Experimental Demonstration of an Interference-Avoidance-Based Protocol for O-CDMA Networks

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Abstract: We demonstrate the transmission scheduling algorithm in an O-CDMA network to avoid congestion collapse in an O-CDMA network. Our result shows that transmission scheduling increases the performance of the system by orders of magnitude.

OCIS codes: (060.2330) Fiber optics communication, (060.2360) Fiber optics links and subsystems

1. Introduction

There has been renewed interest in optical code-division-multiple-access (O-CDMA) systems due to its potential for multi-user reconfigurable local-area-networks (LANs). especially when considering fine granularity of traffic in local-area-networks (LANs) [1,2].

A critical limitation of O-CDMA networks is the reduction of throughput when many users are attempting to transmit simultaneously over the same medium, thereby producing extreme congestion at high network loads. In fact, networks can suffer from “congestion collapse,” in which the network throughput can actually approach zero under extremely high loads i.e. when several users transmit simultaneously, their packets and hence their code-words overlap. When the optical pulses in the codeword overlap, their optical power is added. Optical pulses from one codeword may be detected by receivers tuned to other code-words. As a result receivers may falsely detect their code-words resulting in packet errors. These false positive errors increase with offered load, resulting in throughput collapse.

Recently, there has been a theoretical report on an O-CDMA network protocol called interference avoidance (IA) that helps manage congestion and maintains a relatively-high throughput even under extreme loads.[3] The proposed media access protocol is interference avoidance. The protocol consists of two different functionalities, state estimation and transmission scheduling. State estimation is a mechanism by which nodes on the network estimate the state of the line. Transmission scheduling is a mechanism by which nodes use the estimated state to schedule their transmissions to avoid packet losses due to interference. To our knowledge, there have been no reports of experimental demonstrations of a network protocol that avoids congestion collapse for O-CDMA systems.

In this paper we propose and demonstrate a transmission scheduling algorithm. We use an O-CDMA network supporting 6 users. Each user utilizes a code-set of 16 chip-times, 8 wavelength, and code-weight 6. We demonstrate the transmission scheduling by delaying each user’s traffic to have the least interference with the line traffic and show the increase in system performance by orders of magnitude. To establish a comparison with Aloha-CDMA, we transmit the data with random delays and take an average over various line states. Results from the measurements show that transmission scheduling can provide orders of magnitude improvement in bit error rate.

2. Interference Avoidance

Fig.1 shows a shared medium, packet switched optical CDMA LAN in which several nodes are connected to a passive optical coupler to form an all optical broadcast network. The star coupler is a passive optical element with all inputs connected to all outputs. Each node on the network is allocated an optical CDMA codeword, which is a sequence of zeroes and ones that are transmitted asynchronously. When a node wants to transmit, it tunes its transmitter to the receiver's codeword and transmits.

Without using a media access protocol each user starts to transmit whenever the packet is ready. This is called Aloha-CDMA, which leads to congestion collapse in an O-CDMA network. To alleviate this problem, the use of a media access protocol "Interference Avoidance (IA)" is proposed. IA is a contention media access control mechanism that prevents throughput collapse in optical CDMA networks at high offered load. It consists of state

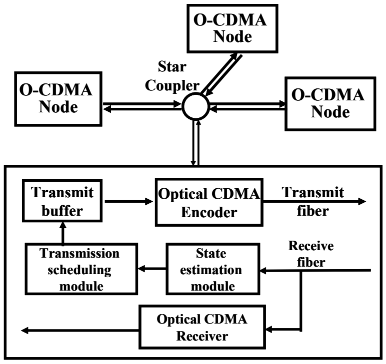

Fig.1 O-CDMA network: Star coupler with various nodes attached to it, and detail hardware of a node

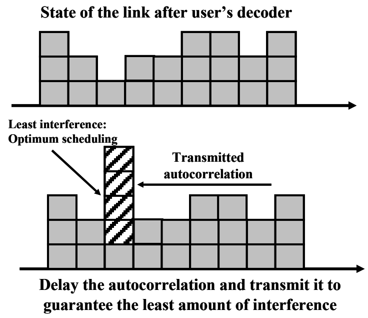

Fig.2 Upper: link after the decoder of user of interest. Lower: the data is transmitted such that the autocorrelation is in the chip time with least interference

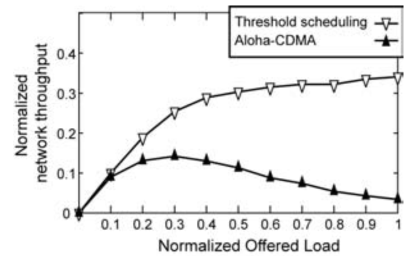

Fig.3. Comparison of transmission scheduling and Aloha CDMA, using TS the throughput of the network does not collapse in high loads

estimation and transmission scheduling. State estimation is a mechanism by which nodes on the network estimate the state of the line. Transmission scheduling is a mechanism by which nodes use the estimated state to schedule their transmissions to avoid packet losses due to interference. A simplified block diagram of an O-CDMA node is also shown in Fig.1.

The concept of the state estimation and scheduling algorithm is shown in Fig.2. To accomplish the state estimation we first pass the traffic from the line through the decoder of the user of interest. This is the traffic as it is seen by the receiver end. We then detect the date using multiple threshold detectors. The minimum interference detected here is the best position to transmit the autocorrelation peak. Now the transmission scheduler delays the packet so that the autocorrelation transmits in the designated chip-time "Minimum interference". The transmission scheduler chooses the marked chip as the lowest MAI and then delays the packet and transmits the autocorrelation peak. It should be noted that as each packet consists of several bits, the state of the link remains constant for a long duration.

In [3] an IA based optical CDMA network was modeled using discrete event based packet simulator The simulator modeled multiple nodes on a broadcast shared medium optical CDMA LAN. The normalized offered load is the arrival rate (in packets/s) expressed as a fraction of the maximum possible arrival rate (in packets/s) of the network when it is used as a single channel network. The arrival rate is defined as the aggregate rate at which packets arrive to all the nodes for transmission on the network. The normalized network throughput is the ratio of the number of packets that are transmitted over the network without error to the total number of packets offered for transmission multiplied by the normalized offered load. The result of the simulation is shown in fig. 3. The results show that the as the offered load increases the throughput of Aloha-CDMA tends to zero, while the use of the transmission scheduling algorithm prevents throughput degradation.

3. Experimental Result

The experimental setup for our O-CDMA system is shown in Fig. 4. We use eight equal space lasers, couple them together and modulate them at 10 Gchip/s. After an EDFA, we use O-CDMA encoder to encode the data and then use a variable delay line to vary the time delay of the user. Each encoder is based on an FBG technology which implements the splitting of the wavelengths and assigning each wavelength chip an appropriate timeslot. This data is transmitted through a short length of fiber and then combined in a star coupler with 5 other users. At the receiver, we amplify the received signal and use a second set of fiber delays to stack the chips to decode the data. At the receiver, a photo-receiver detects the decoded data followed by a threshold detector that samples the data to determine whether it exceeds a set decision threshold.

In our experiment we used the codes with 8 wavelength, 16 chip times, and code weight 6. Our codes are based on code construction function Plot B. [4] and they can support 18 potential users. Our code construction is optimal in terms of the number of code-sets and has at most one pulse per wavelength. The chip rate is 10 Gchip/s and the corresponding bit rate is 625 Mbit/s.

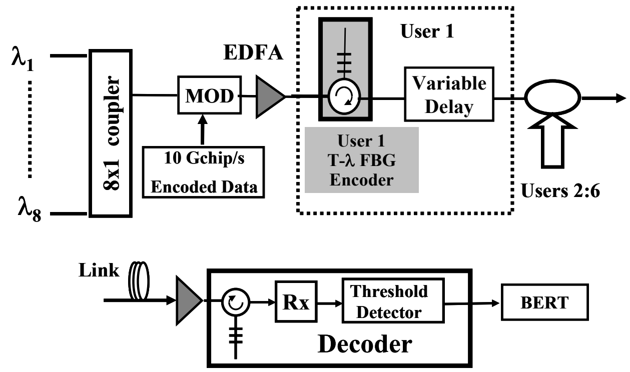

Fig 4. Experimental setup

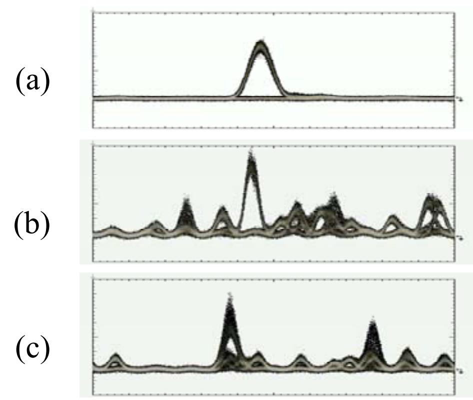

Fig 5. Eye diagram of the correlation for (a) single user (b) multiple user using transmission scheduling (c) random case

Fig. 5(a) shows the eye diagram of the autocorrelation function of a single user. The autocorrelation resembles an RZ signal with 1/16 ratio as there are 16 chip-times. Fig. 5(b) shows the eye diagram of the main user along with multiple interferers. It is clear that by varying the transmission delay of this user, the autocorrelation can move to any point of time. In this case the position of the autocorrelation is optimized resulting in an open eye. Fig. 5(c) shows a random delay of the user which causes severe eye closure.

Fig.6. show the BER curves for increasing number of users. As we added more users to the network, we examined the link interference pattern and optimized the transmission delay of the user of interest. It is clear that using the optimized delay up to 6 users are recoverable with less than 4dB power penalty.

To compare the performance of the IA algorithm with aloha CDMA, we first fixed the number of users and the state of the link. We then vary the delay of the user of interest to find the optimum delay which can achieve the BER of 1E-10 at the least possible optical power, at this point we fixed the optical power and changed the delay of different users to emulate different link state and then vary the user of interest delay to emulate the Aloha CDMA. The average BER resembles the Aloha-CDMA. The results are shown in fig. 7. It should be noted that the respective point for different number of users are achieved for different optical power. Results show that in worst case the BER of system drops below 1E-3 for 5 and 6 users. Moreover using Aloha-CDMA the performance drops as the number of users increases in the network, while using IA algorithm we can maintain the desired performance for increasing number of users.

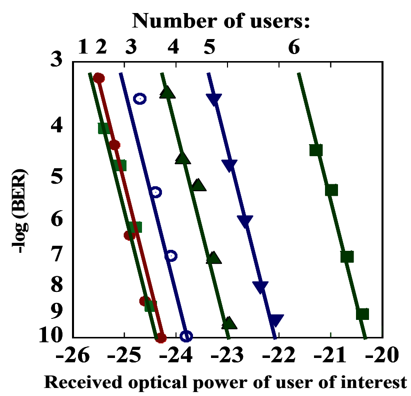

Fig 6. BER v.s. received optical power of user 1 for increasing number of users

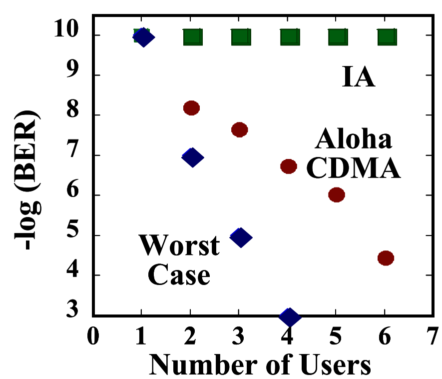

Fig 7. Performance of an O-CDMA system for increasing number of users with transmission scheduling, aloha-CDMA, and worst case

4. References

[1] J. A. Salehi, *et al.*, IEEE Trans. on Communications, **37**, 824-842 (1989)
[2] L. Tancevski, JLT, vol. 14, pp. 2636-2647, 1996
[3] P. Kamath, et all, IEEE Infocom, March 2004, vol. 4, pp. 2208-2219.
[4] R. Omrani, *et al.,* 41st Allerton Conf. Comm., Control, Comp. (2003)