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Performance Analysis of Optical Fiber Network from MAC Layer Perspective

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Abstract— **Optical fiber provides infinite capacity to support the rapid traffic growth which is required to our information society. However, as demand is increased and technology has developed, we have realized that there is a fundamental limit to fiber capacity. In this paper report we present a comprehensive review of how the MAC protocol is used to enhance the capacity in optical fiber networks. For this we have studied basics of optical fiber networks by considering different layers of protocol stack in optical network and their research challenges. The purpose of this project is to find the performance analysis of fiber optics network from MAC Layer perspective. In this project we would like to propose a hybrid MAC Protocol based on aloha, slotted aloha, and TDM structure to improve the channel capacity with resource optimization. Frame based structure of proposed MAC protocol not only helps us to manage on demand traffic but also increases the energy efficiency. We would like to present the thorough numerical and simulation results to back our proposed idea.**

Keywords— **MAC Protocol, slotted aloha, TDM, optical network, throughput, packet drop, energy Consumption**

I. INTRODUCTION

An enormous number of technological advancements in electric devices and electric based transmission have made it possible for devices to communicate at higher speeds. So, a huge amount of data can be transmitted at high transmission rates over long distances and with low latency and minimum errors. There are different types of networks based on different mediums of communication, like wired networks, wireless networks and optical networks etc.

However, in industrial and embedded networks, where large number of devices exists, it is not easy for multiple devices. Depending upon network architecture and the use of the network, the medium of communication is selected. Advancements in communication have made it possible to develop networks having multiple devices which share the data among them. Today, optical networks are commonly used [1].To communicate using the multiple channels due to factors like collision, data congestion, corruption in data, latency etc. The amount of bandwidth per device available is decreased as the numbers of devices are increased. This result in a high demand for bandwidth per device [2, 3].This can be achieved using MAC protocol in optical network. A Medium Access Control (MAC) protocol is required in optical network to coordinate the optical nodes' access to the shared medium. The objectives of MAC protocol for optical network are establishing the communication links between sensor nodes and sharing the communication medium fairly and efficiently [4]. Attributes of a good MAC protocol are high energy efficiency, low delay, high throughput; fairness between the nodes.MAC protocols can be categorized as shown in following

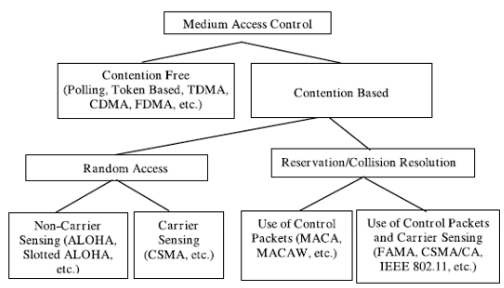

Fig.1:MAC protocol

Our proposed scheme consists of designing MAC protocol using ALOHA, Slotted ALOHA and TDM. This hybrid MAC protocol consist of two kinds of traffic namely on demand traffic and normal or regular traffic. The on demand traffic consists of extra or unscheduled traffic. The normal (regular) traffic) is handled by TDM scheme and uses slotted aloha as the main scheme to handle on demand traffic. The hybrid slotted aloha/TDM can remarkably increase the throughput. The literature survey is done in section II. We describe the different basic protocol and proposed hybrid aloha, slotted aloha and TDM MAC protocol in Section III. Then we have done mathematical modeling for the performance analysis and decide performance parameter. Depending upon mathematical model and system parameter, numerical analysis is done. The comparison of performance in the proposed protocol (new method) and other typical protocols (old method) using both simulation and experimental analysis is done in

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section IV. Then result analysis from simulation results done in section V. We give the conclusion in section VI.

II. RELATED WORK

Many research groups have focused on analyzing the physical layer issues [5, 6] and a few authors have addressed the upper layer impairments of such networks. However, several concerns have been expressed about this potential network: one of the main concerns is to enhance the capacity of optical network for multimedia/high data rate applications. The important role of the MAC layer in Optical networks has been studied in[7]. It is shown that it can reduce or avoid line interference and improve overall network throughput and thus enhance the capacity.

In current times the increasing demand of voice, data and video services from the subscribers, rises attention to the need of inexpensive, simple and scalable access networks development. Optical network the best suitable to solve the access network bandwidth problem. One of the main problems in optical network is that the optical network units (ONUs) should share the channel capacity and resources which causes collision and loss of data. In order to solve these problems channel allocation schemes should be designed. In literature known as Multiple Access Protocols, they resides mostly within the Medium Access Control (MAC), a sub layer of the Data Link Layer (i.e. the second layer) specified in the OSI model [4, 5]. In paper [6] investigated the impact of physical layer on the blocking probability and vulnerability ratio under two different dedicated path protection schemes: dark backup and lit backup. QoT aware HQ outperforms SP in terms of blocking probability and vulnerability ratio in a certain traffic load range in both backup dark and lit protection schemes have been showed in simulation result. In paper [7] [8] they have proposed a wavelength routing scheme without any service interruption in all optical network with survivable traffic grooming capability. In this paper the proposed scheme allows two routes: one for back up path, and another for active path. The proposed scheme is called survivable traffic grooming wavelength retuning (STGWR). The throughput can be increased to some extent in all optical networks using this scheme. In paper [9], an algorithm is proposed for realizing all-to-all routing such that both node load and link load are well balanced. Here results showed that the proposed approach produces clear routing paths, requires fewer wavelengths, and can easily incorporate load balancing The Aloha protocol [10] is a fully decentralized medium access control protocol that does not /perform carrier sensing. The Subsequent slotted-Aloha [10] protocol was introduced to improve the utilization of the shared medium by synchronizing the transmission of devices within time-slots. In this paper they propose the hybrid protocol using slotted aloha's and TDMA through quantitative analysis on throughput, stability, and delay. In paper [11] it presents comparison of Access Techniques used in Medium Access Control (MAC) protocol Optical Networks. Comparison is performed between Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA), Pure ALOHA and Slotted ALOHA (S-ALOHA). Performance metrics used for comparison are throughput (T), delay (D) and offered load (G). The main goal for comparison is to show which technique gives highest Throughput and lowest Delay with increase in Load. In paper [12], Aloha and Slotted Aloha schemes are proposed. Maintaining the collision probability below "Threshold collision probability" is an effective way of ensuring satisfactory performance. In paper [14] they said that Traditional Medium Access control (MAC) Protocol achieves better performance for the traffic type actually they have been assigned for but inadequate for other traffic types. The prevailing multimedia applications need that the MAC protocol should be able to execute all traffic types unvaryingly. To ensure efficient transmission, there should be MAC protocol in an optical network to arbitrate access to the shared medium in order to avoid data collisions and at the same time efficiently share the transmission bandwidth among different traffic classes to guarantee the quality of service (QoS). In this paper they propose a new MAC protocol which accommodates a range of multimedia traffic with dissimilar characteristics and QoS demands. In paper [15] proposed an efficient Medium Access Control (MAC) protocol called iCSMA/CD for improving the efficiencies of optical Wavelength Division Multiplexing (WDM) networks. The proposed protocol for an optical WDM ring network with each node equipped with a wavelength tunable transmitter and a wavelength fixed receiver is more capable in predicting the occupation status of each individual channel, which gives a better system performance in terms of delay and throughput. It has been showed that from simulation that the protocol has significant impacts on improving the system performance.

III. HYBRID MAC PROTOCOL

In this section, we briefly introduce the aloha, slotted aloha and TDM protocol first and then the hybrid MAC protocol is described.

A. *Aloha and slotted Aloha*

The first version of the protocol (now called "Pure ALOHA", and the one implemented in ALOHA net) was quite simple:1)If you have data to send, send the dataIf,2) while you are transmitting data, you receive any data from another station, there has been a message collision. All transmitting stations will need to try resending "later". An improvement to the original ALOHA protocol was "Slotted ALOHA", which introduced discrete timeslots and increased the maximum throughput. A station can only send at the beginning of a timeslot, and thus collisions are reduced. In this case, we only need to worry about the transmission-attempts within 1 frame-time and not 2 consecutive frame-times, since collisions can only occur during each timeslot [19, 10].

B. *TDMA*

In traditional TDMA protocol, multiple access is controlled using time division, namely, each node of networks is assigned with different time slot. When a node's time slot arrives, it transmits a packet. Moreover, each node only transmits once in a TDMA period to avoid packet collisions. The main task in TDMA scheduling is to allocate time slots depending on the network topology and the node packet generation rates [20].

C. Hybrid MAC protocol

To combine the advantages of slotted aloha and TDMA protocol we propose a hybrid MAC protocol which is suitable in optical network application in which data gathered by nodes are to be delivered in timely manner and with collision reduction. This protocol is designed to provide high throughput, low delay and less energy consumption. We have designed super frame structure for transmission traffic control as shown in following figure .The designed super frame structure composed of two parts with respect to traffic: on demand traffic and normal/regular traffic. The normal traffic is handled by TDMA protocol and in demand traffic is handled by slotted aloha.

IV. MATHEMATICAL ANALYSIS

A. Simulation Set Up

Most previous optical network MAC protocol testing has been done using general purpose simulators, such as Ns2,MATLAB and OPNET. The NS2 simulation platform was selected for this work. NS2 is a powerful and flexible simulation environment that allowed the simulation of multiple optical node platforms and various protocols[18]. The network architecture is as shown in following figure

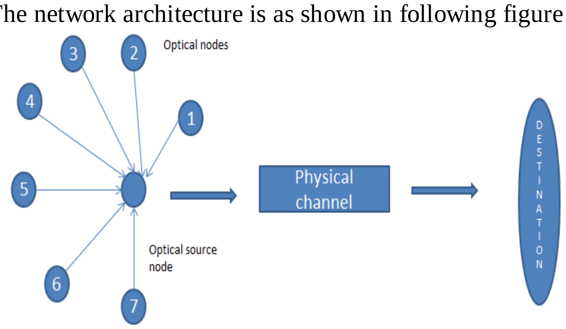

Fig.2: Network Architecture

B. Mathematical Modelling/System Model

We have designed super frame structure for proposed system which is shown as following figure

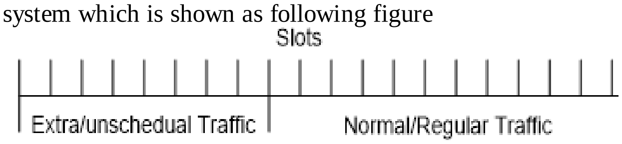

Fig. 3: Super Frame Structure

The super frame structure is divided into two parts-extra/unscheduled traffic and normal traffic.

<u>Assumptions for deciding the size of super frame structure:</u>

Super frame structure is fixed and equivalent to S_m slots. It can be dynamically adjusted as per the requirement of the system; however, making dynamic structure is the out of the scope of this paper. Designer can design the super frame structure based on the application requirements. Let's build our system model based on [1]. There are N sources[1] to compete for S_m for slots. A node can transmit only one data packet per slot [16, 19].

Let n be the number of nodes tries to get the same slot. The probability that n nodes are in the same slot is given by

$$P[X=n]=\binom{N}{n}\left(\frac{1}{S_m}\right)^n\left(1-\frac{1}{S_m}\right)^{N-n} \qquad (1)$$

The average value of the number of slots with n nodes in the same slot is given by

$$E[X=n]=S_m\binom{N}{n}\left(\frac{1}{S_m}\right)^n\left(1-\frac{1}{S_m}\right)^{N-n} \qquad (2)$$

C_n Represents the number of slots being filled with exactly n nodes. So the average number of collided messages is given by

$$\begin{aligned}\sigma &= \sum_{n=2}^{N}\sum_{c_n=1}^{S_m} nP[X=C_n]C_n=\sum_{n=2}^{N} nE[X=C_n]\\ &=\sum_{n=2}^{N} nS_m\binom{N}{n}\left(\frac{1}{S_m}\right)^n\left(1-\frac{1}{S_m}\right)^{N-n} \qquad (3)\\ &=N-N\left(1-\frac{1}{S_m}\right)^{N-1}\end{aligned}$$

from (2) and (3) we can calculate the ratio of the number of successfully transmitted messages and the total number of transmitted messages[2]. The ratio is given by

$$\text{Ratio}=\frac{N-\sigma}{N}=\left(1-\frac{1}{S_m}\right)^{N-1} \qquad (4)$$

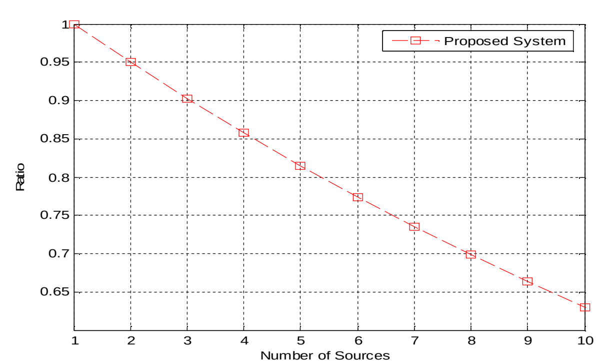

Fig. 4: Number of nodes vs. Ratio

[1] Here 'node' and 'source' terms are interchangeable throughout the paper.
[1] Here Messages means complete data packet transmission.

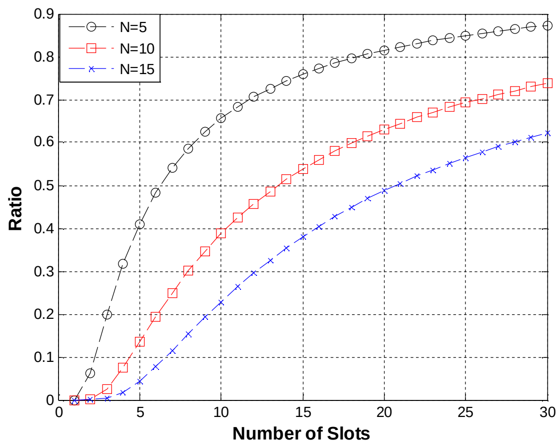

Fig. 5: number of slots vs. ratio

In proposed System, time frame T_{f-X} is given by

$$T_{f-x} = t_{active} + Ct_{s,n} \tag{5}$$

Where C is the number of equal length slots and t_{active} is the additional slots for unscheduled traffic packet which could be 10% of total slots. As per the application and designers preference we can vary the percentage of extra slots time.

In proposed system, a node can communicate n_p packets to maximum n_m nodes within a frame time. So the throughput is given by

$$Th_x = \frac{Ct_s}{t_{active} + Ct_s} = \frac{n_p n_m}{t_{active} + Ct_s} \tag{6}$$

Whereas ideal throughput of a network can be given by $Th_i = n_p n_m t_m$. (7)

Where n_p , n_m and t_m represents packet generated by a source, maximum number of sources and time duration of a active source.

To calculate the approximated drop packets we can simply divide the ideal throughout by super frame duration.

$$D_{rp} = Th_i / T_{f-x} \tag{8}$$

Energy

In this section we consider only two power levels, P_{tx} and P_{rx}. We assume that a node consumes power P_{tx} for transmitting and P_{rx} for being listening [16]. Total power consumption to transmit a data/request packet is given by

$$E_T = E_S + E_C \tag{9}$$

Where E_S, and E_C represents energy consumption energy consumption for successful transmission and energy consumption in collision, respectively. We define the energy efficiency as energy required to successfully transmit one bit of data/request packet and is given by

$$\eta_e = \frac{E_T}{L} \tag{10}$$

where L is the length of data/request payload. The energy consumption for successful transmission is given by

$$E_S = (H_{P+M} + T_{Data/Req})P_{tx} + (T_{ACK} + P)P_{rx} \tag{11}$$

The energy consumption due to collision is given by

$$E_C = (H_{P+M} + T_{Data/Req})P_{tx}E[N_c] + P_{rx}E[N_c] \quad (12).$$

C. *System Parameter*

Table no.1

Parameter	Value
Payload size	66 (Bytes)
MAC header	2 (Bytes)
PHY header	2 (Bytes)
ACK	2 (Bytes)
Data Rate	250 (kbps)
Rx Power	0.065 uw
Tx Power	0..074uw

V. PERFORMANCE ANALYSIS

From simulation programs and system modelling we have achived following result with respect to theoritical analysis, slotted aloha method and praposed i.e. hybrid using slotted aloha and tdm .These methods labeled as theor., old and new method in respectively.The results are summerised as follows

Table no.2

sr.no.	nodes	throughput			energy			drop packet		
		theor.	old	new	theor.	old	new	theor.	old	new
1	5	810	696	789	1.1537	0.7389	1.102	20	7	2
2	7	1041	776	888	2.352	1.734	1.9768	35	18	17
3	10	1657	969	1212	4.2833	2.9678	3.1653	55	68	51

The comparison of simulation results and experiment results can also be seen from Figure 6 to figure 8 . Taking no account of other factors, the experiment results of the throughputs, energy consumption and drop packets are consistent with the simulation results.

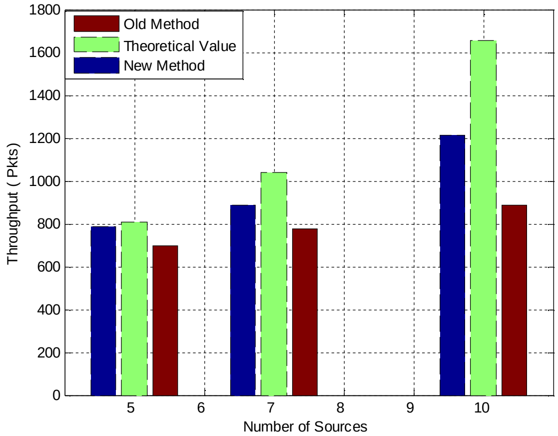

Fig. 6: Throughput vs. number of sources

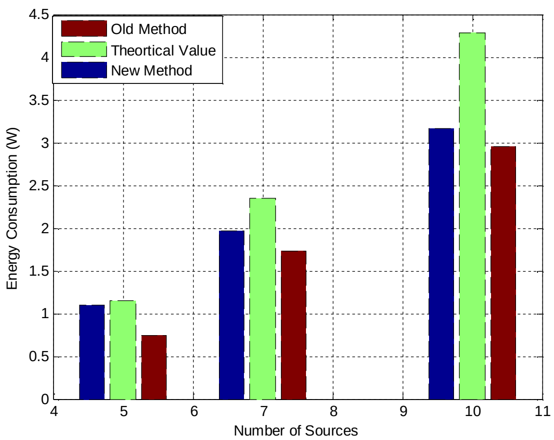

Fig. 7:energy consumption vs. number of sources

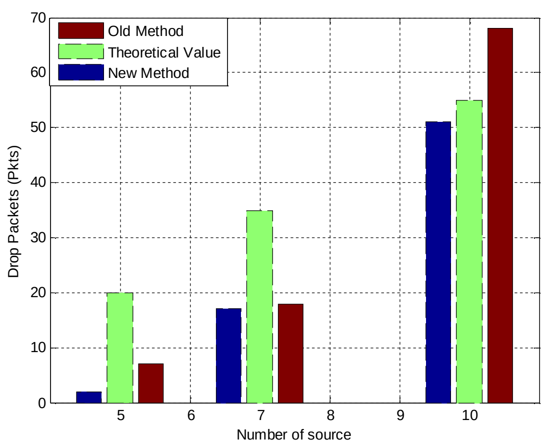

Fig. 8: drop packet vs. number of nodes

From figure.6, theoretical value of throughput is calculated using system parameter as shown in table no.1In old method normal traffic is calculated where as in proposed method on demand traffic can be handled. The comparison is shown in table no2.This shows better results achieved for throughput. Since we can send more number of packets due to slots in super frame structure, we have obtained high value for throughput as shown in fig.6.

From fig.7, in new method energy consumption higher because more number of packets can be sent But this energy consumption is not wasted, this extra energy is used for successful transmission.

From fig.8, the theoretical value for number of drop packet is higher comparatively because we are generating more number of packets through formula. In real system we have used buffer so less number of packets are generated so packet drop is also less comparatively as shown in fig.8.

VI. CONCLUSION

A study of existing MAC protocols for optical networks was carried out. Later, an approximate simulation also be done to find out the facts and figures, we studied. As we know that WDM multiplexing is a source of increasing higher bandwidth utilization in optical communication. By using MAC protocol, we have also seen that network performance increased in terms of throughput, efficiency and network utilization. Performance analysis of fiber optics network from MAC Layer perspective is done. We have proposed hybrid MAC Protocol based on aloha, slotted aloha, and TDM structure to improve the channel capacity with resource optimization. We had presented the thorough numerical and simulation results to our proposed idea. The results showed the hybrid MAC protocol performs well in both throughput and energy consumption.

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