Adaptive Service Analysis for EPON Base on Working Vacation Queueing Model

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***Abstract*—We put forward an adaptive service scheme which combines of working vacation and gated scheme to optimize system performance of Ethernet passive optical network (EPON). We investigate the performance of the EPON upstream channel with adaptive service scheme based on the optical fiber communication Multi-point control protocol (MPCP), making use of discrete time working vacation service and gated service scheme vacation queue models. The queue models are analyzed by using method of the matrix-geometric solution method and the exact performance measures are obtained such as average queue length of traffic and average packet delay time which can provide the theoretic basic for EPON system design. Finally, the numerical examples demonstrate the performance of adaptive service scheme is superior to separate scheme.**

Keywords-EPON; MPCP; working vacation; vacation queue; adaptive service scheme

I. INTRODUCTION

With the rapid decline in the cost of fiber optics and Ethernet equipment, Passive optical network (PON) technology is considered as a promising solution for the next-generation broadband access network because it is simple, cost-effective and scalable. In ITU-T, a series of ATM-based Broadband PON have been recommended [1]. On the other hand, Ethernet PON (EPON) has been discussed in IEEE 802.3ah as one of the extensions of Gigabit-Ethernet [2]. EPON, an extended platform essentially preserves the merits of Ethernet network while reducing the complexities and improving the quality of services (QoS) to an expectation level. Figure 1 shows the typical EPON system. Practically, EPON systems consist of one optical line terminal (OLT) situated at the central office (CO) and multiple optical network units (ONUs) located at customer premises equipment (CPE), and a passive splitter/combiner. EPON provides bi-directional transmissions, in the downstream direction (from OLT to the ONUs), the OLT broadcasts to all ONUs. The frames are sent to their destination ONUs by using media access control (MAC) layer. In the upstream direction (from ONUs to the OLT), because it is a multipoint-to-point network, the fiber channel is shared by all ONUs. Therefore, scheduling is needed to prevent data packet collision from different ONUs. A solution is to assign a time slot to each ONUs while assigning a fixed time slot regardless of its requirement. But this scheme cannot adapt to bursty traffic and may waste bandwidth considerably.

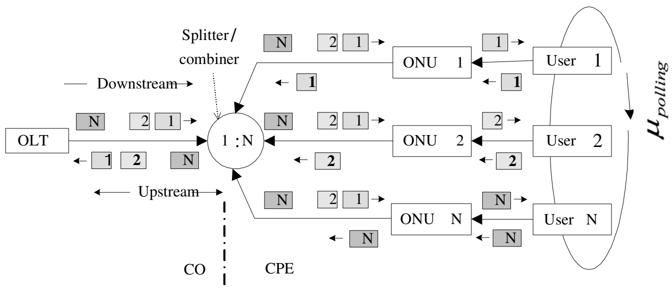

Figure 1 typical structure of EPON

Hence, a robust mechanism is need for allocating time slots and the upstream bandwidth for each ONU to transmit data. In EPON, the mechanism is called MPCP involving both GATE message and REPORT message. The ONUs may send REPORT messages about the queue state of each ONU to the OLT. The OLT allocates upstream bandwidth to each ONU by sending GATE messages with the form of a 64-byte MAC control frame. GATE message contains a time-stamp and grants time slots which represent the periods that ONU can transmit data. So that the OLT can allocate the upstream bandwidth and time slots to each ONU accordingly.

Consequently, through model and simulation to EPON system, to find efficiently schemes are considered by researchers.

J. D. Angelopoulos[3], G. Kramer and G. Pesavento[4], C. Assi, Y. Ye, S. Dixit, and M.A. Ali et al[5] had researched the time-division multiple access in EPON. This approach allowed the ONUs to share a upstream channel in which the OLT allocateed timeslots to each ONU to transmit its traffic in the buffer of the ONUs. Overall, this yielded a very cost-effective solution. Then, G. Kramer, B. Mukherjee, and K. paulikowski [6] presented a simple algorithm for dynamic bandwidth allocation based upon a time interleaving method, i.e. the interleaved polling scheme with an adaptive cycle time (IPACT) scheme. Here, an in-band signaling approach used a single channel for both downstream data and grant transmission. Meanwhile, G. Kramer and B. Mukherjee [7] studied EPON performance with a static bandwidth-assignment algorithm. Subsequently, a large body of work had defined various adaptive dynamic bandwidth allocation (DBA) schemes in order to boost the OLT link efficiency and the inter-ONU fairness, there were some related references in this area and notable examples include the limited, gated, linear credit, and elastic allocation scheme. However, most of authors used simulation method and single scheme. In this paper, we analysis an adaptive scheme, i.e. the gated service and working vacation service scheme were combined together. Meanwhile, simple explicit formulae for the average queue length and average delay time of packet in the queue in ONUs was obtained.

II. MODEL DESCRIPTION AND SERVICE SCHEME

A. Model Description

We model this by either assuming that having multiple wavelengths serving a WDM can be accurately approximated by a single server or, alternately, by assuming that the multiple wavelengths are engineered to indeed perform as if they are a single server. The latter assumption, called the continuous bandwidth mode, is discussed in [8]. So, we consider each ONU separately and treat it as a single server Geom/Geom/1 gated service queue and Geom/Geom/1 multiple working vacation queue model. The EPON system we consider in this paper:

N ONUs (all of the ONUs have infinite buffer capacity);

Interarrival times of data packets arrival to ONU i i =1,2,…,N are independent and identical distributed (i.i.d.) sequences and follow a geometric distribution, denoted by Geom., with the distribution as the following forms:

$$P\{T=k\}=p_i(1-p_i)^{k-1},\ k\geq 1,\quad 0<p_i<1.$$

The distribution for service time $\{S_b^i, i>1\}$ in a regular busy period is

$$P\{S_b^i=k\}=\mu^{w}{}_b^i(1-\mu_b^i)^{k-1}, k\geq 1,\quad 0<\mu_b^i<1.$$

The distribution for service time $\{S_v^i, i>1\}$ in a working vacation period is

$$P\{S_v^i=k\}=\mu_v^i(1-\mu_v^i)^{k-1}, k\geq 1,\quad 0<\mu_b^i<1.$$

Polling time V (viewed as vacation time in the queue model) is a nonnegative i.i.d. discrete-time random variables sequences with the geometric distribution and PGF as the following forms:

$$P\{V_j=j\}=\theta^i(1-\theta^i)^{j-1},\ j\geq 1,\quad 0<\theta^i<1.$$

$$P(V_j=j)=v_j\ ;\qquad v(z)=\textstyle\sum_{j=1}^{\infty}v_jz^j\ ,$$

$$E(V)=v'(1)\ ,\ E(V(V-1))=v(1)''$$

The inter-arrival time and the service time are independent of vacation time mutually, the transmission order is a First Come First Served (FCFS) scheme.

B. Gated Service Schem

The gated service scheme is that when the ONU i requires the right of sending data, it closes the gate at the beginning of every transmission period, the ONU i only transmits data packet which have been present in this transmission period, and the new arrival data packets will be waiting outside of the gate according to arrival ordering. When the data packets inside gate of ONU i have been transmitted, the system will turn to next ONU $i+1$ and transmit data packet inside the gate of ONU $i+1$. Hence, the EPON system of single ONU with the Gated service can model as Geom/ Geom /1 gated service multiple vacation queue model. It is a special case of Takagi, H. [9] Geom/G/1(G, MV) and Ma Z. Y. and Tian, N. S. [10] Geom/G/1(G, MAV) mode. We can obtain the average queue length and average packet delay time respectively. Because the gated service period can be calculated, the next ONU $i+1$ bandwidth grant information can be transmitted in this ONU i service time. Therefore the additional time and additional queue length are zero. We can obtain the average queue length and the average packet delay time respectively.

$$E(Q_{gated})=\rho+\frac{p^2E(S(S-1))}{2(1-\rho)}+\frac{pE(V(V-1))}{2E(V)}+\frac{p\rho}{1-\rho}E(V) \tag{1}$$

$$E(W_{gated})=\frac{pE(S(S-1))}{2(1-\rho)}+\frac{E(V(V+1))}{2E(V)}+\frac{\rho}{1-\rho}E(V) \tag{2}$$

Where, $\rho=\dfrac{average\ service\ time}{agerage\ interarrival\ time}$, is called traffic intensity. $E(S)=S'(1)$, $E(S(S-1))=S(1)''$

C. Working Vacation Service Schem

For working vacation service scheme, ONU i has permanent wavelengths assigned to it correspond the capability of being serviced at a nominal rate μ_v^i; the polling wavelengths serve at an additional rate of μ^+; the total service rate is $\mu^{w}{}_b^i=\mu_v^i+\mu^+$. If ONU i is currently operating at a total service rate of $\mu^{w}{}_b^i$, when the buffer of ONU i becomes empty at a service completion, the polling wavelengths are reconfigured to ONU i +1 mod (n) , then ONU i instantaneously reducing its service rate to μ_v^i and only after a reconfiguration delay of Δ, ONU $i+1$ mod (n) increasing its service rate to $\mu^{w\,i+1}_{b}=\mu^{i+1}_{v}+\mu^{+}$. This cycle continually repeats itself.

From the case of Reference [11][12], We can obtain the average queue length and average packet delay time respectively. Otherwise, considering the practice situation, the working vacation service scheme of each ONU needs to send REPOT message and the OLT needs to send GATE message to next ONU, So the vacation time should add an addition time. Let the addition time is τ. The average queue length should add $p\cdot\tau$ data packets. We can obtain the average queue length and the average packet delay time respectively.

(1) the average number of packet in the queue

$$E(Q)=\frac{\alpha}{(1-\alpha)}+K^{*}\left(\delta_1+\frac{\delta_2}{1-r}\right)+p\cdot\tau \qquad (3)$$

The average delay time of packet in the queue

$$E(W)=\frac{1}{\mu_b^w(1-\alpha)}+K^{*}\beta_1\frac{\sigma}{1-\sigma}+\tau \qquad (4)$$

Where $\alpha=\frac{p\bar{\mu}_b^w}{\bar{p}\mu_b^w}$; $\rho=\frac{p}{\mu_b}$; $\beta=\theta\bar{\theta}^{-1}$;

$$r=\frac{1}{2\rho\bar{\mu}_v}\left[\beta+p\bar{\mu}_v+\bar{p}\mu_v-\sqrt{(\beta+\rho\bar{\mu}_v+\bar{p}\mu_v)^2-4p\bar{p}\mu_v\bar{\mu}_v}\right];$$

$$K^{*}=\left\{\bar{p}\mu_b^w(1-\alpha)(1-r)[\theta+\bar{\theta}\bar{p}\mu_v(1-r)+\bar{\theta}p]+p\theta\right\}^{-1};$$

$$\delta_1=p\bar{\mu}_b^w(1-r)p\bar{\theta}\,\mu_v\frac{(1-r)}{r};\ \delta_2=p\bar{\theta}(p+r\bar{p})\frac{(1-r)}{r}[\mu_b^w-\mu_v]$$

$$\sigma=\frac{r}{p+r\bar{p}};\ \beta_1=p\bar{\theta}\frac{1-r}{r}(\mu_b^w-\mu_v)$$

D. Adaptive Service Schem

In the adaptive service scheme, according to a criterion, i.e. the delay time of data packets in ONUs is minimal. The ONUs will decide they take which service scheme between gated service and working vacation service scheme. The algorithm is

If $E(W_{gated})<E(W_{exhaustive})$

Then

The adaptive service scheme adopt the gated service

Else

The adaptive service scheme adopt the working vacation service

III. NUMERICAL EXAMPLES

In this section, in order to evaluate the performance of EPON system the upstream channel with the gated service, working service and adaptive service control scheme, we present and compare the results derived from a set of analytical calculations. The system model described from figure 2 to figure 11, the total number of the ONUs in the EPON is 5. If we design data packets is fixed size as 1000 bits and the total transmission speeds of the EPON is 1Gb/s. therefore, the transmission time of a data packet equals to 1 μs (i.e. the time length of a slot). We assume the polling time follow a geometric distribution and the service time $\mu_b=0.95$, $\mu_v=0.05$. For working vacation service scheme, the polling time should add the additional time Assuming equal to 10× traffic intensity ms and $\mu_b^w=\mu_b-n_1\cdot\mu_v$ where n_1 is the number of ONUs

According to the expression (2), (4) and (1), (3), we depict the effect of traffic intensity ρ and vacation time on the average delay time and average queue length respectively (see figure 2 to 11). Evidently, along with the increase of traffic intensity ρ, not only gated service scheme but also working vacation service scheme, both the average queue length and average delay time increase. In figure 2, 6 and 7, when $\rho>0.6$ and E(V)>8ms, the average packet delay in ONUs of the gated service has increase more obviously than working vacation service scheme. In figure 4, 9 and 10, when $\rho>0.6$ and E(V)>8ms, the average queue length in ONUs of the gated service has increase more obviously than the working vacation service scheme. In other situation, the performance of the gated service excels the working vacation service. Therefore, to compare the gated service and working vacation service, we can't find one service scheme to surpass another in all situations. In figure 3, 5, 8 and 12, if we adopt the adaptive service, the performance of EPON can be improved considerably.

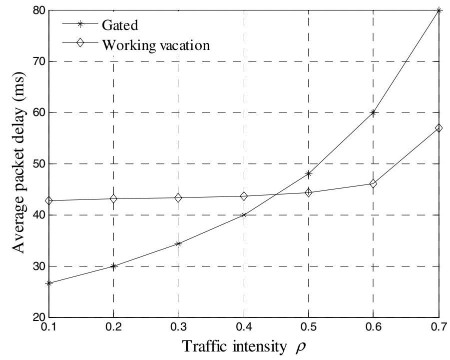

Figure 2 Average packet delay comparisons Between working vacation and gated service. E(V)=6ms

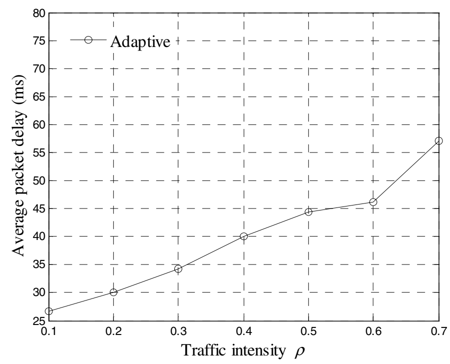

Figure 3 Average packet delay adaptive service

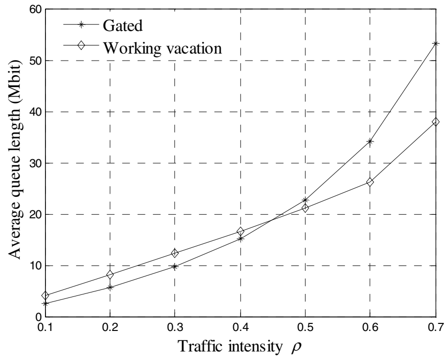

Figure 4 Average queue length comparisons Between working vacation and gated service. E(V)=6ms

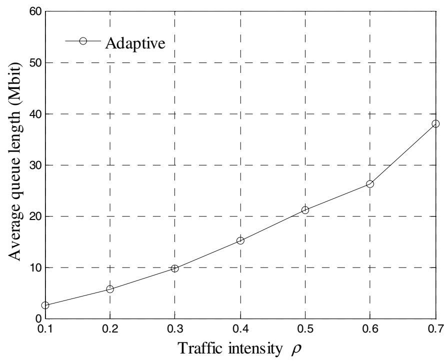

Figure 5 Average packet delay adaptive service E(V)=6ms

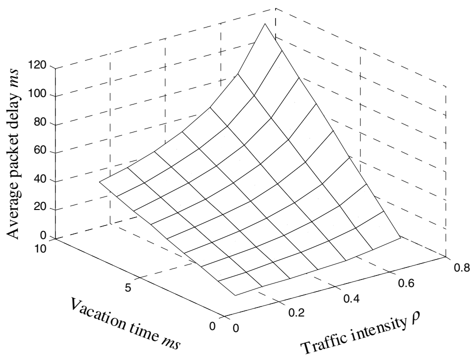

Figure 6 Average packet delay time with gated service

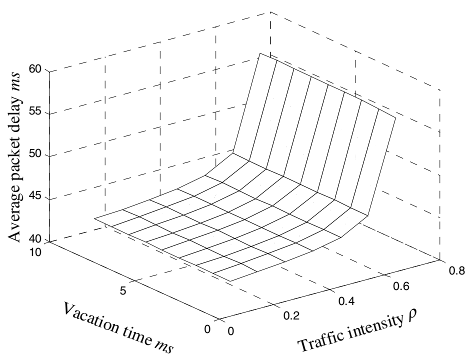

Figure 7 Average packet delay time with working vacation service

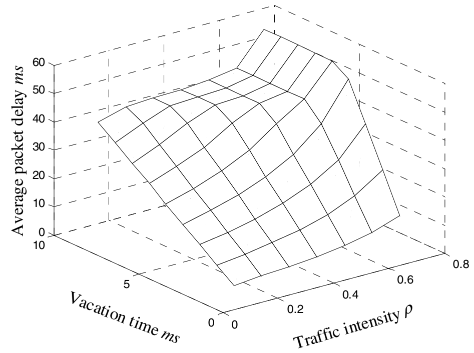

Figure 8 Average packet delay time with adaptive service

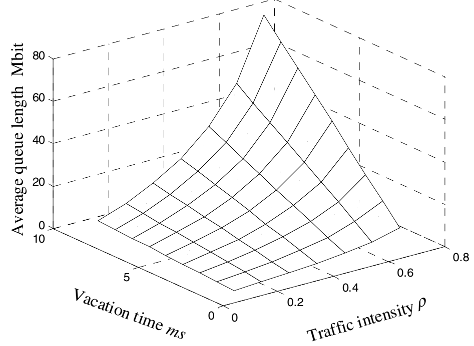

Figure 9 Average queue length with gated service

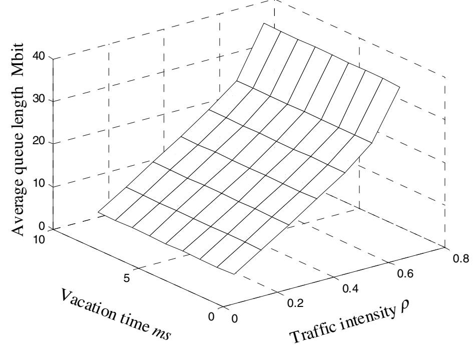

Figure 10 Average queue length with working vacation service

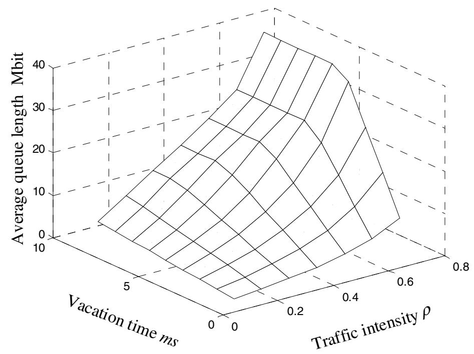

Figure 11 Average queue length with adaptive service

In a word, to compare the three service schemes can provide theoretic basic for EPON design, maintenance and choose the best service scenario.

IV. CONCLUSION

In this paper, using the decomposition approach, we modeled EPON upstream transmission control schemes as Geom/Geom/1 gated service and Geom/Geom/1 multiple working vacation queue model. The average delay time of packet in the queue and the average number of packet in the queue formulas were obtained. The numerical examples have shown that the adaptive service has better performance than the vacation service and the working vacation service scheme. This can provide theoretic basic for EPON design.

ACKNOWLEDGMENT

The authors would like to thank the support from Natural Science Foundation of China #10671170, and this work is also supported by Science Foundation of Yanshan University for the Excellent Ph.D. students. Meanwhile thank support by the International Cooperation and Exchange Foundation of Yanshan University for Ph. D. Students..

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