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以太无源光网络中面向多播业务的节能算法

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摘　要:在面向多播业务的以太无源光网络中引入光网络单元混合休眠模式,提出面向多播业务的节能算法和改进的面向多播业务的节能算法,使光网络单元空闲组件能够得到充分休眠,并通过约束条件降低光网络单元的唤醒次数,从而降低光网络单元能耗.改进的面向多播业务的算法与面向多播业务的算法相比,增加了光网络单元唤醒的约束条件,进一步降低了光网络单元的唤醒次数.仿真结果表明,与现有算法相比,所提算法在保证数据包时延的前提下更加节能.改进的面向多播业务的算法节能效果优于面向多播业务的算法,表明增加的约束条件有助于降低光网络单元的唤醒次数和能耗.

关键词:以太无源光网络;节能;光网络单元;多播业务;独立休眠模式
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Energy Saving Algorithms for Multicast Traffic in Ethernet Passive Optical Network

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Abstract: The hybrid sleep mode of optical network unit was introduced into ethernet passive optical network for multicast traffic, and the energy saving algorithm for multicast traffic and improved energy saving algorithm for multicast traffic were proposed. The two algorithms sleep the idle components of optical network units and reduce the wakeup times of optical network units by constraints, so that the energy consumption of optical network units can be reduced. Compared with energy saving algorithms for multicast traffic, the improved energy saving algorithms for multicast traffic adds a constraint for optical network units wakeup, so reduces the wakeup times of optical network units further. Simulation results show that, the two proposed algorithms save more energy than the previous algorithm with guaranteed packet delay. Moreover, the improved energy saving algorithms for multicast traffic saves more energy than energy saving algorithms for multicast traffic, which shows that the adding constraint contributes to the reduction of the wakeup times and the energy consumption of optical network units.

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0 Introduction

In recent decades, the rapid development of modern industries intensifies the greenhouse effect, which has threatened the survival and development of human. Therefore, energy conservation has already attracted global attention and become the consensus of all over the world. With the popularity of the concept "green network", it is imperative to study the methods and schemes to reduce the energy consumption in networks. As one of the last-mile solutions, broadband access networks[1-3] consume large energy that accounts for about 75% of all the networks[4]. Ethernet Passive Optical Network (EPON) has become the most feasible technology of current broadband access networks due to low energy consumption and wide deployment[5]. Consequently, EPON is the focus of energy conservation in broadband access networks up to today.

The typical EPON is structured as a tree topology, where Optical Line Terminal (OLT) acts as the root node and Optical Network Units (ONUs) act as the leaf nodes. The splitter is used to connect the OLT and the ONUs through optical fibers. Each ONU can support multiple end users. In EPON, ONU is the first level aggregator node collecting the packets from end users while the OLT is the second level aggregator node gathering the packets from ONUs. In upstream, ONUs contends for the same shared wavelength channel in a time division manner. In downstream, OLT broadcasts the packets to all ONUs. However, the packets only can be received by the destination ONU while discarded by other ONUs.

The tree topology enables EPON to be suitable for the multicast traffic and broadcast traffic. With the popularity of multimedia applications, more and more multicast traffic and unicast traffic exist on the same ONU. OLT keeps multicast buffers and unicast buffers for multicast traffic and unicast traffic, respectively. The ONUs receiving the same multicast traffic belong to the same multicast group. All ONUs in a multicast group must keep active to receive the traffic designated to the group. This is the major difference between EPON with unicast traffic and that with multicast traffic. Hence, previous works[6-13] study different energy saving methods. However, they are just for unicast traffic and are not suitable for multicast traffic. Furthermore, few of the existing energy saving methods consider the multicast traffic in EPON[14-15]. We propose an Energy Saving algorithm for Multicast Traffic (ESMT) and an Improved Energy Saving algorithm for Multicast Traffic (IESMT) to save energy consumed by ONUs through independent sleep mode of transmitter and receiver of ONU and adapting the characteristics of multicast traffic.

1 Energy saving algorithm for multicast traffic

In downstream, the ONUs belonging to the same multicast group can receive the multicast traffic simultaneously. However, the upstream channel is shared by all ONUs in the way of Time Division Multiplex Access (TDMA), that is, for any time, only the polled ONU can transmit its upstream traffic. Therefore, at most time, this will lead to the results that the transmission in upstream and downstream cannot be conducted at the same time. In other word, if we adopt traditional sleep mode that the ONUs do not sleep until there is no traffic in both upstream and downstream, unnecessary energy waste will be produced. Consequently, the sleep process of ONUs becomes more complicated with multicast traffic. However, more energy can be saved by adopting the independent sleep mode of transmitter and receiver, which has been presented in our previous work[9]. The transmitter and the receiver are able to sleep independently according to their own traffic. It is notable that our previous work in Ref. [9] is oriented to unicast traffic in downstream. We solve the sleep problem of ONUs in EPON with multicast traffic, and also solves the challenges produced by independent sleep of the transmitters and receivers at the same time, e. g., the modification of Multi-Points Control Protocol (MPCP). Specially, we insert a GATE control message when needed according to the proposed algorithm, and the GATE control message has been extended by some fields according to the sleep and wakeup processes of the transmitter and the receiver.

The j^{th} multicast group is denoted as $G_j(n, O_j[n])$, where n denotes the number of ONUs contained in the j^{th} multicast group and $O_j[n]$ is used to store each ONU index in the j^{th} multicast group. For simplicity, use G_j to represent $G_j(n, O_j[n])$ for short. Each multicast group traverses only one slot, and the slot length depends on the transmission time of the traffic of the multicast group that traverses this slot. Furthermore, each slot only can carry the downstream traffic of one multicast group. In particular, take downstream unicast traffic as a special kind of multicast traffic where $n=1$.

Fig. 1 shows the traffic scheduling in one cycle. The first multicast group contains two ONUs, i. e., ONU_2 and ONU_3. Hence, we can obtain the first multicast group $G_1(2,O_1[2])$, where $O_1[2]=\{2,3\}$. Similarly, we can obtain the second multicast group $G_2(2,O_2[2])$, where $O_2[2]=\{1,2\}$, the third multicast group $G_3(2,O_3[2])$, where $O_3[2]=\{3,4\}$, and the fourth multicast group $G_4(1,O_4[1])$, where $O_4[1]=\{1\}$. It can be seen that OLT first sends GATE control message to each ONU which includes upstream and downstream transmission slots, sleep start time and wakeup time for each ONU. Therefore, before sending the GATE control message, OLT should obtain the information of transmission slots for both upstream and downstream. Especially in downstream, any ONU may receive downstream traffic successively, which makes the computation for the sleep process and wakeup process of ONUs become much more complicated. Since the wakeup process consumes energy that cannot be neglected, we need to make sure the wakeup times for each ONU. Here, a novel energy saving method named ESMT is presented to solve this problem. The detailed procedure for the proposed ESMT algorithm is as follows.

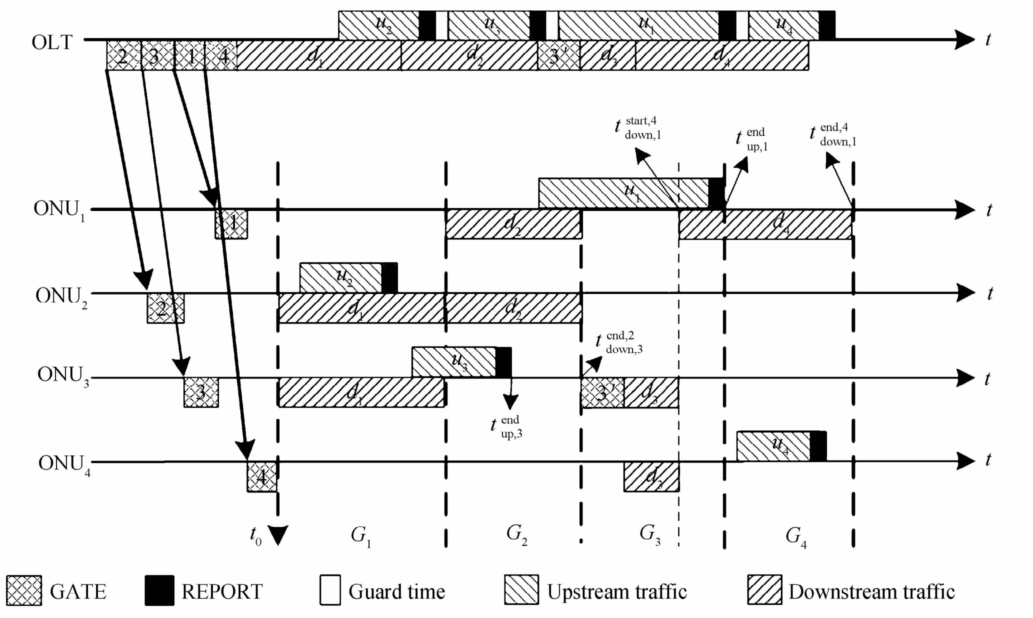


Fig. 1 Traffic scheduling in EPON

Step1: Make sure the sequence of upstream transmission for all ONUs. According to the order of the multicast groups, we sort the ONUs in the order of ascending order in each multicast group. Hence, we can get the sequence of the upstream transmission for all ONUs in Fig. 1 as: ONU_2, ONU_3, ONU_1, and ONU_4. Store the indices of these ONUs by this order into an array S.

Step2: Compute the start time $t_{\mathrm{up},i}^{\mathrm{start}}$ and end time $t_{\mathrm{up},i}^{\mathrm{end}}$ of the upstream transmission for each ONU_i, where i denotes the index of ONU and $i=\{1,2,3,4\}$. It is obvious that $t_{\mathrm{up},i+1}^{\mathrm{start}}=t_{\mathrm{up},i}^{\mathrm{start}}+B_i^{\mathrm{up}}/R+T_{\mathrm{guard}}$ and $t_{\mathrm{up},i}^{\mathrm{end}}=t_{\mathrm{up},i}^{\mathrm{start}}+B_i^{\mathrm{up}}/R$, where B_i^{up} denotes the allocated upstream bandwidth of ONU_i, R denotes the transmission rate and T_{guard} denotes a guard time between two neighboring transmissions.

Step3: Compute the wakeup times of each ONU_i and make sure the number, the content, and the sending time of GATE control messages that are sent to ONU_i. For each ONU_i, there is a GATE control message at the beginning of the polling cycle wakeup process (i. e., the wakeup times of each ONU equal to 1), and the sending sequence is set according to S.

Case1: If the ONU_i belongs to several successive multicast groups, for example, ONU_2, or the ONU_i belongs to only one multicast group, for example, ONU_4, only one GATE is needed before receiving downstream traffic. Therefore, the wakeup times do not increase;

Case2: If the ONU_i does not belong to successive multicast groups, for example, ONU_1 and ONU_3, compute the start time $t_{\mathrm{down},i}^{\mathrm{start},j}$ and the end time $t_{\mathrm{down},i}^{\mathrm{end},j}$ of the downstream transmission. 1) If $t_{\mathrm{down},1}^{\mathrm{start},4}<t_{\mathrm{up},1}^{\mathrm{end}}<t_{\mathrm{down},1}^{\mathrm{end},4}$, the ONU_1 needs not to sleep after the transmission of the downstream traffic of G_2. Therefore, the wakeup times do not increase. 2) If $t_{\mathrm{down},3}^{\mathrm{end},2}-t_{\mathrm{up},3}^{\mathrm{end}}>T_{\mathrm{ov}}$, the ONU_3 needs to sleep and wake up at $t_{\mathrm{down},3}^{\mathrm{end},2}$. Then the wakeup times increase by 1. Here, T_{ov} is the duration time that each ONU used to wake up[9].

In conclusion, the constraint for ONU wakeup can be described as the idle time of ONU is more than the overhead time.

2 Improved energy saving algorithm for multicast traffic

Waking up the ONUs frequently is a main factor for high energy consumption. To reduce the wakeup times of ONU further, a new algorithm IESMT is proposed by adding an additional constraint for ONU wakeup into ESMT. This constraint is that, the energy saved by ONU in idle time should be more than the energy consumption of ONU wakeup. The procedure of IESMT is described as follows.

Step1: The same as step1 in ESMT.

Step2: The same as step2 in ESMT.

Step3: Case1: The same as case1 of step3 in ESMT;

Case2: If ONU_i does not belong to successive multicast groups, for example, ONU_1 and ONU_3, compute the start time $t_{down,i}^{start,j}$ and the end time $t_{down,i}^{end,j}$ of the downstream transmission.

1) The same as 1) in case2 of step3 in ESMT.

2) If $t_{down,3}^{end,2} - t_{up,3}^{end} > T_{ov}$ and $(t_{down,3}^{end,2} - t_{up,3}^{end}) \cdot \Delta P > T_{ov} \cdot P_{wakeup}$, ONU_3 should go to sleep state and wake up at $t_{down,3}^{end,2}$. Hence, the wakeup times increase by 1. ΔP is the power difference of ONU_3 when it does not sleep and it sleeps during the idle time $(t_{down,3}^{end,2} - t_{up,3}^{end})$. P_{wakeup} is the power consumed by the wakeup of ONU_i.

In conclusion, there are two constraints for ONU wakeup in IESMT. The first one is that the idle time of ONU is more than the overhead time. The second is the energy saved during the idle time should be more than the energy consumption of ONU wakeup. ONU can go to sleep state and wakeup when the above two constraints are satisfied simultaneously.

3 Simulation results

In the simulation, we investigate the performances of the proposed two algorithms in the network topology with four ONUs compared with the algorithm in Refs. [14-15] denoted by Ref algorithm in the simulation figures. For simplicity, assume that each multicast group contains two ONUs at most. Set the average packet size as 482 Byte, and the wakeup power of each ONU as 0.481 25 mW[9]. Other parameters can refer to Ref. [7]. The energy consumption of all ONUs in each polling cycle is calculated by Eq. (1).

$$E=\sum_{i=1}^{N}(t_i^{tx} \cdot P_{tx} + t_i^{rx} \cdot P_{rx} + t_{sim} \cdot P_{sleep} + n_i^{wakeup} \cdot P_{wakeup}) \quad (1)$$

where N is the maximum number of ONUs deployed in the simulation network; n_i^{wakeup} is the wakeup times of ONU_i; t_i^{tx} and t_i^{rx} are the working time of the transmitter and the receiver of ONU_i, respectively; t_{sim} is the simulation time in this cycle; P_{tx} and P_{rx} are the power consumed by the transmitter and the receiver of ONU_i, respectively. Therefore, the first part $t_i^{tx} \cdot P_{tx}$ is the energy consumed by the transmitter of ONU_i. The second part $t_i^{rx} \cdot P_{rx}$ is the energy consumed by the receiver of ONU_i. The third part $t_{sim} \cdot P_{sleep}$ is the energy consumed by ONU_i in sleep state. And the last part $n_i^{wakeup} \cdot P_{wakeup}$ is the energy consumed by ONU_i when it wakes up. Hence, the total energy consumption of all ONUs in simulation is the sum of E in all polling cycles during the simulation time 1s.

In Table 1, the ONU wakeup times of the three algorithms are compared with the change of downstream packet arrival rate in the simulation. Obviously, the wakeup times of the proposed ESMT and IESMT are much smaller than that of compared algorithm. Furthermore, IESMT outperforms ESMT because the strategy used in IESMT further reduces the ONU wakeup times due to more constraints. This is the direct reason that energy consumption of IESMT is less than that of ESMT. Due to the fixed sleep duration, Wakeup Time of ONUs (WTO) of Ref algorithm does not change with the increase of downstream packet arrival rate. However, WTO of ESMT and IESMT fluctuate at different downstream packet arrival rates. This is because WTO is determined by the relationship between upstream and downstream transmissions rather than the change of the latter one.

Table 1 Comparison of ONU wakeup times

Downstream packet arrival rate/($\times 10^3$ packets $\cdot$ s^{-1})	20	40	60	80	100
ESMT	1 485	1 781	1 780	1 484	2 076
IESMT	1 188	1 760	1 772	1 188	2 060
Ref.	13 728	13 728	13 728	13 728	13 728

Table 2 Comparison of total energy consumption of ONUs

Downstream packet arrival rate/($\times 10^3$ packets $\cdot$ s^{-1})	20	40	60	80	100
ESMT	11.475	10.746	10.984	11.191	11.555
IESMT	9.571 4	8.705 3	8.922 3	9.111 7	9.486 3
Ref.	18.616	18.616	18.616	18.616	18.616

Table 2 shows the comparison of energy consumptions of all ONUs in the three algorithms with the change of downstream packet arrival rate in simulation. As we can see that, the comparing algorithm consumes the most energy, and IESMT consumes the least energy. Since ONU wakeup times keep unchanged, the energy consumption of the comparing algorithm is also fixed. However, the energy consumption is related to not only ONU wakeup times, but also the sleep of the transmitter and the receiver. Hence, the variation trends of the energy consumption of the two proposed algorithms are not the same as ONU wakeup times.

Despite all this, at each downstream packet arrival rate, the IESMT consumes less than ESMT.

The total receiver energy consumptions in ESMT and IESMT have nothing to do with the wakeup times of ONUs, so that they are the same. The value of the total receiver energy consumptions in the two proposed algorithms is shown in Fig. 2 with the change of downstream packet arrival rate in the simulation. As we can see that, the total receiver energy consumption increases with the increase of downstream packet arrival rate in simulation. This is because that the work time of receivers of ONUs become longer with more downstream packets. Since the upstream packet arrival rate is set as a constant, the total transmitter energy consumptions in the two proposed algorithms do not change with the downstream packet arrival rate. Therefore, we do not give the simulation results of the total transmitter energy consumptions.

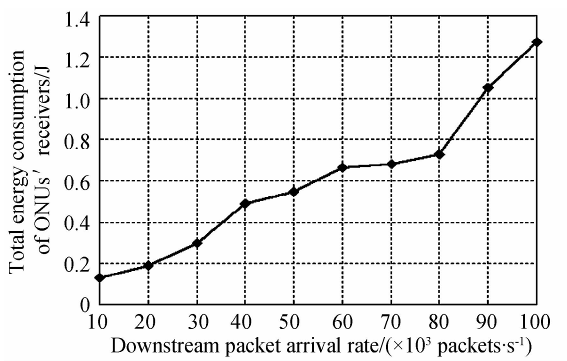
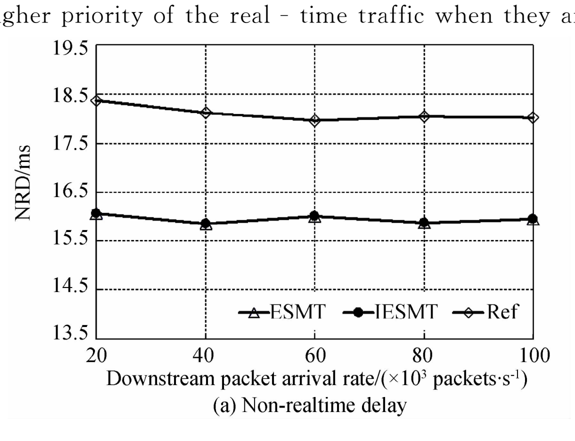


Fig. 2 Total energy consumption of ONUs' receivers

Similarly, the average delay of non-realtime traffic and realtime traffic in the two proposed algorithms are also the same, respectively. Fig. 3 shows the results of the average delay of non-realtime traffic and realtime traffic of the three algorithms with the change of downstream packet arrival rate. NRD and RD denote the average delay of non-realtime traffic and realtime traffic, respectively. Obviously, NRD and RD of the proposed two algorithms are much less than that of the comparing algorithm. Furthermore, RD of the three algorithms is much less than NRD. This is because of a higher priority of the real - time traffic when they are transmitted. IESMT can save more energy than ESMT while the performances of total receiver energy consumption and traffic delay remain unchanged.



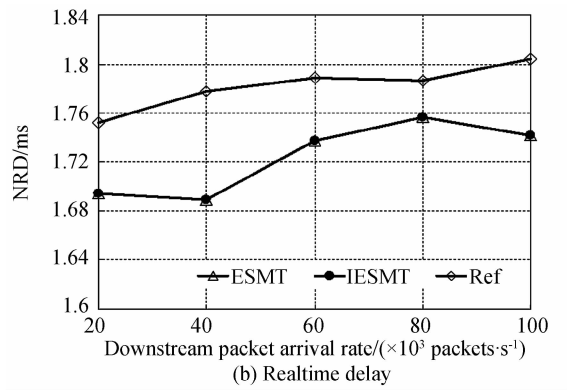


Fig. 3 Average delay for non-realtime traffic and realtime traffic

4 Conclusions

In this paper, energy saving in EPON with multicast traffic was considered. To solve the energy saving problem with both upstream and downstream traffic, we introduced the independent sleep mode of the transmitters and the receivers of ONUs, and presented an energy saving method named ESMT. To reduce the energy consumption of ONUs further, we added a constraint to improve ESMT, that is, the ONU will not sleep if its energy consumption in sleep time is less than that by the wakeup, and the improved method is named as IESMT. The simulation results demonstrated the advantages of the proposed algorithms and IESMT outperforms ESMT in terms of energy saving.

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