Providing Multiclass of Services in Optical CDMA Packet Networks

Sina Khaleghi
IEEE Student Member
Electrical Engineering Department
Sharif University of Technology
Tehran, Iran
Email: si_khaleghi@ee.sharif.edu

Mohammad Reza Pakravan
IEEE Member
Electrical Engineering Department
Sharif University of Technology
Tehran, Iran
Email: pakravan@sharif.edu

Hadi Goudarzi
IEEE Student Member
Electrical Engineering Department
Sharif University of Technology
Tehran, Iran
Email: h_goudarzi@ee.sharif.edu

Abstract— **In this paper we discuss and analyze an enhanced media access control (MAC) layer protocol which uses the signaling method benefits of physical layer in order to provide different quality of service (QoS) levels in optical code-division multiple-access (OCDMA) packet networks. In the proposed network architecture the users are categorized into the high and low classes of service. Users of each class transmit at the same power level and different from the other classes' users. Also, the MAC of each user estimates the amount of interference on the channel and adjusts the packet transmission's time to improve network performance. Through simulation it is shown that the combination of appropriate power assignment to users and proper MAC algorithm can provide various QoS metric levels on metrics such as normalized throughput and channel access delay. This is achieved by dividing the available resources of the OCDMA network between the users of each class.**

Index Terms– **Quality of service (QoS), Optical code-division multiple-access, Media access control layer, Multilevel and multiclass signaling.**

I. INTRODUCTION

Optical CDMA technique is one of the best candidates which can be used in optical fiber transmission systems due to the large bandwidth of fiber [1], [2]. Also, it is a good candidate for optical access networks such as passive optical networks (PON) in the current and future communication and computer networks [3], [4], because the OCDMA networks allows simultaneous users to access the same optical channel.

In OCDMA networks, each user is assigned a unique codeword from the optical orthogonal code (OOC) set as its own address. An OOC is a set of $(0, 1)$ sequences (codeword) with constant length that satisfies certain auto-correlation and cross-correlation constraints [1]. Each 0 or 1 of the codeword is called a *chip* and the sequence stands for *bit*. The number of 1 chips in the codeword is named the codeword's weight and is equal in all of an OOC set members. At the transmitter side, each user sends a codeword, corresponding to the address of its intended destination, for a data bit one, but transmits nothing for a data bit zero (ON-OFF keying modulation). At the receiver end, a detection model is working which is based on correlating the received signal with the desired codeword.

Many research groups have focused on analyzing the physical layer issues [5] and a few authors have addressed the upper layer impairments [6]-[11] of such networks. However, several concerns have been expressed about this potential networks, one of the main concerns is supporting differentiated QoS for multimedia applications. Previous works have proposed a few methods which satisfy only bit rate and bit error rate (BER) metrics [12]-[19]. Also, all of them have worked on the construction methods of OOCs, beside the power level variation of optical signal in order to meet these QoS requirements and none of them have used the major potential of the MAC layer. The important role of MAC layer in OCDMA networks have been studied in [11]. It is shown that it can reduce or avoid line interference and improve overall network's throughput.

We have combined the MAC layer abilities with the multilevel transmit power in OCDMA packet networks, to satisfy important QoS metrics such as *normalized class throughput* and *channel access delay*. It is shown that it is possible for an OCDMA network to have for examples two classes of service simultaneously, each of them having its own, but different guaranteed throughput and channel access delay, resulting in two types of network services. Also, it is shown that the proposed method increases the total network throughput and allows more users to simultaneously receive their packets without error.

The remainder of this paper is structured as follows. In Section II a brief description of the proposed OCDMA packet network architecture which guaranties QoS metrics and the need of MAC layer in these networks will be presented. Section III, is devoted for the mechanisms of MAC layer algorithms with multi-leveling feature. The simulation results and a comparison between the performances of the mentioned proposed methods is presented in Section IV. Finally, we conclude the paper in Section V.

II. BACKGROUND

A. OCDMA Network Architecture with QoS Feature

The architecture of an OCDMA packet network which guaranties QoS requirements is shown in Fig. 1 The network provides two classes of service, class #1 and class #2. As we know, in many multiclass access networks one or more users can have a better QoS at the cost of higher power consumption without any effect on the performance of the low

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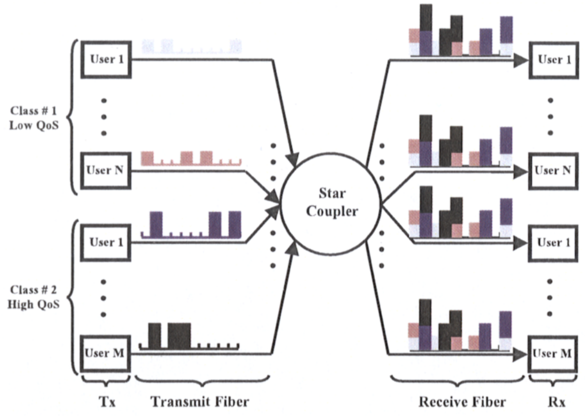


Fig. 1. An OCDMA packet network architecture with QoS provisioning feature.

power consumer users [12]. In our proposed network N users transmit at the power level 1 (*low* QoS) and M users transmit at the power level 2 (*high* QoS). All of the nodes are connected to each other by optical fiber to a passive star coupler, i.e. the input powers are merged in the coupler and the result is split equally among the receive fibers and is transmitted on all outputs. For the sake of simplicity we ignore fiber loss.

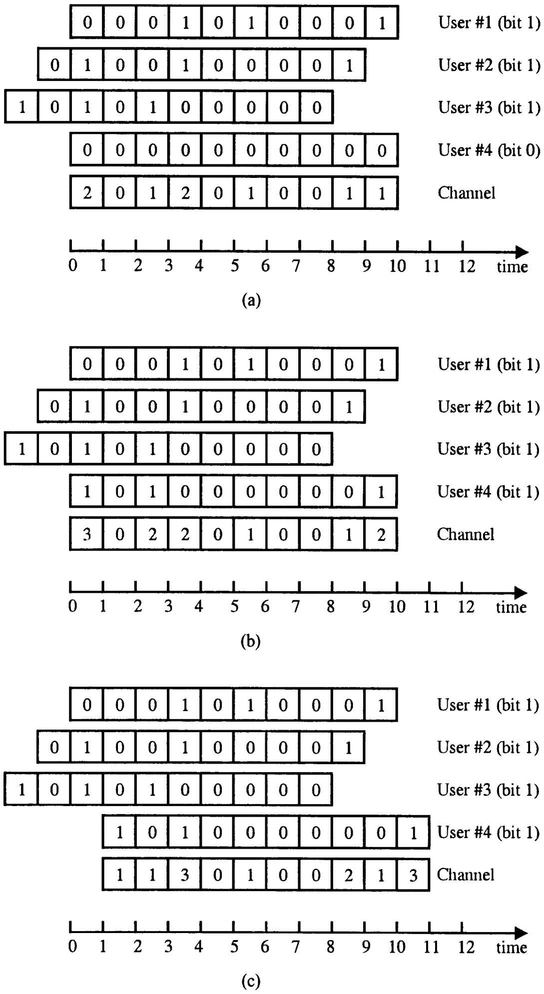
The physical layer is OCDMA that uses unipolar encoding and intensity modulation over a single wavelength (ON-OFF keying). We assumed that the length of the OOCs is L chips. The number ω represents the number of 1 chips of a codeword of the codeset and is called the OOC's weight. Also we show the maximum cross-correlation parameter by κ. So a particular codeset is specified by the parameters (L, ω, κ). The codeset used in this work is generated by the greedy algorithm [18].

At the receiver end of our proposed OCDMA packet network the hard-limiting correlation receiver is deployed [1]. The receiver decodes the codeword in the received signal and regenerates the transmitted data. In this type of receivers, the received signal is hard-limited first and after that it will be correlated with the desired OOC in order to recover the transmitted data. In our network model we assumed that the threshold value of hard-limiting process in the receiver is 1 for the class #1 users and 2 in the class #2 users.

The network is based on *Tunable Transmitter-Fixed Receiver (TT/FR)* architecture. A receiver chooses a codeword to receive on and it will not change ever during the network activities. The transmitter which needs to communicate with a receiver should tunes to the receiver's codeword. Also we assume that each node is running a frame synchronization algorithm which allows the nodes to identify whether their frame has arrived and where the first bit of the frame begins.

B. MAC Layer in OCDMA Packet Networks

Interference occurs due to the multiplexing of packets on a receive fiber and will increase as the offered load on the network increases. It was shown [11] that without any MAC, the throughput of the OCDMA packet network approaches zero in highly loaded conditions. But by using the proper features of MAC algorithms the overall throughput of OCDMA networks can be improved [10].



User #1 (bit 1)			0	0	0	1	0	1	0	0	0	1	
User #2 (bit 1)		0	1	0	0	1	0	0	0	0	1		
User #3 (bit 1)	1	0	1	0	1	0	0	0	0	0			
User #4 (bit 0)			0	0	0	0	0	0	0	0	0	0	
Channel			2	0	1	2	0	1	0	0	1	1	

(a)

User #1 (bit 1)			0	0	0	1	0	1	0	0	0	1	
User #2 (bit 1)		0	1	0	0	1	0	0	0	0	1		
User #3 (bit 1)	1	0	1	0	1	0	0	0	0	0			
User #4 (bit 1)			1	0	1	0	0	0	0	0	0	1	
Channel			3	0	2	2	0	1	0	0	1	2	

(b)

User #1 (bit 1)			0	0	0	1	0	1	0	0	0	1	
User #2 (bit 1)		0	1	0	0	1	0	0	0	0	1		
User #3 (bit 1)	1	0	1	0	1	0	0	0	0	0			
User #4 (bit 1)				1	0	1	0	0	0	0	0	0	1
Channel				1	1	3	0	1	0	0	2	1	3

(c)

Fig. 2. Interference pattern of 4 users in an OCDMA packet network (a) user #4 sends 0 bit (b) user #4 sends 1 bit (c) user #4 sends 1 bit with 1 chips delay.

When two or more packets overlap at a point on a receive fiber, the codewords of the packets overlap. Codeword overlaps may cause interference errors at the receiver end. When a codeword overlap occurs, at least two 1 chips of different codewords may overlap. This is termed a *chip overlap*. An *interference error* will occur during the reception of a codeword if there are enough other codewords on the line which have chip overlaps with the codeword being received. Fig. 2 shows codewords from a $(10, 3, 3)$ codeset. The figure is a snapshot of data bits on an optical fiber sent by four nodes. Their combined signal on the channel is indicated below the codewords. As we can find in the Fig. 2 the codewords are chip synchronous (Salehi [1] has studied the effect of both chip synchronous and chip asynchronous transmission and showed that the chip synchronous case is a upper bound on the BER

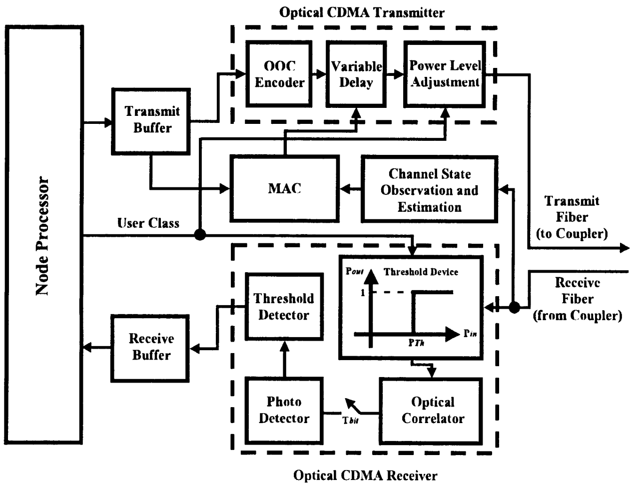


Fig. 3. QoS provider block diagram in OCDMA packet networks.

of the system. So, we have assumed in this work that all codewords are chip synchronous on the fiber as shown in the figures.).

In Fig. 2, User #4's codeword is the received codeword. User #1 and User #2 have 1 chips and User #3 has 2 chips that overlap with User #4's 1 chips. Fig. 2(a) shows the case when a 0 data bit is transmitted by the User #4. Fig. 2(b) shows the case when a 1 data bit is transmitted. In Fig. 2(a) the receiver will erroneously detect a codeword of User #4 because three other codewords overlap with its weighted chips and will falsely detect a 1 data bit. So the packet that consists of this bit will be received with an error. We can easily see that the condition for correct reception of a codeword is that at least one of its 1 chips must not have a chip overlap with any other codeword on the line. We have assumed that if an interference error occurs in at least one bit of a packet, then the entire packet is lost, which we will give us the lower band of our QoS metrics.

Now consider the case in which the codeword of User #4 is transmitted as shown in Fig. 2(c), i.e. it is sent at one chip time later. It is clear that when the packet is delayed, codeword of User #4 has at least one chip that does not interfere with codewords of User #1, User #2 and User #3. Hence no false positive can occur and it will be received correctly. Interference avoidance uses the above principle. A transmitting node estimates the state of the line and schedules its packet transmissions to avoid interference errors.

III. QoS PROVISIONING IN OCDMA PACKET NETWORKS

This section defines and explains each part of the QoS provider block diagram in detail. After that we will look at the proposed MAC algorithms which provide different QoS levels in our OCDMA packet network.

A. *QoS Provider Block Diagram*

The QoS provider block diagram is shown in Fig. 3 . The main parts of the proposed system are an OCDMA transmitter, OCDMA receiver, channel state observation/estimation module and the MAC module. We will explain each of these important parts in this subsection.

When a packet is ready for transmission it will come to the transmit buffer from the node processor and waits until the MAC module allows it to be sent. The channel state observation/estimation module receives a sequence (in the scale of bit duration) of multilevel signal from the receive fiber to estimate the channel state. This module is running continuously in a loop which collects the channel observations and estimates the channel state. The channel state is forwarded to the MAC module next. We define the state of the channel, a vector of length L (codelength), equal to the sum of the codewords at the output of the star coupler. We assume that all nodes are transmitting 1 bits in order to calculate the channel state (This assumption results the worst case in deriving the performance of an OCDMA network, because in this case the channel is experimenting the highest amount of interference.). There are several methods which can be used to estimate the channel state. This work assumes that all of the nodes on the OCDMA packet network know the exact channel state, i.e. *perfect channel state estimation.*

The MAC module which is the main part of our proposed model runs an algorithm that will provide QoS in our network. Several MAC layer algorithms are proposed all of which are looking for an appropriate delay value k (between 0 and L) such that the QoS metric of each class is guaranteed if the packet's transmission is delayed by k chips times relative to the packet's arrival times.

When the appropriate transmission delay is calculated by the MAC module, the OCDMA transmitter encodes the data, shifts the data by the calculated variable delay, adjusts the power level of the signal based on the node's class of service begins transmission.

At the other side, when the transmitted packet is received, it will first go through the threshold device. The output of the threshold device is determined noting the intensity of the received optical signal; if the received intensity is greater than the threshold value (P_{th}) the output of the nonlinear device is one, otherwise it is zero. The threshold value is determined by the node processor and depends on the type of services which is going to be provided for that user. The output of the threshold device will be correlated with the receiver OOC codeword to recover the received data.

B. *QoS Provisioning Algorithms*

In this subsection we will explain the proposed MAC algorithms which will guaranty the QoS requirements. The mechanism of two algorithms will be studied in depth and all of their important features will be pointed out.

The QoS provisioning is a process by which a node, given a channel state estimate, a codeword to be transmitted and the level of transmitting power, calculates a variable delay such that QoS is provided. This work can also being mentioned as a

TABLE I

MAC #1-OCDMA ALGORITHM

```
Code_Word ← Codeword of the user
Channel_State ← Estimate of the channel
threshold ← 1
Hard_Limited_State ← hardlimit (Channel_State,threshold)
For shift_value = 0 to Code_Length-1
  if ((Hard_Limited_State & Code_Word) ≠ Code_Word) then
    save shift_value as an acceptable delay
  end if
  shift circularly the Code_Word pattern to the right by one chip
end for
selected_delay ← any acceptable delay
```

scheduling algorithm in the MAC layer plus the multileveling technique in the physical layer.

As we discussed before the variable delay is calculated with respect to the estimated state of the channel. If the transmission is not possible (no variable delay is found), then the packet transmission is deferred. The deferring mechanism uses the idea of binary exponential backoff which is widely used in Ethernet MAC layer. After first unsuccessful trial, the packet is delayed for a duration $T_\triangle$. On the next unsuccessful trials the delay time is increased to $2T_\triangle, 4T_\triangle, \ldots$ up to $10T_\triangle$ to reduce the chance of collision in highly loaded conditions. The node will re-try five more times using the delay of $10T_\triangle$ and if all ten trials fail, it will drop the packet because of the very poor channel conditions. The value of $T_\triangle$ can be chosen to reduce the total channel access delay while avoiding network congestion.

The transmitting node does not have a receiver to detect errors in its transmitted packet during transmission. Therefore packets which experience interference error during transmission are transmitted until completion. Also we assume that the propagation delay is zero and there is no delay between the channel state estimation process and the transmission process, if there will be an acceptable delay for the arrived packet.

We propose two different algorithms to coordinate channel access while providing differentiated QoS metrics. We compare the results of these algorithms with Aloha-OCDMA [10] and show the relative performance improvement of the proposed algorithms in the next section.

1. *MAC #1-OCDMA*: In this algorithm both QoS class users work like each other. The channel state will go through a nonlinear threshold device with a threshold value of 1. So the result will be a state in which the 1 chips show the presence of intensity and 0 chips show the chips where there is no intensity. This algorithm transmits a packet if the new channel state (state after going through the threshold device) permits transmission without loss of its own packet. The detail of algorithm operation is specified in Table I The algorithm searches for variable delays where at least one of the weighted chips from the codeword to be transmitted aligns with a 0 chip in the channel state vector. It chooses one of these variable delays at random.

TABLE II

MAC #2-OCDMA ALGORITHM

```
Code_Word ← Codeword of the user
Channel_State ← Estimate of the channel
if (the user is in the high QoS class) then
  threshold ← 2
else
  threshold ← 1
end if
Hard_Limited_State ← hardlimit (Channel_State,threshold)
For shift_value = 0 to Code_Length-1
  if ((Hard_Limited_State & Code_Word) ≠ Code_Word) then
    save shift_value as an acceptable delay
  end if
  shift circularly the Code_Word pattern to the right by one chip
end for
selected_delay ← any acceptable delay
```

2. *MAC #2-OCDMA*: The detailed steps of this algorithm are shown in Table II . MAC #2 is an extended version of the MAC #1. In this algorithm all of the users with low QoS are working like MAC #1 users, but the users in the high QoS class are transmitting their packets with a different method. The high QoS users will set their threshold parameter of the channel state estimation module to 2. So, the result of the threshold device will mark the channel state 2 and more $(3, 4, \ldots)$ chips with 1 and the 0 and 1 chips with 0. It is clear that the users of this class are able to transmit their packets more than the users of low QoS class, because there will be more 0 chips in the channel state of the high QoS users to align their weighted chips on them. On the other hand, the threshold value for the high power user's receiver (P_{th}) is set to 2. In this case the interfering pulsed chips with power level 1 (low QoS users) are eliminated at the output of the threshold device of the high QoS power user's receiver. So, for example, when at least two low QoS power users hit on a marked chip of the high QoS power user, this chip is interfered. So we expect that the throughput increases and the channel access delay decreases, in MAC #2 for the high QoS users compared to the MAC #1.

IV. SIMULATION RESULTS

In this section the QoS provider algorithms are simulated and compared with the Aloha-OCDMA algorithm. The QoS metrics which are used to evaluate the performance of the proposed algorithms are normalized class throughput and channel access delay at different values of the normalized offered load. The normalized offered load is the arrival rate expressed as a fraction of the maximum possible arrival rate 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 class 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

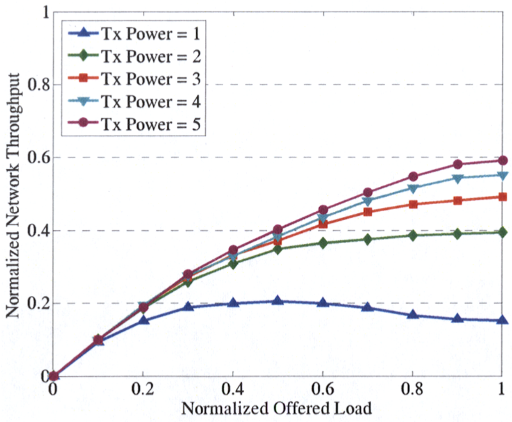


Fig. 4. Comparison of the Aloha-OCDMA algorithm for different transmission power of high QoS users.

by the normalized offered load. The channel access delay is the time between the packet's arrival and packet's transmission. The value of the channel access delay is normalized to the time length of an average size packet. Also, we will look at the simultaneous active users parameter which is the average number of users at any time and any point of line, accessing the channel during the simulation.

We have developed an OCDMA packet network simulator. To demonstrate the performance of the proposed algorithm, a network with ten nodes is analyzed in which five nodes are set to high QoS level and five nodes are set to low QoS level. The codeset used was $(10, 3, 2)$ and the results of the simulation are the mean of 10 simulation runs in which each node transmits 1000 packets during simulation. The inter-arrival time distribution of packet arrival time is assumed to be exponential and the packet size distribution is exponential with an average of 200 bytes. We change the mean of inter-arrival time in order to adjust the normalized offered load. The value of $T_{\triangle}$ is set to the required transmission of two bytes.

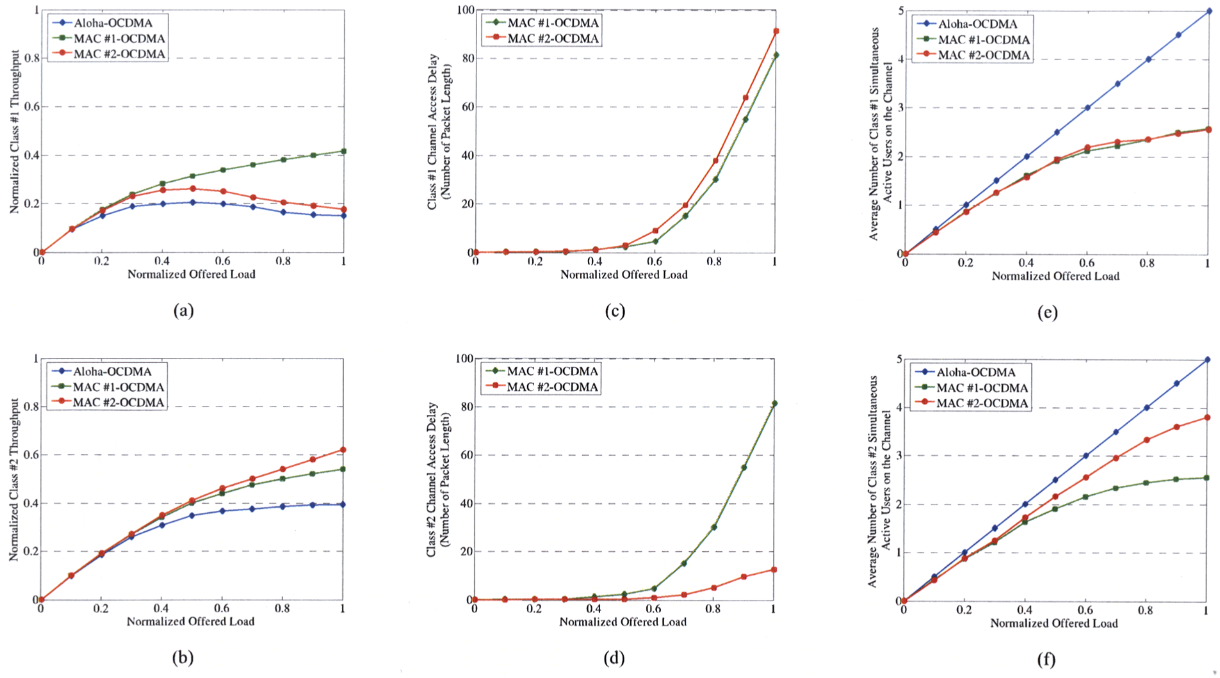
At first we have simulated a two class OCDMA packet network which does not have any MAC algorithm (Aloha-OCDMA). The normalized class throughput of each class is shown in Fig. 4 , where the transmission power of low QoS users is assumed to be 1 and the transmission power of high QoS users is varied from 2 to 5. It is important to notice that we should change the threshold value of threshold device of the receiver, when we change the transmission power, accordingly. As we can find in Fig. 4, by increasing the level of transmission power we can achieve more throughput in our high QoS class without decreasing the throughput of the low QoS class. Also we can see that the throughput of the low QoS class will degrades when the offered load increases. We can prevent from this phenomenon by using MAC algorithms.

Fig. 5 shows the QoS metrics described before for the MAC #1, MAC #2 and Aloha algorithms, where the transmission power of the low QoS class and the high QoS class are fixed at 1 and 2 respectively. In Fig. 5(a) and Fig. 5(b) we can find that the MAC #1 and MAC #2 algorithms will increase the amount of normalized class throughput for both classes of service. This is because of the nice feature of the proposed QoS provider algorithm which will schedule the packet transmission time to decrease the amount of interference. Also we can see in the MAC #2 algorithm that the throughput of high QoS class is higher than MAC #1 algorithm. This result is achieved at the cost of increasing the interference of the low QoS class, which leads to a throughput degradation in low QoS class. The higher interference is because of the higher threshold value (2) which was assigned to the threshold device of the channel state estimation module of the high QoS class receiver. If we remember the MAC #2 algorithm in high QoS class assumes that 1 chips and 0 chips are both without intensity. Because if high QoS users align their weighted chips on these chips (0 and 1 chips in the channel state), they are not ever determined as an interfered chip from the point of high QoS users view [12]. So, there will be more available empty chips for packet scheduling in the MAC #2 algorithm for high QoS users and the channel access delay is decreased very much as we can see in Fig. 5(d). But because of the more interference which are driven from the high QoS users on low QoS users the number of available empty chips will decrease for the low QoS users, lead to an increase in the channel access delay of this class of service (Fig. 5(c)). By the same reason we can conclude that the average number of simultaneous active users will be more than the low QoS class for MAC #2. This is shown in Fig. 5(e) and Fig. 5(f). We know that the extreme value for the average number of simultaneous active users is in Aloha-OCDMA algorithm where the nodes will always send their packets without any limitations. So the nodes have access to the shared channel any time they want.

We can derive from the above results that our proposed QoS provider algorithms have divided our OCDMA network into 2 classes of service with different QoSs which are all guarantied during network activities. As we discussed before the plotted throughput values are the lower bound of the performance of such networks. That is because we have assumed the chip synchronous scenario and all 1 packet transmission. Therefore, the real throughput will be certainly more in more realistic network conditions.

V. CONCLUSION

This work has analyzed and simulated the QoS provisioning algorithms in OCDMA packet networks. The proposed algorithms used the multilevel optical power transmission (a feature of physical layer) and adaptive delay adjustment (a feature of MAC layer) to provide different QoS metrics to different users. Two different MAC algorithms are proposed and their performance is compared with that of Aloha-OCDMA algorithm. It is demonstrated that both proposed MAC algorithms improve the throughput of both classes of service, but in the second algorithm the users of class #2 will use the network's resources more than the users's of class #1. So the high QoS users will achieve better QoS metrics.



(a) (c) (e)

(b) (d) (f)

Fig. 5. Comparison of the performance of the Aloha-OCDMA, MAC #1-OCDMA and MAC #2-OCDMA algorithms (a) Normalized throughput in low QoS class. (b) Normalized throughput in high QoS class. (c) Channel access delay in low QoS class. (d) Channel access delay in high QoS class. (e) Average number of simultaneous active users in low QoS class. (f) Average number of simultaneous active users in high QoS class.

ACKNOWLEDGMENT

Authors wish to thank Salman Khaleghi for his helpful comments on the paper. Thanks are also extended to the Iran Telecommunication Research Center (ITRC) for supporting this work.

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