Interference Avoidance in Optical CDMA Networks

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***Abstract*— Interference Avoidance is a media access control mechanism that prevents throughput degradation in a broadcast all optical Local Area Network (LAN) built on optical Code Division Multiple Access (CDMA) technology. Optical CDMA is a multiplexing technology that allows the utilization of the large transmission capacity of an optical fiber. However, the throughput of an optical CDMA broadcast LAN network degrades quickly due to multiuser interference. *Interference Avoidance* controls interference and prevents throughput degradation due to interference at high loads. It is based on two mechanisms: *state estimation* and *transmission scheduling*. Algorithms for state estimation and transmission scheduling are proposed and evaluated. Analysis and simulation show how they prevent degradation of throughput at high loads. A testbed implementation of state estimation and transmission scheduling hardware is in progress.**

I. Introduction

Optical CDMA is a code division multiplexing technology that allows several transmitters to transmit simultaneously on an optical fiber. Nodes transmit using codewords from an Optical Orthogonal Codeset (OOC) [1]. An OOC is a set of (0,1) sequences of length N that satisfies certain autocorrelation and cross-correlation constraints. The term *codeset* is used to refer to the set of such sequences, and the term *codeword* is used for a member of the set. Each 0 or 1 of a sequence is called a *chip*, and the sequence represents a data *bit*. The number w of 1 chips of a codeword of the codeset is called its Hamming weight. Codesets are designed so that the autocorrelation of any codeword and the cross-correlation between any pair of codewords in the codeset is constrained below a value called the *Maximum Collision Parameter* κ.

A node transmits data by ON-OFF keying (OOK) of a codeword. Optical CDMA receivers are correlation receivers. By connecting nodes on the network in a star, bus or ring topology any node can transmit to any other using the receiver's codeword. More details on the system architecture of an optical CDMA network may be found in [2].

The advantage of optical CDMA is that it allows utilization of the available transmission capacity of an optical fiber. Data processing can occur at electronic speeds while encoding and decoding can be done all optically at a higher chipping rate [3].

The main problem with using optical CDMA in a LAN is that at high loads multiuser interference errors result in low network throughput [4]. The reason is that a correlation receiver set to receive a particular codeword will erroneously detect a 1 bit if there are other codewords on the line which have '1 chips' in the same locations as the expected codeword.

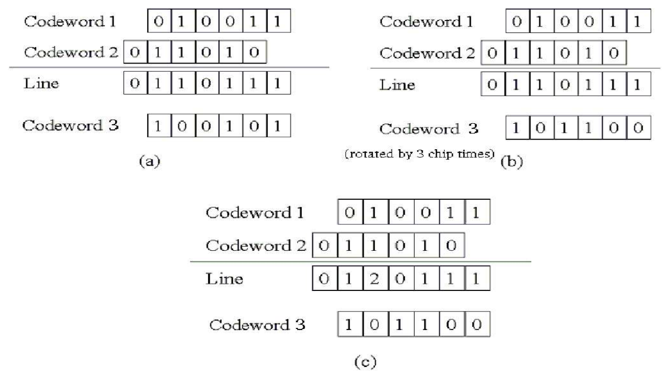

Fig. 1. Interference avoidance

If the receiver is currently receiving a packet, this kind of *false positive* error can result in the loss of the packet.

Related work in the area of Optical CDMA mostly focuses on code design [1] or system design [3]. A survey of related work may be found in [2].

This work demonstrates thats *Interference Avoidance* can control interference and improve the throughput of an optical CDMA LAN at high loads.

II. Interference Avoidance

Consider the codewords shown in Figure 1(a). The figure is a snapshot of data bits sent by two nodes (codewords 1 and 2). A third node is preparing to transmit on codeword 3. If transmitted with the chip offset shown in Figure 1(a) a false positive error would probably occur. If it was sent three chip times later (Figure 1(b)), all three packets could be transmitted correctly. (Codeword 3 has at least one chip that does not interfere with codewords 1 and 2. Hence no false positive can occur and it will be received correctly).

Interference Avoidance uses the above principle. A node estimates the state of the line (*state estimation*). Given the state estimate and the codeword to be transmitted, it decides the appropriate time instant to transmit such that there is no interference (*transmission scheduling*). Interference avoidance reduces interference and improves throughput. Note that any packet arrivals in the time between the state estimation and the transmission can still cause interference.

III. STATE ESTIMATION

Assume that several nodes on an optical CDMA LAN are transmitting simultaneously on different codewords. Each codeword is shifted by a different phase shift that depends on the exact instant it was transmitted. The state of the line at a point on the line is the sum of the codewords taken over a window of N chips. *E.g.*, in Figure 1(c), the state of the line is $[0120111]$.

Arrivals and departures of packets continuously change this state of the line. The on-off keying of the codewords also changes the state of the line. The objective of state estimation is to determine the *true state*, *i.e.* the sum of the codewords being transmitted with appropriate phase shifts. A *window based state estimation* algorithm can give a reasonable estimate of the true state of the line. The node determines the state by sampling the line. This is called the *sensed state* This is repeated for a window of time, say W bits. The estimated state is twice the average of the sensed states taken over over the window. State estimation can be either performed *continuously* or *on-demand*, *i.e.* when a packet arrives.

The performance of an on-demand window based state estimation algorithm has been measured through simulation and the results of system performance are described in Section V.

State estimation hardware needs to be implemented using sampling over several bits because chips are arriving faster than the maximum electronic processing rate. The hardware for state estimation is currently being implemented.

IV. TRANSMISSION SCHEDULING

Given an accurate estimate of the true state of the line, a node can use a transmission scheduling algorithm to determine the appropriate time to transmit.

The following classes of transmission scheduling algorithms have been identified:

- Selfish algorithms: These algorithms schedule the transmission of a packet such that other codewords on the line will not interfere and cause loss of this packet
- Cooperative algorithms: These algorithms schedule the transmission of a packet such that the transmission of this codeword will not interfere and cause loss of other packets on the line.
- Pseudo-cooperative: These algorithms control interference by limiting either the number or size of ’1’ chip overlaps.

Transmission scheduling algorithms can be analyzed using a Markov chains [5] approach by reducing the state description to a simpler form to make it mathematically tractable. The average throughput of different transmission scheduling algorithms may obtained from this model. The average throughput of the algorithms may be compared to an upper bound on the throughput of an optical CDMA network obtained through a combinatorial analysis [5].

The transmission scheduling algorithms will be implemented in electronics while the transmission delays can be controlled by selecting from a set of optical delay lines. The transmission scheduling hardware is currently being implemented.

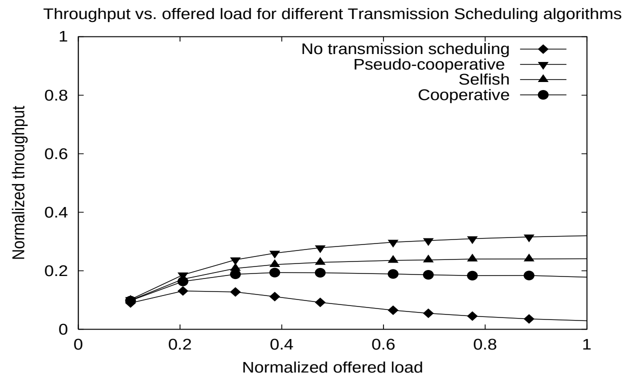

Fig. 2. Throughput vs. offered load for different transmission scheduling algorithms for simulation of a star network using a (10, 3, 2) codeset. A continuous window based state estimation algorithm was used with sensing window = 10 bits. Four transmission scheduling algorithms were evaluated: Selfish, Pseudo-cooperative, Cooperative and None (Aloha-CDMA). A 1-persistent defer algorithm was used with a retry limit of 10.

V. SYSTEM PERFORMANCE

The performance of an Interference Avoidance system is dependent on a large number of factors such as traffic patterns and network topology. An analysis based on Poisson arrivals, exponentially distributed packet lengths random codeword assignment, perfect state estimation may be found in [2]. Figure 2 shows the results of a realistic simulation that uses a traffic model based on real network traffic. The protocol is called *Interference Sensing/Interference Detection (IS/ID)*. Nodes estimate the state and schedule transmissions. If interference is detected during transmission, the transmission is aborted and the node backs off. The simulation assumed a star network, a window based on demand state estimation algorithm, three different types of transmission scheduling algorithms and a defer algorithm for retransmission [6].

Both analysis and simulation confirm that the throughput of a system without Interference Avoidance degrades with increasing load, while the throughput of an Interference Avoidance system remains constant at high loads.

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