A RESERVATION AND COLLISION-FREE MEDIA ACCESS PROTOCOL FOR OPTICAL STAR LOCAL AREA NETWORKS

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Abstract

A new multiple access protocol is developed for optical local area networks based on a passive star topology. The protocol uses wavelength division multiplexing (WDM), and is highly bandwidth-efficient. Each station in the network is guaranteed a minimum bandwidth and a maximum access delay to the network, allowing the protocol to be used for both datagram and connection-oriented traffic. No central control is required, and the amount of processing required by each station is small. Time is divided in fixed-sized slots. Before transmitting its data, a station must compete with others for the right to use a slot in a preassigned wavelength, using a collision-free procedure. The protocol is suitable for networks where the number of users is larger than the number of available channels. The scheme can operate with at least a single tunable transmitter/receiver pair in each station. The paper includes plots wehre results obtained from simulations and from the application of models are compared.

1 Introduction

Computer communications have benefited greatly from the introduction of optical fiber as the next-generation transmission medium. Tremendous transmission speeds can now be achieved, limited mainly by bottlenecks in processing and in opto-electric interfaces. As in any communication system that uses a shared transmission medium, computer communications that use optical fiber require a communication protocol for an ordered access to the transmission media. Usually, the main objectives of such communication protocols are to maximize throughput and to minimize delay. The characteristics of these protocols are heavily influenced by the span of the network they are designed for. In the past few years, several of these protocols have been proposed [1–11] for Local Area Networks (LANs). Every protocol design should try to achieve fairness, minimize delay and processing, and maximize throughput. Other characteristics, such as scalability, and the ability to easily add and remove stations from the network are highly desirable. Also, central control schemes should be avoided. But obviously, and like in any good engineering problem, it is not possible to have everything in a given scheme and compromises need to be made.

In the proposed protocol, stations reserve bandwidth dynamically. A minimum of one tunable transmitter/receiver pair is required per station. The scheme requires at least one control channel, and depending on the number of available data channels, it can support hundreds and up to a few thousand users. The number of users is generally much larger than the number of available channels.

In contrast to the proposed scheme, in order to support a network of N stations, protocols like [3,5,6,8,10] require more than N wavelengths ($2N$ for [11], $N+1$ for [5,6,8,10]), imposing a serious restriction on the maximum number of users using the network, typically limiting this number to no more than a hundred stations. Protocols like [1,2,4,7] present a throughput curve that diminishes after a certain offered load is exceeded, due to collisions in the data channels. Since in the proposed scheme collisions in the control or data channels cannot occur, the throughput of the protocol is basically a monotonically increasing function of the input load.

The rest of this paper is organized as follows. Section

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2 presents the proposed protocol. In Section 3, we analyze the maximum achievable throughput of the protocol in terms of the number of stations, number of data channels, and number of receivers per station, assuming a Bernoulli process for the arrival of new packets to every station. Numerical results of several simulations of the protocol in operation and their comparison with results obtained from developed models are presented in Section 4. A summary and our concluding remarks are presented in Section 5.

2 The Protocol

The protocol presented here has its roots in the protocol described in [4]. Contrary to that protocol, however, collisions in the data channels cannot occur, resulting in a protocol with a bandwidth utilization and throughput that basically does not decrease as the number of stations attempting transmission increases (as explained in Section 4.1, throughput can diminish if multiple stations simultaneously attempt to send packets to a station that has a small number of receivers). Here, we assume that all stations in the network are synchronized by using a common global clock, and that guard times between transmissions from different stations are essentially non-existent. The synchronization problem has been studied and solved in [12,13].

2.1 Basic Scheme

Assumptions:

- There are $N+1$ channels (λ_0, λ_1, ...,λ_N) in the fiber (typically, the total number of channels is between 10 and 100).
- There is a single control channel λ_0.
- There are a total of M stations numbered m_1, m_2, ..., m_M in the network.
- The number of stations M is a multiple of the number of data channels N so that $Nq = M$, where q is an integer.
- Each station has at least a tunable transmitter/receiver pair.
- Transmitter and receiver tuning times (to and from any allowed channel), propagation delays, and control packet processing times are negligible.

The control channel is divided into equally-sized slots. Each slot consists of two parts, the reservation part and the tuning part, as shown in Figure 1. The reservation part is divided into N minislots, and each of these minislots is divided into q microslots. This corresponds to dividing all stations into N groups, where each group consists of up to q stations. Therefore, there is a single and unique microslot for each possible station in the network, and each station belongs to a single group.

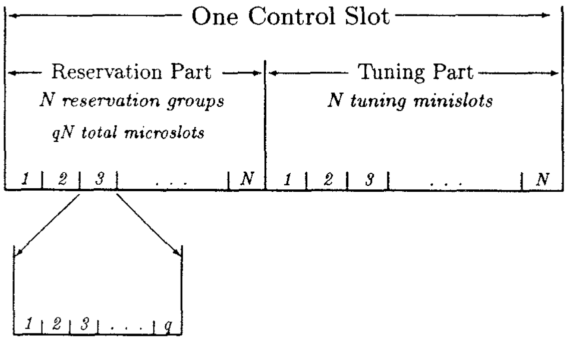
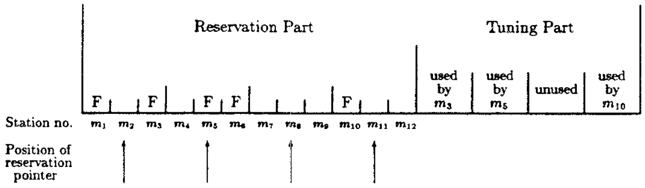


Figure 1: Structure of a Control Slot.

The tuning part of the control channel is also divided into N minislots. For each of the N groups of stations there is a corresponding minislot in the tuning part, e.g., group 1 uses tuning minislot 1, group 2 uses tuning minislot 2. In each of the N groups, and in every control slot, up to q stations compete for the opportunity to use the tuning minislot assigned to their group. The tuning minislot is required because it is in this minislot where a station specifies its intended receiver. Apart from the intended receiver's address, the tuning minislot could also contain other information, such as the sender's address, or type of traffic. However, if the amount of information in the control slot is to be minimized, the sender's address can be included in the corresponding data packet.

Each microslot in the reservation part is one bit wide. Whenever a station needs to send data to another station, it first raises a flag in its assigned microslot, as shown in Figure 2. The purpose of the flag is to tell the other stations in the same group that a given station needs to use the minislot in the tuning part assigned to the group. Since up to $q-1$ other stations may also be trying to use the tuning minislot at the same time, i.e., in a given control slot, the following contention scheme is used.

Associated with each of the N groups, there is a pointer (called the "group pointer") that uniquely determines the station that can use the tuning minislot in the present control slot. At any given time, the group pointer indicates the number of the station that has the right to use the tuning minislot, provided that



F - Flag that indicates intention to use the tuning minislot.
($N = 4$, $q = 3$, $M = 4 \cdot 3 = 12$)

Figure 2: An Example of Stations Trying to get hold of a Tuning Minislot.

the station raised the flag in this control slot. If the station in question did not raise the flag, then another candidate is sought by "rotating" a copy of the group pointer until a raised flag is found. Accordingly, in Figure 2, stations m_3, m_5, and m_{10} in groups 1, 2, and 4 respectively, will use their tuning microslot in this control slot. Note that since no station raised its flag in group 3, tuning minislot 3 will be unused during this control slot.

To prevent a condition where only the first of two stations with contiguous microslots gets a better opportunity to send a large number of data packets just because it is closer to the group pointer, each station that has been selected to use the tuning minislot has to count the number of stations C_{fr} in its group that raised their flag during the current control slot. Then, the station using the tuning minislot can raise its flag again only after at least C_{fr} control slots have passed.

For the basic protocol described here, the winning station of each group needs only to fill its tuning minislot with the address of the intended receiver. The wavelength to use for the transmission is implied by the tuning minislot number. For example, stations using tuning minislot one would send their data on wavelength λ_1. The length of the data slots is equal to the length of the control slots. The transmission of the data slots needs to occur at the end of the control slot.

Since two or more stations may be sending data to a given station during the same slot, a scheme is required to resolve conflicts that could arise if the designated station has a number of receivers that is smaller than the number of expected data packets. Following the ideas described above for the group pointers, all stations could implement a second pointer (that would be synchronized among all stations) for this purpose.

3 Performance Evaluation

Modeling Assumptions:

- Packets are generated in each station as independent Bernoulli processes. The probability of a new packet arriving to any station at the end of a slot is equal to σ, the ratio of the input load I to the number of stations M.
- Each station has an FT/FR pair for the control channel. For the data channels, each station has a single FT for its assigned data channel, and one or more TRs. Moreover, the number of tunable receivers per station is the same and is denoted by R.
- Each station has a large buffer size for data packets, i.e, packets cannot be lost due to buffer overflows.

Here, the input load of the network I is considered to be the average rate of data packets generated by all stations in the network. The offered load to the network G is equal to the average rate of data packets being carried by the network.

The fact that each station has independent receivers for the control and data channels allows a station to receive a data packet and to watch the control channel at the same time, reducing the possibility of a lost packet. Also, a station transmitting a data packet can simultaneously place a request for a tuning minislot in the control channel.

3.1 Maximum Achievable Throughput of the Network

Network throughput is considered to be the total rate of data being transmitted between all stations and normalized by the total network capacity. If two or more stations send a packet during the same data slot to a station that has a single tunable receiver, all but one of the data packets sent to that station will be lost. Obviously, increasing the number of tunable receivers reduces the number of packets that are lost (assuming that the station has the hardware to process messages that arrive at the same time), resulting also in higher network throughputs.

In [14], we derive an expression for the maximum achievable throughput S_{MAT} of any network configuration as a function of the number of stations M, data channels N, and receivers per station R. For brevity,

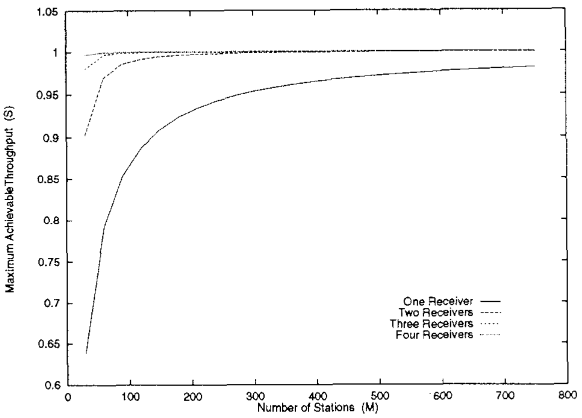


Figure 3: Maximum Achievable Throughput of the Network with N=30.

here we only present the plot for the S_{MAT} of a network with $N = 30$, a wide range of the total number of stations, and up to four receivers per station. This plot is shown in Figure 3. In the past, it has been considered that the number of packets lost due to simultaneous packet arrivals to a station with few receivers is negligible. Figure 3 shows that this consideration is not adequate, specially when the stations have a single receiver.

4 Numerical Results

In this section, we present results obtained from simulations and from the application of models developed in [14]. We simulated and modeled a network system with 30 data channels ($N = 30$), a varying number q of stations per group, and different conditions for the input load I. In addition, each station had a FT/FR pair for the control channel, a FR for its assigned data channel, and a single TT for transmission to any data channel.

Figure 4 presents the throughput versus offered load characteristics for different network configurations with a total of $M = 60, 150, 600$ stations. It is evident from this figure that, contrary to ALOHA and CSMA-based protocols, the throughput of the presented protocol never decreases as the offered load increases. It is interesting to point out that in a network with N TR per station, and regardless of the total number of stations M in the network, the values for throughput, normalized input, and normalized offered loads are identical for $0 \leq I \leq N$, and the network is able to achieve a throughput equal to unity.

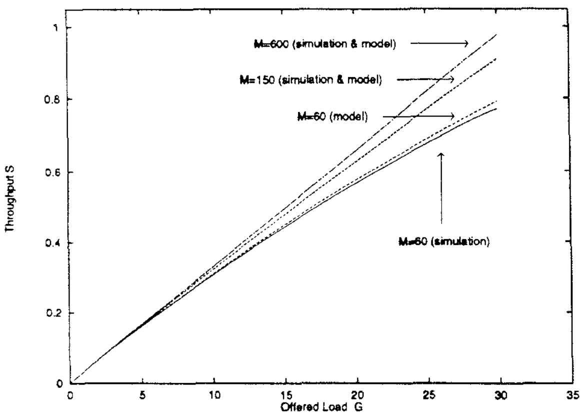


Figure 4: Throughput S versus Offered Load G, with N=30.

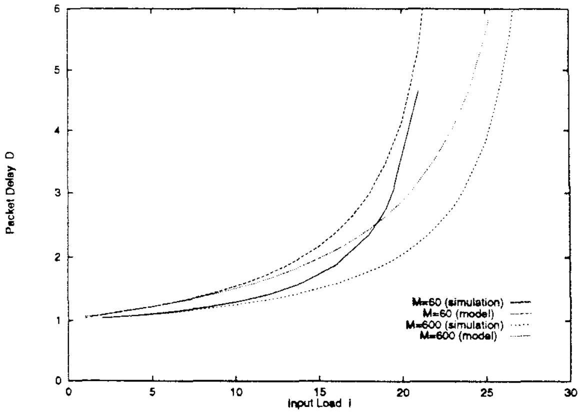


Figure 5: Packet Delay D versus Input Load I, with N=30.

Delay versus input load is plotted in Figure 5. It is interesting to observe that values of the normalized input load less than two thirds of the maximum achievable throughput result in packet delays of two slots or less! Obviously, higher values of the input load place the corresponding delay values in the steep portions of the curve. All delay versus throughput curves show an asymptotic behavior, with the asymptote located at $I = N \cdot S_{MAT}$. The asymptote and the curves shift to the right as more receivers per station are added. When every station in the network has N tunable receivers, the asymptote is located at $I = N$. In this case, every station is guaranteed a minimum bandwidth of $1/q$ of a channel, and a maximum delay of q slots before it can use a data channel.

5 Summary and Conclusions

In this paper, we developed a new collision-free media access protocol for optical networks where the number of users can surpass the number of available data channels. The proposed protocol is totally distributed and allows small data slots. The usage of network bandwidth is distributed among stations within a group in a round-robin-like fashion. Every station in the network is guaranteed a transmission opportunity in at most every q slots. The proposed protocol requires moderate processing, and stations only need to monitor certain sections of a control slot. We showed that the common assumption that the number of packets lost due to simultaneous transmission to a single station is negligible is not always valid, and can have a significant effect on the throughput of those networks with a small number of stations. In a real network with specialized servers, it is evident that to achieve high throughput, the servers will be required to have multiple receivers. Moreover, with enough receivers, a network using the proposed protocol can achieve a throughput equal to unity. This is in sharp contrast to other protocols that actually have their throughput reduced as the offered load is increased. The protocol presented here is fair to every station within a group in that on the average, every station among competing nodes gets the same opportunity for access to the network.

In this work, we considered that propagation delays were negligible. The protocol can easily be extended to consider non-negligible propagation delays. In this case, stations may send numerous requests using different control slots before they can verify if their first request was successfull. This occurs when the corresponding control packet returns after a round-trip propagation delay through the network. Preliminary work shows that most performance parameters (with the exception of packet delay times) are basically unaffected by propagation delays [15].

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