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Dynamic Bandwidth Allocation Algorithm for Orthogonal Frequency Division Multiplexing Access-passive Optical Network

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Abstract:An architecture of next generation access network namely orthogonal frequency division multiplexing passive optical network was presented, which has high spectrum efficiency, fine bandwidth granularity and low cost. A novel efficient dynamic bandwidth allocation algorithm based on orthogonal frequency division multiplexing passive optical network namely fixed cyclic polling in pipeline dynamic bandwidth allocation algorithm was investigated. To meet the quality of service requirements under multi-services access scenario, two level bandwidth allocation mechanisms, bandwidth pre-request for expedited forward service and the smallest bandwidth request allocated the first principle for assured forwarding and the best effort services were applied in this algorithm. A simulation was conducted to study the performance of fixed cyclic polling in pipeline dynamic bandwidth allocation algorithm in orthogonal frequency division multiplexing passive optical network. The results show that the proposed algorithm supports expedited forwarding services with low packet average delay and low jitter, balances priority and fairness between assured forwarding services and best effort services, and achieves bandwidth allocation fairness among different optical network units in the same priority. Compared with the traditional dynamic bandwidth allocation algorithms, fixed cyclic polling in pipeline algorithm meets the quality of service requirements excellently, and adapts orthogonal frequency division multiplexing passive optical network better with higher bandwidth efficiency and lower algorithm complexity.

Key words: OFDM-PON; Quality of Service (QoS); Dynamic Bandwidth Allocation (DBA); Fixed Cyclic Polling in Pipeline (FCPP)

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0 Introduction

Passive Optical Networks (PONs) have been widely recognized as promising wired access network schemes to meet high-bandwidth and multi-service scenario in the future. Most PONs are based on Time Division Multiplexing Access (TDMA) technology, such as ATM-PON (APON), GPON and EPON. Moreover, they can provide tens of Mbps bandwidth to each user cheaply and reliably[1]. Nevertheless, bandwidth demand of wired access networks grows rapidly because of the emerging high-bandwidth services, such as High Definition Television (HDTV), high-speed data transfer, multimedia conference and multiplayer online game etc. And, existing PON technologies have some difficults on meeting these demands. For example, Wavelength Division Multiplexing-PON (WDM-PON) can offer high-speed data access service to each user with dedicated wavelength[2]. However, costly equipment, oversized bandwidth granularity and lack of Quality of Service (QoS) guarantee are the fatal flaws of WDM-PON. Thus, it lately leads to research towards increased-capacity optical access network solutions.

Orthogonal Frequency Division Multiplexing (OFDM) technique has been widely recognized as a promising digital multi-carriers modulation scheme for high-speed data transmission both in wireless

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and wired systems[3]. This technique utilizes a serial low bit rate sub-carriers to carry different Quadrature Amplitude Modulation（QAM）symbols simultaneously. Great benefits could be achieved when we combine PON with OFDM Access（OFDMA）techniques[4]. Compared with traditional PONs，OFDM-PON supports multi-service，provides QoS guarantee and enables dynamic sub-carriers allocation to provide bandwidth sharing among multiple Optical Network Units（ONUs）and applications. Currently，100 Gb/s optical access network technology based on OFDM-PON has been demonstrated[5]，and some of the key technologies have been achieved[6-9]. Based on the above，OFDMA-PON can be regarded as a very promising solution for future PON-based access network.

In this paper，the architecture of OFDM-PON is presented and a novel efficient DBA algorithm namely FCPP based on OFDM-PON is proposed. After that，a simulation is conducted to study the performance of FCPP algorithm. And the result shows that FCPP not only meets QoS requirements excellently but also adapted OFDM-PON better with higher bandwidth efficiency and lower algorithm complexity.

1 Network architecture and MAC protocol in OFDM-PON

A flexible，high bandwidth and cost-effective next-generation PON based on Point-to-Multiple Point（PMP）topology，namely OFDM-PON，is presented in Fig. 1. In order to discuss QoS performance of OFDM-PON，Service Level Agreement（SLA）is applied. And access services are divided into three types，which are Expedited Forwarding（EF）service for voice and TDM applications，Assured Forwarding（AF）services for video applications and Best Effort（BE）service for Internet access applications etc.

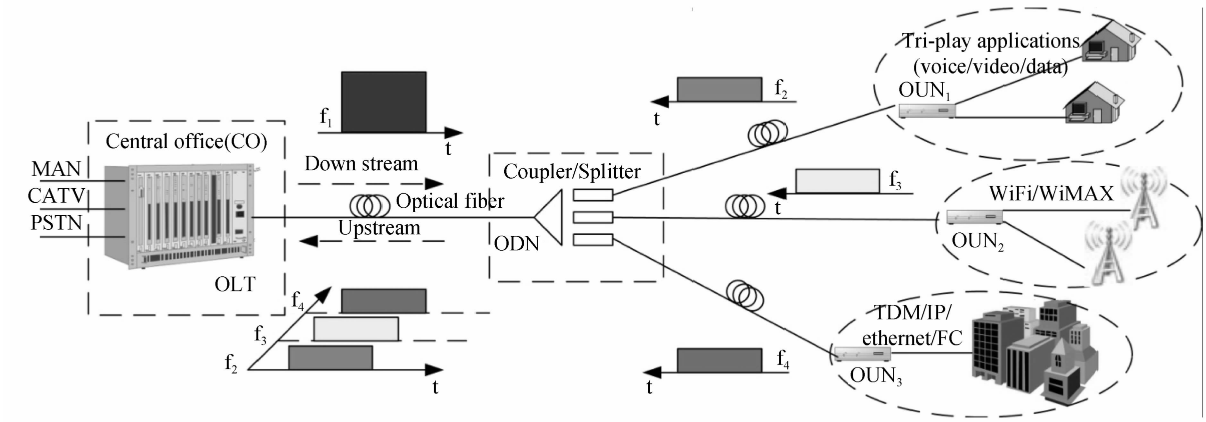


Fig. 1　Schematic diagram of sub-channel allocation in OFDM-PON system

Optical Line Terminal（OLT），Optical Distribution Network（ODN）and ONU are three major components in an OFDM-PON. OLT takes the responsibility of broadcasting downstream traffic flow to each ONU and transferring upstream traffic flow to different service centers. Furthermore，dynamic bandwidth allocation of sub-carrier/time slots among ONUs is also conducted intelligently by OLT.

In order to provide QoS guarantee，each ONU is set three buffers for each service. On one hand，ONU takes the responsibility of collecting traffic flows from each user and requesting bandwidth resource from OLT according to the amount of traffic flow in each service buffer. On the other hand，ONU listens and selectively receives downstream frames broadcasted by OLT.

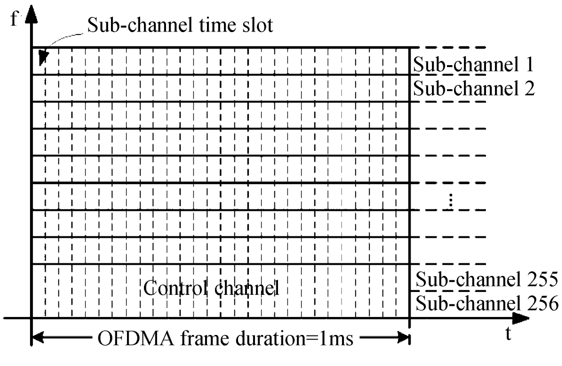
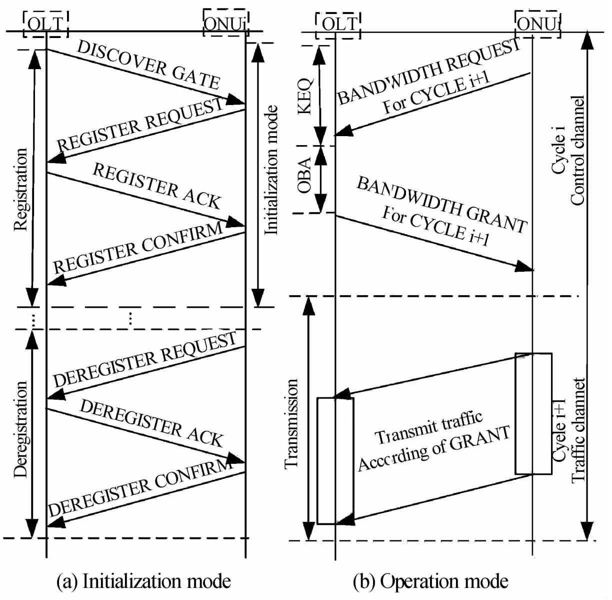


Fig. 2　Schematic diagram of upstream sub-channel allocation in OFDM-PON

Fig. 2 is the schematic diagram of upstream sub-channel allocation in OFDM-PON. Since it is a multi-carrier multiplexing system，bandwidth resource is divided into sub-carrier/time slots. Thus，compared to traditional PONs，it greatly reduces bandwidth granularity which can improve QoS performance effectively . And several sub -

carriers are dedicated as a control channel for transmission signaling from ONUs to OLT cyclically.

Fig. 3 illustrates the control signaling interaction between OLT and ONUs in Fixed Cyclic Polling in Pipeline (FCPP) DBA algorithm. Multi-Point Control Protocol (MPCP), which defines two modes: initialization mode and operation mode, is used as the control protocol to support ONU dynamic access and work in OFDM-PON[10]. In the initialization mode, a control method similar to three-way handshake protocol is used for ONU automatic discovery process as shown in Fig. 3. Besides, in operation mode, dynamic bandwidth allocation and ranging are achieved by bandwidth request and bandwidth grant frames. Bandwidth is allocated dynamically by OLT according to the bandwidth request messages sent by each ONU. After DBA operation completion, bandwidth grant frame is broadcasted to each ONU to inform the bandwidth allocation result for next cycle data transmission.



(a) Initialization mode (b) Operation mode

Fig. 3 Control message interaction of FCPP in OFDM-PON

2 Dynamic bandwidth allocation algorithm

Based on the characteristics of OFDM-PON, we proposed a novel DBA algorithm called FCPP. It collects bandwidth request and delivers grant frames cyclically in pipeline. Moreover, two-level bandwidth allocation mechanism which is bandwidth allocation among and within priority is used to ensure QoS requirements in FCPP.

In cycle i, OLT run FCPP algorithm after collecting all bandwidth requests from each ONU through control channel in turn[11]. And then OLT broadcasts the grant message to each ONU before the end of cycle i. Thus, in cycle $i+1$, each ONU transmits traffic flows to OLT according to the grant message sent by OLT in previous cycle.

$$\begin{cases} W_{\mathrm{EF}} = \sum\limits_{i=1}^{N} B_{\mathrm{EF}}[i] \\ W_{\mathrm{AF}} = (W - W_{\mathrm{EF}}) \times m \\ W_{\mathrm{BE}} = (W - W_{\mathrm{EF}}) \times (1-m) \end{cases} \tag{1}$$

$$m = \frac{\sum\limits_{i=1}^{N} B_{\mathrm{AF}}[i]}{\sum\limits_{i=1}^{N} B_{\mathrm{BE}}[i]} + k,\ 0 \leqslant k \leqslant 1 - \frac{\sum\limits_{i=1}^{N} B_{\mathrm{AF}}[i]}{\sum\limits_{i=1}^{N} B_{\mathrm{BE}}[i]} \tag{2}$$

$$W_{\mathrm{EF}}[i] = B_{\mathrm{EF}}[i], i=1,2,3,\cdots,N \tag{3}$$

Firstly, bandwidth pre-divided among priorities which expressed as (1) is used to provide QoS among different priorities. The bandwidths demands of EF service are fully meet, because not only it's a delay and jitter sensitive service, but also its has constant bit rate characteristic. W is the total bandwidth resource, which can be allocated. W_{EF}, W_{AF}, W_{BE} are bandwidth pre-allocated to EF, AF and AF services, respectively. $W_{\mathrm{EF}}[i]$, $W_{\mathrm{AF}}[i]$, $W_{\mathrm{BE}}[i]$ are the bandwidth allocation results for each service in each ONU. $B_{\mathrm{EF}}[i]$, $B_{\mathrm{AF}}[i]$, $B_{\mathrm{BE}}[i]$ are the bandwidth request arrays for EF, AF and AF services, respectively. And parameter m calculated by (2) is used to divide the remaining bandwidth to AF and BE services. Parameter k is priority and fairness balance parameter between AF and BE services. N is the number of active ONU in OFDM-PON.

Secondly, EF requests are processed by FCPP. Because it is the top priority service, and its traffic flow can be predicted, all bandwidth requests for EF traffic would be satisfied by OLT as shown in (3). Owing to the jitter and delay sensitive feature, bandwidth pre-request mechanism is applied in dealing with EF traffic. That is, each ONU uses this cycle EF traffic amount to predict the traffic amount of next cycle. The steady traffic flow makes sure that the prediction has high reliability. Thus, FCPP could realize a pipeline structure, which requests bandwidth in previous cycle, transfer traffic flows real-time for EF service. And fixed one cycle delay brought by pipeline is eliminated. The DBA algorithm for EF is similar to circuit-switch[12-13].

Thirdly, AF request is processed by FCPP as shown in Fig. 4. AF request would be satisfied as long as the total request amount does not exceed W_{AF}. However, if total EF request exceeds W_{AF}, smallest bandwidth request first principle would be applied. That is, to ensure fairness in the same priority among ONUs, bandwidth resource would satisfy ONUs who have smallest bandwidth request first. And map[i] is an array with N elements all been set to 1 to mark bandwidth whose request has been satisfied.

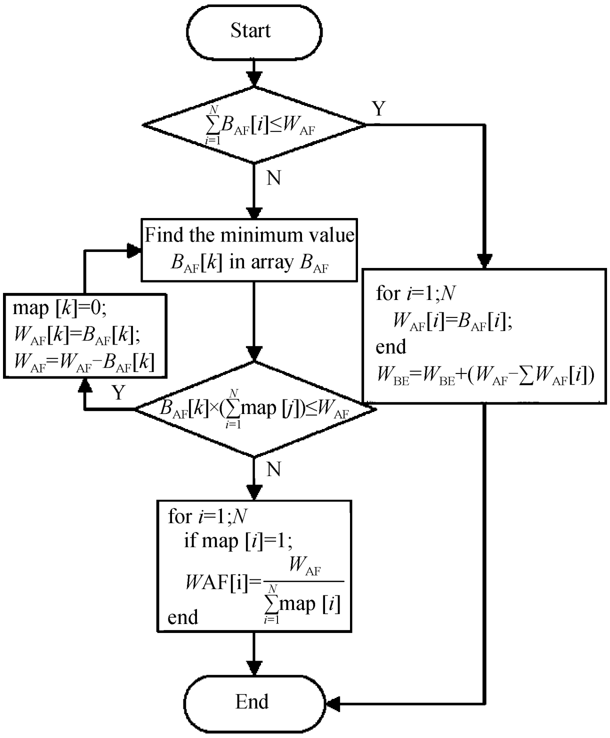


Fig. 4 Flowchart of processing AF request by FCPP

Last, the remaining bandwidth would be allocated to BE as the same process as AF.

After OLT finish DBA, the bandwidth grant frame contains $W_{EF}[i]$, $W_{AF}[i]$, $W_{BE}[i]$ are sent to each ONU as the next cycle of upstream bandwidth allocation result.

3 Performance

In order to verify the performance of FCPP, a simulation is conducted to study the impact of different DBA algorithms on the upstream performance in OFDM-PON. The simulation scenario is set as follows: a typical PMP topology with 128 ONUs and one OLT is assumed. The OFDM physical channel using 16-QAM modulation with 2.5 GHz baseband divided into 2 048 sub-carriers. And the sub-carriers are further grouped into 256 sub-channels. Bandwidth allocated to each priority is shown as (1) and (2), and the value of k is set to 0.2 to give priority to AF dominated relatively more bandwidth than BE. Each buffer in ONU for different services is set to 0.5 MB. The polling cycle is set to 1ms. The control channel occupies 16 sub-carriers. All the control frames are 64 Bytes, which is the minimum length of an Ethernet frame.

To illustrate the performance of FCPP, a classic DBA algorithm namely Constant Bit Rate (CBR) based on EPON[14] under the same scenario is also simulated. CBR is also a two level DBA. But, difference is that CBR allocate bandwidth according to the total requests of each ONU first. Then, bandwidth is allocated to each service by each ONU itself. Moreover, CBR, which based on TDMA, has no dedicated control channel.

Our simulation mainly focuses on the QoS performance parameters of throughput, Packet Loss Ratio (PLR), Packet Average Delay (PAD) and jitter. As expected, Fig. 5 shows that the ultimate throughput of FCPP is reached 95%, when CBR is 90%. It is because that FCPP eliminates idle time by using independent control channel and smallest bandwidth granularity.

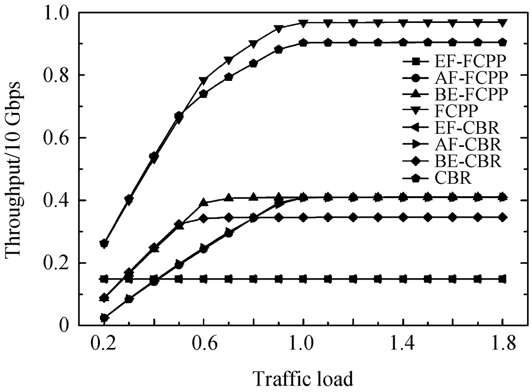
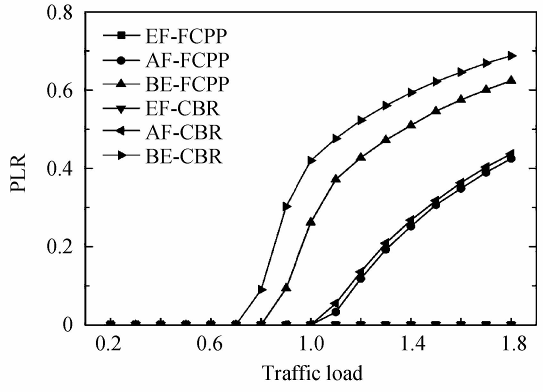
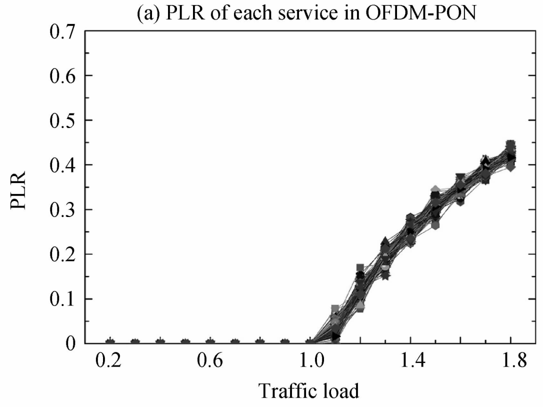


Fig. 5 Throughout performance of FCPP and CBR

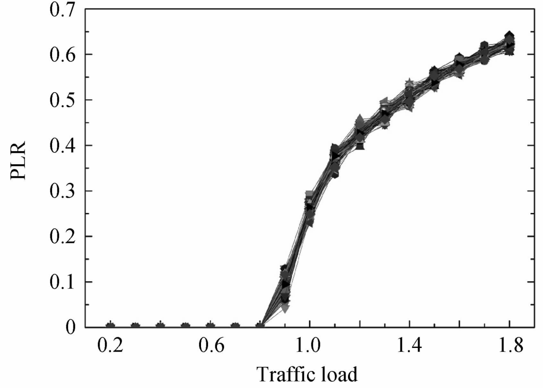
Fig. 6 plots PLR lines of FCPP and CBR in OFDM-PON. Fig. 6 (a) shows the PLR lines of each service in OFDM-PON. The PLR of EF traffic remains 0 under different traffic loads. The reason is that both FCPP and CBR fully meet the demands of EF bandwidth request. Thus, FCPP provides QoS guarantee to top-priority service such as: voice, TDM with low packet loss rate. Moreover, the PLR performance of AF is better than BE both in FCPP and CBR. Because AF, which is a higher priority service, can occupy relative more bandwidth than BE. And, priority and fairness between AF and BE can regular by parameter k. And, both AF and BE PLR performance of FCPP is better than CBR which is consistent with the throughput performance. Fig. 6 (b) and Fig. 6 (c) show each ONU's AF and BE PLR performance of FCPP. High overlap PLR lines fully illustrate high fairness of bandwidth allocation among ONUs in the same priority.



(a) PLR of each service in OFDM-PON

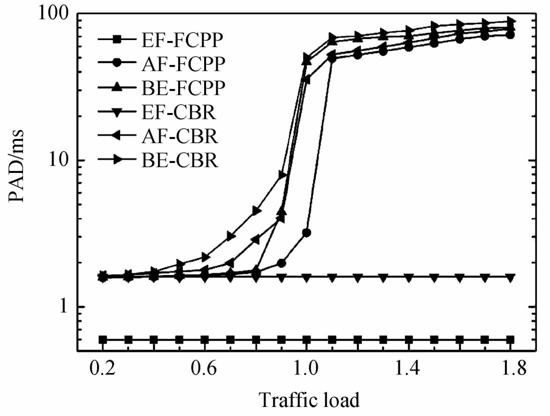


(b) PLR of AF services in each ONU (FCPP)

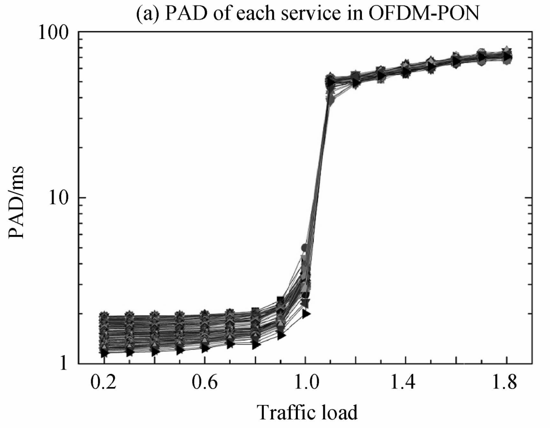


(c) PLR of BE services in each ONU (FCPP)

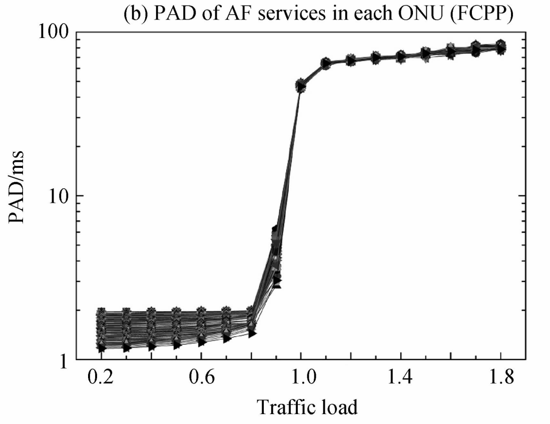
Fig. 6 PLR lines in OFDM-PON of each DBA algorithm



(a) PAD of each service in OFDM-PON



(b) PAD of AF services in each ONU (FCPP)



(c) PAD of BE services in each ONU (FCPP)

Fig. 7 PAD lines in OFDM-PON of each DBA algorithm

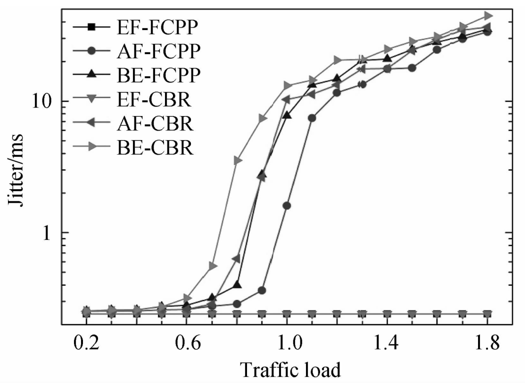


Fig. 8 Jitter performance of FCPP and CBR

Fig. 7 illustrates PAD lines of FCPP and CBR. It shows that the PAD of EF is about 0.6 ms, meeting the 1.5ms standard recommended by ITU-T for voice and TDM access traffic[15]. The improvement is brought by eliminating the fixed one cycle delay in pipeline by applying bandwidth pre-request mechanism. Fig. 7(b) and (c) show each ONU's AF and BE PAD lines of FCPP. They also illustrate high fairness of bandwidth allocation among ONUs in the same priority. And, it shows that each ONU's AF and BE PAD is uniform distributed between 1.2 ms to 2.2 ms under low traffic load condition. It is caused by bandwidth request message reported by ONU through control channel in turn. But, it is acceptable, because AF and BE are not delay sensitive services. Fig. 8 is the jitter performance of FCPP. It shows that the jitter of EF service is about 240 μs, also meet the 250 μs standard which is recommended by ITU-T for voice and TDM access service[16]. And, under not heavy traffic load, the performance of AF and BE is also well. In the end, we can conclude that the performance of FCPP is better than CBR.

4 Conclusion

In this paper, an optical access network namely OFDM-PON is presented and a DBA algorithm namely FCPP is discussed. OFDM-PON, which has high spectrum efficiency, fine bandwidth granularity and huge bandwidth, has been recognized as a promising technique for next generation PON. FCPP supports EF service with low jitter and delay by applying bandwidth pre-request mechanism, balances priority and fairness between AF and BE by applied two level bandwidth allocation mechanism, achieves high fairness bandwidth allocation among ONUs in the same priority by employing smallest bandwidth request first principle. Thus, FCPP achieved high efficiency, fairness, high throughput and provide QoS guarantee excellently.

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基于正交频分复用无源光网络的动态带宽分配算法研究

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摘　要:介绍了一种应用于未来大容量、多业务接入场景下的称为光正交频分复用无源光网络的下一代接入网技术,并提出了一种基于此结构的称为基于服务质量需求的固定周期流水线轮询动态带宽分配算法.该算法通过应用二级带宽分配机制、带宽预申请机制和最小带宽申请优先原则等方法,有效地保障了在大容量、多业务接入场景下各个业务不同的服务质量需求.为研究其性能,建立了该算法的仿真模型并进行了对比仿真.仿真结果显示该算法以低时延和低抖动有效地支持快速转发业务,同时平衡了确保转发业务和尽力而为业务之间的优先性和相对公平性,并且实现了不同光网络单元间的同优先级业务带宽分配的公平性.与传统的动态带宽分配算法算法相比,基于服务质量需求的固定周期流水线轮询动态带宽分配算法具有执行效率高、算法复杂度低、性能良好等优点,并且能够更好地适应光正交频分复用无源光网络的特性,发挥网络最大的性能.

关键词:正交频分复用无源光网络(OFDM-PON);服务质量(QoS);动态带宽分配算法(DBA);固定周期流水线轮询(FCPP)