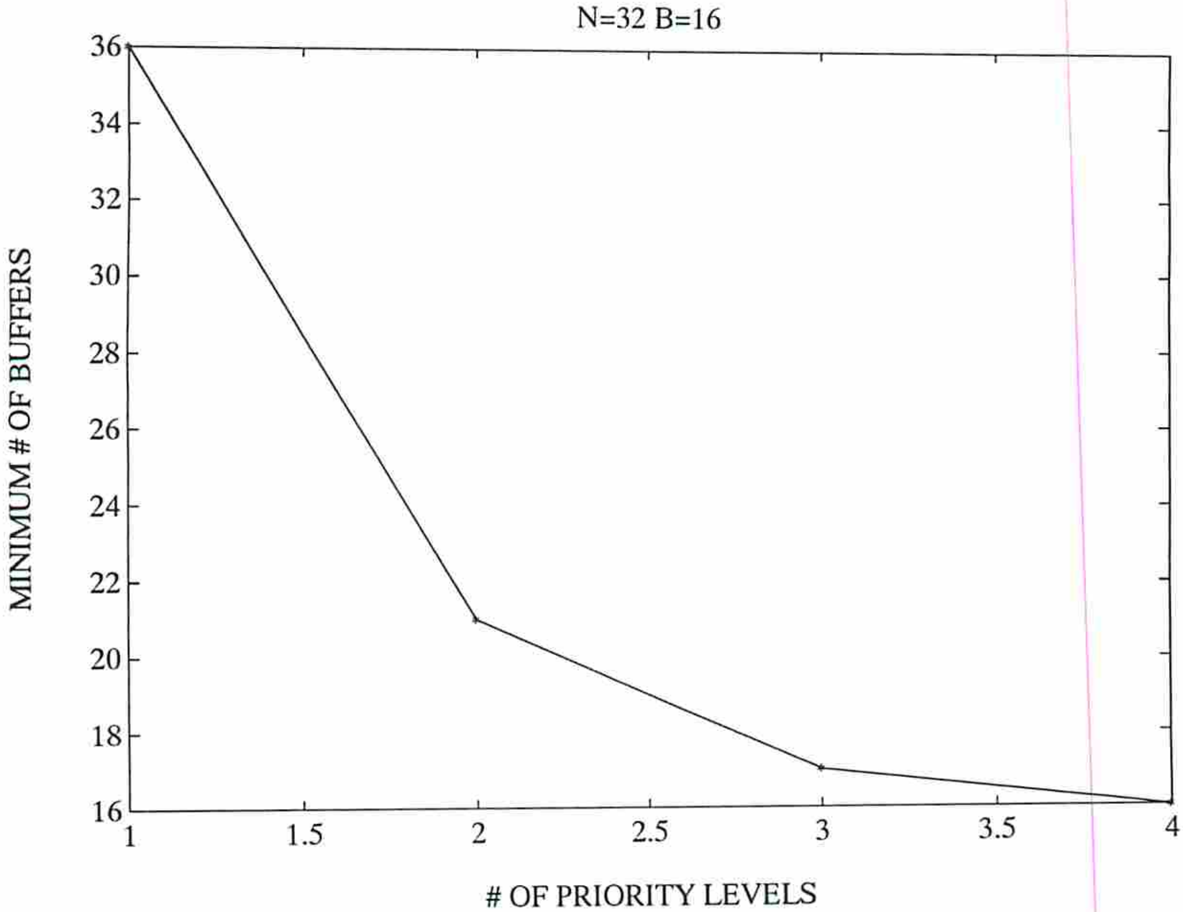

Figure 3: buffer requirement to carry table 3 traffic scenario

	A	B	C	D
load	0.05	0.3	0.15	0.2
loss	10^{-12}	10^{-9}	10^{-7}	10^{-5}

Table 3: traffic scenario to be transported

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APPENDIX

In this appendix, we show the complete definition of the Markov Chain described in section IV.

Notation:

i _ number of high priority class cells in the queue (excluding server)

j _ number of low priority class cells in the system;

n_h _ number of high priority cells that arrived in the current slot;

n_l _ number of low priority cells that arrived in the current slot;

N _ maximum batch size;

B _ number of buffers;

P_i _ probability of transmission of a high priority cell, $P_i = \frac{i}{i+j}$

P_j _ probability of transmission of a low priority cell, $P_j = \frac{j}{i+j}$

T (k,s) _ Trinomial function, given a maximum number of events equal to N;

$$T(k, s) = \frac{N!}{k! \times s! \times (N-k-s)!} \times q_h^k \times q_l^s \times (1 - q_h - q_l)^{N-k-s}$$

where q_h, q_l high and low priority load

P_{ij} _ probability of having *i* high priority cell and *j* low priority cell at the begining of a slot;

$P_{ij,ks}$ _ transition probability between state *ij* and *ks*

The following restrictions express the behavior of the system :

a) Maximum # of queued cells

$P_{ij} = 0$ if $i + j > B$

b) No high priority class push out

$P_{ij,ks} = 0$ if $k < i - 1$

c) Push out only if buffer is full

$P_{ij,ks} = 0$ if $s < j - 1$ & $k + s < B$

d) No unnecessary push out

$P_{ij,ks} = 0$ if $k + s < i + j - 1$

The transition probabilities $P_{ij,ks}$ are given by :

i) $k < i \quad s \leq j$

$$P_i \times T(0, 0)$$

ii) $k = i - 1 \quad s \in [j + 1, B - i]$

$$P_i \times T(0, s - j)$$

iii) $k = i - 1 \quad s = B - i + 1$

$$P_i \times \sum_{n_l = B - i + 1 - j}^{N} T(0, n_l)$$

iv) $i > 0 \quad \text{or} \quad j > 0 \quad \text{and} \quad k + s < B$

$$P_i \times T(k - i + 1, s - j) + P_j \times T(k - i, s - j + 1)$$

v) $i > 0 \quad \text{or} \quad j > 0 \quad \text{and} \quad k + s = B$

$$P_i \times T(k - i + 1, s - j) + P_j \times \sum_{n_l = s - j + 1}^{N - (k - s)} T(k - s, n_l)$$

vi) $i = j = 0 \quad \text{and} \quad k + s < B$

$$T(k, s)$$

vii) $i = j = 0 \quad \text{and} \quad k + s = B$

$$\sum_{n_l = s}^{N - k} T(k, n_l)$$

viii) $k + s < B \quad \text{and} \quad s = j - 1 \; (j > 0)$

$$P_j \times T(k - i, 0)$$

ix) k+s < B and s= j and $(i = 0 \Rightarrow j > 0$ or $j = 0 \Rightarrow i > 0)$

$$P_i \times T(k-i+1, 0) + P_j \times T(k-i, 1)$$

x) i = j = 0 and k < B

$$T(k, 0)$$

xi) k + s = B s < j k < B (s > 0 k > 0)

$$P_i \times \sum_{n_l = 0}^{N-(k-i+1)} T(k-i+1, n_l) + P_j \times \sum_{n_l = 0}^{N-(k-i)} T(k-i, n_l)$$

xii) k+s = B s= j i < B (s>0 k>0)

$$P_i \times \sum_{n_l = 0}^{N-(k-i+1)} T(k-i+1, n_l) + P_j \times \sum_{n_l = 1}^{N} T(k-i, n_l)$$

xiii) k = B and i > 0

$$\sum_{n_h = B-i+1}^{N} \sum_{n_l = 0}^{N-n_h} T(n_h, n_l) + P_j \times \sum_{n_h = B-i}^{N} \sum_{n_l = 0}^{N-n_h} T(n_h, n_l)$$

xiv) i = j = 0 and k = B

$$\sum_{n_h = B}^{N} \sum_{n_l = 0}^{N-n_h} T(n_h, n_l)$$