An MAC Protocol with High Throughput and Low Packet Delay for OFDMA PONs

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Abstract: An efficient MAC protocol has been proposed for OFDMA PONs. Simulation results illustrate the proposed MAC protocol obtains higher throughput performance and large network capacity, reduces average packer delay and improves the bandwidth utilization efficiency.

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1. Introduction

With the development of the access technology, passive optical networks (PONs) have been evolving from time division multiplexing (TDM), wavelength division multiplexing (WDM) PONs [1] to orthogonal frequency multiplexing access (OFDMA) PONs [2-4] recently. Compared to TDM-PONs or WDM-PONs, OFDMA PONs has numerous advantages such as high spectral efficiency, high dispersion-tolerance, and flexible granularity of bandwidth allocation.

The media access control (MAC) is an important issue in OFDMA PONs, which has been introduced in [5]. There are two main protocols in OFDMA PONs. One is similar with the protocol in TDM-PONs, where each ONU transmit their data over time slots allocated by optical line terminal (OLT) so as to avoid data collision. Therefore, synchronization among ONUs and OLT is required. The requirement of the synchronization, on the one hand, improves the sophistication of the OFDMA PON systems. On the other hand, the time wasted in the synchronization might reduce bandwidth utilization. To eliminate the synchronization in OFDMA PONs, one way is to allocate fixed subcarriers for each ONU, which is similar to the wavelength allocation in WDM PONs, where each ONU is allocated one or more wavelengths. However, the statistical multiplexing gain cannot be exploited among ONUs. Zhang et.al proposed a new MAC protocol which combines the advantages of TDM-PON and WDM-PON to improve the throughput and reduce the packet delay [6].

In this paper, taking the advantages of the abundance of the OFDMA subcarriers, we proposed a novel MAC protocol for OFDMA PON systems. In this MAC, except that some subcarrier are fixedly allocated to each ONU as control channel, the other subcarriers are dividing into non-overlaps and each set is dynamically allocated to each ONU. Therefore, no time synchronization and burst mode transmission are required in ONUs. Furthermore, the packet delay is reduced due to the novel control message transmission in the proposed MAC protocol. From simulation results, compared with the traditional MAC protocol and the recently proposed one in [6], our proposed MAC protocol not only has higher throughput performance and larger network capacity, but also reduces the average packet delay and improves the bandwidth efficiency.

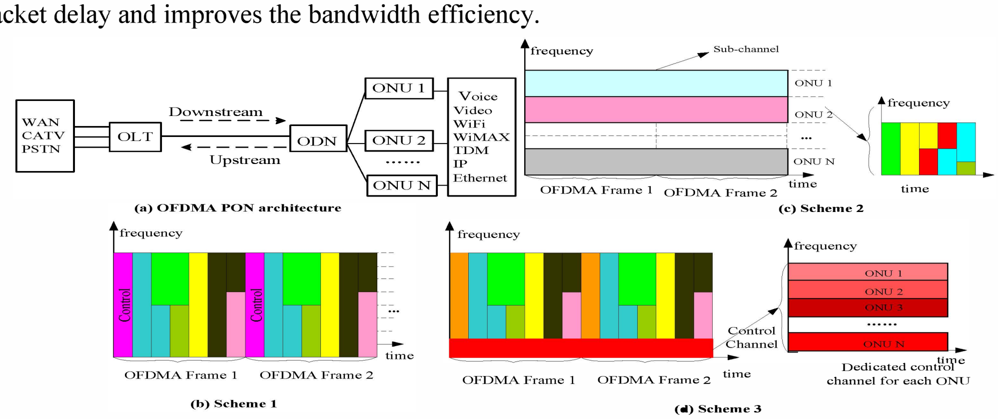


Fig.1 OFDMA PON architecture and MAC schemes

2. Network architecture and existing MAC protocols

A typical OFDMA PON architecture is described in Fig.1 (a). There are three major components, namely OLT, optical distribution network (ODN) and ONUs. OLT will broadcast downstream traffic data flow to each ONU and transfer upstream traffic data flow to different service centers such as wide area network (WAN), cable television (CATV) and public service telecom network (PSTN). ONUs will selectively receive downstream frames broadcasted by OLT and transfer it to users, meanwhile different service data from each user is transmitted to OLT by each ONU in upstream traffic flow. ODN is collecting data from each ONU in upstream and splitting data from OLT to ONUs in downstream, respectively. Here, three MAC protocol schemes are illustrated in Fig. 1(b), Fig.1 (c) and Fig.1 (d) for OFDMA PON systems.

Scheme1: One MAC protocol for OFDMA PON systems is all subcarriers are shared among all ONUs. Thus, statistical multiplexing gain is similar to Ethernet PON (EPONs) with single wavelength and can be exploited among traffic of ONUs. However, ONUs need to be synchronized with OLT.

Scheme2: Another MAC protocol for OFDMA PON systems is dividing all subcarriers into non-overlap sets and each set is fixedly allocated to each ONU. Obviously, such scheme is similar to WDM-PON scheduling. This MAC protocol will eliminate the needing of synchronization, simplify the ONU structure and reduce system cost. Unfortunately, low bandwidth utilization and low network performance will be resulted due to the failure of exploiting statistical multiplexing gain.

Scheme3: The proposed MAC protocol for OFDMA PON systems in [6] is a number of subcarriers dedicated for control message transmission and the other subcarriers shared by all ONUs using different time-slots. This MAC protocol will eliminate the synchronization requirement and also exploit the traffic statistical gain, but burst-mode transmission is required in ONU due to time multiplexing.

3. The proposed MAC protocol

To exploit statistical multiplexing gain and eliminate the needing of the synchronization in the OFDMA PONs, meanwhile improve the network throughput and reduce the packet delay, a novel MAC protocol is proposed as below.

(1) Similar to scheme 3, some subcarriers are used for control message transmission only. These control channels are fixedly allocated to each ONU during each OFDMA Frame cycle. Each ONU will report their traffic information to OLT by the control channels during each OFDMA Frame cycle.

(2) Similar to scheme 2, all subcarriers are divided into non-overlap sets, but each set is dynamically allocated to each ONU based on the proportion of each ONU transmitted data among the total transmitted data.

(3) OLT sends out the grant message to each ONU right before the OFDMA Frame cycle begins in the control subcarriers. The grant is set out at time $t(i)$-RTT, where $t(i)$ is the beginning time of OFDMA Frame cycle i and RTT refers the trip time from OLT to ONU. The grant message contains the allocated subcarriers to each ONU.

(4) In the control subcarriers of the OFDMA Frame cycle i, ONUs will register and each ONU keeps updating its status to OLT based on the estimation of the data needing to be transmitted in each ONU during the next OFDMA Frame cycle i+1.

(5) An ONU immediately starts its data transmission when grants sent from OLT are received.

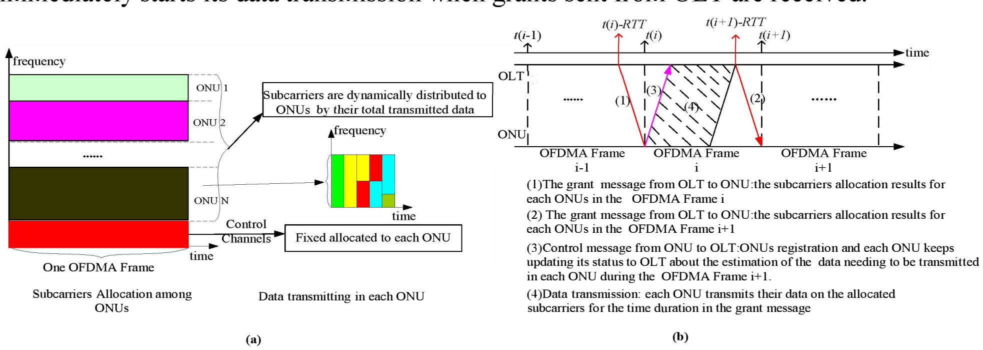


Fig.2 The proposed MAC protocol for OFDMA PONs

Fig.2 (a) illustrates the proposed MAC protocol. From Fig.2 (a) we can know that a number of subcarriers are fixedly allocated to each ONU for control message transmission and the other subcarriers are dynamically distributed among OUNs by their total transmitted data during each OFDMA Frame cycle. Fig.2 (b) shows the detail of the message and data transmission between OLT and ONUs. ONUs keep updating their data status to OLT using its control channels and OLT sends out the grant message to each ONU just before the next OFDMA Frame cycle begins. The ONU status updating and OLT grant message transmission are simultaneously working with the data transmission between OLT and ONU in each OFDMA frame since they are operated in different subcarriers. In this novel MAC protocol, we consider that the subcarriers allocation results for each ONU in the OFDMA Frame cycle i+1 is finished in its former OFDMA cycle i. By doing so, we can save the time wasted in the transmission of the subcarriers allocation results in the cycle i+1,then improve the efficient of bandwidth utilization and enhance the capacity of the network.

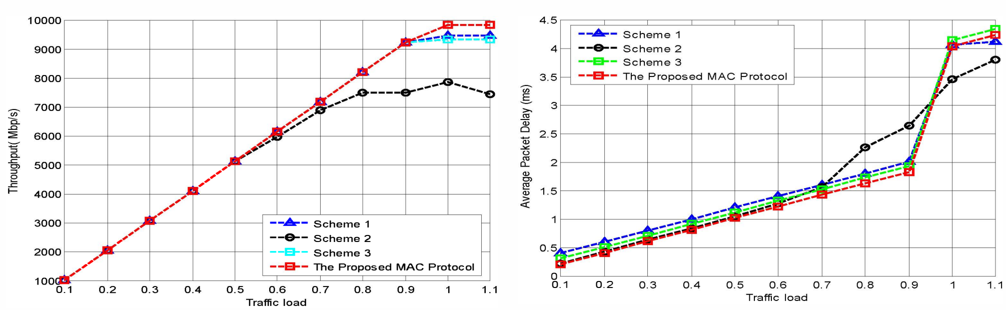
In generally, there are three main advantages of the novel proposed MAC protocol. Firstly, the subcarriers allocation for each ONU in the OFDMA Frame i+1 is finished in its former OFDMA Frame i. As a result, the time wasted in reporting the amount of transmitted data in each ONU to OLT at the beginning of the OFDMA Frame i+1 can be saved. Therefore, the efficiency of bandwidth utilization can be improved and the capacity of the network can be enhanced. Secondly, all the other OFDM subcarriers are dynamically allocated to each ONU by the proportion of their own transmitted data among the total transmitted data, thus facilitating the exploration of the statistical multiplexing gain. Finally, due to all subcarriers are divided into non-overlap set and each set is dynamically allocated to ONUs, no time synchronization and burst-mode transmission are required in ONUs.

4. Performance evaluation

The packet delay and throughput performances of our novel proposed MAC protocol are investigated in this section. The simulation setup is as follows. We assume that the OFDMA PONs support 32 ONUs and the capacity rate is set as 10Gbit/s. There are 2048 OFDMA subcarriers and each ONU has one subcarrier as message control channel. *RTT* is set as 0.1ms, and the OFDMA Frame cycle T_{cycle} is set as 4ms. Traffic load is defined as the ratio between the total arrival traffic over the whole network capacity. Simulation results for this novel MAC protocol are shown as below. For comparison purpose, scheme 1, scheme 2, and scheme 3 are also simulated under the same conditions.

The throughput performances of the four MAC protocols are shown in Fig.3 (a). When traffic load<0.7, throughputs of those MAC protocol are similar to one another. However, when traffic load>0.7, the throughput of scheme 2 is smallest because the statistical multiplexing gain is failure to be exploited due to each ONU is fixedly assigned with subcarriers for their data transmission. The throughput of our proposed MAC protocol is the highest. For one reason, the time wasted in reporting the amount of transmitted data in each ONU to OLT at the beginning of the OFDMA Frame can be saved. For the other reason, the statistical multiplexing gain is to be exploited due to the subcarriers are dynamically allocated to each ONU. Thus the efficiency of bandwidth utilization can be improved and the capacity of the network can be enhanced in the novel proposed MAC protocol. Just as mention in [6], the throughput of scheme 3 is higher than scheme 2 and lower than scheme 1 when the traffic load is heavy.

Fig.3 (b) shows the average packet delay performance produced by the four MAC protocols. In our proposed scheme, traffic flow can be immediately reported to OLT while it has to wait for some time before being reported in scheme 1; OLT sends out the grant message to each ONU right before the OFDMA Frame cycle starting while the same thing has to be done at the beginning of the OFDMA Frame cycle in scheme 2 and scheme 3. Thus, when the network is lightly loaded, our proposed MAC protocol yields smallest average packet delay of all. When the network is heavily loaded (load>0.9), the average delay of the proposed MAC protocol is similar to scheme 1 and scheme 3 and is large than that of scheme 2 due to the using of some subcarriers as control channel.



(a) The throughput performance. (b) Average packet delay

Fig.3 The throughput and average packet delay for different MAC protocols.

5. Conclusions

This paper presents a novel MAC protocol for OFDMA PON systems. Compared with existing MAC protocols, the proposed MAC protocol has higher throughput performance and larger network capacity when the traffic load is heavy. Furthermore, this MAC protocol reduces the average packet delay and improves the bandwidth efficiency.

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