Ethernet data frames before releasing the channel to the next ONU. The "more data" bit was not used, and so these results underestimate the true achievable throughput.

Fig. 3 presents the channel utilization of FULL-RCMA versus offered load for several cases. Cases 1 and 2 use frame bursting, while ONUs in cases 3 and 4 do not implement frame bursting. In cases 1 and 3, there are 32 active ONUs, and in cases 2 and 4 there are 16. The traffic intensity was increased to full load by reducing the OFF periods. In all cases, over 87% channel utilization can be achieved when the channel is fully loaded. When frame bursting is implemented, over 95% of the time is spent carrying payloads on the broadcast channel. These results confirm the full utilization property of FULL-RCMA.

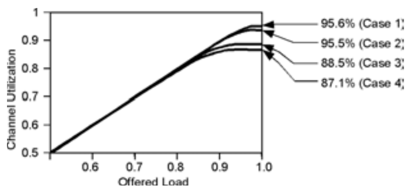

Fig. 3. Channel utilization versus offered load for FULL-RCMA

4. References

[1] G. Kramer and G. Pesavento, "Ethernet Passive Optical Network (EPON): Building a Next-Generation Optical Access Network," IEEE Communications Magazine, February 2002, pp. 66-73.

[2] C. H. Foh and M. Zukerman, "A Novel and Simple MAC Protocol for High Speed Passive Optical LANs," in Proceedings of Networking 2002, Pisa, Italy, 2002.

[3] G. Kramer, B. Mukherjee, and G. Pesavento, "IPACT: A Dynamic Protocol for an Ethernet PON (EPON)," IEEE Communications Magazine, February 2002, pp. 74-80.

TuR4 **5:30 PM**

A Distributed Collision Avoidance Protocol using Pilot Tone-based Carrier Sense Mechanism for Passive Optical Networks

Y. T. Tse, L. K. Chen, C. K. Chan, *Dept. of Information Engineering, The Chinese University of Hong Kong, Shatin, Hong Kong Special Administrative Region of China, Email: yttse1@ie.cuhk.edu.hk.*

A distributed collision-avoidance scheme employing pilot-tone based carrier sensing mechanism is proposed for the upstream multi-access in PONs. Simulation results show the proposed algorithm outperforms the conventional CSMA/CD scheme in terms of network throughput and delay.

I. Introduction

Carrier sense multiple access with collision detection (CSMA/CD) scheme has been used as an effective multiple access control for Ethernet built with bus topology for many years. Recent research interest on the first/last mile problem led to the development of packet-based passive optical network (PON) technology. In PON, the downstream channel is broadcast in nature while the upstream channel uses multi-access. One difficulty in upstream multi-access is that data frames sent from one ONU are only received by the optical line terminal (OLT), but not the other ONUs. Thus, different ONUs may transmit simultaneously and may lead to collision of data at the aggregation point of the remote node (RN). Media access control (MAC) used by IEEE802.3ah task force provides an efficient approach that allows request-and-grant mechanism to coordinate the multi-access of data [1]. Nearly 95% channel utilization and quality of service (QoS) can be achieved by controlling the granted data size and priority. However, synchronization is needed among all ONUs and global knowledge of distance from each ONU to the OLT should be known by the OLT in order to process the request and grant.

A recent multiple access research on tree topology network tried to eliminate the use of MAC message by optical CSMA/CD [2]. A small part of the optical power was fed back to the ONUs such that every ONU could know the data transmission status of the others. In this paper, we propose to use pilot tones, which are permeable to optical data, to enable optical signaling (carrier-sensing) and achieve collision avoidance (CA), instead of CD. Similar to the optical CSMA/CD scheme in [2], some of the optical power is fed back to the ONU and carrier-sensing is performed by detecting the presence of the distinct pilot tones in the reflected optical power. Unlike the case in 802.3ah, the OLT is not responsible for the multiple access in the uplink. It is shown that channel utilization of over 90% is possible when there are 32 ONUs in the network, compared with only 70% by using the conventional CSMA/CD scheme.

II. Protocol Description

In our proposed scheme, each ONU is assigned with a distinct pilot tone frequency for signalling, which will be multiplexed to the baseband data as in [3]. The spectra for the data and the pilot tone are regarded as the data channel and the tone channel, respectively. The pilot tone is sent by the ONU before they transmit data and is reflected at the congregation point of the RN back to every ONUs. Whenever there is data collision at the RN, the ONU will sense there is more than one pilot tone in the reflected signal. Based on this signaling information, a proposed collision avoidance algorithm will then be preformed. Figure 1 presents the state diagram when an ONU has a data packet to send. In order to assure fairness for all ONU nodes with different distances from the RN, the ONU will go into "sleep" mode after sending a pilot tone for transmission request. This sleep time, T_s, should be set at least larger than the round-trip time of the ONU that is farthest from the congregation point at the RN.

Figure 2 shows an example of tone sending and

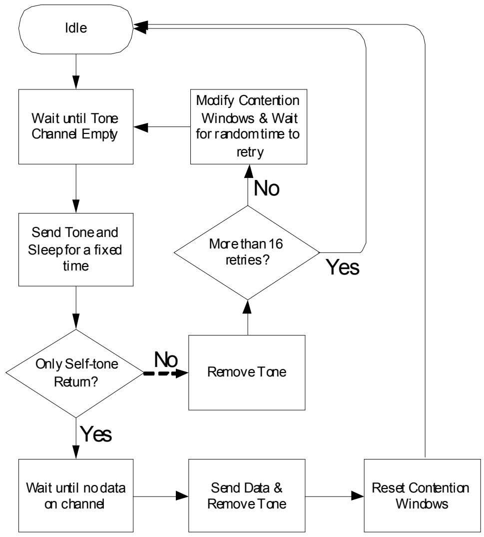

Fig. 1 Algorithm of the Collision Avoidance Protocol Pilot Tone-based carrier sense mechanism

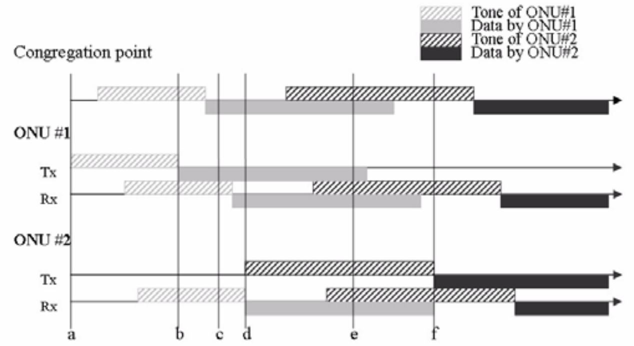

Figure 2. An Example showing the case when there is no contention occurs.

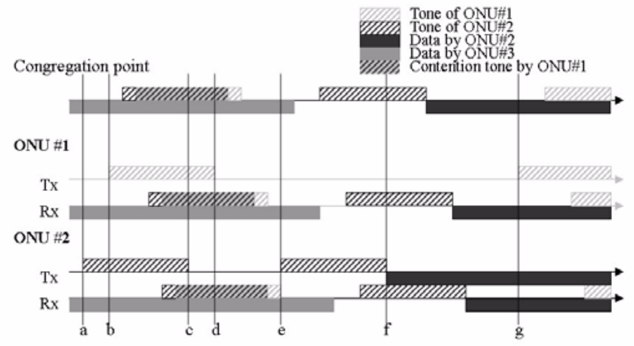

Figure 3. An Example showing the case when there is contention.

data transmission when there is no contention occurs, assuming that ONU #2 is further away from the congregation point than ONU #1. At time <a>, ONU #1 detects no other tone in the reflected tone channel and it sends out its tone. It then sleeps until time <b> and it senses only its own tone present in the reflected tone channel. It also checks the reflected data channel and confirms that no other ONU is sending data. ONU #1 therefore sends out its data immediately and removes its tone on the channel. At time <c>, when data is available for transmission at ONU #2, ONU #2 finds that there is a tone in the reflected tone channel. It waits until time <d> when all other tones are cleared, then it sends out its own tone. ONU #2 awakes at time <e> and discovers that the reflected tone channel contains only its own tone, meaning that it can send data immediately when the data channel is empty. It holds its tone on until time <f> when it detects that the data channel is vacant. Again, it removes its tone and transmits data immediately. Note that <b>-<a>=<e>-<d>= T_s. Here we assume that every ONU reacts immediately after the occurence of certain trigger conditions, such as empty data channel and single tone in reflected tone channel.

Figure 3 illustrates the case when there is contention. At time <a>, ONU #2 senses that there is no tone on the reflected tone channel, therefore it sends out its tone to notify other ONUs. Assuming a brief moment later at <b>, ONU #1 also senses that the reflected tone channel is empty, thus it sends out its tone in order to transmit its data. The tones of ONU #1 and ONU #2 collide at the congregation point of the RN and then feed back to all ONUs. Both ONU #1 and #2 detect there are more than one tone on the tone channel at time <c> and <d> respectively, and thus both of them remove their tones from the tone channel immediately. According to the algorithm, when contention occurs, both of the ONUs will retry requesting transmission after a random back-off time, in which the maximum random time depends on the number of collisions encountered. In this example, ONU #2 is assumed to have zero back-off time and is able to retry immediately and ONU #1 waits for a longer time. Thus, ONU #2 monitors the reflected tone channel until it becomes vacant at time <e>, then it sends out its tone immediately. At <f>, it finds that there is no contention and the data channel is empty, thus it transmits data and removes the tone at the same time. ONU #1 retries at time <g> and the whole process continues.

III. Simulation

The simulation assumes that the individual distance of each ONU from the congregation point of the RN ranges from 1km to 10km, giving a maximum round trip time of 0.1ms. That is, T_s=0.1ms. The number of ONUs in the network considered is ranging from 1 to 128. We assume that data packets arrive at the ONU will be grouped into a packet frame of variable length. The sending time for this packet frame varies from 0.1ms to a certain value, given by the α value which is defined as the ratio of the maximum round-trip time T_s to the time required to send a frame with the maximum frame size. Binary exponential back-off algorithm[4] is used, similar to the approach in IEEE802.3.

a) Throughput Performance

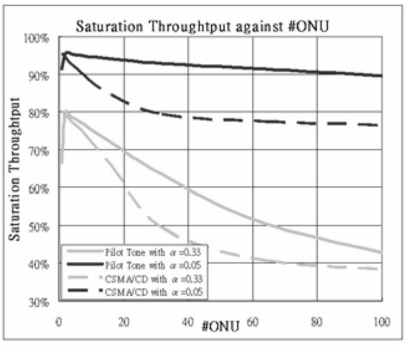

Figure 4. Throughput performance against number of ONU

Fig. 4 shows the throughput performance repect to the numbers of ONUs in the network for different values of α, which corresponds to different maximum frame sizes and different mean distance of ONUs from the congregation point. The throughput performances for the proposed scheme and the CSMA/CD scheme are compared. It is found that with 40 ONUs, the proposed scheme is around 13% better than the CSMA/CD scheme. A smaller value of α gives a higher throughput as the larger maximum frame size results in smaller proportion of unused time-slot. In TDMA scheduling such as IEEE802.3ah using MAC control message, it can obtain a maximum throughput of 95%, depending on the guard time between two consecutive frames. In our work, maximum throughput of 95% can be achieved when α is smaller than 0.1, with a tradeoff of increasing the network delay.

b) Delay Performance

Network delay is referred to the delay time from a packet arrived at the head of queue to the first-bit of the packet being sent out from the ONU. Simulation results (Fig. 5) show that network delay saturates after the saturation data rate, which is the rate that the throughout is saturated. If the input rate is high, packets will accumulate at the ONU buffer such that every ONU is trying to send packets. As shown in the figure, smaller α value gives a higher delay due to the larger frame size. Compared with CSMA/CD scheme, the proposed scheme shows 5-10ms improvement in the delay time when the network is saturated. The delay performances of both schemes are nearly the same when the network load is low.

IV. Conclusion

An optical collision avoidance scheme using pilot tone for PONs is proposed and analyzed. The carrier sensing is performed by means of the presence of the distinct pilot tones in the reflected power from the RN. The contention resolution protocol is carried out distributedly by the ONUs such that data collision is avoided. It simplifies the network control by eliminating the process of traffic scheduling and additional OEO conversion in processing the MAC messages. It is shown that it has a better performance than the conventional CSMA/CD scheme in terms of throughput and delay.

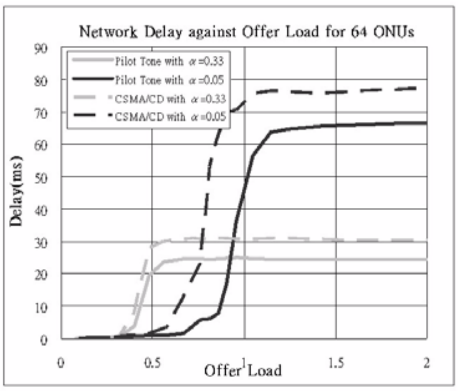

Figure 5. Network Delay against network load

V. Reference

1. G. Kramer, et al., "IPACT a dynamic protocol for an Ethernet PON (EPON)," *IEEE Communications Magazine*, Vol. 40 No. 2 , pp. 74 -80, 2002.
2. C. J. Chae, et al, "Optical CSMA/CD media access scheme for Ethernet over passive optical network," *IEEE Photon. Techno. Lett.*, Vol. 14 No. 5, pp. 711 -713, 2002.
3. C. K. Chan, et al., "Realization of a time-slot access WDMA photonic dual bus/ring packet network node using centralized light sources," *IEEE Photonics Technology Letters*, Vol. 9, No. 12, pp. 1661-1663, Dec. 1997.
4. A. S. Tanenbaum, "Computer Network," *Prentice Hall*, 3rd edition, Sect. 4.3.

TuR5 **5:45 PM**

Nonlinear Raman Cross-Talk in a Video Overlay Passive Optical Network

F. Coppinger, L. Chen, D. Piehler, *Harmonic Inc., Sunnyvale, CA, Email: fred.coppinger@harmonicinc.com*.

We investigate experimentally and analytically effects due to stimulated Raman scattering on a 1550 nm sub-carrier multiplexed video signal when co-propagating with 1490 nm digital traffic in a passive optical network. We propose design rules for mitigating any signal degradations. The access network is a bottleneck in bringing high bandwidth to residential users or businesses. The passive optical network (PON), a point-to-multipoint TDMA technology, is attracting great interest. In a two-way PON (such as an ITU/G.983.3 ATM-PON or an IEEE 802.3ah Ethernet-PON) the downstream digital traffic is carried at 1490 nm and split 32 ways before reaching the customer, while the upstream traffic is carried at 1310 nm. The standard reserves the 1550 nm wavelength window for simultaneous broadcast video delivery. Figure 1 shows a typical video overlay of sub-carrier multiplexed (SCM) CATV signal atop a two-way PON. In this presentation we analyze both experimentally and analytically the carrier-to-noise (CNR) degradation of the 1550 nm SCM video signal due to Raman cross-talk from the 1490 nm digital signal. If certain design rules are not followed, up to 5 dB of CNR degradation at the lowest frequency video channel is possible.

Figure 2 shows the experimental set-up used to analyze the Raman cross-talk in a video PON (VPON) application. A 1542-nm externally modulated transmitter was driven with 80 un-modulated RF carriers. The output of the transmitter was then amplified using an EDFA and combined with a 1482 nm signal using a WDM coupler. The 1482 nm laser was directly modulated with a gigabit Ethernet (1.25Gb/s) 2^{31}-1 pseudo random bit stream.

A polarization controller was used in the 1482 nm path. The optical powers launched into the fiber were 3 dBm and 17 dBm for the 1482 nm and 1542 nm signals respectively. After co-propagating in the fiber the 1550 nm signal was separated from the 1480 nm signal using a second WDM and directed into a video receiver. The received optical power was -3 dBm. The points in Figure 3 shows the measured CNR as a function of channel frequency for fiber lengths of 4.4 km and 12.2 km respectively. For these measurements the polarization of the 1482 nm signal was carefully adjusted to be parallel with the 1542 nm signal polarization, in order to produce the maximum degradation of CNR. As expected, the CNR degradation is greatest at NTSC channel 2 (55.25 MHz). As the fiber length increases, the walk-off of the two wavelengths due to dispersion averages out the noise transfer at higher frequencies.