

BUFFERED CSMA/CD BASED ETHERNET OPTICAL LAN AVOIDING PACKET LOSS

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Abstract

CSMA/CD based Ethernet suffers from the capture effect and is unsuitable for supporting real-time multimedia traffic. It behaves poorly under heavy load conditions, leading to an excessive delay, throughput degradation and packet loss because of the excessive collisions. This paper provides a technique to increase throughput and reduce average packet transfer delay of CSMA/CD based LAN by reducing collisions and eliminating packet loss. Here, each user has a finite buffer that helps to reduce collisions and Ethernet capture effect. At the same time, to eliminate packet loss, a new special-jamming signal is used. The proposed network performance in terms of throughput, average packet transfer delay and the percentage of collision is evaluated in Gigabit Ethernet environment. The throughput is increased more than 44% whereas the average packet transfer delay and percentage of collisions are reduced to less than 1 ms and 2% respectively when compared with the conventional protocol.

Keywords: CSMA/CD, Gigabit Ethernet, optical LAN, packet loss

Introduction

Throughput of the conventional CSMA/CD based LAN reduces drastically at high load as some bandwidth is wasted by collisions and backoff delays. At this time, many packets experience over delay or are dropped after 16 failed retransmission attempts. This results in packet loss and throughput degradation (Fairhurst, 2004). CSMA/CD also suffers from the capture effect (Björkman and Melander, 2000; Melander *et al.*, 2002) i.e. one node in the LAN has an increasing probability of holding

the channel and sending consecutive frames even though other nodes are contending for access. This short term unfairness occurs because of the CSMA/CD backoff algorithm.

Many researchers have already worked on CSMA/CD protocol. Eswaran *et al.* (1981) and Mark, 1980 proposed collision free access protocols using an independent control wire to reserve a data channel. Thanawastien and Blass, 1986 proposed a CSMA/CD-Token Ring hybrid architecture that requires twice the hardware of

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a conventional bus and ring. This system has low channel utilization on the ring at light load levels. The Hybrid Token-CSMA/CD Protocol proposed by Gopal and Wong, 1985 is a combination of token passing and CSMA/CD. This protocol has the disadvantage of repeated collisions and backoffs at heavy load levels. The CSMA/CD with deterministic contention resolution (DCR) proposed by Takagi *et al.* (1983) usually operates as CSMA/CD, but once a collision occurs, it resolves the collision using a kind of implicit token passing. Compared with conventional CSMA/CD, DCR achieves excellent performance in terms of throughput, message delay and delay standard deviation. This makes DCR attractive for combined voice and data traffic. However, a disadvantage is that much of the existing hardware has to be modified to implement DCR. Foh and Zukerman, 2000 introduced CSMA with reservation by interruptions (CSMA/RI). In this protocol, a node that has data to transmit is allowed to interrupt a successful transmission just for a short while. HomePNA2.0 adopts the mature IEEE 802.3 CSMA/CD technology with distribute fair priority queue (DFPQ) (Chung *et al.*, 2003). To reduce the jitter in audio and video streams, a priority mechanism is implemented to allow higher layers to label outgoing frames with differing priority levels. In addition, it guarantees that frames with higher priority have preferential access to the channel over lower priority ones. However, it cannot avoid high delay and low channel utilization by the backoff at heavy load levels due to adaptation of the conventional CSMA/CD (Hwang *et al.*, 2001). Venkatramani and Chiueh, 1994 introduced a completely software based protocol called RETHER for existing Ethernet hardware to provide bandwidth guarantees. However, RETHER has two disadvantages: a non general purpose protocol and lack of scalability. Hwang *et al.* (2000, 2001) proposed the Hybrid CSMA/CD-Token Bus Protocol, which combines the CSMA/CD with token bus. This protocol can provide low delay at light load levels and a bounded delay at the heavy load level. However, it has a disadvantage in that; there exists an overhead for the

maintenance of the current active node list. Tasaka, 1986 analyzed the dynamic behavior of a slotted nonpersistent CSMA/CD system with a finite number of nodes, each having a buffer of finite capacity. He developed an approximate Markovian model of the system and analyzed the model using equilibrium point analysis (EPA). However, none of these works considered packet loss issue, which is an important factor in CSMA/CD protocol. This paper presents a technique to eliminate packet loss.

In this study, to enhance the CSMA/CD based LAN performance, three new concepts are added to the conventional CSMA/CD. The first concept, each node in the LAN has a finite buffer capacity. A node competes to get access in the medium after its buffer is full and transmits all packets in the buffer if access is permitted. To minimize the waiting delay of packets in buffer prior to transmission, a time-out period is set, beyond which a node tries to transmit considering its buffer is full.

In this algorithm, each node has to wait until its buffer capacity is full. Hence, the number of nodes trying to transmit at a time is reduced and thereby the collision rate, bandwidth loss and backoff delays are also reduced. Due to this buffer, each node has the same amount of data to transmit at a time which prevents a single node to dominate the network and significantly reduces Ethernet capture effect.

Secondly, the maximum retransmission attempt limit and backoff limit are reduced from 16 to 10 and from 10 to 8 respectively. One of the intentions of this paper is to guarantee a tolerable delay for multimedia traffic with a high throughput. The backoff algorithm used in CSMA/CD protocol is 'binary exponential backoff' where delay increases exponentially with increasing retransmission attempt. So, in this paper, the maximum retransmission attempt limit and backoff limit are reduced to guarantee a tolerable delay. The delay can be reduced four times (as $2^{10} = 2^8 \times 4$) when the backoff limit is reduced from 10 to 8.

The final one, a special-jamming signal is introduced to eliminate packet loss. It gives transmission priority to the node that has already

finished its maximum retransmission attempt. Thus it eliminates packet loss due to excessive collisions.

Because of the binary exponential backoff algorithm during collision, the presence of multiple special-jamming signals at a time is rare. However, if multiple nodes send a special-jamming signal at a time, a priority scheduler resolves the problem. In this case, multiple nodes send a special-jamming signal almost at the same time. The time-stamp of special-jamming signals is to be used to make a decision in such a condition. When a node generates special-jamming, it is transmitted to all nodes on the network. If a node generates a special jamming signal itself as well as receives from another node within a very short time gap, which event occurs first, will get preference. This means that if a node generates a special-jamming signal before receiving from another node, it will transmit first.

In the worst case scenario, when multiple nodes send a special-jamming signal at exactly the same time (which is highly unlikely, especially when the time stamp among the signals goes down to several decimal places), the node having the smallest source address (SA) will transmit first. During this period, other nodes wait until their access is permitted accordingly. To accomplish this comparison, each node has a comparator unit that compares the source addresses of the nodes with a special-jamming signal and finally finds out the node with smallest SA.

Enhanced CSMA/CD Protocol

The proposed protocol is based on physical bus topology where all N nodes are spaced equally along the bus. All nodes share a single fiber cable that consists of only one wavelength (or channel) for data transmission. Each node is equipped with a transmitter and a receiver. A finite buffer is placed at each transmitter. Each node is also equipped with a comparator unit (CU). The CU is responsible for handling mechanism of data packets transfer in case of multiple nodes finished their maximum retransmission attempts at exactly the same time. The CU is

assumed to have a very fast processing time to reduce the total delay. The flow chart of the protocol is shown in Figure 1. The modifications proposed are contained within the dotted boxes. The rest of Figure 1 represents the conventional CSMA/CD protocol.

In this model, each node has a finite buffer capacity and a fixed time-out period. Whenever a node generates a new packet, it is stored in the buffer if space is available and the number of packets in the buffer is increased by one. This process continues until the buffer is full by the pre-set maximum number of packets or the time-out period is expired. A node having either enough packets to fill its buffer or has expired time-out limit, moves on to check out the channel condition.

If the channel is busy, the node computes delay and random backoff time. Otherwise, it waits for an interframe gap and then begins the transmission by releasing packets in its buffer in an ordered manner. The next step is to detect collision while the transmission is in progress. If a node detects a collision, it aborts the transmission. A modification is also introduced in this collision detection portion. In this algorithm, a node trying to transmit a packet, tries maximum 10 times and after that it sends a 40-bits special-jamming signal which differs from a normal 32-bits jamming signal. This special-jamming signal gives that node the priority to start the transmission, while other nodes backoff. Thus, it ensures no packet is lost or discarded. In the conventional CSMA/CD, the packet is discarded after 16 retransmission attempts. The contents of the common jamming signal and the special-jamming signal are specified in Figure 2.

Synchronization serves to give nodes in the network time to detect the presence of the jamming and the special-jamming signal and being reading the signal before other information arrives. Starting of jamming/special-jamming indicates the start of the jamming/special-jamming. The Source Address identifies the node that originated the jamming and the special-jamming signal. The additional Priority in the special-jamming signal gives the transmission priority followed by the special-jamming

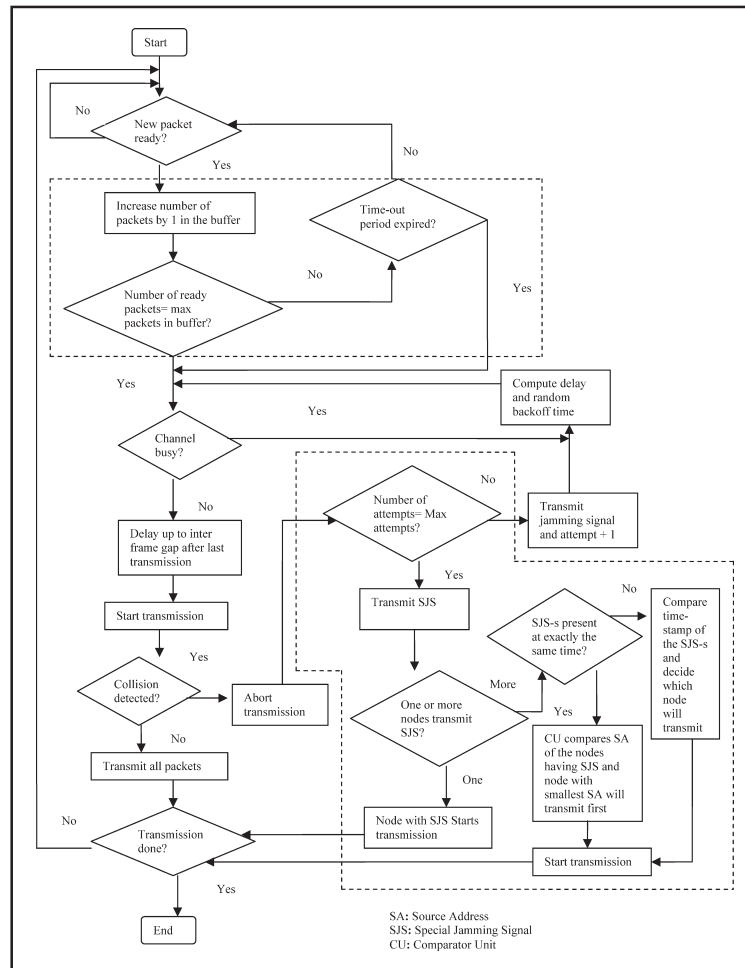


Figure 1. Flow chart of the proposed CSMA/CD protocol

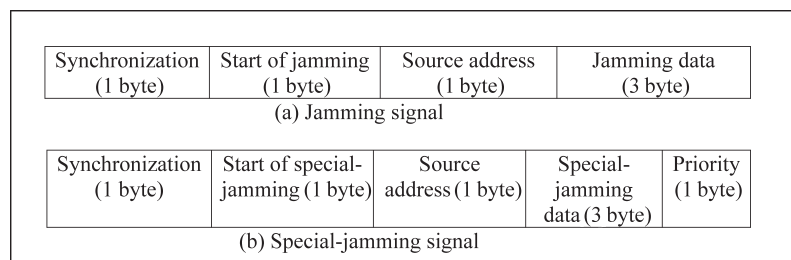


Figure 2. Jamming signal and special-jamming signal format

signal. The size of jamming and special-jamming signal includes all bytes from the source address field through the jamming data field and priority field respectively. The synchronization and start frame fields are not included when quoting the size of a frame.

In case of multiple nodes send a special-jamming signal almost at the same time, there is also a scheduling scheme. In this case, the problem can be resolved depending on either the time-stamp of the special-jamming signals (as explained earlier) or by the smallest source address priority as explained in the subsequent section.

Network Structure

Figure 3 presents network structure of the proposed protocol. Only a comparator unit is extra needed in each node and this will not affect the existing CSMA/CD-based equipments that are exploited in the current networks.

Comparator Unit Operation

When a node transmits a special-jamming signal, the source address value of that node is copied and transferred to the comparator unit (CU). If there is only one input at any time in CU, it does nothing except holding that data

until the completion of the current transmission corresponding to that special-jamming signal. When multiple nodes transmit a special-jamming signal at exactly the same time, multiple inputs are transferred to the CU. In such a condition, the CU becomes active; it compares the input values, and makes a decision about which node will get the chance of transmission first depending on smallest source address priority. This process takes place at all nodes and all of them are expected to make the same prioritization decision since they all receive the same information.

Assumptions

The network performance (i.e. throughput, average packet transfer delay and percentage of collision) based on the proposed CSMA/CD is evaluated within Gigabit Ethernet environment. Assumptions that have been made in the simulation process are as follows:

- Arrivals at all nodes follow a Poisson distribution.
- All nodes generate traffic at the same rate. Packets are assumed to be generated at any node j with nominal rate $R_j = 9,800$ packets/sec (which corresponds to 1% of the maximum packet transmission rate i.e. 1 Gbps). 100 nodes

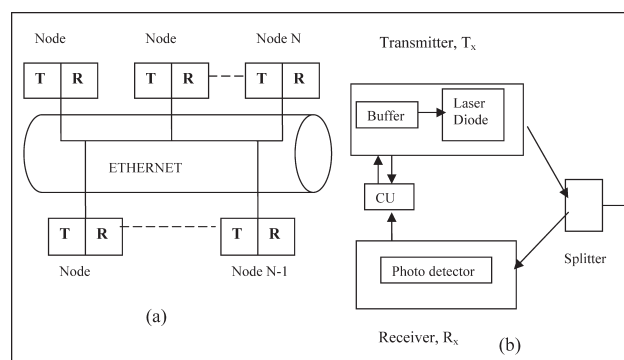


Figure 3. Network structure of the proposed protocol; (a) general structure, (b) structure of a single node

are attached to the network which represents a total of 100% incoming traffic.

- Packets length is fixed to 1,024 bits/packet to make sure that no packet is shorter than twice the minimum frame size, and all collisions are detectable during the transmission time.

- Each node has a finite buffer capacity.
- Nodes are equally spaced along the bus.
- All received packets are error-free.

Errors occur due to collisions only.

- No packet priority is considered.
- The system is lossless i.e. there is no packet loss.

- A new generated packet joins the tail of the queue in the buffer if space is available; otherwise, it is lost. It is also lost when the node is busy i.e. during the transmission or undergoing a collision.

- Each node is allowed to transmit all packets of the buffer during each transmission. Packets in the buffer are assumed to be transmitted on a first-come-first-served (FCFS) basis.

- The packets are deleted from buffer immediately after the successful transmission is completed.

Simulation Parameters

Visual Basic 6.0 is used for simulating the protocol. The pseudo-random number generator used generates Poisson traffic. Effect of different buffer size on throughput, average packet transfer delay etc. is observed first and then the optimum buffer size is determined by simulation. The buffer size is optimized in order to determine which buffer size is appropriate for achieving the optimum throughput and average delay. Performance of the protocol is then investigated with the optimum buffer capacity (i.e. 10 packets/buffer).

Some initial waiting time is introduced by the buffer as the first packet arriving in the buffer waits for more packets to arrive before it can be transmitted. In order to minimize the starting delay caused by the buffer for lightly loaded network, time-out period, $T = 0.005$ sec is chosen considering a 20% network load condition. Here, at 100% offered load, a packet

generation rate at any node is 9,800 packets/sec. At 20% offered load, a packet generation rate is 1,960 packets/sec. According to this rate, 0.005 sec is required to generate 10 packets. So, the time-out period of 0.005 is chosen.

Throughput, average packet transfer delay and percentage of collision are performance parameters under consideration for the proposed protocol. Optical fiber is used as the transmission medium. The protocol is implemented over single channel LAN for simplicity. However, it can also be implemented over multi-channel LAN in future. To observe the proposed protocol's performance, the bus length is kept fixed at 500 m. Most of the conventional LANs are operated within the bus length of 200 m. In order to compare the performance enhancement of this protocol, the higher bus length is chosen. Slot time, interframe gap, minimum frame size and packet size with carrier extension are chosen according to Gigabit Ethernet standard. All the parameters used in the simulation are summarized in Table 1.

Results and Discussions

Throughput

Throughput, denoted by S is defined as the number of packets transmitted successfully per unit of time (Rodellar *et al.*, 1998a, 1998b). It can be computed as the total number of packets successfully transmitted over a specific time (i.e. total transmission time) (Sadiku and Illyas, 1995). In this simulation, the transmission involves fixed length packet and packets are further divided into bits. So, the throughput results are presented in bits per second (bps) form. Throughput versus number of nodes of the proposed CSMA/CD at 100% offered load is shown in Figure 4.

Throughput drops from 1 Gbps to 841 Mbps. An increase in number of nodes causes many nodes attempt to transmit packet at the same time which causes increased collisions. Increased collisions results in more waiting time due to more backoff delay. So, with the increasing number of nodes, the network

becomes congested and packets are transmitted using higher total delay. The overall nature is decreasing throughput with increasing number of nodes. In the conventional protocol, throughput drops to a very low value with a large number of nodes whereas in this protocol, due to the special-jamming signal, no packet is lost and, therefore, throughput maintains a considerable high value even at a large number of nodes.

In the conventional CSMA/CD, a node transmits only one packet whenever it gets access to the transmission medium. On the other hand, according to this protocol, whenever a node gets access to the transmission medium, it transmits all packets stored in the buffer. So, many packets are transmitted within a short period of time. This gives higher throughput when compared with the conventional CSMA/CD. Lastly, the reduced collision rate when compared with the conventional protocol also results in better throughput.

The minimum throughput at 100 nodes is 841 Mbps, which means 84.1% utilization rate, whereas it is only 37% for the same number of nodes for the conventional CSMA/CD (Tse

et al., 2003) as shown in Figure 5. This is much higher when compared with the conventional protocol where a 40% utilization rate is considered good enough on a congested network (Pascucci, 1999).

Average Packet Transfer Delay

Average packet transfer delay is the delay experienced by a packet from the beginning of its first transmission attempt to the end of its successful transmission (Rodellar *et al.*, 1998a, 1998b, 1998c). It is computed by dividing the total delay of all packets by the number of packets successfully delivered (Sadiku and Illyas, 1995).

Average packet transfer delay versus the number of nodes of the proposed CSMA/CD is shown in Figure 6 where the bus length is fixed at 500 meters and the offered load is 100%.

Contention problem increases with increasing nodes because a larger number of nodes leads to a larger number of transmission attempts. This causes an increase in a collision rate (Figure 7), re-sensing and retransmission process. Consequently, the waiting time of packets in each node is increased. As a whole,

Table 1. Simulation parameters of the proposed CSMA/CD

Design parameters	Values
Maximum station, N	100
Transmission rate	1 Gbps
Data packet length	1,024 bits
Packet size with carrier extension	512 bytes
Optical fiber bus length	500 m
Maximum packets	100,000
Propagation speed	2×10^8 m/s
Slot time	4,096 bits
Interframe gap	0.096 μ s
Buffer size	10 packets
Time-out period, T	0.005 sec
Attempt limit	10 times
Backoff limit	8 times
Jam size	32 bits
Special-jamming size	40 bits
Minimum frame size	512 bits

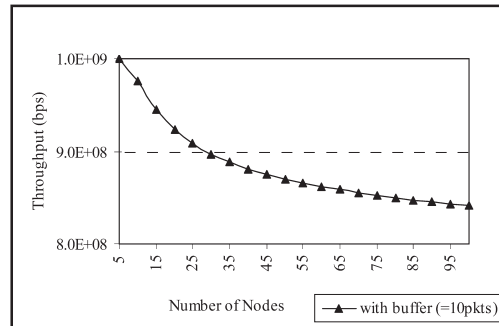


Figure 4. Throughput vs. number of nodes

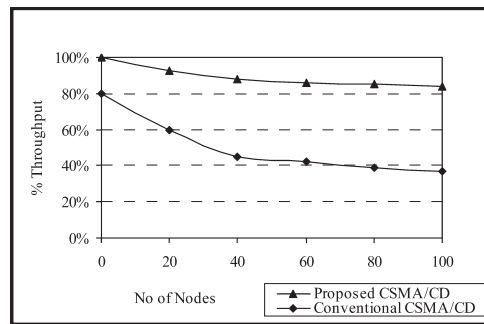


Figure 5. Comparison of percentage throughput vs. number of nodes

average packet transfer delay increases with an increasing number of nodes.

In Figure 6, average packet transfer delay rises from 0.63 ms to 0.77 ms. At the maximum number of nodes of 100, average delay obtained is less than 1 ms. This is much smaller when compared with the typical acceptable delay of 100 ms (Molle *et al.*, 1997a, 1997b) and the delays obtained in (Kweon and Shin, 2003).

The delay obtained here is very close to the packet delay using VoIP carrying voice and data, where the packet delay without QoS is from 0.8 ms to 1.16 ms and with QoS is from 0.58 ms to 0.66 ms (Yoe and Lee, 2001). As a whole, the average delay performance of this system is good enough and can be used for real-time traffic applications too.

Percentage of Collision

The percentage of collision versus the number of nodes of the proposed protocol at 100% offered load is shown in Figure 7.

This is a single channel system and only one node is allowed to use the channel while others have to backoff. With an increasing number of nodes, the probability of transmission attempts at the same time by various nodes increases which causes more packets to collide as appears in Figure 7. Although the collision increases almost linearly with an increasing number of nodes, the overall collision tendency is reduced considerably in this buffered model. Here, the maximum collision rate for 100 nodes is only 1.45%, whereas a 50% collision rate is

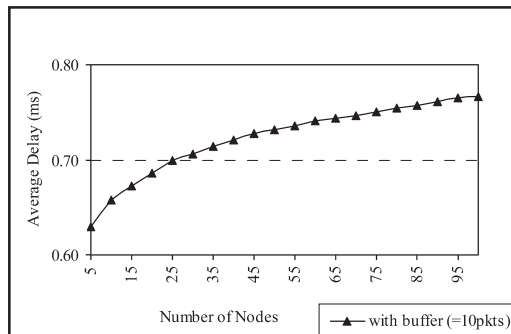


Figure 6. Average packet transfer delay vs. number of nodes

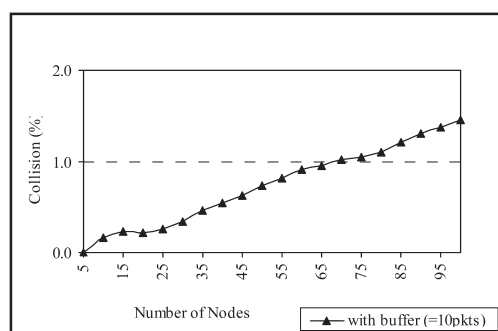


Figure 7. Percentage of collision vs. number of nodes

acceptable in the conventional CSMA/CD (Dripps, 2001).

Conclusions

This paper shows the performance enhancement of CSMA/CD based Gigabit Ethernet single channel optical LAN in terms of throughput, average packet transfer delay and percentage of collision. Here, the collision rate is minimized to less than 2% and the packet loss is eliminated. Moreover, (84 - 40%) 44% increased throughput is obtained within an average delay of 0.77 ms when compared with the conventional CSMA/CD. Based on this improvement, the protocol can be implemented over multi-channel Ethernet LAN in future.

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