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Full Length Research Paper

Bahar: A new hybrid of GA and auction method for dynamic bandwidth allocation based on EPON networks

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One of the major challenges in the Ethernet Passive Optical Networks (EPON) technology in providing quality of service for the network users is the optimum and dynamic allocation of bandwidth that has been requested by the users. In this paper, a hybrid method is proposed that is based on the genetic algorithm and the auction theory where the requested bandwidth is calculated precisely with the genetic algorithm and subsequently the bandwidth is allocated through an auction process. For performance evaluation, the proposed Bahar method was compared with IPACT and FSD-SLA bandwidth allocation methods. Simulation results show that Bahar in comparison with IPACT and FSD-SLA (Failure Sensibility Degree-Service Level Agreement) experiences more delay but regarding other quality of service parameters such as packet loss ratio, line utilization, and throughput, it has better performance.

Key words: Ethernet passive optical networks (EPONs), dynamic bandwidth allocation (DBA), auction theory, genetic algorithm (GA).

INTRODUCTION

As a result of significant increase in the number of network users and their requests for receiving various types of networking services, a new access network technology is needed (Hedayati et al., 2010). One of the new technologies in this regard is being called Ethernet Passive Optical Network (EPON). The advantages of EPON over the older access network technologies include high capacity for implementation, large scale compatibility, and lower cost of bandwidth allocation to users (Kramer, 2005).

One of the major challenges in the EPON technology in providing quality of service for the network users is the optimum allocation of bandwidth that has been requested by the users. There have been several methods developed so far based on the EPON technology which are either static or dynamic, although the precise calculation of optimum bandwidth request and allocation has never been considered in these methods (Kramer et al., 2001).

Therefore, in this paper a hybrid method is proposed that is based on the genetic algorithm and the auction theory where the requested bandwidth is calculated precisely with the genetic algorithm and subsequently the bandwidth is allocated through an auction process (Krishna, 2010; Affenzeller, 2009). This new method noticeably increases the quality of service in EPON-based networks by optimizing the requested bandwidth allocation.

RELATED WORK

Currently, various DBA methods are designed based on the EPON architecture (Figure 1) which can be classified into static bandwidth allocation (STA) and dynamic bandwidth allocation (DBA) methods (Zheng et al., 2009).

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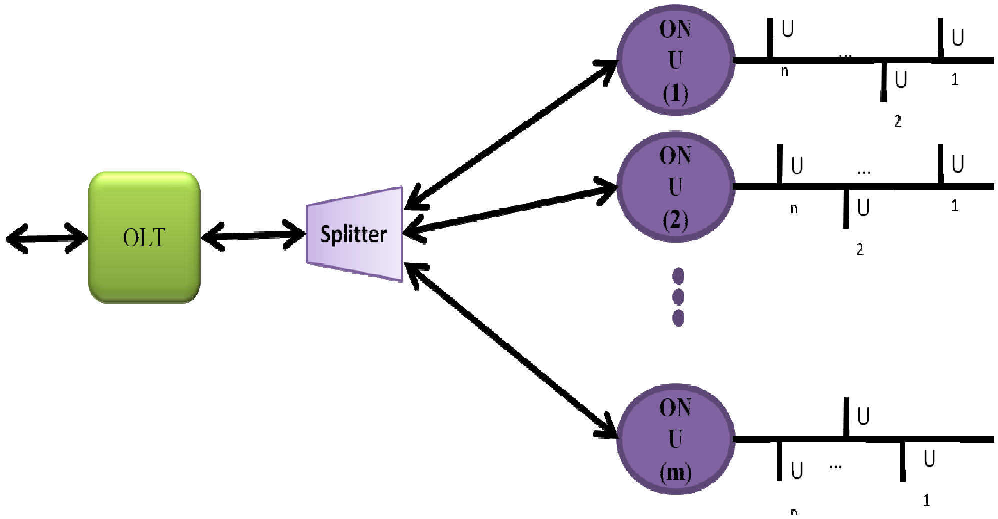

Figure 1. EPON architecture.

Static bandwidth allocation methods

Each optical network units (ONU) is allocated a time slot with a fixed length which does not require bandwidth negotiation and is due to the bursting nature of the network traffic. This, however, may result in a situation in which some timeslots are overflowed even under very light load and causing packets being delayed for several timeslots, while other timeslots are not fully used even under very heavy traffic and, therefore, leading to an underutilized upstream bandwidth. Thus, the static allocation is not preferred (Zheng et al., 2009).

Dynamic bandwidth allocation methods

To increase the bandwidth utilization, the optical line terminal (OLT) must dynamically allocate a variable timeslot to each ONU based on the instantaneous bandwidth requests of the ONUs. Given that QoS is the main concern in EPONs, these methods are classified into DBA without QoS support and DBA with QoS support.

In order to dynamically allocate bandwidth without QoS support, several algorithms have been developed based on 'polling' which are centered around the OLT. One of these algorithms is IPACT which is dynamically responding to the ONUs' requests through the OLT's polling function. Three types of service are offered by the IPACT method including constant service, gate service, and limited service (Kramer et al., 2001). This method has been extended and improved within the following algorithms: IPACT with SARF, IPACT GE, and estimation base DBA (Zheng et al., 2009).

Another DBA without QoS support method is the BGP algorithm which has been developed to guarantee the bandwidth allocation in the EPON architecture. In this method, all of the ONUs are being divided into either the ONUs with a guaranteed bandwidth and the ONUs without a guaranteed bandwidth. However, OLT is still responsible for bandwidth allocation based on the polling function, where all of the ONUs are given a constant polling time and then are allocated a constant bandwidth according

In the EPON system only some of the received data traffic types are based on the best effort and the rest are spontaneous types of traffic such as sound, video, etc. which might face limited bandwidth, delay in packet transfer, and delay jitter. Therefore, to tackle the aforementioned challenges, the DBA approaches with QoS support are needed. One of the major methods in this category is 'Fair Sharing With Dual SLA' where all of the ONUs that require lower bandwidth are given a higher priority and bandwidth allocation occurs in a time period within the upstream level. On the other hand, the ONUs with a greater bandwidth request are given a lower priority. This method is based on the service level agreement, although the major issue in this approach is the starvation that is inevitable during the second level of service level agreement. Thus, to overcome this issue Min-Max algorithm is exploited to allocate the bandwidth in a more justified manner (Banerjee et al., 2006).

Another method under the DBA with QoS support is LSTP which uses adapted mechanisms to allocate the bandwidth in a more effective way. This method can predict the traffic based on the waiting period for receiving a bandwidth, or in other words, the bandwidth allocation can be calculated based on the previous time periods of the traffic. Therefore, the ONU's request for bandwidth allocation is comprised of an estimated queue length which can be then used by the OLT in order to allocate a share of an upstream bandwidth for data transfer. Consequently, the delay and the packet loss ratio will be reduced (Luo et al., 2005).

Other algorithms classified as DBA with QoS service include class-of-service-oriented packet scheduling (COPS), hybrid granting protocol (HGP), dynamic bandwidth allocation with multiple services (DBAM), two-layer bandwidth allocation, limited allocation with excess distribution, queue-based dynamic, bandwidth allocation, QoS-aware dynamic bandwidth allocation, intra-ONU bandwidth scheduling, Intra-ONU bandwidth allocation, fine scheduling, priority-based dynamic bandwidth allocation for emergency handling, admission control for QoS protection, fair bandwidth allocation using effective multicast traffic share (Zheng et al., 2009).

THE "BAHAR" METHOD

The proposed dynamic bandwidth allocation method, Bahar, is a new hybrid method based on genetic algorithm and auction theory that can be exploited in EPON networks. In Bahar, the OLT is responsible for auction management which responds equally and effectively to the bandwidth requests of the users through their own ONUs using the genetics algorithm:

Overall, the major steps in this new auction based method (Figure 2) are listed as follows:

1. First step: Announcing the auction by OLT for the allocation of users that have requested bandwidth and submitting the initial conditions to the users through the ONUs.
2. Second step: Analyzing the initial auction conditions by the users and optimizing the received users' requests that have been sent to the ONUs using genetic algorithm.
3. Third step: Announcing the bandwidth requests' parameters through the ONUs to the OLT. These parameters are the maximum permitted waiting time of an ONU to receive a service, the requested bandwidth from users, and the users' priority.
4. Fourth step: Evaluating the received requests from the ONUs and calculate the bid value of each user followed by selecting the winners and producing a sublist from the received list of each of the ONU's users.
5. Fifth step: Allocation of the requested bandwidths to the winner users through their ONUs and supervision of the bandwidth under use.
6. Sixth step: Repeating the process from the first step.

In Bahar, the type of requested traffic, delay parameter, requested bandwidth, and the priority of users are fully under supervision.

The aforementioned algorithm and the proposed Bahar method are discussed in more details here. In the first step, OLT submits the conditions of auction to all the users, including the allocated time slot to each user in order to send their requests through the ONUs, the maximum bandwidth available from the OLT, and the time required for the OLT to respond to the received requests.

In the next step, the users send their requests to their relevant ONUs after evaluating the OLT's conditions. The ONU accepts the requests up to its maximum buffer size. Equation 1 shows the requested bandwidth from users.

$$B_{ij}^{\mathrm{Req}}(t) = K_{ij}^{Frame}(t) \times L_{ij}^{Frame}(t) \times P_{ij}(t) \quad (1)$$

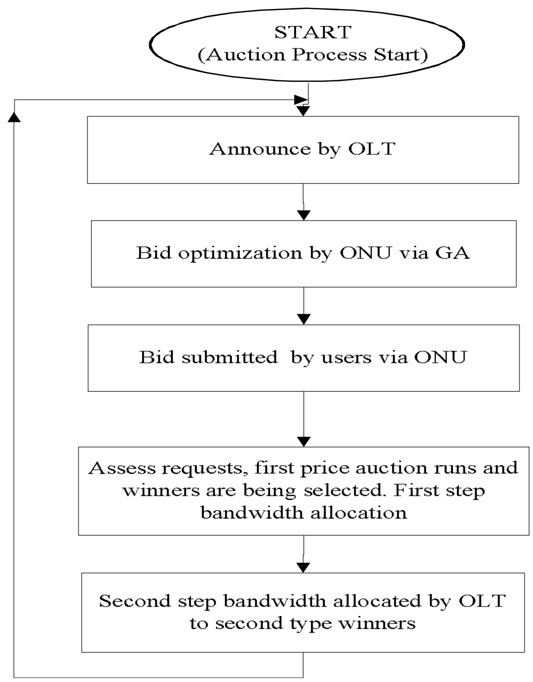

Figure 2. The overall design of the proposed Bahar method.

In Equation 1, $K_{ij}^{Frame}(t)$ shows the number of requested frames from the j[th] user of ONU$_i$ at time *t*, $L_{ij}^{Frame}(t)$ is the length of the frames sent by the j[th] user from ONU$_i$ at time *t*, and $P_{ij}(t)$ is the traffic priority of j[th] user from ONU$_i$ at time *t*.

In this paper and for simulation process, three levels of priority exist for the users' traffics who send their requests to ONU, However different priority levels could be considered. Larger number for $P_{ij}(t)$ demonstrates higher priority.

In Bahar method, these levels are defined to properly simulate the three levels such as: High, medium and low. One of the very significant characteristic of Bahar method is by increasing the number of the priority levels would not have any effect on executing the algorithm so we can imagine different priority levels. Moreover, the priority for all ONUs is the same. Table 1, shows these priorities.

Based on the Equation 1, the total bandwidth requests of all the users who are in ONU's buffer can be calculated by Equation 2.

$$BW_{ONU_i}^{\mathrm{Req}}(t) = \sum_{j=1}^{k} B_{ij}^{\mathrm{Req}}(t) \quad (2)$$

In Equation 2, $BW_{ONU_i}^{\mathrm{Req}}(t)$ is the requested bandwidth of ONU$_i$ which should not be greater than the maximum size of ONU's buffer attime *t*.

Furthermore, In the second step, by using genetic algorithm, the ONU's buffer size, which is equal to the users' bandwidth request, is being maximized. As a result of this maximizing approach, there would be more bandwidth available to respond to the users' requests and, therefore, the equality would be improved. To achieve this, fitness function is used for the total bandwidth of the users (Equation 3).

Table 1. Traffic priority of users.

Priority	Value
High	3
Medium	2
Low	1

$$f(t) = \sum_{j=1}^{n} B_{ij}^{\mathrm{Req}}(t) \times X_{ij}(t) \quad (3)$$

In Equation 3, n is the maximum number of users, and $X_{ij}(t)$ is a boolean variable which equals to 1 when there is a bandwidth request and equals to 0 when there is no bandwidth request at time t. Maximizing the $f(t)$ function means essentially improving the requested bandwidth of ONU_i at time t. By using NGSA-II algorithm (Kalyanmoy et al., 2002), the requested bandwidth values from the users which are registered in ONU's buffer are optimized. Figure 3, illustrates the process of optimizing ONU_i's buffer size based on genetic algorithm.

In the third step, ONU will send the bid value to the OLT based on the optimized value that has been calculated in the previous step (Equation 4).

$$Bid_i^{ONU}(t) = \frac{BW_{ONU_i}^{\mathrm{Req}}(t)}{BS_i^{ONU}} \quad (4)$$

In Equation 4, $BW_{ONU_i}^{\mathrm{Req}}(t)$ is the requested bandwidth received from ONU_i at time t and BS_i^{ONU} is the maximum buffer size of ONU. The suggested bid value would be between 0 to 1.

In the fourth step, based on the auction theory, K numbers of winners who have the highest bid values are selected and their requested bandwidth is allocated as a result in fifth step. Equation 5 shows the allocated bandwidth to the auction winners.

$$BW_{Allocate}^{ONU}(t) = \begin{cases} BW_{onu_i}^{\mathrm{Req}}(t) & ABW_{OLT}(t) \geq \sum_{i=1}^{k} BW_{ONU_i}^{\mathrm{Req}}(t) \\ 0 & Otherwise \end{cases} \quad (5)$$

The final step is repeating the auction process and optimizing based on genetic algorithm for evaluating bandwidth requests.

In each step of the auction, there are `*N-K*` numbers of ONUs who have not been successful in winning the auction and may starve. Therefore, in this method, the remaining ONUs are credited in order to increase the chance of success of their Bid values. This is achieved by multiplying the bid values from each step of the auction by an α factor. Equation 6 shows the new bid value which has been calculated to prevent starvation and create more equality and effectiveness.

$$Bid_i^{ONU}(t) = [1+\alpha] \times Bid_i^{ONU}(t-1) \quad (6)$$

where,

$$\alpha = Ther[Bid_i^{ONU}(t-1)] - Bid_i^{ONU}(t-1) \quad (7)$$

In Equation 7, $Ther[Bid_i^{ONU}(t-1)]$ is the threshold bid value which is the lowest winning bid value in the previous round. By using a credit-based system, in this new method, the probability of experiencing starvation will be declined and the line utilization would be improved. Figures 4 and 5 shows the detailed proposed method with its pseudo code.

SIMULATION RESULTS

In order to compare the performance of Bahar with other dynamic bandwidth allocation methods, a C++ based EPON simulator is designed. In the simulation process, a multipoint to point network, based on the EPON architecture is being used. Table 2 shows the simulation parameters.

The proposed Bahar method was compared with IPACT and FSD-SLA bandwidth allocation methods within the previously mentioned simulation environment. The comparison was done based on QoS parameters such as delay, packets throughput rate, packet loss ratio, and line utilization.

Figure 6 illustrates the comparison between the delay factors of the aforementioned methods. It can be observed that there is a delay in the proposed Bahar method at the beginning of the auction. This is greater since the calculation of the requested amount of bandwidth from all ONUs should be accomplished based on genetic algorithm and optimizing the buffer size before being sent as a parametric bid. On the other hand, over the course of running the auction, due to the decrease in the number of requests, less calculation time is required and, thus, the behavior of the proposed method is approximately the same as the behavior of the IPACT method. By the end of the third step of the proposed method, as the number of requests increase, more delay will be expected. In this evaluation, however, FSD-SLA has the greatest delay consistently which is due to the greater time required for analyzing the SLAs that are received from the requesting users proposed Bahar method. The Bahar method demonstrates a lower level of packet loss ratio since all the users who submit a greater bid value can win the auction and receive a bandwidth relevant to their bid values, which have been optimized based on the genetic algorithm, and transfer their packets. Whereas in the FSD-SLA approach, through evaluating the SLAs, the smaller packets are given higher priority and vice versa. Therefore, the larger packets with lower priority would be lost. Moreover, in IPACT, according to the rules, round robin will be sent out to the ONUs without any limitation and only in their allocated time slot. Furthermore, as can be noticed in Figure 7 , the packet loss ratio is significantly higher in the IPACT method since in this method based on the round robin concept, the ONUs are only permitted to send packets without any limitations at a specified time slot. Thus, many packets are lost due to over-riding the time limit of receiving the service.

Figure 8 shows the throughout rate of the packets in

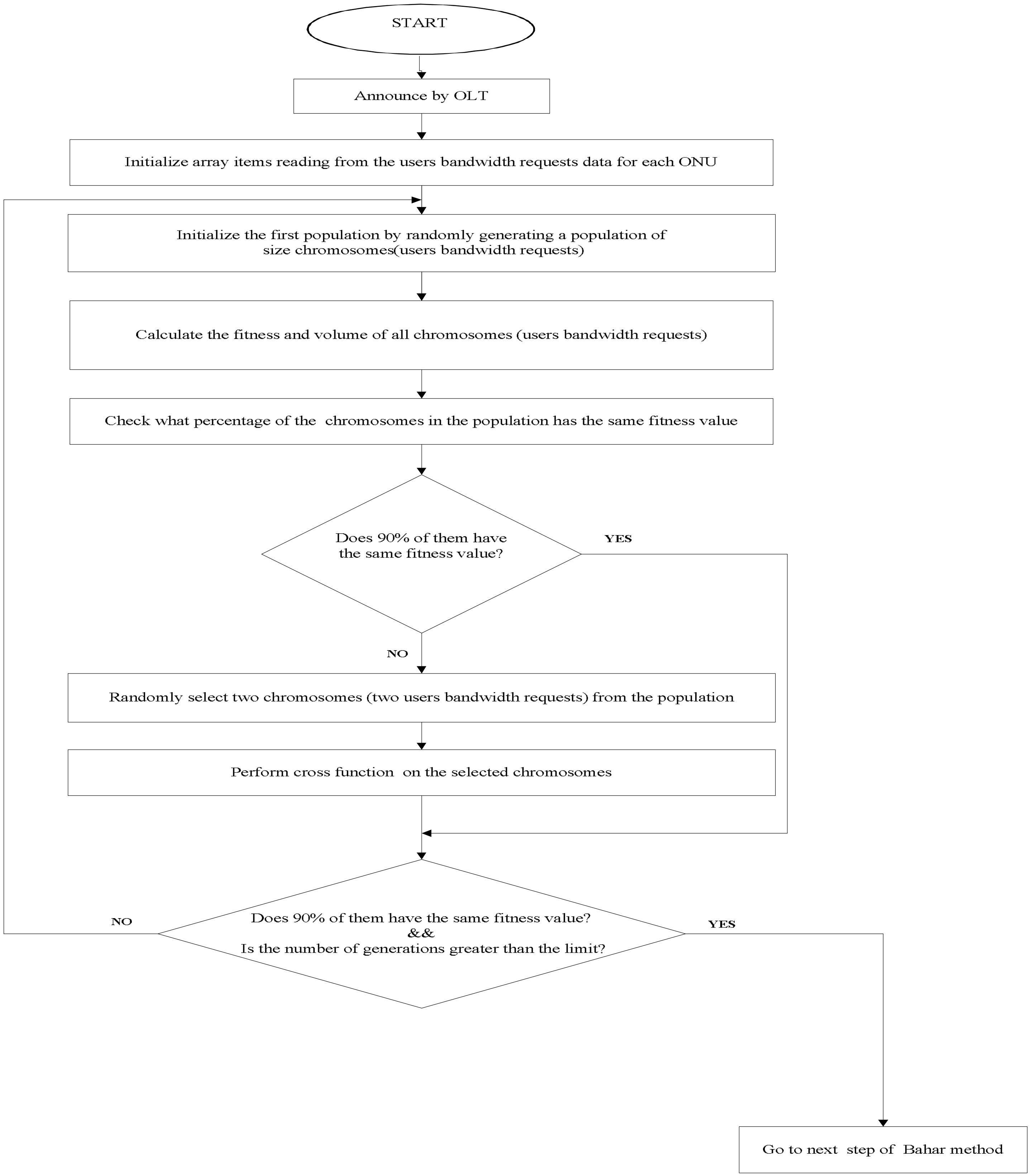

Figure 3. The overall optimizing process based on genetic algorithm.

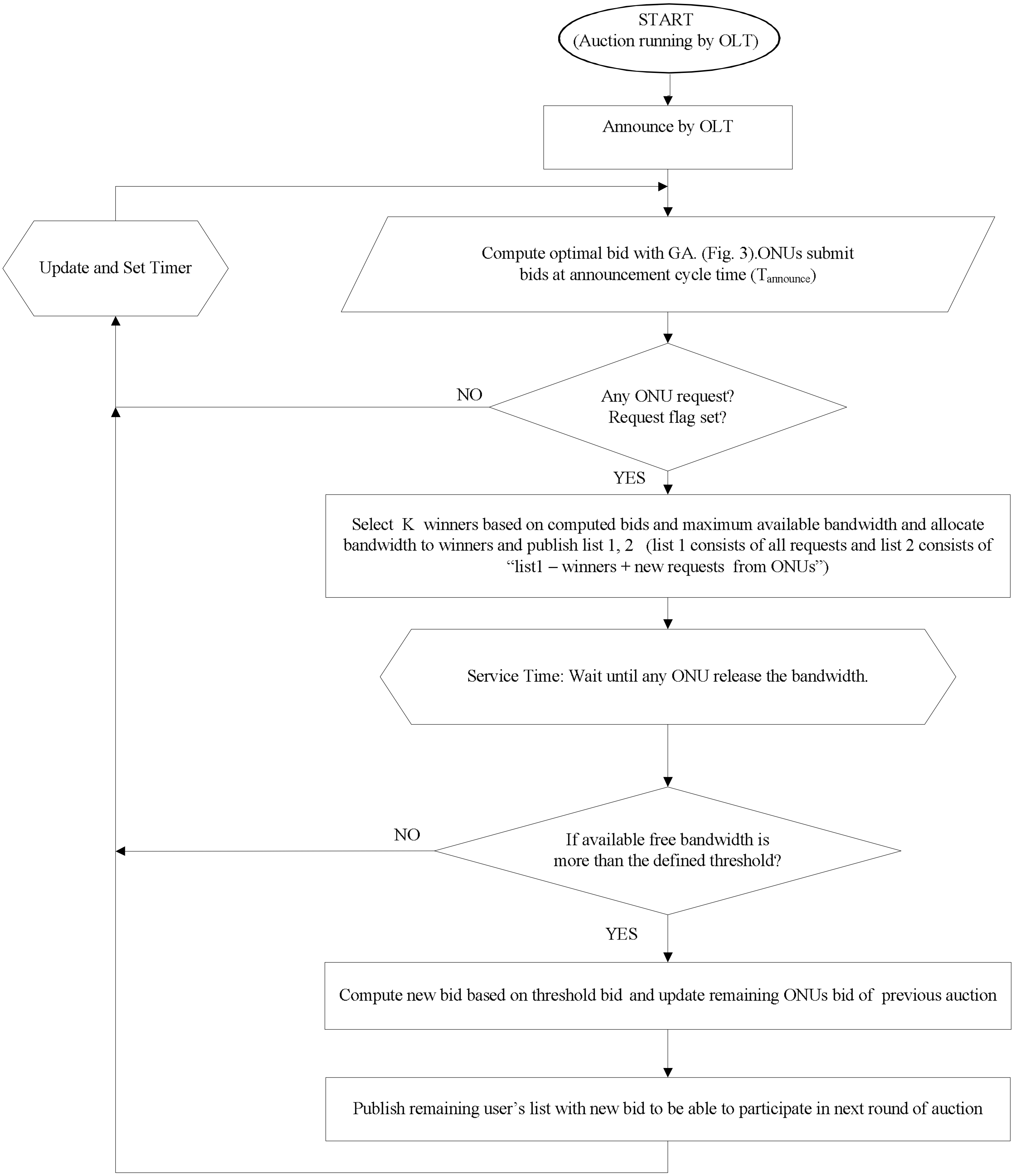

Figure 4. Schematic diagram of overall execution process in Bahar method.

```
Start of Bahar Method
:STEP I
    Run (Auction process by OLT)  /*Auction process running by OLT*/
    Send (announce signal from OLT to users via ONUs)
:STEP II
    If (ONUj has a request?)
        Then
          For j=1 to L Do
            Compute (bid based on GA)
          End For
        Else
          Send (Auction_out_msg)/*Send exit message from auction and wait until receive new request*/
    End If
:STEP III
    For i=1 to n Do
        Submit (Optimal bid ) /*Send parametric bid from users to OLT by ONU*/
    End For
:STEP IV
    For j=1 to n Do
      Bid_Computation (non busy userj)
    End For
    For L=1 to n Do
      Select (Winners) /*Select k winners by OLT based on first price sealed bid auction*/
    End For
    Publish list 1. /*list 1 consists of all users' requests*/
    Publish list 2. /*list 2 consists of (list 1) - (K winners)*/

:STEP V
    Until (ABW_OLT >  BW_THRESHOLD)  Do
        Wait(Service_Time)
    End Until
    For j=1 to m Do
        Bid_Computation (Users from list 2) /*New bid computation with threshold of  bid*/
        Generate list 3. /*list 3  consists of "remaining users from previous auction"+"new requests from users"*/
    End For
    Publish list 3. /*List 3 for next round of auction*/
:STEP VI
        Goto (STEP I)
End of Bahar Method
```

Figure 5. The Bahar-related pseudo code.

Table 2. Simulation parameters.

Parameter	Value
Number of ONUs	16
Amount of bit rate for `ONU to OLT` connection	5 to 57.5 Mbit/s
Two-way fiber delay	200 µs
Average `total auction` processing time	35 µs
Packet size	15000 Byte (30 Packets)
Ethernet overhead	38 Byte
Request message size	570 Bit
Upstream bandwidth	1 GBit/s
Maximum transition window	10 Packets
Guard time	5 µs
Max cycling time	2 ms
Buffer capacity	10 Mbyte
Traffic type	CBR (Poisson distribution)
IPACT condition	Fixed

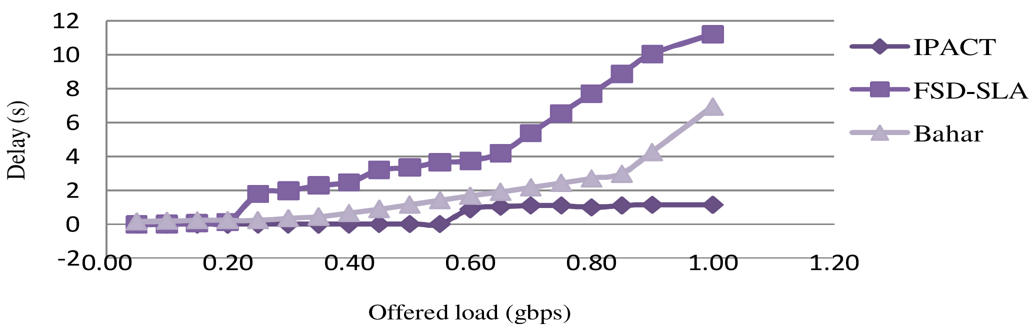

Figure 6. Comparison of average delay in Bahar, IPACT and FSD-SLA.

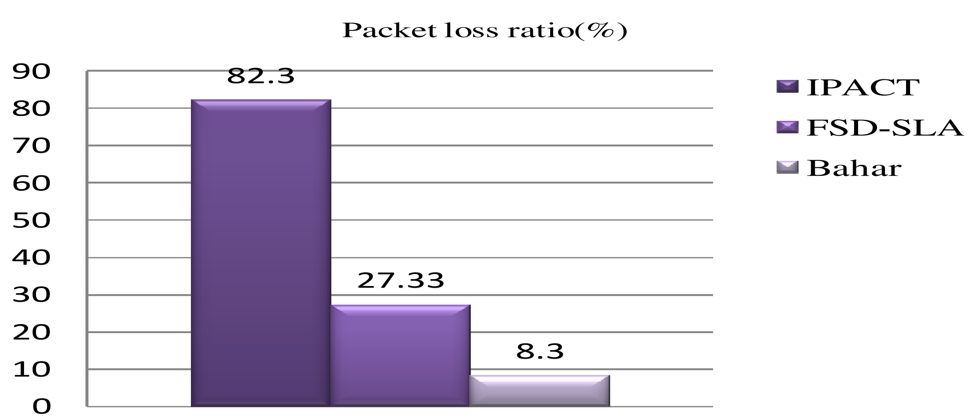

Figure 7. Comparison of packet loss ratio in Bahar, IPACT and FSD-SLA.

Figure 7 demonstrates the packet loss ratio in both IPACT and FSD-SLA methods compared with the the compared methods. As it can be observed, in IPACT, since a stable period of time is given to each ONU

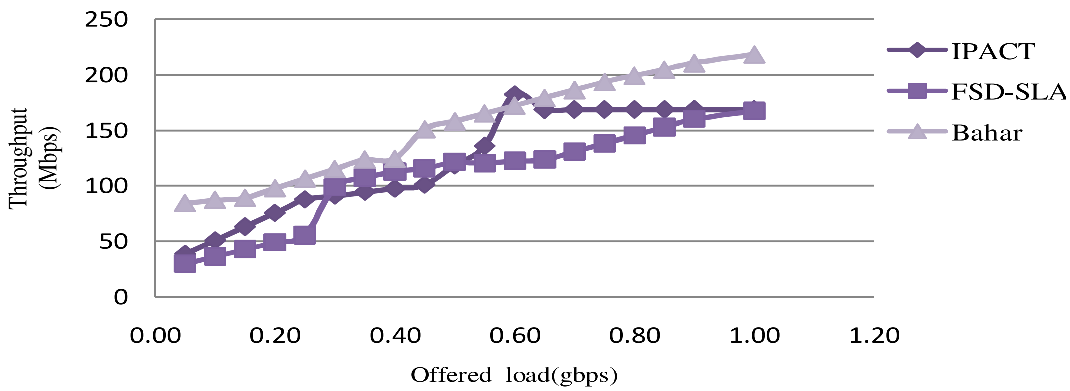

Figure 8. Comparison of throughput in Bahar, IPACT and FSD-SLA.

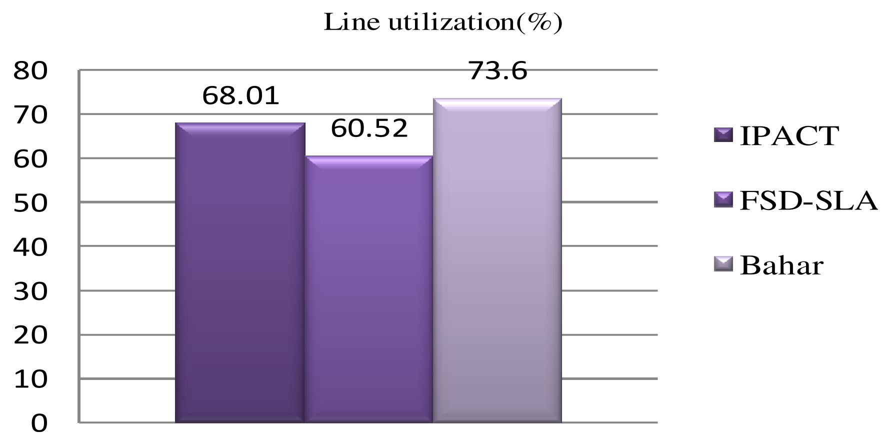

Figure 9. Comparison of line utilization in Bahar, IPACT and FSD-SLA.

according to its buffer size, the throughput rate shows a similar behavior against the increased traffic load. Therefore, in IPACT, the throughput rate is lower as a result of lack of variety between the allocated bandwidth to the ONUs. Although the condition of throughput in the FSD-SLA is better in comparison with IPACT, the allocation priority is defined according to the SLAs with lower size of traffic load. Therefore, the throughput rate is lower at the beginning and it will improve by increasing the traffic load and using the min-max solution. On the contrary, our proposed method demonstrates a better throughput rate because the bandwidth is allocated in a more robust manner based on the first price auction theory where the designed conditions allow all the users with requests to participate in the auction that is comprised of different steps. This observed improvement in the throughput rate is due to the bandwidth allocation to all the users through their ONUs which is shown to be a better approach in various types of traffics.

Finally, Figure 9 illustrates the percentage of line utilization. As it can be observed in the Figure, the proposed Bahar method confers a better line utilization because in this method, all the packets are submitted at different time points and, therefore, the line is utilized in the best possible way. Moreover, there is no time limitation for sending the packets, although line remains unused only at the beginning of the cycle to allow the ONUs to participate in the auction which will subsequently result in an increase in the submission delay. At any other time point, the line is fully utilized. Additionally, in this method by employing the genetic algorithm, a maximized condition is developed for the requests that enter the ONU's buffer which in turn will optimize the line utilization. In IPACT, the line utilization rate is lower despite the fact that each ONU is allocated an unlimited period of time in an alternative manner. In this method, the ONU transmits the data in the allocated period of time according to the data volume and, therefore, with lower data volumes the line utilization would also be reduced. The FSD-SLA method also allocates more priority to the smaller packets and, thus, it cannot have a proper utilization in comparison with other methods.

Conclusion

Regarding the importance of dynamic bandwidth allocation in next generation access networks based on EPON technology in this paper, we have proposed Bahar, a new hybrid GA and auction method for DBA management. In this new method, ONU is responsible for auction process management and bandwidth requests optimized by GA are being sent from ONU to OLT for participating in auction. Simulation results show that Bahar in comparison with IPACT and FSD-SLA experiences more delay but regarding other quality of service parameters such as packet loss ratio, line utilization, and throughput, it has better performance. In proposed method, bandwidth requests optimization by genetic algorithm causes more users to be able to receive needed service and thus improves the performance and efficiency of EPON network. The research potential in dynamic bandwidth allocation process in EPON networks will let us go further and open new research horizons by combining our method with heuristics methods such as cellular automata, neural networks etc., for our future research work. Moreover, it would be possible to apply this new DBA method in Wi-Fi, and WiMax environments and evaluate the performance.

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