THROUGHPUT ANALYSIS OF BUFFERED CSMA/CD BASED SINGLE CHANNEL FAST ETHERNET OPTICAL LAN

Shamima Kabir, Sabira Khatun, M.K. Abdullah, M.A. Mahdi and S.B. Ahmad Anas
Department of Computer and Communication Systems Engineering, Faculty of Engineering,
Universiti Putra Malaysia, 43400 UPM Serdang, Selangor

ABSTRACT

This paper provides the throughput performance of a buffered CSMA/CD based single channel Fast Ethernet optical LAN. The conventional CSMA/CD does not provide good throughput due to its inherent unfairness caused by collisions and binary exponential backoff algorithm. Packet loss and Ethernet capture effect make CSMA/CD LANs unsuitable for heavy load conditions and degrade the throughput. Aim of this paper is to improve the throughput of CSMA/CD based LAN by reducing collisions and eliminating packet loss. In the enhanced CSMA/CD system, each node has a finite buffer capacity which helps to reduce the number of collisions and Ethernet capture effect. At the same time, to ensure that no packet is lost or discarded, a new special-jamming signal is used. The network throughput performance based on the proposed CSMA/CD is evaluated against several design parameters i.e. number of nodes, bus length and offered load. Throughput performance of the system is also compared to the conventional CSMA/CD system which shows significant improvement. Throughput against number of nodes and offered load are increased more than 10% and 13% respectively compared to the conventional system.

Keywords : *CSMA/CD, Fast Ethernet, Single Channel LAN, Buffer, Packet Loss, Throughput*

1.0 INTRODUCTION

At high load, throughput of the conventional CSMA/CD reduces drastically as some bandwidth is wasted by collisions and backoff delays. At this time, a lot of packets experience over delay or be dropped after 16 failed retransmission attempts. This results in packet loss and throughput degradation of the system [1]. CSMA/CD is also suffered by capture effect [2-4] i.e. one node in the LAN has an increased 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.

CSMA/CD based LAN throughput performance has already been studied by many researchers. Metclafe provided the first detailed measurement analysis of a 3 Mbps Ethernet calculating throughput as a function of packet length [5]. Their results showed a near 100% throughput for large sized packets and drop to about 37% for smaller packets. Many researchers groups [6-8] analysed CSMA/CD networks under finite population size. They measured throughput against offered load and also studied the effect of the time taken to detect a collision on the throughput. Takagi [6] showed that maximum throughput achievable by CSMA/CD is 60% when infact [9] implementation proved that for large packet size Ethernet throughput could be as high as 97%. However, none of these works consider packet loss issue which degrades the throughput.

In this study, to enhance the CSMA/CD based LAN performance, three new concepts are added to the conventional CSMA/CD. The first concept is that each node in the LAN has a finite buffer. A node competes to get access in the medium after its buffer is full and transmits all the packets in its buffer if access is permitted. To minimise the waiting delay of packets in the 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 the buffer capacity is full. So, the number of nodes trying to transmit at a time is reduced and thereby 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 any single node to dominate the network and significantly reduces the Ethernet capture effect.

Secondly, the maximum retransmission attempt limit and backoff limit are reduced from 16 to 10 and from 10 to 8 respectively to guarantee a tolerable delay with a high throughput.

The final one is the special-jamming signal, which is introduced to eliminate packet loss. It gives transmission priority to the node that already has finished its maximum retransmission attempt. Thus it eliminates packet loss due to excessive collisions.

However, if more than one node sends the special-jamming signal at a time, a priority scheduler will resolve the problem. In this case, more than one node sends the special-jamming signal almost at the same time. The time-stamp of the special-jamming signals is to be used to make a decision in such condition. Whenever a node generates special-jamming, it is transmitted to all nodes on the network. If a node generates special-jamming signal itself as well as receives from another node within a very short time gap, which event occur first, will get preference. This means, if a node generates special-jamming signal before receiving from another node, it will transmit first.

If more than one node sends special-jamming signal at exactly the same time (which is a highly unlike case, 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 special-jamming signal and finally finds out the node with the smallest SA.

This paper is organised as follows. Section II deals with proposed CSMA/CD protocol. Comparator unit (CU) operation of the proposed protocol is discussed in Section III. Assumptions and simulation parameters are then addressed in Section IV and V respectively. Results and discussions are covered in Section VI. Finally the paper is concluded in Section VII.

2.0 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 the data packets transmission in case of more than one node 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 proposed protocol is shown in Figure 1. The modifications proposed, are contained within the dotted boxes. The rest 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 incremented 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 the 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, the node waits for interframe gap and then begins to transmit by releasing the packets in its buffer in an ordered manner. The next step is to detect collision while transmission is in progress. If any node detects a collision, it will abort 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 attempts. After that it sends a 40-bits special-jamming signal which differs from the normal 32-bits jamming signal. This special-jamming signal gives the node priority to start transmission while other nodes backoff. Thus it ensures no packet is lost or discarded. But in conventional system, the packet is discarded after 16 attempts. The contents of the common jamming signal and the special-jamming signal are specified in Figure 2.

However, in case of more than one node sending the special-jamming signal almost at the same time, there is also a scheduling scheme. In this case, the problem can be resolved depending on the smallest Source Address priority as explained in the next section.

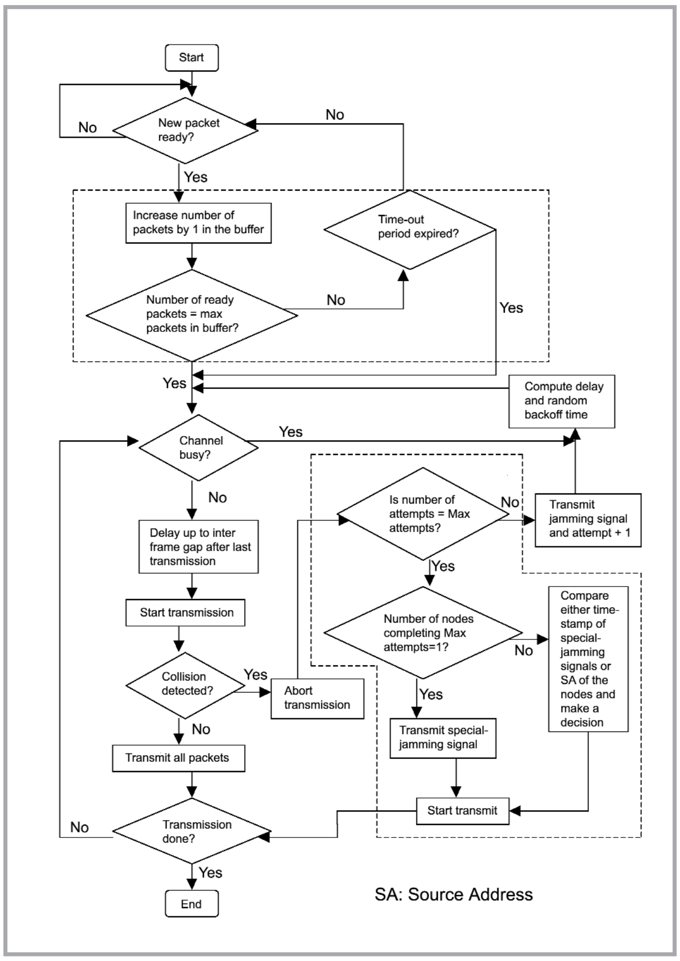

Figure 1: Flow chart of the proposed CSMA/CD protocol

Synchronisation (1 byte)	Start of Jamming (1 byte)	Source Address (1 byte)	Jamming Data (1 byte)

2(a) Jamming signal

Synchronisation (1 byte)	Start of Special-jamming (1 byte)	Source Address (1 byte)	Special-jamming Data (1 byte)	Priority (1 byte)

2(b) Special-jamming signal

Figure 2: Jamming signal and special-jamming signal format

3.0 COMPARATOR UNIT OPERATION

Whenever a node transmits 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 the CU, it does nothing except holding that data until the completion of current transmission corresponding to that special-jamming signal. When more than one node transmits special-jamming signal at exactly the same time, more than one input is transferred to the CU. At this condition, the CU becomes active; it compares the input values, makes a decision about which node will get the chance of transmission first depending on the smallest Source Address priority. This process takes place at all nodes and all of them are expected to make the same prioritisation decision since they all receive the same information.

4.0 ASSUMPTIONS

The following assumptions have been made in the simulation process:

- 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 Rj = 980 packets/sec (which corresponds to 1% of the maximum packet transmission rate). 100 nodes 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 transmission or undergoing a collision.
- Each node is allowed to transmit all the packets in its 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 the buffer immediately after the successful transmission is completed.

5.0 SIMULATION PARAMETERS

Visual Basic 6.0 is used for simulating the protocol. The pseudo-random number generator used generates Poisson traffic. In the process of protocol designs and deployments, it is important to determine which buffer size is appropriate for achieving the optimum throughput in an actual network environment. For this reason, the optimum buffer size of the proposed protocol is to be determined first. Then the network throughput should be evaluated maintaining the optimum buffer size. The effect of different buffer size on throughput is observed in Figure 3 and the optimum buffer size is determined from this result.

Buffer size is varied form one packet to twenty packets per buffer. 100 nodes are attached to 500 meter long bus network at 100% offered load. Figure 3 shows that throughput increases with increase in buffer size. This happens because, increase in buffer size causes reduced collision rate. Moreover, numbers of transmitted packets per channel access increases with increasing buffer size as all packets of a buffer are transmitted when a node gets access of the transmission medium. As a whole, many packets are transmitted within a short period of time which results in increasing throughput with increase in buffer size. Throughput increases from 71 Mbps to 99.6 Mbps. Initially throughput is increased at a higher rate. At this time, packets transmission time is smaller due to small buffer size. With larger buffer size, packets transmission time is increased and throughput is increased at a slower rate. Throughput increases slowly after buffer size = 10 packets. Increase in throughput up to buffer size = 10 packets are 26.5 (i.e. 71-97.5) Mbps. After that throughput increases only 1.8 (i.e. 97.8-99.6) Mbps. So, buffer size can be optimised at 10 packets per buffer.

Some initial waiting time is introduced by buffer as the first packet arriving in the buffer waits for more packets to arrive before it can be transmitted. In order to minimise the starting delay caused by buffer for lightly loaded network, the time-out period, T = 0.05 sec is chosen considering 20% network load condition.

All the parameters used in the simulation are summarised in Table 1. The throughput performance is influenced by number of nodes, bus length and offered load. The number of nodes varies from 10 to 100 in steps of 5. Optical fiber is used as the transmission medium so that the maximum bus length can be 2 km. To observe the protocol performance influenced by bus length, it is varied from 200 meter to 2 km in steps of 100 meter. The offered load varies from 10% to 100% in steps of 5%. To observe the proposed protocol's performance influenced by the number of nodes and offered load, bus length is kept fixed at 500 meter. Most of the conventional LANs are operated within bus length of 200 meter. In order to compare performance enhancement of this protocol, a higher bus length is chosen.

Table 1: Simulation parameters of the proposed system

Design parameters	Values (Fast Ethernet)
Maximum station, N	100
Transmission rate	100Mbps
Packet length	1,024 bits
Optical fiber bus length	200m – 2 km
Maximum packets	100,000
Propagation speed	2×10^8 m/s
Slot time	512 bits
Interframe gap	0.96µs
Buffer size	10 packets
Time-out period, T	0.05 sec
Attempt limit	10 times
Backoff limit	8 times
Jam size	32 bits
Special-jamming size	40 bits
Minimum frame size	512 bits

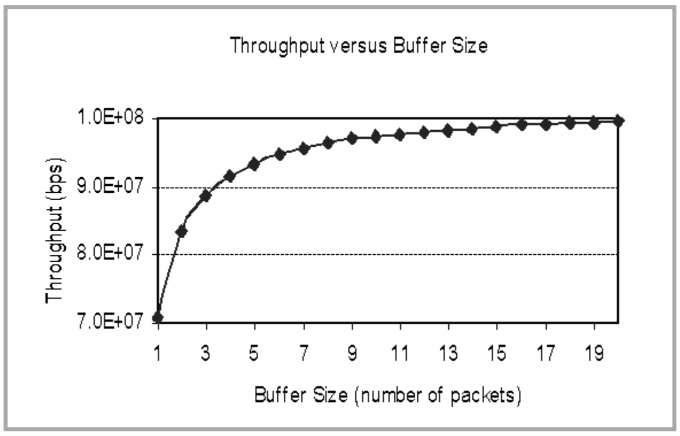

Figure 3: Throughput versus buffer size of the proposed protocol

6.0 RESULTS AND DISCUSSIONS

Throughput, denoted by S is defined as the number of packets transmitted successfully per unit of time [10-11]. It can be computed as the total number of packets successfully transmitted over a specific time (i.e. total transmission time) [12]. In this simulation, transmission involves fixed length packet and packets are further divided into bits. Thus, definition of throughput is derived as given by Equation 1.

$$\textit{Throughput, } S = \frac{\textit{Total Number of Packets Successfully Transmitted}}{\textit{Total Transmission Time}} = \frac{\textit{Total Bits Sent}}{\textit{TransmissionTime} + \textit{Propogation Time} + \textit{Waiting Time}} \qquad (1)$$

In this model, it is assumed that the transmitted packets do not experience any transmission errors. Any occurrence of error is only due to collisions. The throughput results are presented in bits per second (bps) form.

6.1 THROUGHPUT VERSUS NUMBER OF NODES

Throughput versus number of nodes of the proposed CSMA/CD protocol is shown in Figure 4. Throughput drops from 100 Mbps to 87.9 Mbps. The increasing number of nodes causes many nodes attempt to transmit packet at the same time which results in

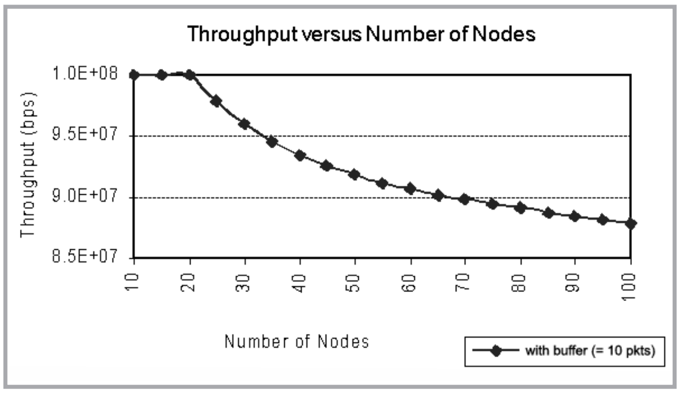

Figure 4: Throughput versus number of nodes of the proposed protocol

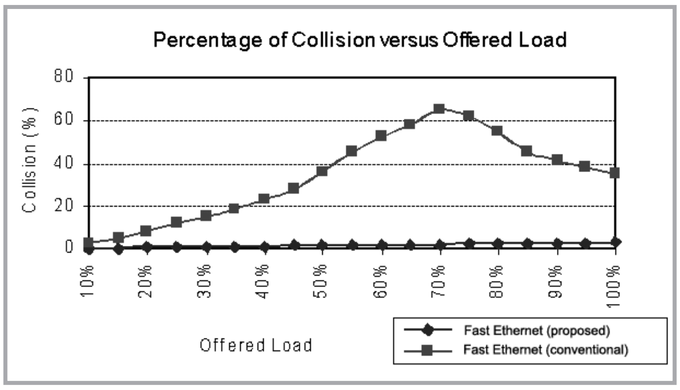

Figure 5: Comparison of percentage of collision versus offered load

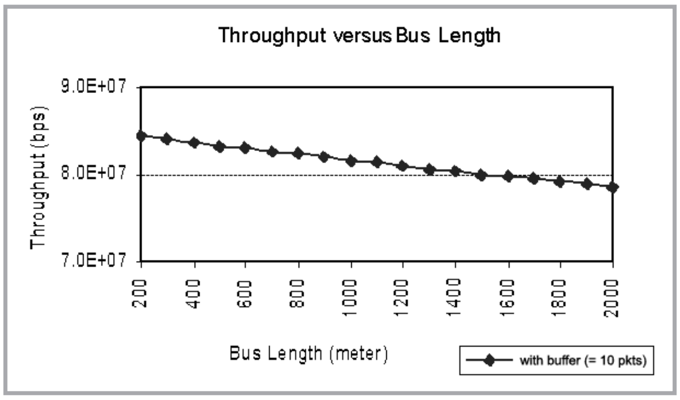

Figure 6: Throughput versus bus length of the proposed protocol

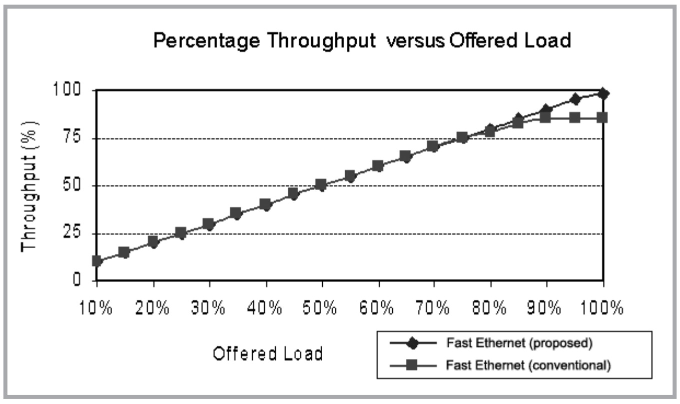

Figure 7: Comparison of throughput versus offered load

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

The throughput performance of the proposed protocol is much better compared to conventional bufferless protocol. In conventional protocol, a node transmits only one packet when it gets access to the transmission medium. On the other hand, according to the proposed protocol, when a node gets access to the transmission medium, it transmits all its packets stored in the buffer one by one. Here, the number of transmitted packets per channel access is higher than the conventional bufferless system. So, many packets are transmitted within a short period of time. This larger amount of total packets transmission makes throughput high enough compared to the protocol without buffer. Moreover, the reduced collision rate shown in Figure 5 compared to the conventional protocol [13-14] also results in better throughput performance.

In this study, using the enhancement of CSMA/CD protocol, a high value of throughput is obtained as compared to the conventional

protocol. Here, the minimum throughput at 100 nodes is 87.9 Mbps, which means 87.9% utilisation rate whereas, it is 77% for the same number of nodes of the conventional CSMA/CD system with $\propto$ = .05 [15]. This is much higher compared to the conventional protocol where 40% utilisation rate is considered good enough on a congested network [16].

6.2 THROUGHPUT VERSUS BUS LENGTH

The effect of bus length on throughput can be observed in Figure 6. Here, bus length is varied from 200 m to 2 km with 100 nodes connected at 100 Mbps.

With increasing bus length, propagation time increases as packets spend more time in propagation. So, throughput is inversely proportional with bus length. Throughput drops from 84.4 Mbps (at 200 meter) to 78.6 Mbps (at 2 km). The minimum throughput of this proposed protocol is 78.6 Mbps (i.e. 78.6% utilisation) which is quite a good throughput compared to typical acceptable 40% utilisation rate of the conventional protocol [16]. This higher throughput is due to more packets transmission per channel access and also for reduced collisions than the conventional bufferless protocol.

6.3 THROUGHPUT VERSUS OFFERED LOAD

Throughput versus offered load of the proposed protocol is shown in Figure 7. Offered load is varied from 10% to 100% with fixed 100 nodes.

Fundamental relationship between throughput and offered load is, Throughput = Offered load * Probability [frame suffers no collisions] [17]. As throughput is directly proportional with offered load, it increases with increasing offered load. Throughput increases from 8.52 Mbps (at 10% offered load) to 83.5 Mbps (at 100% offered load). In conventional CSMA/CD system, throughput keeps increasing up to 85% of offered load. After that it saturates due to packet loss for excessive collisions [13-14]. In this proposed protocol, as there is no packet loss, throughput increases up to 100% offered load. At 100% offered load, throughput is 98% whereas it is 85% for the conventional protocol [13-14]. This performance improvement is also shown in Figure 7.

7.0 CONCLUSIONS

This paper shows the throughput performance of a single channel Fast Ethernet optical LAN using an enhanced CSMA/CD protocol. The goal is to develop a buffed CSMA/CD protocol with minimum collision rate. This work also presents a technique to eliminate packet loss due to maximum retransmission attempts. Here, collision tendency is reduced to less than 3% due to buffer and finally there is no packet loss due to special-jamming signal. Throughput performance of the proposed system is determined and compared to the conventional CSMA/CD based systems. Using this protocol, more than 10% (87.9%-77%) increased throughput is obtained against number of nodes. Throughput of this proposed protocol goes on increasing up to 100% of offered load and 13% (98%-85%) increased throughput is obtained against offered load. Hence, the main objective of this study i.e. reduced collisions and thereby increased throughput compared to the conventional CSMA/CD based LAN is successfully achieved. ■

REFERENCES

[1] G. Fairhurst, "Carrier Sense Multiple Access with Collision Detection (CSMA/CD)". http://www.erg.abdn.ac.uk /users/gorry/course/lan-pages/csma-cd.html. Accessed on Aug 2004.

[2] B. Melander, M. Bj¨orkman, P. Gunningberg (2002). "Long Distance Visibility of the Ethernet Capture Effect", Proceedings-PAM 2002.

[3] M. Bj¨orkman, B. Melander, "Impact of the Ethernet Capture Effect on Bandwidth Measurement", Conference Proceedings on Networking 2000, pp. 156-167, Paris, France, May, 2000.

[4] TechFest Ethernet Technical Summary, Chapter3. http://www.techfest.com/networking/lan/ethernet3.htm. Accessed on Aug 2004.

[5] R.M. Metcalfe, D.R. Boggs, "Ethernet: Distributed Packet Switching for Local Computer networks", Communications of the ACM, vol. 19, no. 7, July, 1976.

[6] H. Takagi, L. Kleinrock, "Throughput analysis for persistent CSMA systems", IEEE Transactions on Computers, vol. COM-33(7), pp. 627-638, July, 1985.

[7] F. Tobagi, N. Gonzalez-Cawley, "On CSMA/CD local networks and voice communication", IEEE INFOCOM, pp. 122-127, Las Vegas, Nevada, USA, 1982.

[8] F. Tobagi, V. Hunt, "Performance analysis of carrier sense multiple access with collision detection", Computer Networks, vol. 4, pp. 245-259, Oct/Nov, 1980.

[9] D.R. Boggs, J.C. Mogul, C.A. Kent, "Measured capacity of an Ethernet: Myths and reality", ACM SIGCOMM Conference, pp. 222-234, Stanford, California, Aug,1988.

[10] D. Rodellar, C. Bungarzeanu, H. Garcia, C. Brisson, P.A. Nicati, A. Kung, Ph. Robert, "A new multichannel Ethernet protocol for passive optical star local area networks using coherent transmission". SYBEN'98, May, 1998.

[11] D. Rodellar, C. Bungarzeanu, H. Garcia, C. Brisson, P.A. Nicati, A. Kung, Ph. Robert, "A multichannel Ethernet protocol for a WDM local area star network". LANMAN'98, The 9th IEEE Workshop on Local and Metropolitan Area Networks, pp.263-268, May, 1998.

[12] M.N.O. Sadiku, M. Illyas, "Simulation of Local Area Networks". First Edition, CRC Publications, 1995.

[13] M. Molle, M. Kalkunte, J. Kadambi, "Frame Bursting: A Technique for Scaling CSMA/CD to Gigabit Speeds". IEEE Network, vol. 11, no. 4, pp. 6-15, July, 1997.

[14] M. Molle, M. Kalkunte, J. Kadambi, "Scaling CSMA/CD to 1 Gb/s with frame bursting". 22nd Annual Conference on Local Computer Networks, pp. 211-219, Nov, 1997.

[15] Y.T. Tse, L.K. Chen, C.K. Chan, "A distributed collision avoidance protocol using pilot tone-based carrier sense mechanism for passive optical networks". Optical Fiber Communications Conference, OFC 2003, vol. 1, pp. 284-285, March, 2003.

[16] C. Pascucci, "Desktop ATM versus Fast Ethernet". http://www.networking.ibm.com/nhd/webnav.nsf/pages/atm:atm25fe.html#fast, Accessed on Aug 2004.

[17] "Multi-access Protocols". http://www.ctr.kcl.ac.uk/lectures /vasilis/Course/Multi-access%20Protocols.pdf. Accessed on Aug 2004.