Optical Logic Circuits:
A New Approach to the Control of Fiber Optic LANs

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Abstract

The centralized filtering of the transmitted packets has been the base of a family of high-performance protocols for WDM Star Networks [19],[20]. Protocols of this family have been proved to achieve a significantly higher performance than the well-known contention-oriented or round-robin protocols. However, the need for electronic control of the filtering mechanism as well as the use of slowly tunable acoustooptic filters have been limiting factors in their performance. Furthermore, since the network hub of WDM Star Networks represents a single point of failure, the extensive use of electronic circuits at this point reduces the reliability of the system. In this paper, an all-optical centralized protocol is introduced. According to this protocol, the passing of the transmitted packets to the star coupler is controlled by means of optical logic circuits, without the need of optical to electronic translation or electronic processing of the network feedback information. In this way, the processing time is drastically reduced, while the need for acoustooptic filters is eliminated. Therefore, a significant performance improvement is achieved. Furthermore, due to the all-optical nature of the network hub, the reliability of the system is improved. The performance of the proposed protocol is studied via extensive analytical and simulation results which indicate that a WDM Star network operating under this protocol achieves a high throughput-delay performance under any load conditions.

1. Introduction

The introduction of broadband services and multimedia applications has led to a dramatical increase in the bandwidth demands of the emerging new generation of fiber optic LANs and MANs.

Due to the limited speed of the stations' electronic circuits, single channel optical networks - such as FDDI, DQDB, Fasnet, Expressnet, etc - were not proved capable of supporting Gigabit data rates. The Wavelength Division Multiplexing (WDM) technique [1],[2] solves this problem by dividing the available optical bandwidth into multiple channels of lower bandwidth which can be easily supported by the stations' electronic circuits. Both, multiplexing and demultiplexing of the multiple channels, are performed in the optical domain without the need of optical to electronic translation and vice versa. In this way, the WDM technique allows the implementation of all-optical networks which are capable of providing Gigabit data rates by using present-day optical and electronic technology.

Broadcast-and-Select Star networks (figure 1) - which are a special category of WDM networks - use a Passive Star Coupler in order to broadcast all inputs to all outputs. There are four possible configurations of the Broadcast-and-Select Star architectural form: a) Fixed optical transmitters and fixed optical receivers [1], [4], b) tunable optical transmitters and tunable optical receivers [1],[12]-[16], c) fixed optical transmitters and tunable optical receivers [1],[3],[5],[9]-[11],[18], and d) tunable optical transmitters and fixed optical receivers [1],[6],[7],[17],[19],[20]. The latter configuration is considered in this paper.

The centralized filtering of the transmitted packets has been the base of a family of high-performance protocols for WDM Broadcast-and-Select Star Networks [19],[20]. Protocols of this family have been proved to achieve a significantly higher performance than the well-known contention-oriented or round-robin protocols. However, the need for electronic control of the filtering mechanism as well as the use of slowly tunable acoustooptic filters have been limiting factors in their performance. Furthermore, since the network hub of WDM Star Networks represents a single point of failure, the extensive use of electronic circuits at this point reduces the reliability of the system.

In this paper, an all-optical centralized protocol is introduced. According to this protocol, the passing of the transmitted packets to the star coupler is controlled by means of optical logic circuits, without the need of optical to electronic translation or electronic processing of the network feedback information. In this way, the processing time is

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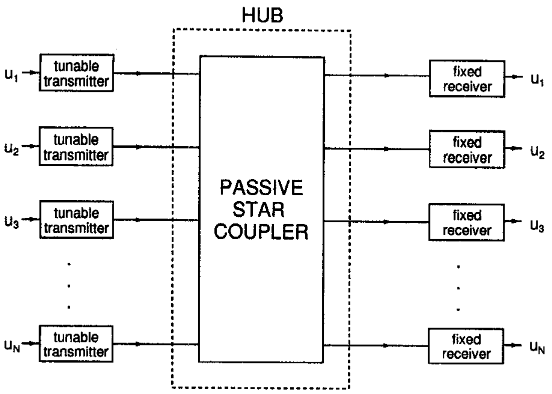

Figure 1: A WDM Broadcast-and-Select Star Network using tunable lasers and fixed optical filters.

drastically reduced, while the need for acoustooptic filters is eliminated. Therefore, a significant performance improvement is achieved. Furthermore, due to the all-optical nature of the network hub, the reliability of the system is improved. The performance of the proposed protocol is studied via extensive analytical and simulation results which indicate that a WDM Star network operating under this protocol achieves a high throughput-delay performance under any load conditions.

The paper is organized as follows: The proposed Optically Controlled Optical Network (OCON) is presented in Section 2, while the Optical Logic Circuit which is the core element for the implementation of OCON is extensively discussed in Section 3. The performance analysis of the proposed protocol in Section 4, is followed by the presentation of simulation results in Section 5. Finally, concluding remarks are given in Section 6.

2. The Optically Controlled Optical Network

The OCON network can be divided into two basic modules which are described below: The Broadcast-and-Select Module and the Packet Filtering Module. The reader can consult figure 2 in order to study an example of the OCON network for four stations and three wavelengths.

2.1. The Broadcast-and-Select Module

The Broadcast-and-Select module is based on the network architecture which is presented in [6] and [7].

The set of nodes is defined as $U = \{u_1, \ldots, u_N\}$, where N is the number of nodes. The set of wavelengths is defined as $\Lambda = \{\lambda_1, \ldots, \lambda_W\}$, where W is the number of wavelengths.

Each transmitter is provided with a tunable laser which can be tuned to each one of the W wavelengths. Optical fibers are used to connect the outputs of the lasers to the network hub. There, the optical signal is fed to a Passive Star Coupler after passing through a packet filtering mechanism, which will be described in Section 2.2.

Each output port of the star coupler is connected to the corresponding receiver, by means of an optical fiber. Each receiver is provided with a set of R fixed optical filters with each of them passing a different wavelength. Therefore, each receiver is capable of concurrently receiving up to R packets which are transmitted on different wavelengths. R is usually very small ($1 \leq R \leq 3$), since a large number of receivers per station would lead to an increase of the network complexity.

2.2. The Packet Filtering Module

The Packet Filtering Module filters the packets arriving at the network hub in such a way, that at most one packet per wavelength is allowed to pass to the star coupler. Its role is similar to a MAC layer firewall, except that it is used for collision avoidance reasons rather than for security ones. It can be separated into three stages.

The first stage consists of an array of N WDM Demultiplexers which separate the different wavelengths of the incoming signals. Since during a time slot each node can transmit at only one wavelength, it follows that at most one of the W output ports of each Demultiplexer contains an optical signal.

The second stage consists of an array of W Optical Logic Circuits (OLCs) with each wavelength being controlled by a separate OLC. The outputs of the demultiplexers which contain wavelength λ_i (for $i = 1, \ldots, W$) are connected to the corresponding OLC which controls this wavelength. Only one of the optical signals which enter the OLC is allowed to exit. All the other signals are blocked. Since, only one packet per wavelength is allowed to pass to the star coupler, collisions are avoided. The design and implementation of the OLC are discussed in Section 3.

The third stage consists of N WDM Multiplexers which recombine the optical signals in order to be fed to the N input ports of the Passive Star Coupler.

2.3. The Operation of the OCON protocol

The time axis is slotted. At the beginning of each time slot, each ready station randomly selects a packet from the waiting queue, chooses at random one of the R wavelengths which the destination node of the packet is capable of receiving and then, it tunes its laser to this wavelength

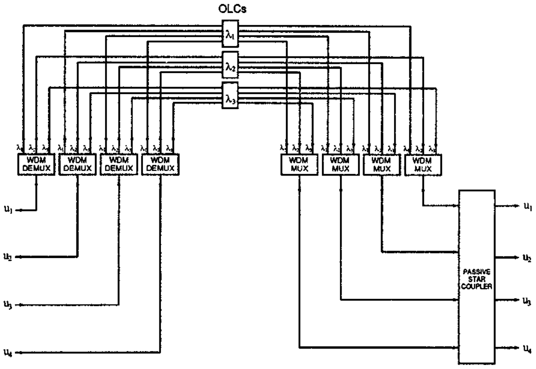

Figure 2: The hub of the Optically Controlled Optical Network.

and transmits the packet. The transmitter can ascertain the result of its transmission by using one of the methods which are reported in [8]. The round-trip propagation delay is assumed to be negligible. Therefore, the feedback information is immediately available. If the transmitted packet is not blocked by the Packet Filtering Module, then the transmitting node deletes the packet from the waiting queue. Otherwise, the packet remains in the queue.

3. The Optical Logic Circuit

The key element of the OCON architecture is the Optical Logic Circuit (OLC). It is an optical device with N input and N output ports which allows only one of the incoming signals to pass to the corresponding output port.

The basic operations of the OLC are the following:

a) Senses the input ports in order to find out which of them contain incoming signals.

b) Selects one of the incoming signals.

c) Allows the selected signal to pass to the corresponding output port, while all the other signals are blocked.

d) The selection of the passing signal must be implemented fairly. None of the input ports must be favored among the others.

e) The device must be all-optical, without any O/E translation of the incoming signals.

First, the logical structure of the OLC device is described at logic gate level and its operation is analyzed. Then, the implementation of the device by means of Directional Couplers is presented. The reader can consult figure 4 in order to study an OLC device with four input and four output ports.

3.1. The OLC Logical Structure

The OLC logical structure can be divided into two basic modules:

1. The packet blocking module
2. The control module

The packet blocking module consists of N AND-NOT gates H_k ($k = 1, \ldots, N$) which act as taps which allow or block the passing of the incoming packets. It has N input ports I_k, N output ports O_k and N control ports C_k (the "NOT" input ports of the AND-NOT gates), for $k = 1, \ldots, N$. Since, $O_k = \overline{C_k}\, I_k$ it follows that, if a control port C_k is set to 0, then the signal of input port I_k is allowed to pass to the corresponding output port O_k. Otherwise, if control port C_k is set to 1, then the signal of input port I_k is blocked. Since only one of the output ports (say O_p) may contain an optical signal, it follows that C_k ($k = 1, \ldots, N$) must be defined in such a way that $\overline{C_p}\, I_p = 1$, while $\overline{C_m}\, I_m = 0$, for all $m \neq p$.

The control module controls the operation of the packet blocking module by driving the control ports of the latter. Its role is to sense the incoming signals I_k ($k = 1, \ldots, N$) and to define C_k's in such a way that only one output port $O_p = \overline{C_p}\, I_p$ is equal to 1, while all the other output ports are set to 0.

In order to simplify the description of the control module we first consider a simplified version of the OLC (figure 3) which satisfies the requirement of leaving only one of the incoming signals to pass, but takes no care about the fairness of the system. After the simplified version is discussed, then the final version of the OLC is presented as an extension of the simplified version.

The core of the control module is an array of N serially connected OR gates (figure 3). Each OR gate G_k evaluates C_k by taking as inputs I_{k-1} and C_{k-1}, for $k = 2, \ldots, N$. In the simplified version, C_1 is always set to 0. Since, $C_k = C_{k-1}+I_{k-1} = I_1+I_2+\ldots+I_{k-1}$ (for $k = 2, \ldots, N$) it follows that: $O_k = \overline{C_k}\, I_k = \overline{I_1 + I_2 + \ldots + I_{k-1}}\, I_k = \overline{I_1}\,\overline{I_2}\ldots\overline{I_{k-1}}\, I_k$. In other words, $O_k = 1$ only when $I_k = 1$ and $I_m = 0$ for all $m < k$. Therefore, only one of the incoming signals is allowed to pass to the corresponding output port. All the other signals are blocked.

However, this scheme has a serious disadvantage. Since the serial search for an active input port I_p always begins from the same port (I_1), the scheme is not fair. In order to overcome this limitation, the OR gates are cyclically connected, while an AND-NOT gate $F_k(k = 1, \ldots, N)$ is placed between each pair of consecutive OR gates (figure 4). The laser diode which controls the AND-NOT gates transmits a light pulse every N time slots, while each pulse is delayed for a time slot before reaching the next gate, by means of a delay line. In this way, only one AND-NOT gate $F(t)$ is disabled at each time slot t. Furthermore,

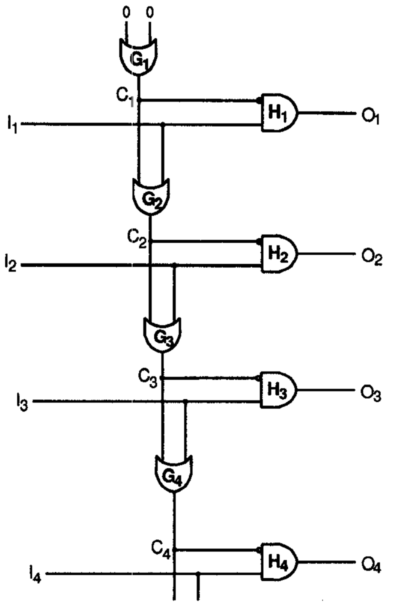

Figure 3: A simplified version of the Optical Logic Circuit.

the disabled gate is cyclically shifted at each time slot. Thus, if $F(t) = F_m$, then $F(t+1) = F_{(m \bmod N)+1}$. If $F(t) = F_m$, then the serial search for an active input port begins from port I_m. Since, F_m is cyclically shifted at each time slot, no input port is favored among the others. Therefore, the resulting scheme is fair.

3.2. Directional-Coupler-Based Implementation

The all-optical approach has met with considerable difficulties, above all due to the high power consumption involved in optical-optical interaction [22]. An intermediate step to the all-optical network would be electrically controlled optical switches, gates etc. operating at high speed.

The system that is described in this paper could be considered all-optical in the sense that information is in optical form except at the point where electronic signal is used to control the switch.

The well developed technology of $LiNbO_3$ directional coupler was chosen, in this work, as a logic device for the nanosecond switching speeds, the low crosstalk and the low insertion loss. Furthermore the $LiNbO_3$ directional coupler is the simplest device that can provide the logic functions needed for the circuit described above. The glass fiber loop was used as a delay-line [23].

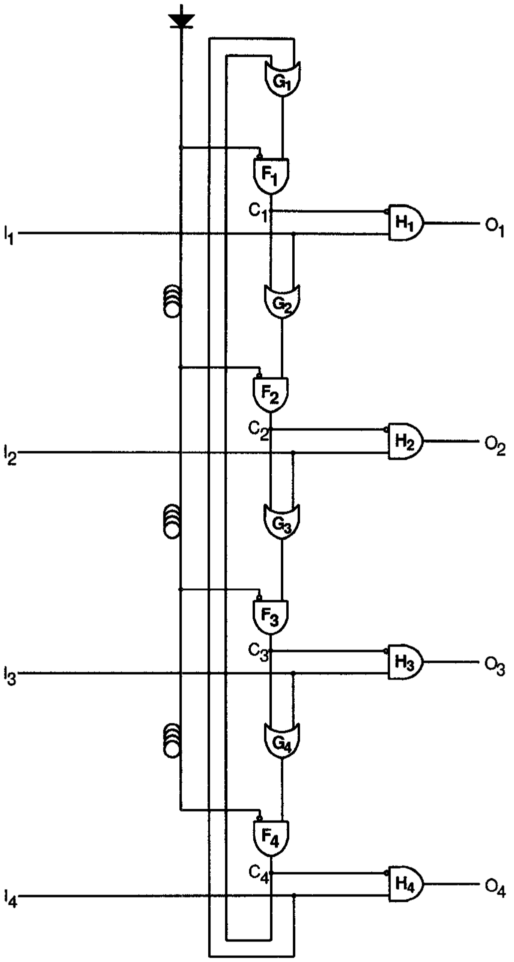

Figure 4: The Optical Logic Circuit.

The switch shown in figure 5 has two optical inputs, A and B, and two optical outputs, D and E. There is also an electronic control input C. The switch requires also a static bias voltage 5V to minimize crosstalk. In the absence of an externally applied voltage at terminal C, light entering input A will emerge at E. Likewise, light entering at B will emerge at D. This is referred to as cross state. Application of the correct voltage at terminal C will cause light entering at A to emerge at D and light entering at B to emerge at E. This is referred to as bar state. The switching voltage applied at C is 5V. The switching depends on electrode configuration and geometry.

From the point of view of the OLC logical structure the $LiNbO_3$ directional coupler can demonstrate the AND-NOT logic function (figure 6) that is utilized in the circuit. The OR logic function is passively implemented by means

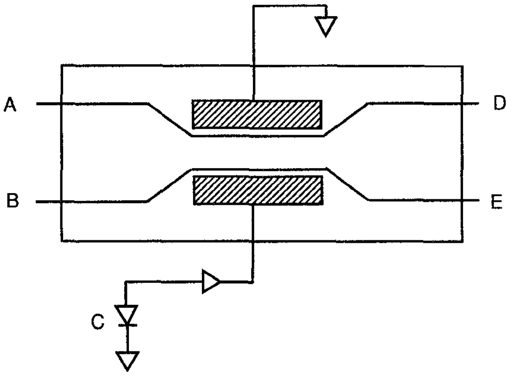

Figure 5: A $LiNbO_3$ directional coupler.

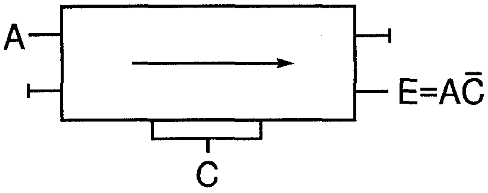

Figure 6: A directional-coupler-based implementation of the AND-NOT gate.

of a combiner (figure 7).

The signal source is a 1310 nm laser diode and the pulse power is adjusted to 1mW. Important parameters that affect the number of stages in the circuit and also the optical power required, are the insertion loss and the crosstalk. The insertion loss was estimated 5 dB and the crosstalk to <20dB. Therefore, there is a need for some means of amplitude restoration along the way of the signal in the circuit described above.

The switching speed of the directional coupler was 0.3 ns which was considerably faster than the switching speed of the drive electronics of the device (1 ns) [24]. The AT&T $LiNbO_3$ switches used were polarization-dependent, thus the inputs require in-line polarization controllers [25].

There are two important issues which must be taken into account in the implementation of OCON.

a) The inputs of the control module must be stable during the slot duration. Thus, an input must be in the "1" state when there is an incoming packet in the corresponding input port, while being in the "0" state when there is no incoming packet. Since, an incoming packet is a sequence of "0" and "1" bits, there are two ways to keep the input of the control module stable: i) To use Phase Modulation (BPSK) [21] at the transmitters, so that the intensity of the incoming light signal is stable during each slot. ii) To use Amplitude Modulation [21] at the transmitters and make a proper selection of the light intensity levels which correspond to "0" and "1", so that even when a "0" bit enters the control module, the light intensity is high enough to be considered as "1" by the control module.

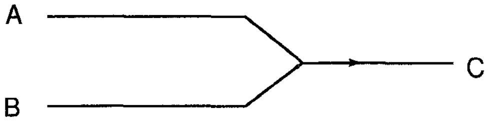

Figure 7: A passive OR gate.

b) At the beginning of each time slot the output of the OLC is unstable for a time interval t_u, equal to the propagation delay of the loop $G_1, F_1, G_2, F_2, \ldots, G_N, F_N, G_1$ (figure 4). Therefore, each packet must have a "dummy" preamble of duration t_u. In practice, t_u consists of the delay which is introduced by the logic gates. This delay is in the nanosecond range [23]. Thus, it is three orders of magnitude smaller than the packet duration. So, the introduction of the "dummy" preamble does not affect the performance of the network.

3.3. A Future Perspective: Bistable-Optical-Device-Based Implementation

There is a great deal of interest in developing and using bistable optical devices for implementing optical logic gates. However, even though the use of these devices is very attractive mainly due to the fact that could provide an all-optical network and thus very high speed and reliability, the technology is not yet mature enough. The bistable devices considered in the literature are either having high power consumption or problems with temperature stability. A future perspective for the proposed OLC is its implementation by means of bistable optical devices as soon as they are available.

4. Analysis

In this section we present an analysis of the OCON's performance. The presented analysis approximates the mean throughput and the mean packet delay of a network operating under the OCON protocol. We use an analytical model similar to the one presented in [6]. Let Q be the

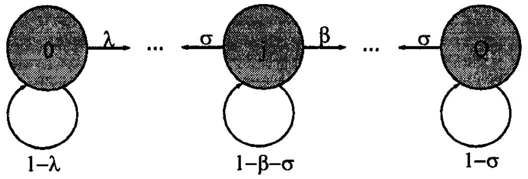

Figure 8: Markov chain for the OCON protocol.

size of the waiting queues, while P denotes the transition probability matrix for a node of the network. Assume that at the beginning of each time slot each node generates a new packet with probability λ (if the offered load is G packets per wavelength per slot, then $\lambda = \frac{W}{N}G$).

P_{jk} represents the transition probability from j packets in the queue of node i at the beginning of a slot to k packets in the queue at the beginning of the next slot (after the new packet arrivals). To calculate the elements of the matrix P we use S, the probability of a successful transmission by this node. Denote,

$$\beta = \lambda(1-S) \quad ; \quad \sigma = S(1-\lambda)$$

β and σ are the "birth" and "death" probabilities at state j, i.e., the probabilities that the state increases by 1 or decreases by 1, respectively (except for state 0 for which the birth probability is λ).

The transition probabilities for a node (see figure 8), are then given by

$$P_{jk} = \begin{cases} 1-\lambda & j=k=0 \\ \lambda & j=0, k=1 \\ \sigma & 0<j\le Q,\ k=j-1 \\ 1-\beta-\sigma & 0<j<Q,\ k=j \\ \beta & 0<j<Q,\ k=j+1 \\ 1-\sigma & j=k=Q \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

Let Π denote the steady-state probability vector of the above Markov chain, where Π_j denotes the steady-state probability that a node has j packets in its waiting queue at the beginning of a slot (after the new packet arrivals). By solving the set of equations,

$$\Pi P = \Pi \quad ; \quad \sum_{j=0}^{Q} \Pi_j = 1 \tag{2}$$

we obtain

$$\Pi_j = \frac{\lambda}{\beta}\left(\frac{\beta}{\sigma}\right)^j \Pi_0 \quad ; \quad 0<j\le Q \tag{3}$$

and,

$$\Pi_0 = \left[1 + \frac{\lambda}{\sigma}\frac{(\frac{\beta}{\sigma})^Q - 1}{\frac{\beta}{\sigma} - 1}\right]^{-1} \tag{4}$$

Since the successful transmission of a node depends on the occupancy of all the other nodes, S is a function of the steady state probability Π_0. Assuming that $\lambda > 0$ and $S > 0$ the Markov chain for each node is ergodic, hence having a unique steady state distribution. We are therefore, assured of converging to the correct values.

It remains to calculate S, the probability that a node (say u_i) successfully transmits, given this node is busy.

$$\begin{aligned} S &= \sum_{m=0}^{N-1}\Big(Pr\{m \text{ other nodes are also busy}\} \\ &\qquad \times Pr\{u_i\text{'s packet is allowed to pass}\}\Big) \\ &= \sum_{m=0}^{N-1}\left(\binom{N-1}{m}(1-\Pi_0)^m(\Pi_0)^{N-m-1}\right. \\ &\qquad \left.\times \sum_{k=0}^{m}\frac{1}{k+1}\binom{m}{k}\left(\frac{1}{W}\right)^k\left(1-\frac{1}{W}\right)^{m-k}\right) \end{aligned} \tag{5}$$

Once the Π_j's are obtained, the throughput of a node can be calculated as follows: Given a node is busy, the probability of a successful transmission is S, hence,

$$T = (1-\Pi_0)S \tag{6}$$

The total system throughput H (in packets per wavelength per slot) is given by

$$H = \frac{N}{W}T \tag{7}$$

The average queue length L can be obtained using

$$L = \sum_{j=0}^{Q} j\Pi_j = 1 \tag{8}$$

and the average delay of a packet D can be found by using the Little's Theorem

N_1	Throughput		Delay	
Load	Analysis	Simulation	Analysis	Simulation
0.2	0.2000	0.2000	1.13	1.13
0.4	0.4000	0.4000	1.36	1.39
0.6	0.6000	0.6000	1.94	2.07
0.8	0.7831	0.7725	4.03	4.27
1.0	0.8552	0.8403	7.43	7.07

N_2	Throughput		Delay	
Load	Analysis	Simulation	Analysis	Simulation
0.2	0.2000	0.2000	1.12	1.13
0.4	0.4000	0.4000	1.35	1.37
0.6	0.6000	0.5998	1.89	1.98
0.8	0.7851	0.7819	3.87	4.07
1.0	0.8612	0.8550	7.28	7.26

Table 1: Analytical and simulation results of the OCON protocol when applied to networks N_1 and N_2.

$$D = \frac{L}{T} \tag{9}$$

It must be noted that in any case the analytical results are very close the simulation ones. Both analytical and simulation results for two different networks N_1 and N_2 which operate under the OCON protocol are presented in Table 1. The specifications of networks N_1 and N_2 are given in the next section.

5. Simulation Results

In the following, the proposed OCON protocol is compared to two other collision-free protocols: RTDMA [6],[7] and HARP [20]. A critical parameter of the HARP protocol is the tuning time T of the acoustooptic filters. Simulation results are presented for T=0 and T=0.2 slots.

The protocols which are under comparison were simulated to be applied to six different networks (N_1, N_2, N_3 and N_4). The number of stations N, the number of data wavelengths W, the queue length Q and the number of receivers R of each simulated network, were taken to be as follows:

a) Network $N_1 : N = 40, W = 20, Q = 5, R = 2$.
b) Network $N_2 : N = 20, W = 10, Q = 5, R = 2$.
c) Network $N_3 : N = 20, W = 5, Q = 5, R = 2$.
d) Network $N_4 : N = 60, W = 20, Q = 10, R = 3$.

We have used the following two broadly used performance metrics in order to compare the two protocols:

1) The delay versus throughput characteristic.

2) The throughput versus offered load characteristic.

The delay versus throughput characteristics of the compared protocols when they are applied to networks N_1, N_2, N_3 and N_4 are appeared at figures 9, 11, 13 and 15 correspondingly. The throughput versus offered load characteristics of the compared protocols when they are applied to networks N_1, N_2, N_3 and N_4 are appeared at figures 10, 12, 14 and 16, correspondingly. Each characteristic was constructed by using 21 points, with each point corresponding to a different value of the offered load. The load values were taken to be from 0.005 to 1.00 packets per wavelength per slot.

The following results can be obtained from the above graphs:

1) Under low load conditions, OCON achieves an optimum packet delay, equal to one slot. Under these conditions, each newly arriving packet is transmitted immediately. Since it is probably the only packet in its wavelength, it is not blocked by the corresponding OLC. So, the packet delay is equal to the packet transmission time. On the other hand, the HARP protocol achieves a delay of about two slots: one slot to set a reservation and one slot to successfully transmit the packet. Finally, the RTDMA, due to its round-robin nature, suffers from a high delay, since each station has to wait for about $\frac{N}{R}$ slots before transmitting a newly arriving packet.

2) Under high load conditions, OCON and HARP achieve a high throughput, with OCON achieving a significantly higher throughput than HARP. When the ratio $\frac{N}{W}$ becomes high, the throughput of OCON tends to unity since, at any time slot, there is not any wavelength having no transmissions. On the other hand, RTDMA achieves a significantly lower throughput than OCON and HARP, since it suffers from a large number of idle slots. At a time slot t, a station operating under the RTDMA protocol is allowed to transmit on at most one wavelength. If its waiting queue does not contain packets which can be transmitted on this wavelength the station remains idle and the slot is wasted.

3) When the tuning time of the acoustooptic filters becomes high, an additional overhead is introduced in the operation of the HARP protocol. Under these conditions, the performance of HARP is significantly degraded, making the superiority of OCON even higher.

From the above discussion, as well as from the presented simulation results it becomes clear, that, under any load conditions, OCON achieves a significantly higher throughput and a lower delay than protocols RTDMA and HARP.

6. Conclusion

This paper has presented a new protocol for WDM Star

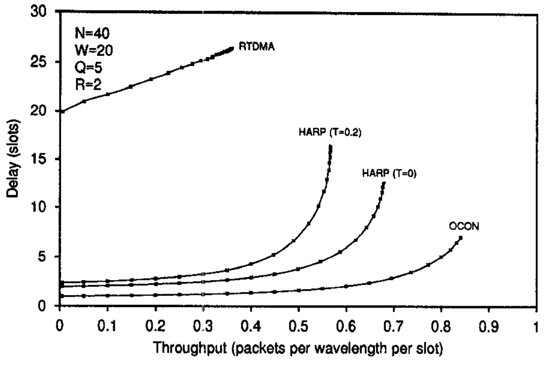

Figure 9: The Delay vs Throughput characteristics of OCON, HARP and RTDMA when applied to network N_1.

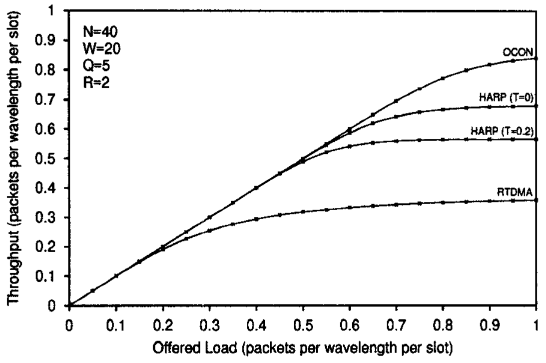

Figure 10: The Throughput vs Load characteristics of OCON, HARP and RTDMA when applied to network N_1.

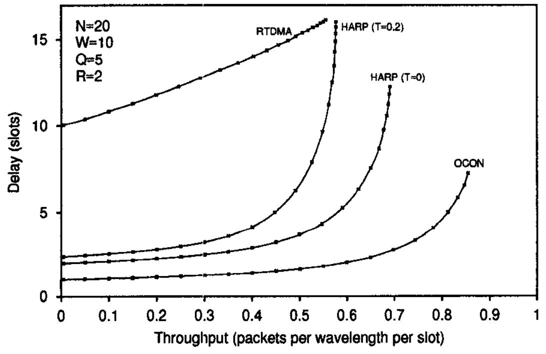

Figure 11: The Delay vs Throughput characteristics of OCON, HARP and RTDMA when applied to network N_2.

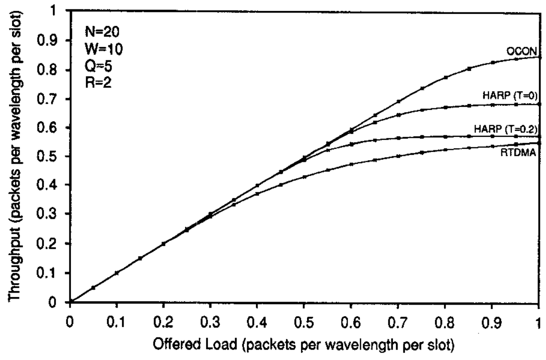

Figure 12: The Throughput vs Load characteristics of OCON, HARP and RTDMA when applied to network N_2.

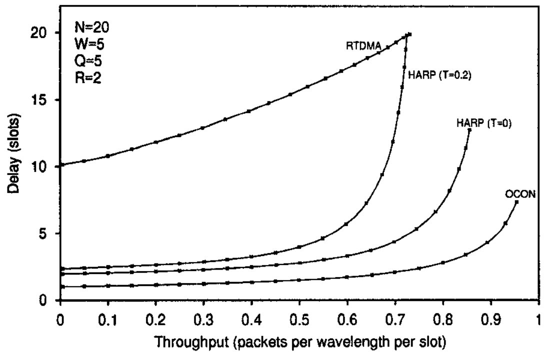

Figure 13: The Delay vs Throughput characteristics of OCON, HARP and RTDMA when applied to network N_3.

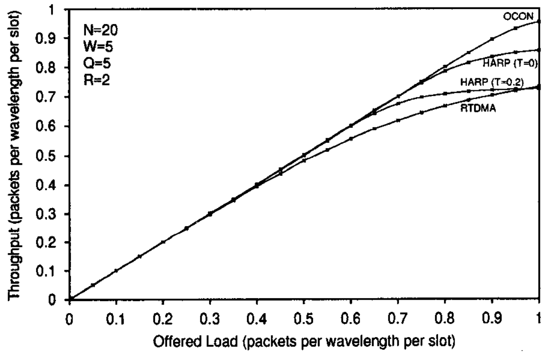

Figure 14: The Throughput vs Load characteristics of OCON, HARP and RTDMA when applied to network N_3.

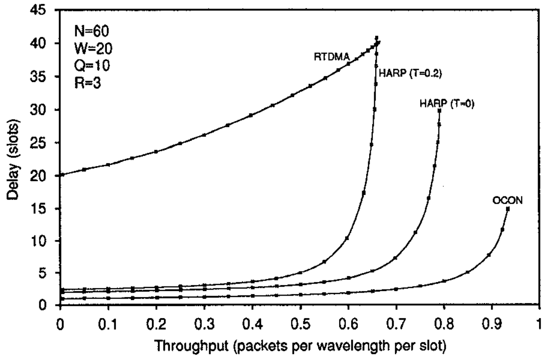

Figure 15: The Delay vs Throughput characteristics of OCON, HARP and RTDMA when applied to network N_4.

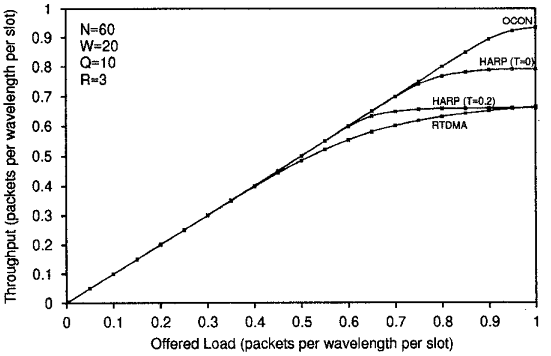

Figure 16: The Throughput vs Load characteristics of OCON, HARP and RTDMA when applied to network N_4.

Networks. According the proposed OCON protocol, the network hub is embellished with an all-optical packet filtering mechanism which controls the passing of the transmitted packets to the Star Coupler. In this way, collisions are prevented so that the network is capable of achieving a high performance under any load conditions.

The main advantages of the proposed OCON protocol are summarized below:

a) The network feedback information is processed in its original form without the need of O/E translation. The use of Optical Logic Circuits instead of a combination of electronic control circuits and acoustooptic filters leads to a significant decrease of the processing time, while the tuning time of the acoustooptic filters is eliminated. Therefore, OCON achieves a high throughput-delay performance under any load conditions.

b) Since the network hub represents a single point of failure, the use of optical control circuits at this point instead of electronic ones leads to a significant increase of the system's reliability.

On the other hand, the extensive use of optical devices leads to a significant increase of the implementation cost. However, the cost increase is limited by the fact that all the optical devices are placed at the same site and consequently, they can be arrayed in a common device. The idea of using optical logic circuits in order to control the operation of optical networks can be the base of a new generation of high performance protocols for fiber optic LANs. We are currently working on this direction.

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