論文 96-21-10-9

Performance Evaluation of a High-Speed LAN using a Dual Mode Switching Access Protocol

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이중 모드 스윗칭 억세스 프로토콜을 이용한 고속 근거리 통신망의 성능평가

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ABSTRACT

In this paper, a new high-speed local area network using a dual mode switching access (DMSA) protocol implemented on a dual unidirectional bus is described. By utilizing the implicit positional ordering of stations on a unidirectional bus, the proposed system switches between random access mode and the token access mode without unnecessary delay. Therefore, unlike other hybrid systems such as Buzz-net and Z-net, DMSA does not show a rapid degradation in performance as the load increases.

We obtain the average channel utilization and the average access delay by using a simplified analytic model. The numerical results obtained via analysis are compared to the simulation results for a partial validation of the approximate model. The performance characteristics of DMSA are also compared to those of Expressnet via simulations. The main advantages of DMSA are superior delay-throughput characteristics at light and medium loads, compared to other LAN systems, and the capability of providing a single active station with full capacity of the channel.

요 약

본 연구에서는 이중 단방향 버스에 기초한 이중 모드 스윗칭 억세스 (DMSA) 프로토콜을 이용한 새로운 고속 근거리통신망을 제안하고 해석하였다. 제안된 시스템은 단방향 버스상에서 각 스테이션의 위치에 묵시적인 순서가 정해짐을 이용하여 불필요한 지연없이 랜덤 억세스 모드와 토큰 억세스 모드 사이를 스윗칭할 수 있다. 이에따라 DMSA 시스템은 기존의 하이브리드 시스템에서 나타나는 부하 증가에 따른 급격한 시스템 성능저하 현상을 보이지 않는다.

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接受日字:1996年 7月 12日

시스템을 단순화한 해석적 모델을 구축하여 시스템의 채널이용률과 억세스 지연시간을 구하였다. 시뮬레이션을 통하여 해석적 모델의 타당성을 보였으며 Expressnet과 성능을 비교하였다. DMSA 시스템은 다른 근거리 통신망과 비교하여 중,저부하 영역에서 우수한 delay-throughput 특성을 보이며, 필요시 한 스테이션에 시스템의 전 채널용량을 제공할 수 있다.

I. Introduction

In the recent past, several LAN protocols aimed at high data rates have been proposed. Most of these protocols are token passing schemes (either explicit or implicit) based on unidirectional dual bus architecture[1][2][3]. These token passing protocols allow all stations a fair round robin access to the channel with a bounded delay, and provide good performance at high data rates. Under these protocols, however, there exists a delay that a station experiences between two consecutive transmissions even at very light loads. An implication of the existence of this delay (intercycle latency) is that the channel utilization is poor if the number of packets transmitted in a cycle is so small that the intercycle latency dominates the cycle length. Another problem caused by the intercycle latency is that it can prevent a station from fully utilizing the bandwidth even when there are no other stations contending for the channel[4]. Consequently, in order to overcome the intercycle latency problem, some authors have proposed hybrid protocols that combine the advantages of token passing and random access schemes[5][6][7][8]. These protocols perform access mode switching between the random access and the token access modes.

Buzz-net[5] and Z-net[6] are hybrid protocols implemented on a unidirectional dual bus architecture shown in Figure 1 (a). Under the medium access control of Buzz-net, the system switches from the random access mode to the controlled access mode using the buzz signal transmission procedure when collisions occur. In Z-net, a station has an active switch on the left-to-right (L-R) channel and a passive switch on the right-to-left (R-L) channel. Z-net performs switching implicitly via active switches on the L-R channel which block the signal propagation along the channel. The main advantage of Buzz-net and Z-net is the lack of medium access delay at light loads. A drawback of Buzz-net and Z-net is a rapid degradation of performance as load increases[4]. For instance, Buzz-net is superior to Expressnet at light load, but it is outperformed rapidly by Expressnet as load increases.

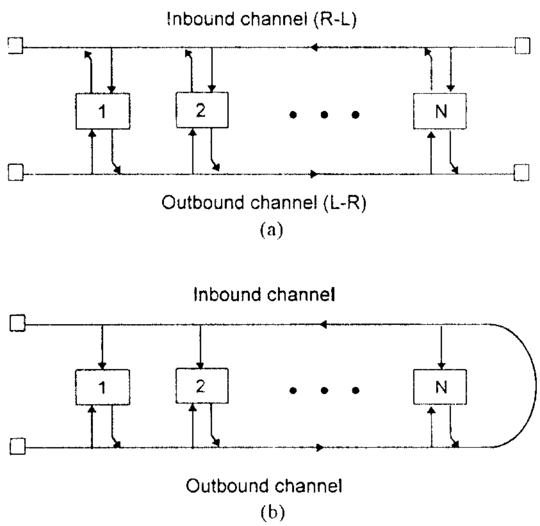


Fig 1. Unidirectional bus architectures: (a) dual bus and (b) single-folded bus.

DDMNET[7] is implemented on a singled-folded unidirectional bus architecture shown in Figure 1 (b). Under this protocol, each station transmits packets on the outbound channel as long as the channel is sensed idle. When a collision is detected in the inbound channel, the most upstream station (Station 1) initiates the controlled access mode by transmitting a control frame called LOCOMOTIVE. The main strength of

DDMNET is a good delay-utilization characteristic for a wide rage of loads. However, in the random access mode, due to asymmetry of the single-folded bus architecture, DDMNET exhibits unfairness among the participating stations. Another problem of DDMNET is that the protocol requires the most upstream station to assume a special control responsibility, which should be taken by some other station when the control station fails.

CTRA protocol[8] is a hybrid protocol based on a ring topology. This protocol uses a buffer-insertion mechanism to superimpose a random access mode to the basic timed-token access protocol. The add-on random access mode enhances network efficiency by utilizing the slack capacity not attainable by the token access protocol. CTRA, however, uses an active buffer in the station-ring interface which is not desirable for local area networks since it may results in extra cost as well as an increase in the probability of a network failure.

In this paper, we propose a new hybrid protocol, called DMSA, based on a unidirectional dual bus architecture. The proposed protocol is similar to those of other hybrid protocols in that it switches back and forth between the random access and the controlled access modes as collisions occur. The main difference is in their switching algorithms. Under DMSA, switching between the two access modes is done by utilizing the implicit positional ordering of stations on a unidirectional bus. The switching method of DMSA has a smaller latency compared to other methods based on a unidirectional dual bus architecture. Therefore, DMSA does not show a rapid degradation in performance as the load increases. In addition, unlike other hybrid protocols such as CTRA and DDMNET, DMSA does not use active station-network interfaces, and not require a specific station to perform a special control operation.

The rest of the paper is organized as follow: Section II describes DMSA protocol and presents detailed state transition diagrams. Section III presents performance analysis using an approximate model under several assumptions. In Section IV, the performance characteristics of DMSA protocol are investigated via simulations. The numerical results obtained in Section III are compared to the simulation results to provides a partial validation of the approximate model. The performance characteristics of DMSA protocol are also compared to those of Expressnet to demonstrate a niche for the protocol. Finally, Section V concludes the paper.

II. Description of Dual Mode Switching Access Protocol

Under hybrid access protocols, upon experiencing or detecting a collision, stations switch back and forth between the random and the controlled access modes according to their switching rules. Buzz-net uses a global switching procedure in which the buzz signal is transmitted to elect unanimously a station that is supposed to initiate the controlled access mode. In DDMNET, the controlled access mode is always started by the most upstream station on the bus when the station detects a collision on the inbound channel. Z-net and CTRA perform switching implicitly using active station-network interfaces.

The basic idea of our switching algorithm is that, by virtue of the unidirectional property of the dual bus, each station involved in a collision can determine its relative position on the bus among the backlogged stations by observing collisions on the bus. A station that assumes itself as the leftmost station initiates the controlled access mode immediately without waiting for a global event. Therefore, unlike other hybrid protocols such as Buzz-net and DDMNET, the system under DMSA protocol can resolve multiple collisions concurrently.

The medium access control of DMSA protocol consists of two different access modes: random access and controlled access. The controlled access mode is further divided into two submodes: token passing and suspended. Under light loads, a station is typically in the random access mode, but it enters the controlled access modes occasionally when experiencing or dectecting a collision. Under heavy loads, a station is in the controlled access mode most of the time due to the high probability of collision.

1. The Random Access Mode

The access scheme in the random access mode is essentially CSMA/CD whereby a ready station attempts to access the channel whenever it senses the channel idle, and it aborts the transmission if a collision is detected. The state transition diagram for the random access mode is shown in Figure 2. In this diagram, the labels on the arrows are the conditions that cause the transitions to occur, and the corresponding outputs of the transitions are to the right of the slash. For example, CS/CI Tx means that a station detects carrier on the bus and it transmits a CI (Collision Indicator) upon the transition. CI is a short jamming signal used to reinforce a collision. The label (CI, L-R) represents the event that a station detects a CI on the L-R bus.

2. The Suspended Mode

Figure 2 also shows a state transition diagram of the suspended mode. A non-backlogged station, upon detecting a CI, moves to the suspended mode. The station remains silent and waits for the end of the implicit token passing procedure to resume packet transmission. Note that, if a station in the Hold III state has any packet to transmit, it moves to the Interior state of the token passing mode. Therefore, a station that moves to the Hold III state with a packet ready to transmit immediately makes a transition to the Interior state. This allows a station in the Hold III state to join the token passing mode transparently without causing a disturbance.

3. The Token Passing Mode

A state transition diagram in the token passing mode where stations transmit their packets via implicit token passing procedure based on an attempt-and-defer mechanism is shown in Figure 3. As in Figure 2, the labels on the arrows are the conditions that cause the transitions to occur separated by a '/' from the outputs of the state transitions. Each station involved in a collision moves to the token passing

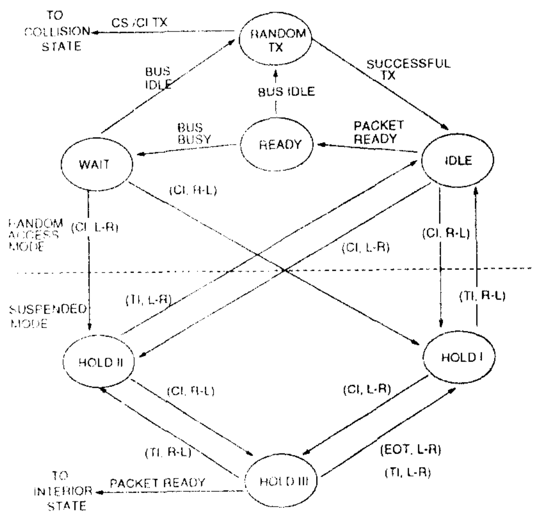


Fig 2. The state transition diagram of the random access and the suspended modes.

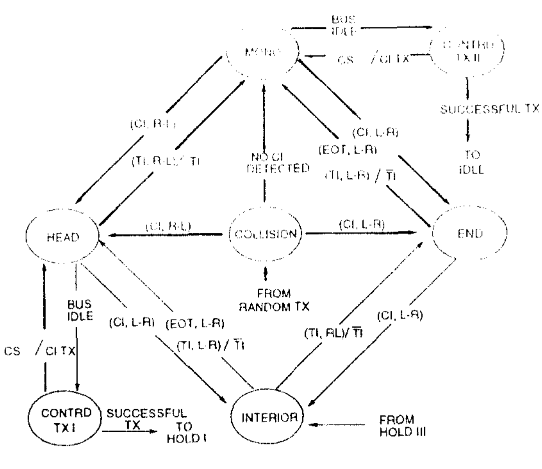


Fig 3. The state transition diagram of the token passing mode.

mode (see transition from the Random Tx state in Figure 2). By virtue of the unidirectionality of the channels, a backlogged station can easily determine its relative position among the backlogged stations by observing the CIs injected onto the bus by the backlogged stations. For instance, if a backlogged station * detects a CI propagating on the R-L channel, it knows that there is a backlogged station to its right on the bus. On the other hand, detecting no CI on the R-L channel indicates that there are no backlogged stations to its right. Therefore, if the station detects the CI only on the R-L channel, it assumes itself to be the leftmost station among the backlogged stations.

Figure 4 illustrates the above procedure for the case of two collided stations. In this figure, the system is in the random access mode, and Stations 2 and 4 start transmission of their packets at approximately the same time. When each station, while transmitting its packet, senses the transmission of the other station, it aborts its transmission and injects a CI onto the bus. Within the propagation time between the two stations, the CIs injected by each station will arrive at the other station. Upon detecting the CI injected by

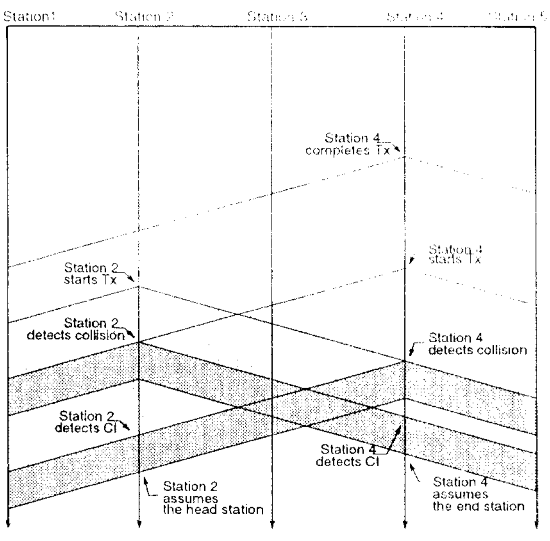


Fig 4. A Space-time diagram of a two station collision.

Station 4 on the * R-L channel, Station 2 assumes itself to be the leftmost station. Similarly, Station 4, upon detecting the CI injected by Station 2 on the L-R channel, assumes itself to be the rightmost station. Stations 1, 3, and 5 are in the Idle state. Upon detecting the CIs, they move to either the Hold I or the Hold II state of the suspended mode based on the transition rules.

The implicit token passing procedure, where each backlogged station takes its turn for a packet transmission, is initiated by the leftmost station. Then, stations in the implicit token passing mode transmit their packets according to the positional ordering via an attempt-and-defer mechanism(1). Eventually, the rightmost station terminates the implicit token passing mode by transmitting a control packet refered to as the TI (Termination Indicator) in the state transition diagram. Upon detecting the TI, each station moves to the random access mode.

Ⅲ. Performance Analysis

In this section, we evaluate the performance of the proposed protocol via both analysis and simulation. The performance measures of the primary concern are the channel utilization and the access delay. We first build an analytic model reflecting the characteristics of our system, and we then apply the method presented by Gerla et. al. (5) to the analytic model. To build an analytically tractable model, we introduce the following assumptions:

(i) There are an infinite number of single buffer stations in the system. Stations are uniformly placed on the bus.

(ii) In the random access mode, the signal propagation delay is negligible, and stations immediately transmit their packets upon arrival without sensing the bus.

(iii) In the controlled access mode, only backlogged stations take part in the implicit token passing procedure.

(iv) The CI and TI are immediately sensed by all stations on the bus. The preamble transmission time, the carrier detection time, and the TI and CI transmission time are also ignored.

Assumptions (i) and (ii) are made to simplify the random access mode analysis. Based on these assumptions, we can reduce the system in the random access mode to a one dimensional model (i. e. subsequent events occurring on the time axis) instead of a two dimensional space-time model. Assumption (iii) simplifies the analysis of the controlled access mode. Under this assumption, the number of packets transmitted in a controlled transmission cycle depends only on the length of the previous controlled transmission cycle. Therefore, the assumption makes it feasible to obtain a recursive formula for the successive controlled transmission cycles. Assumption (iv) makes the system immediately switch back to the random access mode when the controlled access mode ends.

With the above assumptions, the simplified model of the system behaves as follows. Initially, it is assumed that the system operates in the random access mode. When there occurs a collision, the system immediately switches to the controlled access mode and starts the token passing procedure. Due to the Poisson arrival assumption and Assumption (iv), the number of the stations involved in the initial collision leading to the first controlled transmission cycle is always two. Now, let's assume that the token passing procedure has ended. Then, stations having generated packets during this time period will attempt transmission of their packets. If the number of those stations is greater than one, there will be a collision. Then, after the bus becomes silent, the second token passing procedure will begin. The period consists of a contention period and a token passing period is defined as the controlled transmission cycle. If no station or only one station has generated a packet during the first controlled transmission cycle, the controlled access mode ends, and the system will switch back to the random access mode. This situation will be repeated at the end of the second controlled transmission cycle, and so on. Therefore, the bus activity of the simplified model shows a cyclic pattern alternating between the random access mode and a series of controlled transmission cycles C_is as shown in Figure 5.

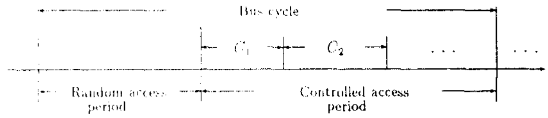


Fig 5. The bus cycle of the analytic model.

We define the random access period as the time interval during which the system operates in the random access mode, and the controlled access period as the time period which consists of a finite number of successive controlled transmission cycle. We also define the bus cycle as the time period from the beginning of a random access period to the that of the next random access period. In the following sections, we will evaluate the average bus cycle length and determine the useful portion (i.e. time spent in transmitting packets) of the controlled access and the random access periods. The channel utilization of the system is then evaluated as the ratio of the sum of the useful portions to the average lengths of the bus cycle.

1. Controlled Access Period Analysis

We assume that the arrival process to the system is Poisson with mean arrival rate λ and that the packet transmission time is fixed to T. The one-way medium propagation time is denoted by τ_B and the i^{th} controlled transmission cycle is denoted by C_i. Let us assume that the length of C_{i-1} is z_{i-1}, and that n_i packets have arrived to the system during C_{i-1}, then, as shown in Figure 6, z_i can be expressed as follows:

$$z_i = \begin{cases} d_i + n_i T & \text{if } n_i \geq 2 \\ 0 & \text{if } n_i = 0, 1. \end{cases} \tag{1}$$

The random variable d_i represents the period from the beginning of C_i until the rightmost station detects the first packet transmitted in C_i, and it depends on the random variable n_i since the distance between the leftmost and the rightmost stations in C_i is dependent on the number of arrivals in C_{i-1}. Unfortunately, with d_i random, we were not able to obtain a * recursive formula we seek due to this dependency. Thus, to make the analysis possible, we approximate d_i as D_i obtained based on the average value of z_{i-1}(see Appendix). We will discuss the impact of this approximation on the analytic results when we compare analytic and simulation results of the simplified model.

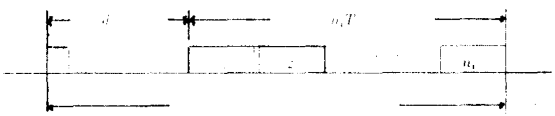


Fig 6. Illustration of the controlled access period.

Now, replacing d_i by D_i in (1), and taking the Laplace transform on both sides, we get

$$Z_i(s \mid n_i > 1,\ z_{i-1}) = E[e^{-sz_i}] = e^{-D_i s}[e^{-Ts}]^{n_i} \tag{2}$$

and

$$Z_i(s \mid n_i \le 1,\ z_{i-1}) = 1. \tag{3}$$

Removing the conditioning in (2) and (3) on the Poisson variable n_i, we have

$$\begin{aligned} Z_i(s \mid z_{i-1} = z_{i-1}) &= (1+\lambda z_{i-1})e^{-\lambda z_{i-1}} \\ &+ \sum_{n_i=2}^{\infty} e^{-D_i s}[e^{-Ts}]^{n_i} \frac{(\lambda z_{i-1})^{n_i}}{n_i!} e^{-\lambda z_{i-1}} \\ &= (1+\lambda z_{i-1})e^{-\lambda z_{i-1}} + e^{-D_i s} e^{-(\lambda-\lambda e^{-Ts})z_{i-1}} \\ &- e^{-D_i s} e^{-\lambda z_{i-1}} - \lambda z_{i-1} e^{-D_i s} e^{-\lambda z_{i-1}} e^{-Ts}. \end{aligned} \tag{4}$$

Removing the conditioning in (4) on z_{i-1}, we have

$$\begin{aligned} Z_i(s) &= \int_0^{\infty} Z_i(s \mid z_{i-1}) f_{z_{i-1}}(z_{i-1})\, dz_{i-1} \\ &= (1-e^{-D_i s})Z_{i-1}(\lambda) + e^{-D_i s} Z_{i-1}(\lambda - \lambda e^{-Ts}) \\ &- \lambda(1-e^{-D_i s} e^{-Ts}) Z'_{i-1}(\lambda) \end{aligned} \tag{5}$$

where $Z_{i-1}(\cdot)$ and Z'_{i-1} are the Laplace transforms of z_{i-1} and the derivative of the transform, respectively. From the moment generating property of the Laplace transform of a random variable, we obtain the first moment of z_i as follows:

$$\begin{aligned} \overline{z_i} &= -Z'_i(s)|_{s=0} \\ &= D_i(1 - Z_{i-1}(\lambda) + \lambda Z'_{i-1}(\lambda)) + \rho(\overline{z_{i-1}} + Z'_{i-1}(\lambda)) \end{aligned} \tag{6}$$

where $\rho = \lambda/T$. Beginning with (2), we also have the following results for the first controlled access cycle where $n_i = 2$

$$Z_1(s) = e^{-D_1 s} e^{-2Ts}, \tag{7}$$

$$\overline{z_1} = (D_1 + 2T). \tag{8}$$

Since the values of $Z_1(\lambda)$, $Z'_1(\lambda)$, and $\overline{z_1}$ can be obtained from (7) and (8), respectively, the average length of C_i for all i can be derived recursively from (5) and (6). The length of the controlled access period, L_C, is then given by

$$L_C = \sum_{i=1}^{\infty} \overline{z_i}. \tag{9}$$

Now, we evaluate the useful period in C_i for $i > 1$. Assuming that $z_{i-1} = z_{i-1}$, the conditional expected value of n_i, $i > 1$, is given by

$$\begin{aligned} E[n_i \mid z_{i-1} = z_{i-1}] &= \sum_{n_i=2}^{\infty} n_i \frac{(\lambda z_{i-1})^{n_i}}{n_i!} e^{-\lambda z_{i-1}} \\ &= \lambda z_{i-1}(1 - e^{-\lambda z_{i-1}}). \end{aligned} \tag{10}$$

Removing the conditioning in (10) on z_{i-1}, we have the average number of packets transmitted in C_i as follows:

$$E[n_i] = \int_0^{\infty} E[n_i \mid z_{i-1} = z_{i-1}] f_{z_{i-1}}(z_{i-1})\, dz_{i-1}$$

$$=\lambda(\overline{z_{i-1}}+Z'_{i-1}(\lambda)). \tag{11}$$

Since the number of packets transmitted in C_1 is always two, the total number of packet transmitted in the controlled period, N_C, is given by

$$N_C=2+\sum_{i=2}^{\infty}\lambda(\overline{z_{i-1}}+Z'_{i-1}(\lambda)), \tag{12}$$

and we have the following expression for $\hat{L}_C$, the useful time in the controlled access period,

$$\begin{aligned}\hat{L}_C&=T\cdot N_C\\&=2T+\sum_{i=1}^{\infty}\rho(\overline{z_i}+Z'_i(\lambda)).\end{aligned} \tag{13}$$

2. Random Access Period Analysis

The random period begins if there has been no more than one arrival during the last controlled transmission cycle, and it continues until a collision occurs. Let's assume that k packets have been successfully transmitted before the arrival of the $(k+1)^{th}$ packet, which then experiences a collision. Then the random access period, denoted by l_R, can be divided into three independent parts as shown in Figure 7. The first part is the time period from the end of the controlled access period until the begining of transmission of the first packet in the following random access period. The second part is a series of k successive successful transmissions until the $(k+1)^{th}$ packet experiences a collision. the last part is the transmission time of the $(k+1)^{th}$ packet until the transmission is aborted.

Let's first evaluate the average length of the second part denoted by r_2. This part is a series of k successive successful transmissions until the $(k+1)^{th}$ packet experiences a collision. Given an arrival at a station, based on Assumption (ii), the probability P_s that the transmission of the arriving packet is given by

$$P_s=e^{-\lambda T}, \tag{14}$$

and unsuccessful with probability $(1-P_s)$. Therefore, the average number of successful transmissions in the random access period, denoted by N_R, is given by

$$N_R=\frac{P_s}{(1-P_s)} \tag{15}$$

The useful portion of the random period is the time spent in successful transmissions. Thus, we have that the average length of the useful portion in the random access period, denoted by $\hat{L}_R$, is given by

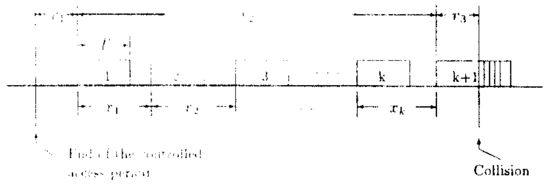


Fig 7. Illustration of the random access period.

$$\begin{aligned}\hat{L}_R&=N_R\cdot T\\&=\frac{P_s}{1-P_s}\cdot T.\end{aligned} \tag{16}$$

Since the arrival process to the system is a Poisson, the interarrival time x between two consecutive packets has an exponential distribution. The transmission of i^{th} packet is successful if the interarrival time of the $(i+1)^{th}$ packet is larger than the packet transmission time T, Otherwise, it is collided with the $(i+1)^{th}$ packet. Thus, assuming that the i^{th} packet is transmitted successfully, we have the conditional mean of x as follows

$$E\{x|x>T\}=\frac{1}{\lambda}(1+\lambda T). \tag{17}$$

The average length of r_2 is then give by

$$R_2=\frac{1}{\lambda}(1+\lambda T)\cdot N_R. \tag{18}$$

The last part, denoted by r_3, is the transmission time of the $(k+1)^{th}$ packet until the transmission is aborted due to the arrival of the next packet. Hence, the average length of this part is given by

$$R_3 = E\{x \mid x < T\} = \frac{1 - e^{-\lambda T}(\lambda T + 1)}{\lambda(1 - e^{-\lambda T})} \quad (19)$$

The first part denoted by r_1 is the time period from the end of the controlled access period until the beginning of transmission of the first packet in the following random access period. The probability that there is no arrival during the i^{th} controlled transmission cycle C_i is given by

$$\int_0^\infty e^{-\lambda z_i} f_{z_i}(z_i)\, dz_i = Z_i(\lambda). \quad (20)$$

Similarly, the probability that there is one arrival during C_i is given by

$$\int_0^\infty \lambda z_i e^{-\lambda z_i} f_{z_i}(z_i)\, dz_i = -\lambda Z_i'(\lambda). \quad (21)$$

At the end of the i^{th} controlled transmission cycle C_i, the controlled access period ends with probability $(Z_i(\lambda) - \lambda Z_i'(\lambda))$ or continues with probability $(1 - Z_i(\lambda) + \lambda Z_i'(\lambda))$. The probability $p_0(i)$ that the controlled period ends at the end of the C_i with no arrival is given by

$$p_0(i) = Z_i(\lambda) \prod_{k=1}^{i-1} [1 - Z_k(\lambda) + \lambda Z_k'(\lambda)]^k. \quad (22)$$

Similarly, the probability $p_1(i)$ that the controlled period ends at the end of the C_i with one arrival is

$$p_1(i) = -\lambda Z_i'(\lambda) \prod_{k=1}^{i-1} [1 - Z_k(\lambda) + \lambda Z_k'(\lambda)]^k. \quad (23)$$

The average length of r_1 is $1/\lambda$ with probability $\sum_{i=1}^{\infty} p_0(i)$, and zero with probability $\sum_{i=1}^{\infty} p_1(i)$. Hence, we have the average length of the first interarrival time in the random access period

$$R_1 = \frac{1}{\lambda} \sum_{i=1}^{\infty} p_0(i). \quad (24)$$

Now, the average length of the random period, L_R, is given by the sum of the three parts

$$L_R = R_1 + R_2 + R_3 = \frac{1}{\lambda} \sum_{i=1}^{\infty} p_0(i) + \frac{1}{\lambda}(1 + \lambda T) N_R + \frac{1 - e^{-\lambda T}(\lambda T + 1)}{\lambda(1 - e^{-\lambda T})}, \quad (25)$$

where $p_0(i)$ and N_R are given by (22) and (15), respectively.

The channel utilization of the proposed system can be expressed as the ratio of the length the useful portion to the length of the bus cycle. Thus, we finally have the channel utilization of the proposed system as follows:

$$U_s = \frac{\hat{L_R} + \hat{L_C}}{L_R + L_C}. \quad (26)$$

3. Delay Analysis

The average access delay can be evaluated as the total waiting time of all packets that are successfully transmitted in a bus cycle divided by the number of those packets in the bus cycle. Figure 8 illustrates the waiting times for the stations that generated packets during the $(i-1)^{th}$ controlled transmission cycle C_{i-1} until they transmit their packets successfully in the i^{th} controlled transmission cycle C_i. Assume that $n > 1$ stations generated their packets during the $(i-1)^{th}$ controlled transmission cycle C_{i-1}, whose length is z_{i-1}. Then the station waits $z_{i-1}/2$ seconds on the average until the i^{th} controlled transmission cycle C_i begins. From the beginning of C_i, all stations wait $\hat{\delta_i}$ seconds until the token passing procedure begins. The k^{th} station waits d_{1k} seconds, which is the propagation time between the leftmost station and itself, prior to detecting the beginning of the first packet of the token passing procedure. After detecting the beginning the first packet, the k^{th} station waits $(k-1) \cdot T$ seconds until it starts the successful transmission of its packet.

From the above argument, the wating time w_k of the k^{th} station in C_i can be expressed as

$$w_k(z_{i-1} = z_{i-1}) = \frac{z_{i-1}}{2} + \hat{\delta_i} + d_{ik} + (k-1)T. \quad (27)$$

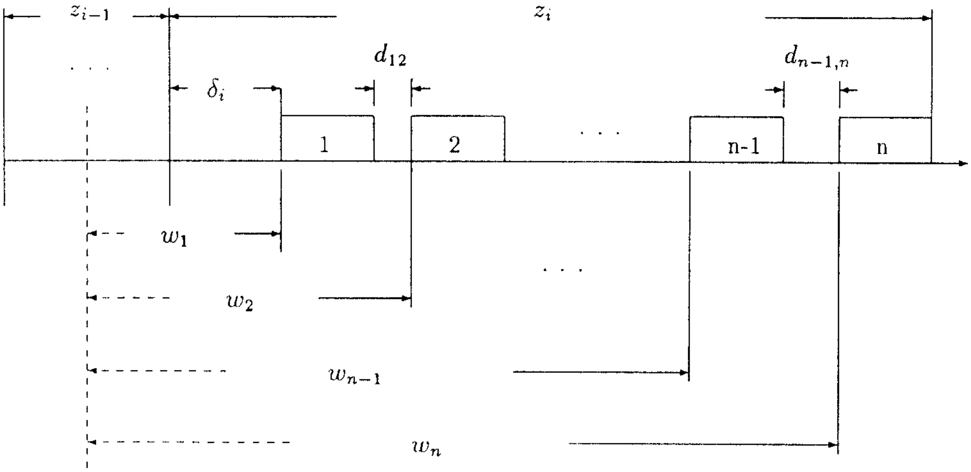


Fig 8. Illustration of the waiting time in C_i.

Thus, the sum of the waiting times of $n > 1$ stations in C_i is given by

$$\bar{\Omega}_i (z_{i-1} = z_{i-1} \mid n) = \sum_{k=1}^{n} w_k$$

$$= n \frac{z_{i-1}}{2} + n\hat{\delta}_i + n \frac{\hat{\delta}_i}{2} + \frac{n(n-1)}{2} T, \qquad (28)$$

when n is one, the average wating time is $z_{i-1}/2$. Removing the conditioning on n and z_{i-1} in (28), we obtain the total average wating time of packets transmitted in C_i as follows:

$$\bar{\Omega}_i = \frac{\lambda(1+\lambda T)}{2} \overline{z_{i+1}^2} + \frac{3\hat{\delta}_i}{2} (\overline{z_{i-1}} + Z'_{i-1}(\lambda)), \; i \geq 2. \qquad (29)$$

Recall that the number of stations in the first controlled transmission cycle is always two. From the beginning of the first controlled transmission cycle, the leftmost station waits $\hat{\delta}_i$ seconds and the rightmost station waits $(2\hat{\delta}_i + T)$ seconds, respectively, to start their packet transmissions. Thus, the average total waiting time of the two stations in C_1 is given by

$$\bar{\Omega}_1 = R_3 + 3\hat{\delta}_i + T, \qquad (30)$$

where R_3 is the additional waiting time of the station that aborted its transmission upon sensing the later transmission of the other station.

The second moment of z_i that is required to compute $\bar{\Omega}_i$, can be derived from (5) as follows:

$$\overline{z_i^2} = Z''_i(s)|_{s=0}$$

$$= \begin{cases} D_i^2(1 - Z_{i-1}(\lambda) + \lambda Z'_{i-1}(\lambda)) + \rho(2D_i + T)(\overline{z_{i-1}} + Z'_{i-1}(\lambda)) \\ + \rho^2 \overline{z_{i-1}^2}, & i \geq 2 \\ (D_1 + 2T)^2, & i = 1 \end{cases} \qquad (31)$$

where $\rho = \lambda / T$.

The total average waiting time Ω_C for the packets that arrive during the controlled access period is given by

$$\Omega_C = \sum_{i=1}^{\infty} \bar{\Omega}_i. \qquad (32)$$

Since packets transmitted in the random access period experience no access delay, we can express the average access delay at light to medium load as follows:

$$D_s = \frac{\Omega_C}{N_R + N_C}. \qquad (33)$$

Ⅳ. Numerical and Simulation Results

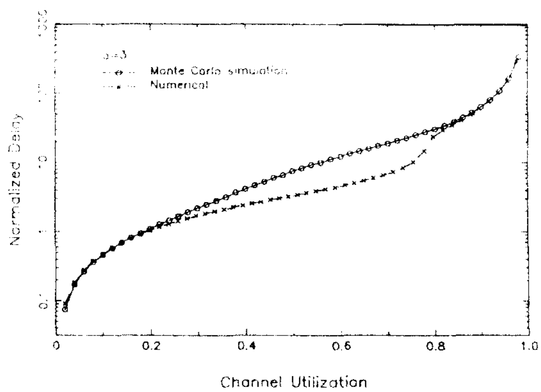
In this section, we compare numerical results obtained from the expressions for the channel utilization and the average access delay in the previous sections to simulation results for both the simplified model and the actual system.

Given an arrival rate, we computed $Z_i(\lambda)$ and $Z_i'(\lambda)$, $i = 1, 2, \cdots$, using the recursive expressions (5), (6), (7), and (8). We then computed all the values required to obtain the channel utilization and the average access delay from (26) and (33), respectively. For $\lambda < 9.4$, the average length of the controlled transmission cycle reached 99% of the steady state value at $i \leq 100$. For $\lambda > 9.4$, the controlled access period reached the steady state more slowly. For example, for $\lambda = 9.7$, the controlled transmission cycle reached 99% of the steady state at $i \approx 150$. Thus, when λ is less than 0.94, the computation of $Z_i(\lambda)$s and $Z_i'(\lambda)$s was performed for $i \leq 500$ (The difference between the results of 500 iterations and 900 iterations was less than 0.1%). For $\lambda > 9.4$, the iteration number was increased to 900.

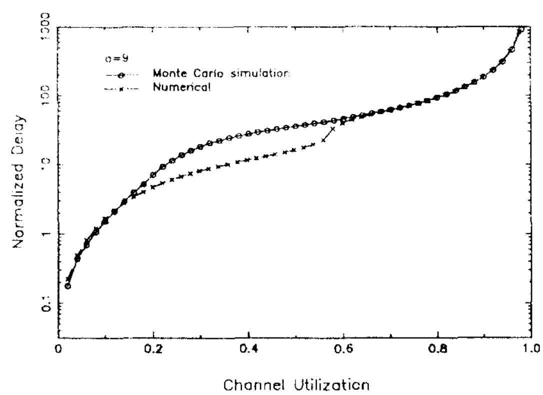
Table 1. Network parameters used in the simulations.

Parameter	value
Number of stations	101
Bus length	1 to 15 km
Data rate	100 Mbps
Permble lenght	64 bits
Data packet length	1000 bits (fixed)
Carrier detection time	20 bits
Medium propagation delay	100 μs/km

In Figure 9, the numerical results are compared to the results obtained via Monte Carlo simulations of the simplified model built for the analysis. We assume that the packet transmission time is fixed to 10 μs, and vary the bus length from 3 km to 9 km to get values of the normalized medium propagation delay a ranging from 3 to 9. Figure 9 shows that numerical results match the simulation results very well in the low and high utilization regions. In the medium utilization region, our analytic approximation appears to overestimate • the simplified model. This results from the approximation of the contention period d_i to the deterministic value D_i based on the average value of the previous controlled transmission cycle length. The approximation is optimistic in that the variation of the controlled transmission cycle length is ignored, and hence results in the overestimation of the analytic model in the medium utilization region. The analytic evaluation in the low utilization region is not affected by the approximation since the random access period dominates the bus cycle in this region.



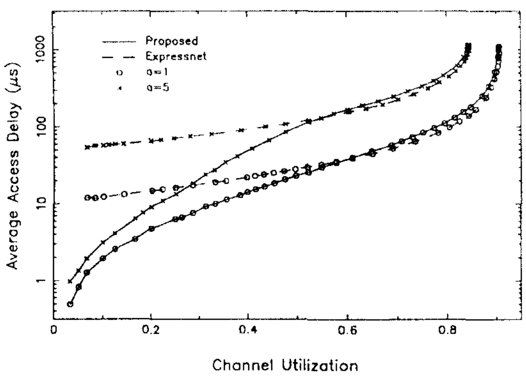
(a)



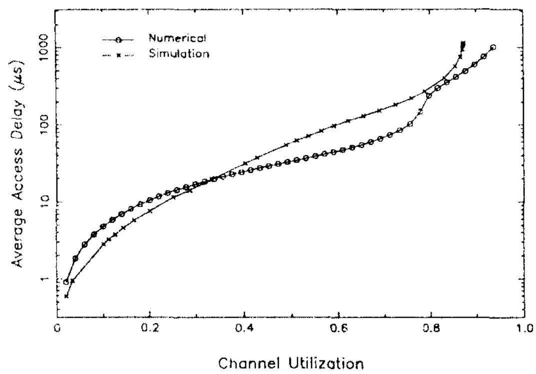
(b)

Fig 9. Comparisons of numerical and simulation results of the analytic model for $a = 3$ (a) and 9 (b).

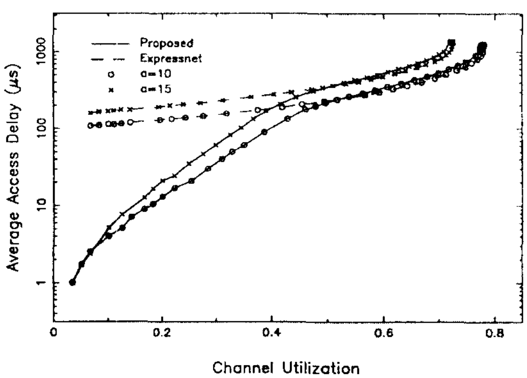
In Figure 10, we compare the numerical results to the results obtained from Monte Carlo simulations of the actual DMSA system. Network parameters used in the simulation are shown in the Table I. We can see that, due to Assumption (ii), the analytic results underestimate the delay of the actual system under light loading. When a is small, the analytic results provide a good approximation of the performance of the actual system under light loading (Figure 10 (a)). The reason for this is that, when a is small, the possibility of the concurrent transmissions are low even under light loading, and hence Assumption (ii) does not have a significant impact on the performance characteristics. Under heavy loading, the analytic results appear to overestimate the delay of the actual system when a is small. This can be explained as follows: The assumption of immediate TI sensing shortens the contention period, and hence results in the overestimation of the delay under heavy loading. Assumption (iii), however, is an unfavorable because it does not allow stations to transmit packets generated after the contention period, and its impact on the performance is pronounced when a is large. Therefore, the analytic results tend to underestimate the delay of the actual system under heavy loading when a becomes larger (Figure 10 (b)).



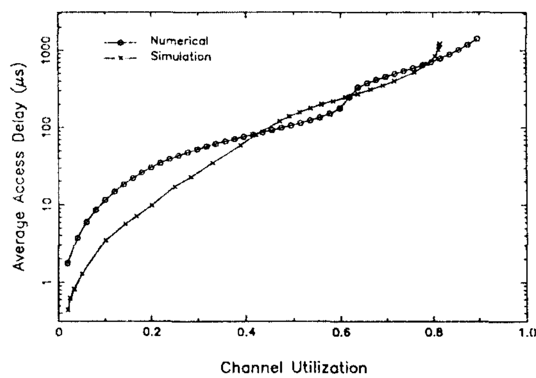
(a)



(a)



(b)



(b)

Fig 10. Comparisons of numerical results of analysis and simulation results of the actual system for $a=3$ (a) and 7 (b).

Fig 11. A comparison of utilization-delay performance of DMSA system and Expressnet for $a=1$, 5 (a), 10, and 15 (b).

In Figure 11, the simulation data presented in Figure 10 are compared to those of Expressnet obtained by using the same network parameters in Table I. We vary the bus length from 1 to 15 km to get values of a ranging from 1 to 15. As shown in the figure, DMSA system has superior performance at light loads. Unlike Buzz-net or Z-net where performance rapidly degrades as load increases, the proposed system system outperforms Expressnet up to a utilization of 0.6. At higher utilizations, Expressnet outperforms DMSA system since it does not have the contention period. When $a=1$, the performance characteristic curves of the two systems are almost identical. As a increases, however, the two systems are significantly different in the low utilization region. The difference in the high utilization region remains relatively unchanged. DMSA system has the same maximum channel utilization and corresponding average access delay as Expressnet since its operation is almost identical to that of Expressnet when all stations are constantly busy.

Ⅴ. Conclusion

In this paper, we developed a new LAN protocol with a dual mode switching access protocol, called DMSA, implemented on a unidirectional dual bus. Using implicit positional ordering of stations on a unidirectional bus, we devised a fully distributed algorithm for switching between the random access and controlled access modes without an unnacessary delay.

The performance of DMSA protocol was investigated using both analytic models and Monte Carlo simulations. Under several simplifying assumptions, we evaluated the channel utilization and the average access delay of DMSA protocol. Although the approximate analytic model is based on several unrealistic assumptions, it appears to retain the basic characteristic of the proposed protocol. We ran simulations of DMSA protocol for various values of the normalized medium propagation delay ranging from 1 to 15. When compared to Expressnet, DMSA system has superior utilization-delay characteristics under light to medium loading.

DMSA protocol eliminates intercycle latency problems that exist with token passing protocols such as Expressnet and FDDI. Unlike other mode switching protocols such as Buzz-net and Z-net, DMSA protocol does not show a rapid performance degradation as load increases. In addition, DMSA does not require active station-network interfaces and a certain station to perform a special control operation. Therefore, DMSA protocol is suitable for high-speed networks operating in the LAN environment.

Ⅵ. Appendix

We evaluate D_i based on the average length of $(i-1)^{th}$ controlled transmission cycle. The probability that there are n_i arrivals during a time interval of $\overline{z_{i-1}}$, which is the average length of C_{i-1}, is given

$$Pr\{\mathbf{n}_i=n_i\}=\frac{(\lambda\overline{z_{i-1}})^{n_i}}{n_i!}e^{-\lambda\overline{z_{i-1}}}. \qquad (\mathrm{I})$$

Assuming that the n_i arrivals during C_{i-1} are evenly distributed along the bus, the average propagation time δ_i between the leftmost and the rightmost stations in C_i is given by

$$\delta_i(\mathbf{n}_i=n_i)=\tau_B\frac{(n_i-1)}{(n_i+1)},\ i>1,\ n_i>1, \qquad (\mathrm{II})$$

where τ_B denote the channel propagation time[9]. Removing the conditioning in (II) on $\mathbf{n}_i$ by using (I), we have the following approximation:

$$\hat{\delta}_i=\sum_{n_i=2}^{\infty}\tau_B\frac{(n_i-1)}{(n_i+1)}\frac{(\lambda\overline{z_{i-1}})^{n_i}}{n_i!}e^{-\lambda\overline{z_{i-1}}}$$
$$=\tau_B\left(1+e^{-\lambda\overline{z_{i-1}}}+\frac{2}{\lambda\overline{z_{i-1}}}(e^{-\lambda\overline{z_{i-1}}}-1)\right),\ i>1.$$

From the beginning of C_i (i.e., from the moment of the collision leading to C_i), the leftmost station waits

$\hat{\delta}_i$ seconds until the bus becomes idle due to the propagation delay between the leftmost and rightmost stations. It then takes another $\hat{\delta}_i$ seconds for the packet transmitted by the leftmost station to arrive at the rightmost station. Hence, it follows that

$$D_i = 2\hat{\delta}_i$$
$$= 2\tau_B\left(1 + e^{-\lambda\overline{z_{i-1}}} + \frac{2}{\lambda\overline{z_{i-1}}}\,(e^{-\lambda\overline{z_{i-1}}} - 1)\right),\ i > 1.$$

From (II), the average distance between the two backlogged stations in the first controlled transmission cycle C_1 is $\tau_B/3$ since $n_i = 2$. Thus, we have

$$D_1 = \frac{2\tau_B}{3}.$$

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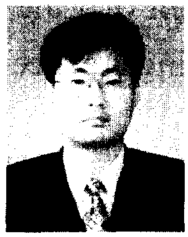

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