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Proposal and Evaluation of a Hybrid Access Control Method for Improving the Delay of Bus Topology LANs

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LANs, applied in different conditions, are of different performance characteristics. For plant control and factory automation, a time critical communication is important for real-time control, though the transmission speed of LANs today has been enhanced to be very high. As a standard, CSMA/CD is one of the most popular underlying technologies of LAN. By CSMA/CD, as load increases, the delay quickly becomes long and transmission time cannot be guaranteed. Here, we propose a Hybrid Access Control Method (HACM) based on CSMA/CD to improve its efficiency and integrate it with Token Bus just by changing the algorism in the MAC layer. In this paper, we propose improving CSMA/CD method to suit not only in the case of a low load but also in the case of a comparatively high load by exchanging to Token Bus according to the communication situation on LANs. As a main performance index of LAN, the delay can be estimated by an approximate formula for theory analysis, but for deciding by which mode is better dynamically, obtaining and processing information are somehow complex and analysis results have some difference from practice. Therefore, considering facility and practicability, we select indexes which can be easily obtained for the proposed HACM. The indexes are proved to be appropriate, and the proposed HACM is efficient according to the results of simulations.

1. Introduction

For design of LANs, high throughput and low delay are requested. And for plant control and factory automation, a time critical communication is important [1),2)], though the transmission speed of LANs was enhanced to be very high today. The media access method is an important factor which influences the performance of a LAN. There are two typical LANs, CSMA/CD [3)] and the token passing [4)]. The former applies to low load and the other applies to relatively heavy load.

A transmission delay of CSMA/CD is relatively short in the case of low load. But, with the load increasing, collisions increase, and the transmission delay becomes long very quickly [5)]. In general, CSMA/CD LAN is used in the case of the load under 20–30%. In the other hand, the performance of token passing LAN is better in the case of comparatively heavy load [6)]. On token passing LAN, in the case of relatively heavy load, because collisions can be avoided, the transmission delay is shorter than that of CSMA/CD. When load falls, the number of sites that have transmission requests decreases, but the token has to turn over all sites. So, in this case, transmission delay becomes longer than that of CSMA/CD.

Considering the above, we propose a Hybrid Access Control Method (HACM) which can be realized by means of reforming the Media Access Control (MAC) of CSMA/CD to make LANs to change the access control method between CSMA/CD and Token Bus in order to make Bus Topology LAN performs better. By this proposed HACM, the transmission delay can be expected to be improved.

CSMA/CD is a popular protocol, and much related work has been done on improving CSMA/CD from it's appearance. Based CSMA/CD, there are several protocols designed, such as acknowledging Ethernet [7)] and method of changing transmitting probability [8)]. The former method is for the transmission of data with priority by changing the packet interval. By the latter method, the carrier detection signal is checked with a certain internal. When finding a carrier, the site increases transmission probability. Otherwise it decreases transmission probability by which the site decides whether it sends a frame when a transmission request comes. By this method, congestion could be alleviated when traffic increases.

Another protocol Rether (Real-Time Ethernet), which can be thought of as a hybrid

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method based CSMA/CD and Token Bus, is developed as an efficient network bandwidth guarantee mechanism over off-the-shelf Ethernet without any hardware changes, thus preserving the enormous investment in the existing network infrastructure [9),10)]. Rether, based on a token passing scheme, regulates the access to the network by passing a control token among the nodes on an Ethernet segment. In particular, Rether features a hybrid mode of operation that automatically switches a local area network between the Rether mode and the CSMA/CD mode, depending on whether there are real-time connections active at the time. In the case of no active real-time connections, the network operates according to the CSMA/CD method.

There is another related research reported, that improving CSMA/CD method by introducing the Token Ring method for optical fiber [11)]. By this method, every site accesses media originally like CSMA/CD. When collision occurs, transmissions will be carried out in the order from the site near one end of bus to the other end like token passing. After all sites finish their transmissions, the access method is changed to a method like CSMA/CD again. The changeover index is very simple and is convenient to be obtained and calculated, but is not strict in some cases.

In this paper, in order to improve delay, we propose an algorithm to the MAC sublayer to make an access method change between CSMA/CD and Token Bus according to communication situation for Bus Topology LANs based on CSMA/CD method, which is widely used. We evaluated this method by simulations and it is proved to be effective. Section 2 provides a proposal and the related problems. The solution of key problem that changeover index and the detail of algorism are presented in Section 3. The simulation results and analysis are given in Section 4. In the last section, results are discussed and further work is referred.

2. Proposal of Hybrid Access Control Method

In this section, we give a proposal of a hybrid access control method and discuss the related problems.

In case of low load, the delay characteristics of CSMA/CD are better, and on the contrary, in case of heavy load, Token Bus is better. Accordingly, we try to propose the Hybrid Access Control Method which changes between two modes, CSMA/CD and Token Bus, according to transmission situation as load changes.

The CSMA/CD protocol requires that before a node is allowed to transmit a signal to another node, it must check the line to see whether it is in use. If no other node is using the line, the node can go ahead and send its message. But if the network is already in use, the node will wait a short, random period of time and try again until the line is free. If more than two sites find the media is free and begin to send frames at the same time, then a collision occurs.

The CSMA/CD mechanism built into the Ethernet at each device solves collisions by algorism of backoff. Collisions increase with traffic load, and the delay rises up very quickly. Consequently, the throughput also decreases. If the system can changeover to the token bus at appropriate situation, we can expect that the delay will improve. Changing access control method of system to Token Bus method can be realized by a mechanism built into MAC sublayer, that when a site on the LAN finds the delay will be improved by Token Bus method, it broadcasts a message to inform the other sites to change access method. In order to transmit frames by Token Bus, mechanism like token bus method needs to be built into MAC sublayer.

Certainly, when a site finds that the delay will be reduced by CSMA/CD, it broadcasts a message to inform the other sites to change access method.

There are several problems that should be considered, which are related to whether the proposed HACM can perform efficiently, such as

- Changeover Index (to CSMA/CD, to Token Bus)
- Overhead of changeover
- Stability
- Equality
- LAN conservation

The first problem above is the key for the HACM. In order to decide when system changes the access method, each site needs to gather information about situation of LAN for changing from CSMA/CD to Token Bus or from Token Bus to CSMA/CD, and calculate the index of changeover. The information selected for obtaining index of changeover must be simple enough to be gathered. Otherwise, gathering information of LAN situation will attach load to the LAN. At the same time, ob-

tained index must correctly reflect that in which method the delay can be decreased in different situation which mainly depends on frame length and load of LAN. Another problem is overhead of changeover. Because HACM can employ same frame format of CSMA/CD or Token Bus, there is no difference in the frame length. But while LANs change access control method, at least, a message needs to be sent for informing the other sites on the LANs. Overhead for changing is related to another problem that stability of the system. Thinking proposed HACM is a protocol that changes access method between CSMA/CD and Token Bus according to situation of LANs, if load of LANs changes drastically in a short interval, there is a possibility that LANs change access method between two modes. We can avoid this problem by selecting appreciative indexes for changing. As for the equality, all sites on the LANs are equal each other for obtaining shared medium to transmit either in mode of CSMA/CD or Token Bus. Similarly, it is necessary that each site is equal to change access method at appropriate situation, which is important to avoid that one site breakdown influences transmission of LANs. About LAN conservation, we can use the same way of CSMA/CD or Token Bus. When there is a new site to join into the LAN, the site needs to do nothing when the LAN is in the mode of CSMA/CD. After it obtains a message changing to Token Bus, the new site needs to carry out algorism of Token Bus method for new site joining to the LANs. Certainly, if the LAN is in the mode of Token Bus, the new site needs to do the same that should be done for Token Bus method.

In the following sections, we will emphatically discuss the key problems of changeover index and changeover algorism.

3. Realization of the Hybrid Access Control Method

In this section, we will investigate the key problem of changeover index and give the algorism for realizing the proposed HACM.

3.1 Analysis of Changeover Condition

When realizing this protocol, the key problem is how to obtain indexes for changeover. The indexes for deciding to change medium access method should satisfy several conditions: (i) reflecting situation of communication exactly in different conditions such as the load and frame length; (ii) making every site on equal term, which every site has equal chance to request for changing transmission mode; (iii) being obtained and calculated simply.

Estimating delays of CSMA/CD and Token Bus has been studied, and the formulas are given respectively. In a fixed system, the transmission delay mainly depends on the load, arrival probability and frame length. With assumption of a fixed frame length, two parameters of the load, arrival probability and frame length are independent. In practice, comparing delays in the case of CSMA/CD and Token Bus by formulas to understand by which method delay is short, is somehow complex. Here, we select simple indexes for changeover between two methods, and verify its validity by analysis and simulations.

For CSMA/CD, every site is on equal term to transmission medium. When load increases, because of congestion, the incidences of collisions and continuous collisions rise up quickly. Consequently the delay increases quite rapidly [12]. So, the continuous collision can be thought as parameter which reflects transmission situation, and is suitable to be chosed as a changeover index for changing from CSMA/CD to Token Bus.

We estimate the incidence of continuous collision versus load in the case of different frame length for CSMA/CD by simulations. The simulation parameters of CSMA/CD are shown as follows:

- Linear bus topology
- Even interval of sites on bus LAN: 20 m
- n sites in LAN
- Delay of cable: 5 ns/m
- Message occurring by interval of exponential distribution
- Fixed frame length in once simulation
- Transmission speed: 10 Mbps
- Frame gap: 9.6 μs

In above parameters of model, the LAN is assumed as a bus type LAN with a same interval of 20 m, which is related to probability of collision in mode of CSMA/CD. Routers for simulation model means extending the interval between sites, which are omited here. Since thinking no special applications here, we assume message occurring in every site as Poisson arrival which is well used for modeling a queuing system. The framelength is set as constant approximately for one time simulation, though the distribution of frame length has some influence on the behavior of LANs.

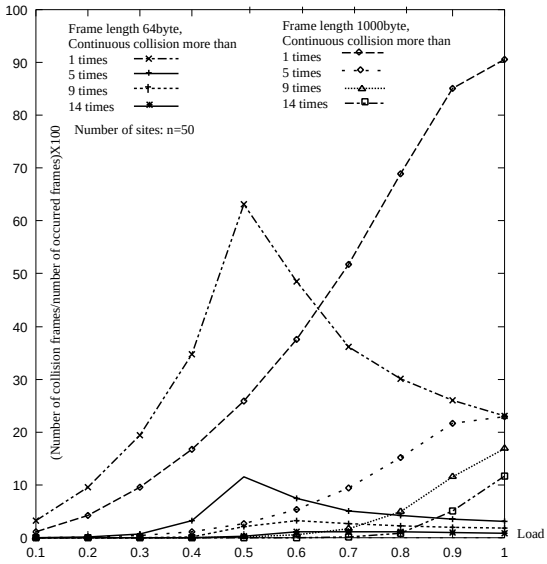

Fig. 1 Incidence of continuous collision.

Simulation results about continuous collisions by CSMA/CD, are shown in **Fig. 1**, whose horizontal axis expresses load, vertical axis expresses number of collision frames regularized by total number of occurred frames. From Fig. 1, we can find that the incidence of continuous collision becomes high when the load rises. Because of aborted frames at heavy load, after a peak, the curves have a drop in case of frame length 64 byte.

As for the index of changeover from Token Bus to CSMA/CD, it is necessary to understand the communication situation of Token Bus LAN, which needs information about the load and the arrival probability. The latter depends on the frame length in the case of a certain load. However, it is troublesome to obtain the number of frames being sent in per unit time on the LAN which will impose load to LAN.

Here, we select the incidence of idle cycle and the average time for a token to traverse the logical ring of sites, which are easy to be obtained, to try to reflect load and the arrival situation for approximately. Here, we give an approximate analysis.

Assuming frame arrivals of every site as Poisson probability with the same arrival probability λ_i, we model a Token Bus LAN as n (number of sites) independent M/G/1 queues with constant x, the time to passing the token between any pair of adjacent sites and constant y, the time that a site holds the token if it has a message to transmit. Although the arrival process defined by the arrivals of the token at any site will not, in general, be Poisson, we make the approximating assumption that the probability of nonempty when a token arrives at a site is the same as in the steady state, that is ρ_i. Then, its service time is $S = nx + Ky$ (average cycle time of token), where the K is binomial with paprameters (n, ρ_i). Let its mean service time be m, we have equation $\rho_i = \lambda_i m$. Then probability of idle cycle for each circle can be expressed as

$$P\{\text{Cycle is idle}\} = (1 - \rho_i)^n \tag{1}$$

and

$$m = \frac{W}{1 - \rho} \tag{2}$$

where W is mean walk time of an idle cycle and ρ is throughput of whole network.

The variance $\mathrm{Var}[S]$ becomes

$$\mathrm{Var}[S] = y^2 n \rho_i (1 - \rho_i) \tag{3}$$

which is related to the selection of sample cycle number in the after section to obtain the average cycle time for changeover.

In general, with above assumption, throughput of every site is equal to each other, that, $\rho_i = \rho/n$ and in the case of low load before aborted frame occurs the load is equal to throughput. Let the frame length be constant L (byte) and transmission speed of network be V (bit/sec), the probability of idle cycle becomes

$$P\{\text{Cycle is idle}\} = \left(1 - \frac{\rho V W}{8Ln(1 - \rho)}\right)^n \tag{4}$$

Above formula is obtained with assumption that when token comes only one frame will be sent. In fact, we should revise the frame length L for practice model. Here, we introduce a coefficient α (> 1) to the L and the formula becomes

$$P\{\text{Cycle is idle}\} = \left(1 - \frac{\rho V W}{8\alpha Ln(1 - \rho)}\right)^n \tag{5}$$

According above formula, we compared with results of simulations shown in **Fig. 2**. The time relay between two sites is assumed as 15.2 μs, and the other related parameters of network are assumed same as those used for CSMA/CD. As shown in Fig. 2, according to three sets of lines with different frame length, 64 byte, 512 byte and 1500 byte, the results of Eq. (5) are close to that of simulation.

According to results of simulation, the inversion load at which delay of CSMA/CD and

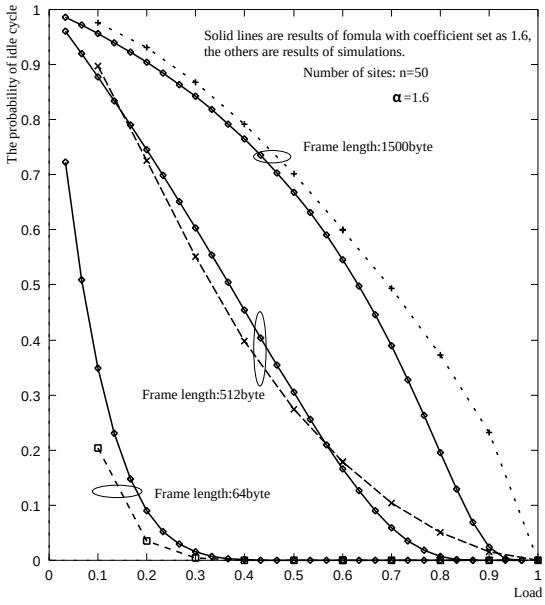

Fig. 2 Incidence of idle cycle.

Token Bus inverses varies with different frame length, the longer the frame length is, the higher the inversion load. If we select the probability of idle cycle as index of the Token Bus to CSMA/CD, for a certain value of P, the change tendency of frame length and load is same as practice according to Eq. (5). Then the incidence of idle cycle is suitable as the index of changeover from Token Bus to CSMA/CD. But, a constant incidence of idle cycle is not satisfied in all cases. So it is necessary to revise P as index with the arrival probability or load, which is discussed in the next section.

3.2 Basic Algorism of Hybrid Access

In this section, we give the algorism of proposed HACM.

3.2.1 Changing from CSMA/CD to Token Bus

The index for changing to Token Bus is selected as continuous collision, which means when a certain times continuous collision occurs at any site, the LAN will be decided to change to Token Bus. Then the site try to send a message by way of broadcast to inform other sites to change to Token Bus without accounting collision times till when it succeeds. If the site succeeded in informing other sites, it will prepare a token and send a messages at first. The procedure changing from CSMA/CD to Token Bus is shown as follows:

Step 1: There is a site trying to transmit a frame, and collision is found occurred continualy for a certain times.

Step 2: The site tries to send a message to all other sites by broadcast to inform that LAN will change to Token Bus method.

Step 3: If the site could not succeed to send change message, it continues to try to do it without accounting collision times.

Step 4: If the site succeeded in informing other sites, then executes a token, and carries out transmission at first.

Step 5: When the site finishes transmission, it carries a token to the next site.

For usual CSMA/CD, when load abruptly rises up to be very heavy, LAN has a probability of deadlock. In this case, any site cannot succeed in sending a message to inform other sites to change to Token Bus. By proposed HACM, though the deadlock cannot be avoided completely, according to simulations, at low load before deadlock, LAN is decided to change to Token Bus and one of the sites almost has a chance to send a frame to inform other sites.

3.2.2 Changing from Token Bus to CSMA/CD

For Token Bus, in the sight of delay, if LAN should change to CSMA/CD is mainly decided by two parameters that the load and arrival probability with assumption of fixed frame length. As index of changeover, load of LAN can be obtained from average cycle time by Eq. (2), but the arrival probability (or average frame length) is difficult to be computed. So we select the incidence of idle cycle as index and revise it with load. We investigated relation of incidence of idle cycle and load at inverse points of delay by simulation whose results are some different from that of analysis formulas. It is found that the relation of the incidence of idle cycle and load at delay inverse points can be approximated as

$$P\{\text{Cycle is idle}\}(\rho) = f(\rho) = a - b/\rho \qquad (6)$$

The above relation has character of derivative $f' > 0$ and $f'' < 0$. The constant a and b are obtained with substitution of two pairs of load and P of inverse points.

So, the index for changing to CSMA/CD is selected as incidence of idle cycle and the load which is obtained by average cycle time. With token arrival watched for a sample number, if the number of idle cycle is found more than a number correspondent to the incidence of idle cycle expressed as Eq. (6) at any site, then the

site informs other sites to change from Token Bus to CSMA/CD. Then the site transmits messages at first if it has a transmission request. After an interval, other sites begin to access the media by CSMA/CD. The detail steps for changing from Token Bus to CSMA/CD are shown as follows:

Step 1: Every site of LAN watches token arrival for a sample number, accounts idle cycle and accumulates cycle time.

Step 2: If the number of token arrival amounts to the sample number, the site calculates the incidence of idle cycle with the average cycle time, and the correspondent number of idle cycle as index of changeover.

Step 3: Compare the number of idle cycle with index of changeover obtained in above step. If the number of idle cycle is more than changeover index, goto Step 5.

Step 4: Set the number of token arrival, timer, idle cycle accounter as 0. Goto Step 1.

Step 5: The site withdraws token.

Step 6: Sends a message to all other sites to inform that LAN will change to the CSMA/CD method.

Then, every site carry out transmission by CSMA/CD method.

How to select the sample number of token arrival is related to the speed of changeover and stability of LAN. If the sample number is small, the LAN can change to CSMA/CD more sensitively, but probability of changeover which is not right perhaps becomes high. If we select a high sample number, the condition becomes contrary. According to Eq. (3), in view of the case of long frame length, the sample number of token arrival should be selected as a comparatively high value because of a higher variance of token cycle time, which can be confirmed by simulation results after.

4. Discussion on Results of Simulation

With index discussed in preceding section and different parameters, the simulations are carried out for HACM in several cases. The default parameters of LAN are same as those used in preceding section, except delay of token relay between two sites is assumed as 15.2 μs which decided by frame format of token bus, THT (Token Hold Time) are set to be 4000 μs as an example.

In **Fig. 3**, two sets of curves show delay versus load obtained by simulations in the case

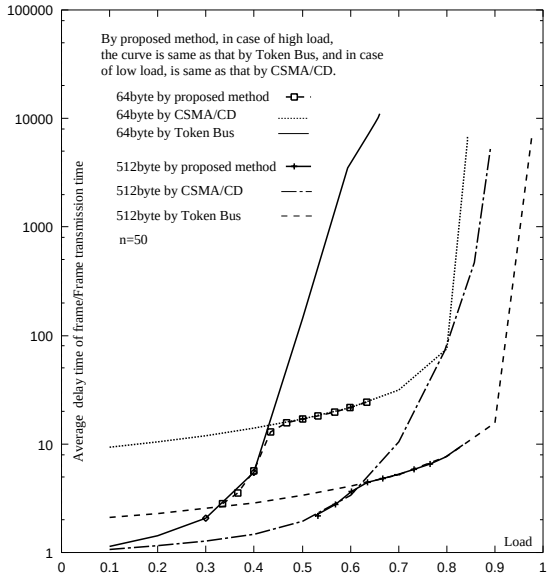

Fig. 3 Delay characteristic of proposed method with frame length 64 byte and 512 byte.

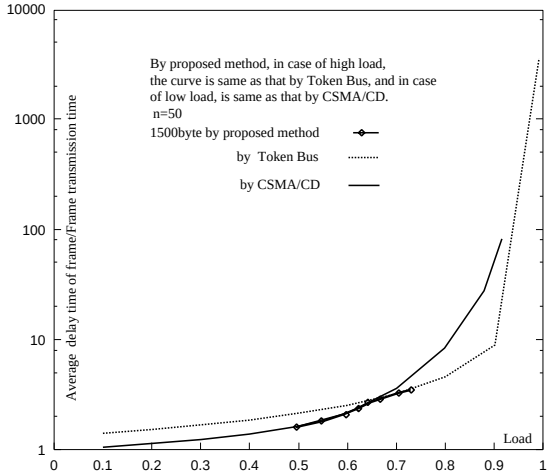

Fig. 4 Delay characteristic of proposed method with frame length 1500 byte.

of 64 byte, 512 byte respectively and that of 1500 byte is shown in **Fig. 4**. Besides delay of proposed method, we attached the results of CSMA/CD and Token Bus for comparing. The index for CSMA/CD to Token Bus is selected as 14 times continuous collision. For Token Bus to CSMA/CD, the index is set as a number of idle cycle correspondent to Eq. (6), in which, two constants a, b are decided with values of load and incidence of idle cycle at inverse points of delay in the case of frame length 64 byte and 1000 byte, and the sample number of token arrival is set as 50 times.

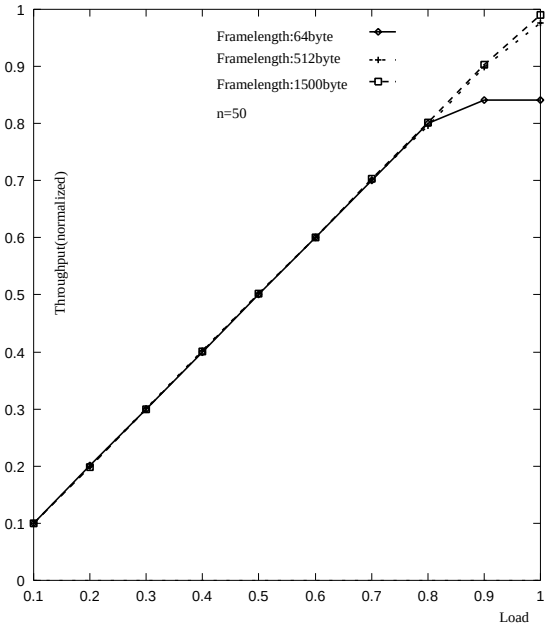

Fig. 5 The throughput of proposed HACM.

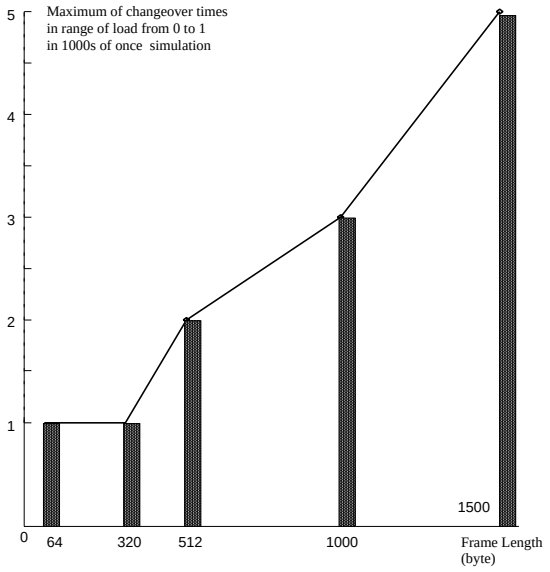

Fig. 6 Changeover characteristic of proposed method.

As shown in Figs. 3 and 4, by HACM, in the case of low load, LAN performs in CSMA/CD method. In case of heavy load, it performs in method of Token Bus. Comparing the delay of proposed method with two other methods, we find the network changes access method appropriately. Near the inverse points of delay by CSMA/CD and Token Bus, the delay by HACM differs a little from that of CSMA/CD and Token Bus, which means that LAN becomes dull for changeover or changes between two modes repeatedly in 1000 s simulation time.

The throughput (Total of frame bits transmitted/channel capacity: 10 Mbps) of HACM obtained by simulation, as shown in **Fig. 5**, is the same as traffic load in case of low load since LAN changes to Token Bus before frame loss occurs with selected changeover index. In case of heavy load, the throughput is decided by the character of Token Bus approximately except that the frame gap of CSMA/CD is reserved. The influence of frame gap to throughput appears in case of short framelength and heavy load. For example, in the case of 64 byte of framelength, throughput is about 84% with 100% load. In the cases of 512 byte and 1500 byte, there are no obvious differences between throughput and traffic load, which means that the framegap and delay of token relay between two sites are much shorter than frame transmission time for each site.

From **Fig. 6**, which shows the maximum number of changeover from load 0 to 100% in the cases of different frame lengthes, we find that LAN just changes access method for one time simulation in case of short frame length. In the case of long frame length, the number of changeover becomes high, for example 1500 byte, it is about 5 times in 1000 s of simulation time near the inverse point of delay. This is related to Variance of token cycle time, which is bigger in case of long frame length, and the selection of index. The number of changeover can be decreased with a more strict index or a bigger sample number of token arrivals, which causes a loss of sensitivity. Near inverse point of delay of CSMA/CD and Token Bus, LAN needs a comparatively long time for changeover, but at fact, in this case the delays of two access methods are not so different. In the sight of times of changing between two methods in 1000 s of simulation time, the overhead which causes delay is acceptable.

5. Conclusions

As a standard, CSMA/CD is the most popular underlying technology of LANs. Here, we proposed the hybrid access control method based on CSMA/CD to improve its efficiency and integrate with Token Bus just by changing algorism in the MAC layer.

For an ideal method, with index, access method changes to the better one of CSMA/CD

and Token Bus according to the delays depending on transmission situations. Though delay can be estimated by approximate analysis formulas, for deciding by which method is better dynamically, information obtaining and processing are somehow complex and analysis results have some difference from practice. Considering facility and practicability, we selected indexes which can be obtained easily for the proposed HACM.

For the CSMA/CD method, because the delay rises up abruptly with collision increasing, when the collisions occur continualy for a certain number of times, the delay will rapidly become higher than that of Token Bus almost unrelated to frame length. Therefore we selected continuous collision as an index for changing to Token Bus which is proved to be effective by simulations.

For Token Bus, load and arrival probability are the two main parameters which decide the delay of Token Bus. Considering the acquirement of index of changeover from Token Bus to CSMA/CD, we used the incidence of idle cycle and introduced an approximating formula for the changeover index. Though it is not perfect, the index is proved to be effective in the view of the results of simulations.

As for further study, we are estimating the proposed HACM in different conditions such as different number of sites, transmission speeds and the frame length distribution. Thinking specific application behavior, it is necessary and important to evaluate HACM in case of a different arrival probability.

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