Performability Estimation of Token Ring Network

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Abstract

The work reported in this paper presents a new method for the performability evaluation of the token ring network.

Performability is a term used to describe performance and reliability. Performance is defined as "quality of service provided the system is correct". Reliability is "the property of a system which allows reliance to be justifiably placed on the service it delivers". However, the problem that arises from evaluating these items separately is that performance depends on reliability. Thus, it is obvious that combining performance and reliability was needed for a complete evaluation; the issue was how to combine them.

The method used for performability evaluation of token ring network is based on analysis describing the action of the token ring network.

It was assumed that the Mean Time Frame Transfer (MTFT) to be the main measure of the performability which is composed of the Mean Waiting Time (MWT) for a free token and the Mean Real Transfer Time (MRTT) of a data frame (together with the acknowledgement receipt), taking in consideration all possible malfunctions.

In addition, the influence of the effective parameters [number of nodes (N), length of the link (L), channel bandwidth (b), exponential distribution ratio of the user access probability (λ) and ratio of malfunctions (k_m)] on MTFT and its components were investigated.

As a general conclusion the present investigation provides a new method for evaluation of performability of the token ring network. It was found that the Mean Time Frame Transfer and its two main components vary linearly with number of nodes, length of the link, exponential distribution ratio of the user access probability and the ratio of malfunction and vary inversely with channel bandwidth.

1. Introduction

With growth in the complexity of computing systems and their applications, means of system evaluation are becoming increasingly more complex and difficult. Development of methods for the evaluation of system performance, reliability, and performability has, thus, become an activity of recognized importance [1].

In the past, most work kept performance and reliability separate [2]. Initially, the reliability of the system might have been satisfied, then the performance optimized. This lead to systems having good performance when the system was fully functional but drastic decline in performance when, inevitably, failure occurred. Improvements on this lead to the design of degradable systems. Because degradable systems are designed to continue their operation even in the presence of errors, their performance can not be accurately evaluated without taking into account the effect of errors. Analysis of the systems from a pure performance viewpoint tended to be optimistic since it ignored the failure-repair behavior of the systems. At other extreme, pure reliability analysis tended to be conservative, since performance considerations were not taken into account. Thus, it was essential that methods for the combined evaluation of performance and reliability be developed: enter performability analysis [2].

The term, Token Ring, generally is used to refer to IEEE 802.5 networks. As its name suggests uses a ring topology and token-passing access method, it consists of a set of stations connected serially by a transmission medium as shown in Fig. 1, with data transmitted sequentially bit by bit from one ring station to the next in one direction , and each station regenerates and repeats each bit. Token ring can run at two speeds which are 4 Mbps (500,000 bytes per second) and 16 Mbps (2,000,000 bytes per seconds) [3].

Figure (1) Token Ring Network
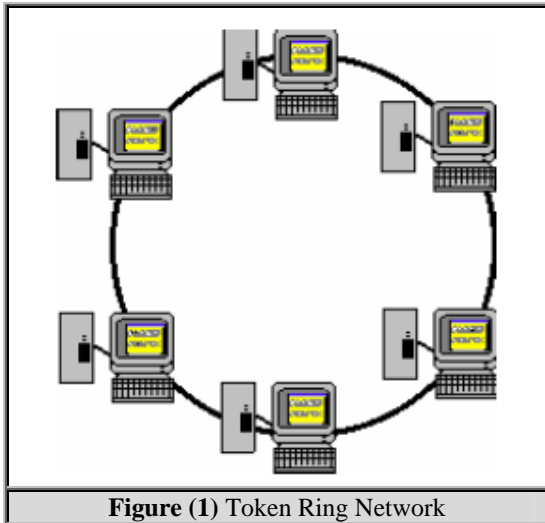
The ring is initialized by circulating a short message (called a token) around the ring. A station must capture the token to gain the right to transmit information onto the ring. A transmitting station replaces the token with a data frame which carries the information to be transferred. The frame circulates the ring and may be copied by one or more destination stations. When the frame returns to the transmitting station, it is removed from the ring and a new token is transmitted. The token then continues round the ring until the next node with data that is ready to transmit receives the token [4].

Most of previous work dealt with the reliability of the networks from hardware point of view. However, as a new attempt, the present work takes into account the reliability of message delivery. In this paper the errors in the token ring local area network have been categorized into two types: - failures and malfunctions.
Failures of the system can be caused by:-
1. Failure of communication links.
2. Failure of network interfaces.
3. Failure of stations.
To eliminate these failures it is necessary to perform hardware and information renewal.

The malfunctions are usually caused by degradation in the electrical signals or environmental electromagnetic interface. Malfunctions are eliminated by the computer system itself. The system comes back to the correct operation by only information renewal without hardware repairing. Malfunctions may influence information transfer in the network too. For example, the data frame in token ring may be lost or destroyed and some transfer operation

must be repeated. The repeated operation affects the response of the networks [5].

There exists an extensive literature on the performance and reliability as applied to Token-Ring Networks but there is a dearth of research work on the performability evaluation of LAN networks.
Falconer, in 1984 [7] discussed four common reliability enhancement techniques for ring local area networks, Bhuyan et al., in 1989 [8] presented performance models of single and multiple ring networks. Bux, in 1989 [9] examined the major technical concept underlying token ring technology and performance issues.
Sanders and Meyer, in 1991 [1] presented a unified approach to the specification of measures of performance dependability and performability. Al-Aloosy, in 1992 [6] evaluated the performability of the Cambridge Ring Network, Van Moorsel and Haverkort, in 1992 [10] discussed a unified approach towards model based quantitative evaluation of both computer systems and communication systems. In this paper the authors constructed a framework, the so-called performability evaluation framework. Meyer, in 1995 [11] discussed the present state performability with respect to both scientific and engineering contributions..

2. Token Ring Performa-Bility Derivation and Evaluation

The Mean Time of the Frame Transfer (MTFT) between two stations is proposed as performability measure of the token ring. This measure depends on:
1. The time of waiting for the free token.
2. The transfer time of data frame between stations and transfer time of the acknowledgement.
3. The size of the ring; i.e. the number of active and passive stations, distance between stations, etc….
4. The probability of improper operation of the ring, that means the probability of malfunctions and failures.

It is assumed that there are only malfunctions during the frames transfer in the considered ring (no failure) and the reliability of all ring devices and links is equal one.
The mean time of frame transfer (MTFT) is evaluated as a sum of the following two main factors which depend on the Round Trip Time of the ring (RTT).
● Mean Waiting Time (MWT) for a free token.

● Mean Real Transfer Time (MRTT) of a data frame (together with the ACK signal receipt).
Thus, it is possible to write that:

$$MTFT=MWT+MRTT \qquad \boxed{1}$$

2.1 An Approximation of the Ring Malfunction Probability

Consider the simplest integrated node of the token ring as shown in Fig. 2.The probability of reliable transmission (Rt), i.e. one without malfunction during the transfer through the node and the link may be approximated as[6]:
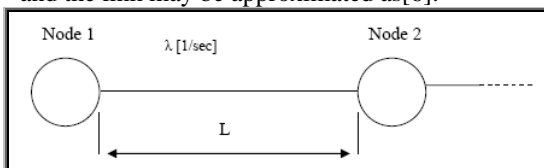
Figure (2) An integrated node of the token ring

$$R_t = R_N R_L \qquad \boxed{2}$$

where,
RN : the reliability of the active or passive node,
R L: the reliability of the link.
All the signals are delayed by 1 bit in the repeaters of the active and passive nodes. Thus, the number of bits stored in the ring is approximated as:

$$B = (L_{total} / C) b + d N \qquad \boxed{3}$$

where:
d: station latency (1 bit),
N: number of stations (nodes) in the ring,
Ltotal: ΣL-the length of the link [m],
C: speed of the light in the cables [m/sec],
b: the bandwidth [bit/sec].

It is assumed that a malfunction occurs with the exponential distribution with ratio km. Thus, the probability of a successful transmission of B bits along the link of the integrated node during time t is:

$$R_L = e^{-k_m B t} \qquad \boxed{4}$$

and the successful transmission across the integrated node is :

$$R_t = R_N e^{-k_m B t} \qquad \boxed{5}$$

Since, $R_N \cong 1$, then

$$R_t \cong e^{-k_m B t} \qquad \boxed{6}$$

The required time for one bit to pass around the ring using b bandwidth is:

$$t = \frac{B}{b}$$

Thus Eq. (6) takes the form:

$$R_t = e^{-km\frac{B^2}{b}} \qquad \boxed{7}$$

Malfunctions of the ring create the Poisson process with rate $\lambda_M = \sum B K_M$, and the probability that n malfunctions occur during the time T, for all stations, [T$\geq$0], is

$$P_n = e^{-\lambda_m T}\frac{(\lambda_M T)^n}{n!} \qquad \boxed{8}$$

2.2 Approximation of the Performability Measures of the Token Ring

To approximate the MTFT of the token ring, it may be assumed that the ring is regular and any station on the ring can transmit only one frame when it catches the token (non-exhaustive service):
The transfer times between nodes are equal to one another.

$$t_{Ti} = t_T \qquad \boxed{9}$$

where
tTi: is the transfer time from the i-th node to the (i+1)th one.
The gap will be neglected, and a user needs an access to the ring source with probability PC. It is assumed that for each user PC is the same and given by an exponential distribution with ratio λ

2.2.1 The mean waiting time

Following the argument reported in [6], and modifying the analysis to suit the case of the token ring. It is assumed that the node which is waiting for a free token has number (i=1). The waiting time for the free token depends on the token position in the ring. The optimistic case will occur when the token is released immediately in the node before the waiting one. The worst case occurs when the token is released in the source node and the next active station (i=2) needs it, and each subsequent active node in the ring also uses it [and all must wait for the ACK signal].

Each active node needs a free token with probability PC

$$P_C = 1 - e^{-\lambda t^*}$$ **10**

t*: time of thinking and waiting
and the transfer time to the next station is equal:

$$P_C(MRTT + t_T) + (1 - P_C)t_T$$ **11**

where:
MRTT: the mean real transfer time of the frame,
tT: the transfer time to the next node.
When the token is just released in the waiting station (i=1), it must be skipped to the following node. The following cases will occur:

For $i=1$ then t_{T1} .

$i=2$ $P_{C2}(MRTT + t_{T21}) + (1 - P_{C2})t_{T21} = T_2$

$i=3$ $P_{C3}(MRTT + t_{T32}) + (1 - P_{C3})t_{T32} + T_2 = T_3$

$i=4$ $P_{C4}(MRTT + t_{T43}) + (1 - P_{C4})t_{T43} + T_3 + T_2 = T_4$

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i $P_{Ci}(MRTT + t_{Ti,i-1}) + (1 - P_{Ci})t_{Ti,i-1} + T_{i-1}$
       $+ T_{i-2} + \dots + T_2 = T_i$

or

$T_i = P_{Ci} MRTT + t_{Ti,i-1} + T_{i-1} + T_{i-2} + \dots + T_2$

The token journey time from node i=j to i=1

$$T_j = \sum_{i=2}^{j} P_{ci} \quad MRTT + t_{Ti,i-1}$$ **12**

Since the token may be at each node with probability Pr{j} then the mean waiting time for the free token is:

$$MWT = \sum_{j=2}^{N} P_r\{j\} T_j + t_{T1,N}$$

$$= \sum_{j=2}^{N} P_r\{j\} \sum_{i=2}^{j} [(P_{Ci} MRTT + t_{Ti,i-1})] + t_{T1,N}$$

Since it was assumed that the ring is regular, then

$$P_r\{j\} = \frac{1}{N}, and \quad \forall i : P_{ci} = P_c, \quad t_{Ti,i-1} = t_T, and$$

$$MWT = \frac{1}{N}[(N-1)(P_c MRTT + t_T)] + t_T$$

$$= \frac{1}{N}[(N-1)P_c MRTT + N_{tT}]$$

If it is assumed that $N_{tT} = RTT$, then

$$MWT = \frac{1}{N}[(N-1)P_c MRTT + RTT]$$ **13**

The "thinking and waiting" time of the node t* may change from the smallest time tT to the biggest one (N-1)(MRTT+ tT) and it depends on the token position.
The mean value of t☐ may be approximated as:

$$E[t^*] = \frac{1}{N}(N-1)MRTT$$

$$P_c \cong 1 - \exp(-\frac{\lambda}{N}(N-1)MRTT)$$ **14**

2.2.2 The round trip time

The Round Trip Time (RTT) in token ring network can be defined as the time that the frame requires to make one trip (cycle) around the ring. This time can be calculated as:

$$RTT = \tau + T_s$$ **15**

where

τ : the propagation time,
Ts: the serving time.
τ = (Ltotal / C) + d N/b
and

$$T_s = \frac{X}{b} \qquad 16$$

2.2.3 The mean real transfer time

The sender retransmits a packet if it is not positively acknowledged (negative acknowledgement (NACK)). Retransmi- ssion of this packet continues until either the data packet is positively acknowledged or a maximum number i of retransmissions have been made. During this period, the sender holds on to the token [12, 13].

Assume that P0 is the probability of a frame being transmitted correctly then; (1- P0) is probability of a frame being transmitted with error. Thus, the probability that it will take i attempts to transmit a frame successfully is i P0 (1- P0) i-1 , in token ring this counter i is up to four tries [14]. The average time for the correct receipt of a frame (or MRTT) is then equals to:

$$MRTT = \sum_{i=1}^{\infty} i\, P_0 (1 - P_0)^{i-1} RTT \qquad 17$$

Thus, the Mean Real Transfer Time (MRTT) of the frame in the ring with N stations is estimated to be:

$$MRTT = RTT\,[P_0 + 2P_0P_1 + 3P_0P_2 + 4P_0P_3] \qquad 18$$

where:
P0: Probability of the successful transfer of the frame,

$$P_0 = P\{n = 0\} = e^{-\lambda_M RTT} \qquad 19$$

P1: Probability of malfunctions during the first transmission of the frame,

$$P_1 = P\{n \geq 1\} = 1 - e^{-\lambda_M RTT} \qquad 20$$

P2: Probability of malfunctions during the second transmission of the frame,

$$P_2 = (P_1)^2 = (1 - e^{-\lambda_M RTT})^2 \qquad 21$$

P3: Probability of malfunctions during the third transmission of the frame,

$$P_3 = (P_1)^3 = (1 - e^{-\lambda_M RTT})^3 \qquad 22$$

From Eqs. (15), (16), (17), (18), and (19), the MRTT can be obtained as follows:

$$MRTT = RTT[e^{-\lambda_M RTT} + 2e^{-\lambda_M RTT}(1 - e^{-\lambda_M RTT})$$
$$+ 3e^{-\lambda_M RTT}(1 - e^{-\lambda_M RTT})^2$$
$$+ 4e^{-\lambda_M RTT}(1 - e^{-\lambda_M RTT})^3] \qquad 23$$

2.2.4 The Mean Time of Frame Transfer

The MTFT may be approximated as the sum of the terms in equations (13) and (23). It can be expressed as follows:

$$MTFT = MWT + MRTT = \frac{1}{N}[(N-1)\,P_c\,MRTT + RTT]$$
$$+ RTT[P_0 + 2P_0P_1 + 3P_0P_2 + 4P_0P_3] \qquad 24$$

3. The Calculation Procedure of the MTFT

Computer instructions were formed using MATLAB 6.1 which computes MTFT for the token ring employing an analytical method and to illustrate the effect of main parameters that influence the MTFT of the token ring. The flowchart that shown in Fig.3 shows the procedure that calculating MTFT for different combination values of the main parameters [N, L, b, λ, and km].

Suitable values were taken in the calculations falling in acceptable practical ranges of the main parameters.
N = 20, 30, 40, …, 100 [node]
L = 20, 30, 40, 50 [m]
km =10 -6 , 10 -5 , 10 -4, ..., 10 -1 [1/sec]
λ = 1, 10 , 10 2…………… 10 6 [1/sec]

4. Results and Discussions

Fig. 4 shows the effect of N for different values of link lengths L between the nodes on MTFT

for the two network rates 4 Mbps and 16 Mbps. It is clearly seen that MTFT increases almost linearly with increasing values of N and L, and that can be due to the facts of:

-The increasing in the number of the nodes means that increasing the number of repeaters in the ring. However, it is well known that each repeater causes 1 bit delay more and thus the MTFT must increase.

- The increasing in the distance between the nodes causes the increasing in the propagation delay.

Fig. 5 shows that the MTFT grows rapidly for values of λ above 102 [1/sec]. This is because λ can affect the probability of requiring the free token by the node PC (Eq. (14)), and when λ exceeds 103 [1/sec] the probability PC will approximately be one, i.e., the case of heavily loaded ring as shown in   Fig. 6. In this case, the MTFT will not increase by increasing the exponential distribution ratio of the user access probability. This figure also shows the effect of ratio of malfunction km on the MTFT. It can be clearly seen that this parameter has very small affects on the MTFT in the range of 10-2 > km >10-6.
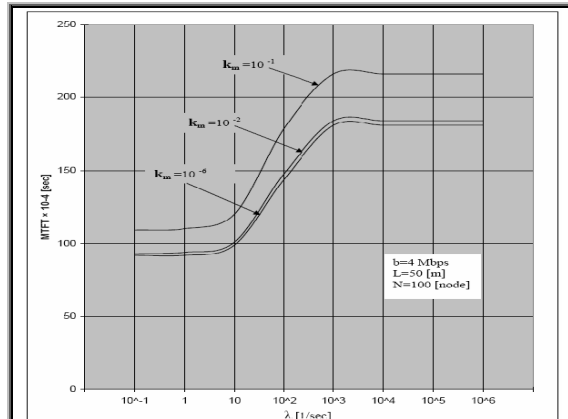

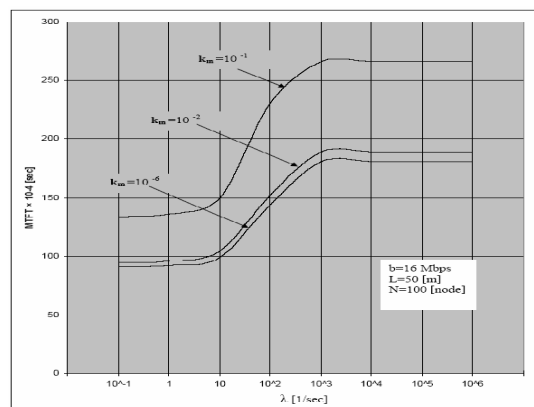**Figure (3)** The flow chart of the computer calculation for MTFT.
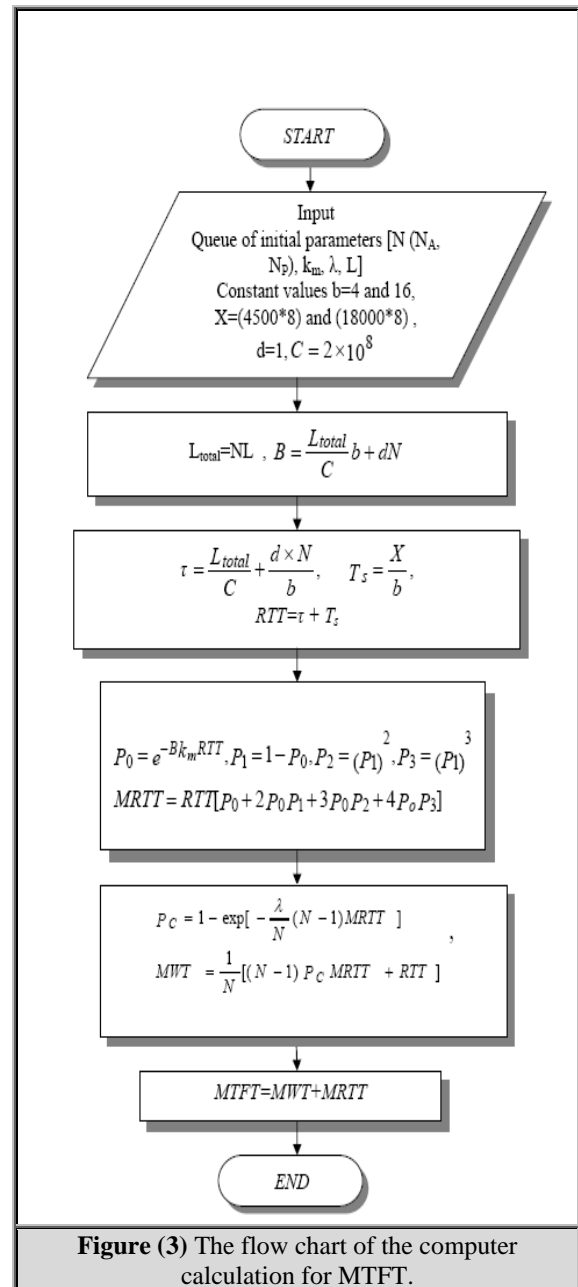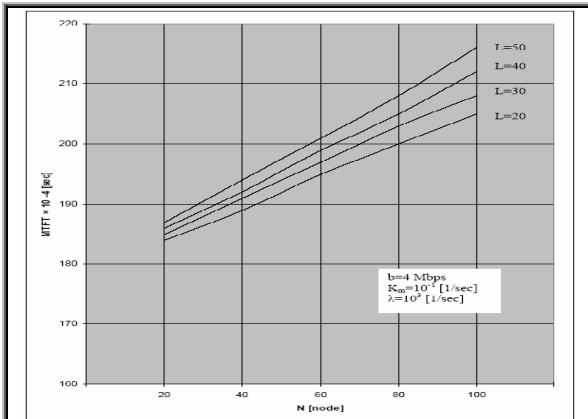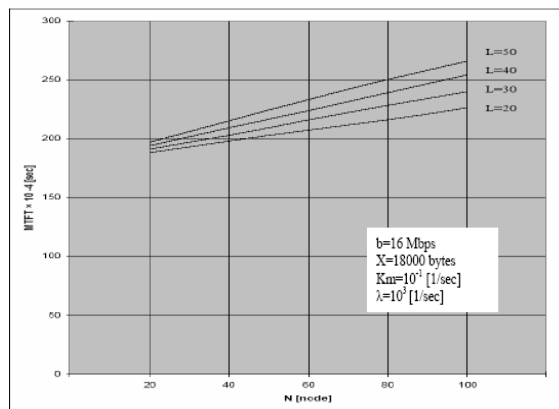
Figure (4) The influence of N on MTFT for different values of L

Figure (5) The influence of λ on MTFT for different values of km

However MTFT shows a noticeable increase in the range $10^{-1} > km > 10^{-2}$.

It is known that km effects the MRTT, since km affects the value of P0 which, in turn, affects the values of P1, P2, P3 as shown in Eqs. ((18), (19), (20), (21), and (22)). These effects can be seen in Fig. 8 and Fig. 9.

It is seen from Fig.7 that when km<10^{-3} and approaching to zero, the value of P0 becomes unity. And for km>10^{-3}, the value of P0 decreases with increasing value of N.

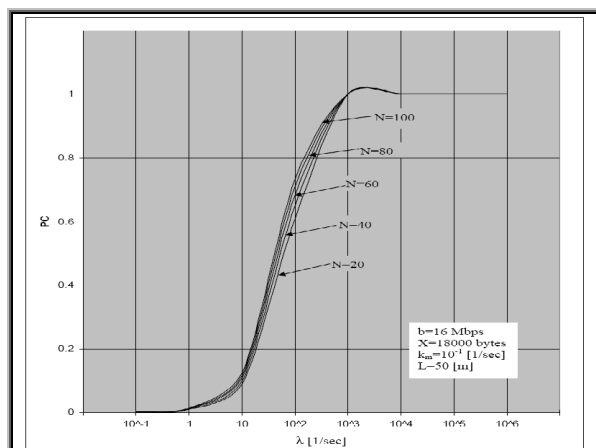And from Fig. 8, it can be seen that when km<10^{-3} and approaching to zero,

Figure (6) The influence of λ on Pc for different values of N
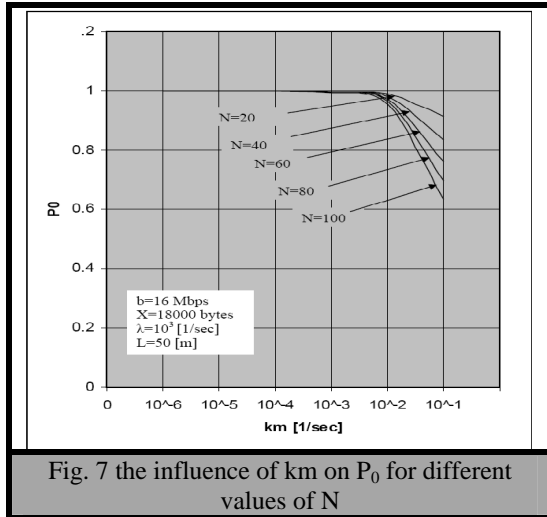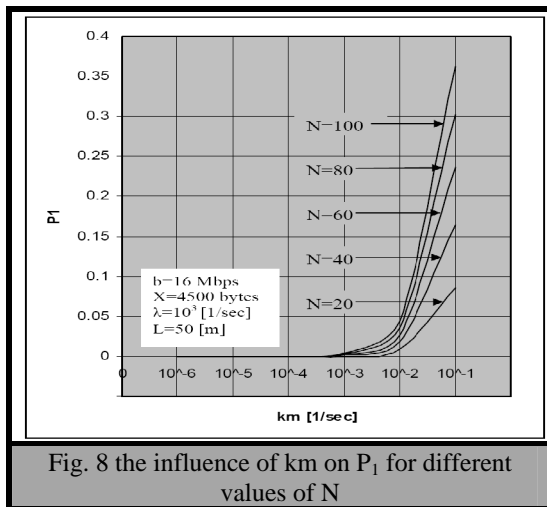
Fig. 7 the influence of km on P_0 for different values of N

Fig. 8 the influence of km on P_1 for different values of N

the value of P1 (so as P2, P3) becomes zero. And for km>10-3, the value of P1 increases with increasing value of N.

In general, when the speed of any network increases the transmission time decreases and that approved in Fig. 4 and Fig. 5 which show the MTFT for the two network bandwidth 4 and 16 Mbps.

At a first view of the foregoing curves, it seems that the MTFT either equals or larger for the larger value of bandwidth (16 Mbps). In fact this speed serves frame size of 18,000 bytes which is four times greater than that of the lower value of bandwidth (4 Mbps) which is 4,500 bytes. This leads to the conclusion that the MTFT decreases with increasing bandwidth.

V. CONCLUSIONS

From the results of the theoretical analysis the following conclusions may be drawn:

1. MTFT is linearly proportional with number of nodes.

2. MTFT is linearly proportional with length of the link.

3. MTFT increases with increasing exponential distribution ratio of the user access probability (λ). When λ approaches infinity, the value of MTFT is about two times the MRTT of the frame. MTFT decreases with decreasing exponential distribution ratio of the user access probability (λ). When λ approaches zero, the value of MTFT

is less than 4/3 times the MRTT of the frame.

4. MTFT decreases with decreasing ratio of malfunctions (km). When km approaches zero, the value of MTFT equal to the Round Trip Time (RTT) of the ring. MTFT increases with increasing km. But this is not applicable for extremely large values of km which physically means either a cut in the link or a station crash (ring failure).

5. MTFT is inversely proportional to the bandwidth (speed) of the ring (b).

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