ISSN: 2229-6948(ONLINE)
DOI: 10.21917/ijct.2022.0383

A NOVEL ALGORITHM FOR OPTIMAL WAVELENGTH AND BANDWIDTH ALLOTMENT IN ETHERNET PASSIVE OPTICAL NETWORK

Shyam Sunder Karma
Department of Electronics Engineering, Dhar Polytechnic College, India

Abstract

Ethernet Passive Optical Network (EPON) is that technology that can rule out the congestion in local loop at the level of user and local exchange. At present, there are many simulators to analyze the EPON but the simplest one is using MATLAB. In this paper, we have first analyzed the bit rate performance of WDM EPON and verified the result using NS2 software. After that in the presented WDM EPON model, we proposed an algorithm for wavelength and bandwidth allocation with full QoS support. The result indicates that traffic generation in both NS2 and MATLAB follow the same trend and the proposed algorithm optimizes the various throughput parameters. We found that the bit error rate varies from 14-22 Mbps, 14-55 Mbps, and 36-48 Mbps for EF, AF, and BE traffic respectively.

Keywords:

EPON, EF Traffic, AF Traffic, BE Traffic

1. INTRODUCTION

EPON networks are basically used to overcome congestion in network traffic [1]-[2]. An optical line terminal (OLT), an optical network unit (ONU), a splitter, and fiber make up the core components of the network. The majority of the connections between these units are made using a tree topology [4]. The signal is sent through fiber optics by OLT, which is provided by the service provider. Optical splitters are then used to divide the signal across two fiber. Then ONUs is provided on the user premises to physically convert the signals present in optical form into electric signals for electronic devices to work upon the network. There are generally three types of traffic models in EPON, namely assured forwarding (AF), expedited forwarding (EF), and best effort (BE). AF has a medium priority level for services that are not sensitive to delays but have a VBR. It usually carries MPEG-4 such as video streaming that has an adaptive rate, and it is also possible that some of the data packets might get lost when the high [4]. EF has the highest priority for delay sensitive services and is defined by constant bit rate (CBR). It can replace other AF and BE packets from their queues if there is space constraint in the queues. A new EF will be lost if there are all EF packets in the queues [4]. And the last one is BE is the lowest level priority, which also has a variable bit rate (VBR) [4].

A lot of work had been done in the field of EPON traffic models. In literature [1], they address about EPON, which says that it is the best network for optical data transfer as it eases the problem of congestion. The paper implements the idea of integrating in-service fault management mechanism at DDF in EPON. According to the literature [2,] EPON networks can achieve excellent energy efficiency by putting free ONU into hibernation mode. These researchers created a new energy-efficient DBA framework that reduces energy usage while ensuring network performance in both up and down directions. They offer a software-defined EPON architecture in the literature [3], which substitutes the hardware element with a reconfigurable DBA module. EPON, they claimed, can achieve lower traffic delays while maintaining strong QoS.

Although they have proposed efficient technique but there are some issues related. In Literature [1], the implementation of EPON in their model introduces overhauls, polling delay and bandwidth allocation that affects the quality of service (QoS) of their model, which they will try to observe in their future research. In literature [2] focuses on energy, efficiency in EPON networks and is a good model. The introduction of MAC control scheme in DBA framework lets ONUs to go into sleep mode thereby saving energy consumption. Two algorithms are applied i.e. one which calculates optimal results in terms of energy consumption while the other one reduces the computation and achieves good results. In Literature [3] talks about architecture model that proposes the idea of software, defined EPONs, which have low traffic delay and provide better traffic differentiation as compared to normal EPONs. Congestion is the very basic thing for which EPONs are applied but the cost is too high for EPONs construction. The software one can greatly reduce that cost of application.

In this paper we are going to deal with the QoS of WDM EPON traffic model and simulation results shows that we are getting better QoS parameters like throughput, packet loss packet delay etc.

Paper Organization: section 2 discusses about the literature reviewed for carrying out the work. Section 3 gives an overview of the WDM used in EPON. The architecture of FWPBA is shown in Section 4. Section 5 gives the proposed model and its analysis. Section 6 presented the results and related discussions and finally, the paper is concluded in Section 7.

2. LITERATURE REVIEW

EPON's services are divided into three categories, as mentioned above: EF, AF, and BE, based on Differentiated Service. The EF class has been allocated the top priority index, which may replace both AF and BE packets if buffer capacity is running out to hold EF packets. A new EF packet is erased only after the buffer is completely filled with packets (EF). The EF model is a real-time traffic simulation with stringent time limits. The traffic rate in EF is either deterministic or constant. It guarantees bandwidth and provides an end-to-end service with low latency, loss, and jitter. It is iterated for a packet length of 70 bytes using a CBR approach [5]. It is used to replicate a T1 carrier circuit over an IP network in the research field. Voice traffic is exemplified by this application. The EF flow chart is illustrated in Fig.1, where rate represents the EPON rate = 1Gbps, and random denotes random noise which should be included into the intended departure timings.

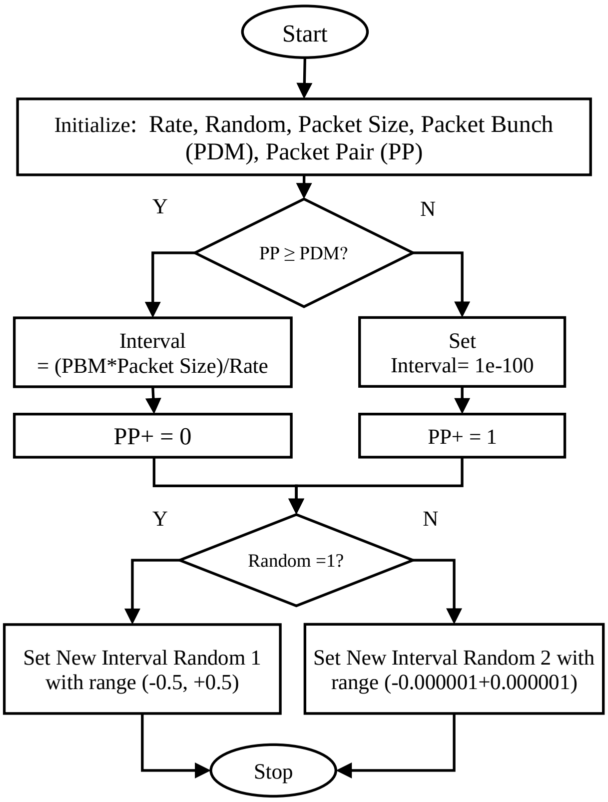

Fig.1. EF Flow Chart

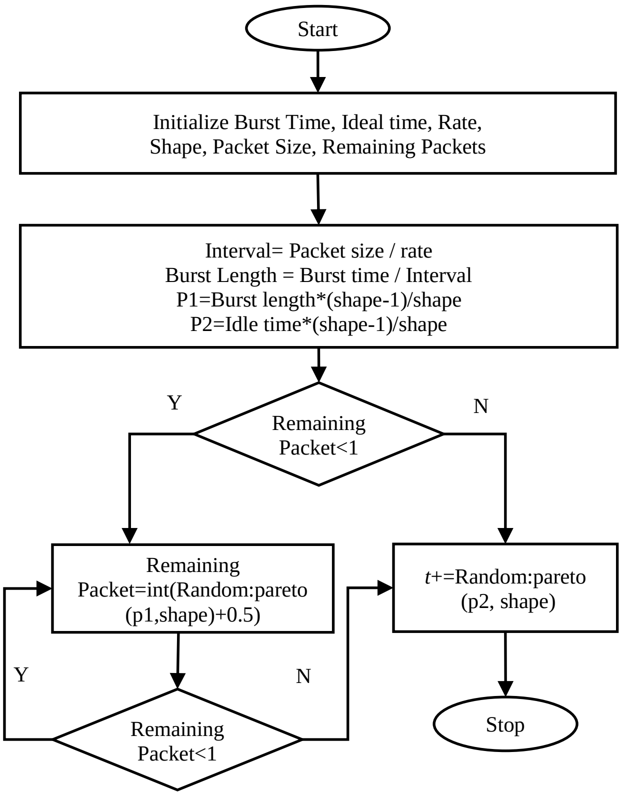

Fig.2. AF Flow Chart

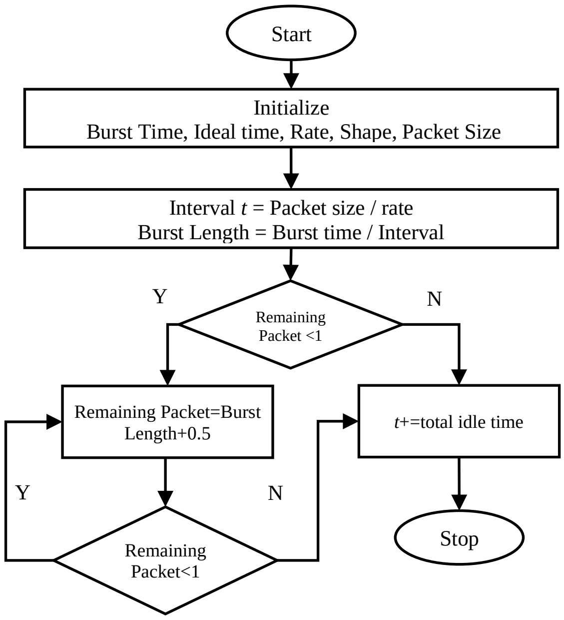

Fig.3. BE Flow Chart

Random 1 is in the range of (-0.5, 0.5), while random 2 is in the range of (-0.5, 0.5) and (-0.000001, 0.000001). The size of the packet is set to 70 bytes. Packet Pair has a packet bunch of 2 and CBR has a packet bunch of 1.

The rate of AF traffic is variable, and it is real-time traffic with strict timing restrictions. It transports adaptive data rate video streaming traffic, for example moving picture (MPEG-4). Because AF traffic is bustier, some packets are lost, which commonly happens when the buffer is filled of EF and AF packets. Despite the fact that AF traffic is unaffected by delays, it still requires guaranteed bandwidth. ON-OFF type source generator is generally used for traffic in AF. The interval for ON and OFF position is decided by using a distribution modelling (Pareto) with a burst (H=0:8). The Pareto distribution is most commonly used to represent internet traffic that is self-similar [6]. This distribution defined by a location and a shape parameter. The mean is finite for this distribution however the variance is infinite. The shape parameter is inspired by observations through real Ethernet traffic as suggested by Leland et al. [7], while the second parameter is a function of the mean and first parameters.

BE is a non-real-time variable bit rate traffic with no stringent timing restrictions. It's a long-distance, self-similar traffic with no guarantees of delivery or service delays. If higher priority queues are empty, only the BE queue is handled in ONU. A data transmission application is a good example of BE traffic.

BE also uses ON-OFF source generator traffic, with ON-OFF intervals defined by a different distribution (exponential). The distribution of the duration of packets produced while the ON state of AF and BE traffic matches the trimodal distribution [8]. The most common packet sizes in backbone and cable networks are 64,594 and 1518 bytes, respectively, for these three modes. In simulation, each of the three packets is created with a frequency of 63%, 10%, and 27.9% of the total packet sizes, respectively. These values are based on measurements of these packets taken at cable network head-ends [9].

The flowcharts for AF and BE traffic are illustrated in Figures 2 and 3. The 'idle time' and 'burst time' are both taken as 50 milliseconds. The 'Rate' parameter has been set to 1 Gbps. The ON and OFF intervals, which are set to 1.4 and 1.2, and are referred to as the 'shape.' The 'Packet size' option is set to trimodal. The Fig.2 shows how we defined some of the parameters and determined the interval, burst length, and p1 and p2 values. Then, if the remaining packet is 0, a condition is added to compute the number of the following packet until we get at least 1. We may calculate the idle time when the remaining packet is at least 1. We define various parameters in Fig.3 and determine the inter-packet interval and average number of packets during the burst. Then a condition is set to see if the remaining packet is zero, and if it is, the number of subsequent packets is computed until we have at least one. Once there is at least one packet left, we can calculate the idle time [10].

3. WDM IN EPON

EPON provides best solution to bandwidth scarcity problem in the access network but EPON belongs to a single-channel system in which the advantage of using optical fiber is not 100% utilized. Bandwidth that is allocated to EPON proves to be insufficient to fulfill the end user requirement. We can logically insert the concept of WDM in the EPON. However, many applications that demand huge bandwidth require QoS in WDM networks. In this paper, a model had been presented namely Fixed Wavelength Priority Bandwidth Allocation (FWPBA) and the result shows the effectiveness of presented model [11].

4. ARCHITECTURE OF FWPBA MODEL

In conventional EPON architecture, end-users are connected to OLT through ONU. But the proposed model is different from the conventional as in conventional EPON support only two wavelength each for upstream and downstream transmission whereas in the proposed model concept of four wavelength is introduced namely λ_0, λ_1, λ_2 and λ_3. The QoS execution in the model is achieved through support for DiffServ architecture where traffic is categorized into three namely EF, AF and BE. In the proposed model λ_1, λ_2 and $\lambda_3$wavelength is allocated for each EF, AF and BE respectively whereas λ_0 is for the transmission of synchronization and control signals. All the four wavelength is selected for C band. Normally fixed –tuned transceiver is used for simultaneous transfer of traffic through different wavelengths in OLT and ONU units. Communication between OLT and ONU is governed by MPCP (multi-point control protocol). A fixed path is used between the types of traffic and the wavelength in the proposed model that is known as OLT, which means no allocation of wavelength, is required [12].

Now the control message (REPORT message) that is generated by ONU is sent to OLT but this process requires certain amount of bandwidth uniquely for each of the wavelength. DBA (Dynamic bandwidth allocation) begins assigning bandwidth to each traffic class in all ONUs as soon as the control message is received from all of them. Every ONU communicates traffic constantly across three distinct wavelengths throughout each complete cycle and maintains all three wavelengths until the transmission procedure on each of them is done. When all three traffic classes have been transmitted through the uplink, ONU leaves the wavelengths open and the next cycle of traffic transmission may begin, as illustrated in Fig.4.

A waiting time $t^{waiting}$ is introduced in the proposed model for wavelength that has to transmit smaller amount of data traffic as they have to wait till the maximum occupied wavelength complete the transmission. Due to the continuous development in the field of multimedia applications, we can conclude that AF is the most common traffic class. There is no waiting time in the AF class. The DBA module distributes the same amount of available uplink bandwidth to each ONU depending on the maximum bandwidth requested, which means it creates a control GRANT data through the authorized amount of bandwidth for each traffic class. This process although simplify the procedure but added inefficiency that there will be unused bandwidth in the other two less occupied wavelength [13].

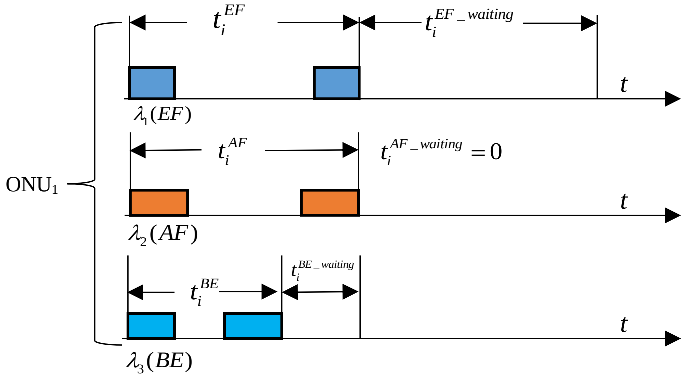

Fig.4. Uplink ONU transmission

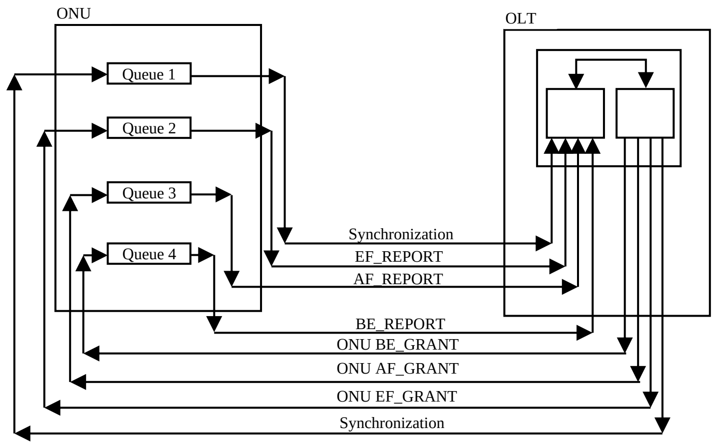

Fig.5. OLT-ONU Transmission

Table.1. Polling

OLT - Polling
$\lambda_1(EF)$ ONU_i $=ONU_j$
$\lambda_2(AF)$ ONU_i $=ONU_j$
$\lambda_3(BF)$ ONU_i $=ONU_j$

The model's bandwidth allocation mechanism is based on the IPACT algorithm, which grants each ONU the requested amount of bandwidth, which cannot exceed the queue's capacity. As a result, we don't assume that the whole network is evenly distributed across all ONUs or that ONUs is equally weighted, and we modify the method to add a weighted component for each ONU.

The total uplink bandwidth for each wavelength over a complete cycle is defined as:

$$W^{total} = R * \left(T_{cycle}^{\max} - T_g\right) \quad (1)$$

where R is known as rate of each wavelength, T_g is known as guard interval and $T_{cycle}^{\max}$ is known as maximum transmission cycle time (MTCT). The allocated bandwidth for *EF*, *AF* and *BE* can be expressed as:

$$W_i^{ONU_{requested}} = \max\left\{W_i^{EF_{requested}}, W_i^{AF_{requested}}, W_i^{BE_{requested}}\right\} \quad (2)$$

$$W_{total}^{ONU_{requested}} = \sum_{i \in N} W_i^{ONU_{requested}} \quad (3)$$

$$w_i = \frac{W_i^{ONU_{requested}}}{W_{total}^{ONU_{requested}}} \quad (4)$$

$$W_i^{ONU_{allocated}} = \begin{cases} w_i * W^{total} & W_i^{ONU_{requested}} < W^{queue} \\ W^{queue} & W_i^{ONU_{requested}} \geq W^{queue} \end{cases} \quad (5)$$

$$W_i^{ONU_{allocated}} = W_i^{EF_{allocated}} = W_i^{AF_{allocated}} = W_i^{BE_{allocated}} \quad (6)$$

where N is the no. of ONU used in the work.

w_i=Weight assigned to ONU_i where $\sum_{i=1}^{N} w_i = 1$;

$W_i^{ONU_{requested}}$ = Requested bandwidth of ONU_i.

$W_{total}^{ONU_{requested}}$ = Requested bandwidth for all ONUs in the system;

$W_i^{EF_{requested}}, W_i^{AF_{requested}}, W_i^{BE_{requested}}$ are the requested bandwidth for *EF*, *AF* and *BE* traffic class.

$W_i^{ONU_{allocated}}$ = Bandwidth allocated for ONU_i;

$W_i^{EF_{allocated}}, W_i^{AF_{allocated}}, W_i^{BE_{allocated}}$ are the allocated bandwidth for EF, AF and BE traffic class.

W^{queue} = Maximum defined length of ONU's queue.

5. PROPOSED MODEL ANALYSIS

As discussed earlier about delay component $t^{waiting}$, the delay in the ONU_i can be expressed as:

$$t_i^{ONU} = \max\left\{t_i^{EF}, t_i^{AF}, t_i^{BE}\right\} \quad (7)$$

$$t_i^{EF_{waiting}} = t_i^{ONU} - t_i^{EF} \quad (8)$$

$$t_i^{AF_{waiting}} = t_i^{ONU} - t_i^{AF} \quad (9)$$

$$t_i^{BE_{waiting}} = t_i^{ONU} - t_i^{BE} \quad (10)$$

where, t_i^{ONU} =Processing time in ONU_i. $t_i^{EF}, t_i^{AF}, t_i^{BE}$ is the transmission time of EF, AF and BE traffic respectively in ONU_i. From Eq.(7)-Eq.(10) we can draw a conclusion that there will be no waiting time for most loaded wavelength so that's why AF traffic class have no delay time and waiting time is more dominant in EF class and lesser in BE class.

The allotted bandwidth is not fully utilized since the bandwidth allocation algorithm allocates the same bandwidth to all traffic classes based on the maximum allowed bandwidth. Each traffic's unused bandwidth is determined by:

$$W_i^{EF_{unused}} = W_i^{ONU_{allocated}} - W_i^{EF_{requested}} \quad (11)$$

$$W_i^{AF_{unused}} = W_i^{ONU_{allocated}} - W_i^{AF_{requested}} \quad (12)$$

$$W_i^{BE_{unused}} = W_i^{ONU_{allocated}} - W_i^{BE_{requested}} \quad (13)$$

$$W_i^{OBU_{unused}} = W_i^{EF_{unused}} + W_i^{AF_{unused}} + W_i^{BE_{unused}} \quad (14)$$

Here $W_i^{EF_{unused}}, W_i^{AF_{unused}}, W_i^{BE_{unused}}$ represent the unused portion of bandwidth allocated for EF, AF and BE traffic class in ONU_i, respectively.

$W_i^{OBU_{unused}}$ represent unused bandwidth allocated for ONU_i. The mathematical calculation of waiting time and unused bandwidth done previously are used to evaluate the efficiency and numerical representation of FWPBA model efficiency.

6. RESULT AND DISCUSSIONS

For observing the recital study of the traffic models, we compared the result obtained via NS-2 to the result obtained through MATLAB. Three results each for the EF traffic, AF traffic and BE traffic are obtained as illustrated in Fig.6-Fig.8 respectively. We have studied the traffic in terms of bit rate (in Mbps) against the time.

The EF traffic is generated using CBR in Fig.6, and the bit rate is deterministic and continuous, ranging from 14-22 Mbps. The Fig.7 depicts AF traffic created by Pareto, which ranges in speed from 14 to 55 Mbps. We can see from the graph that AF traffic is bustier, with a more changeable data rate or bit rate. Fig.8 depicts BE traffic generated using exponential, with a bit rate ranging from 36 to 48 Mbps and increasing and decreasing at a constant rate.

The collected findings show that traffic created using MATLAB and NS-2 follow the same trend, indicating that the MATLAB results are accurately mapping to the NS-2. As a result, our MATLAB traffic generator may be used to replicate different network research. The same WDM EPON network was then assessed for various QoS parameters. The following are the simulation parameters (Table.2)

Table. 2. Simulation Parameters

Parameter	Value
N	16
Rate (R)	1 Gbps
Idle time	50 ms
T_g	1 µs
$T_{cycle}^{\max}$	2 ms
Traffic load	100 Mbps
W^{queue}	1 Mbps
Packet size	70 Bytes

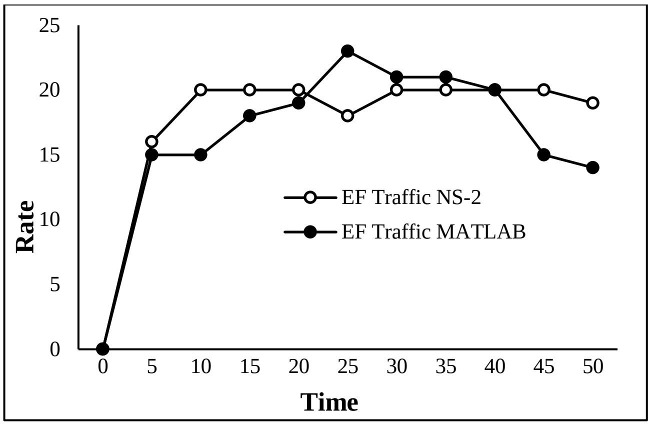

Fig.6. Analysis of Bit Rate vs Time for EF Traffic

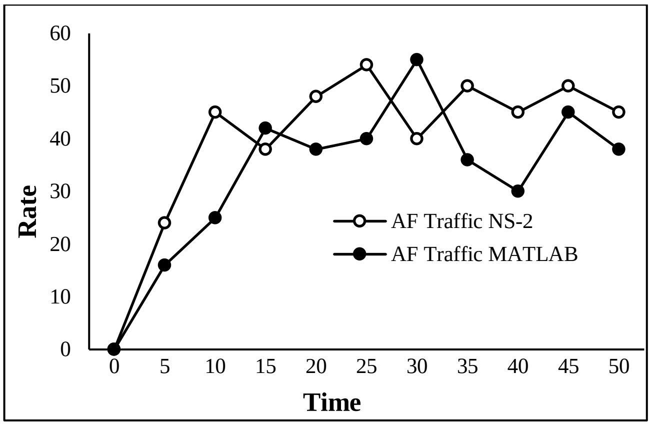

Fig.7. Analysis of Bit Rate vs Time for AF Traffic

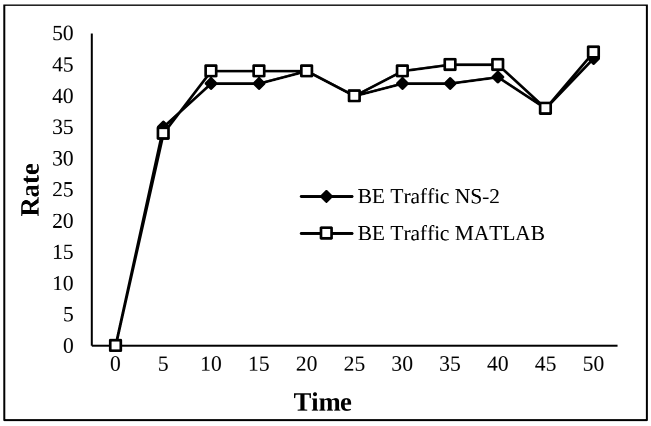

Fig.8. Analysis of Bit Rate vs Time for BE Traffic

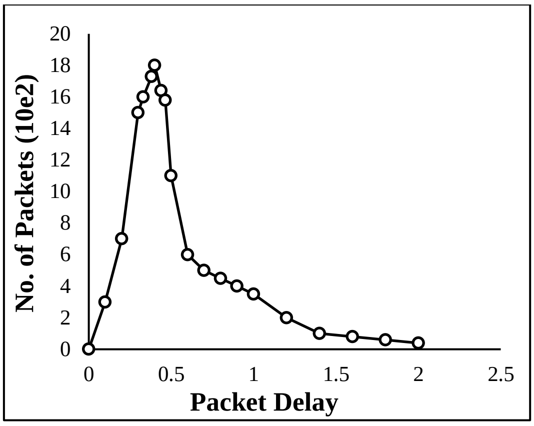

Fig.9. Jitter

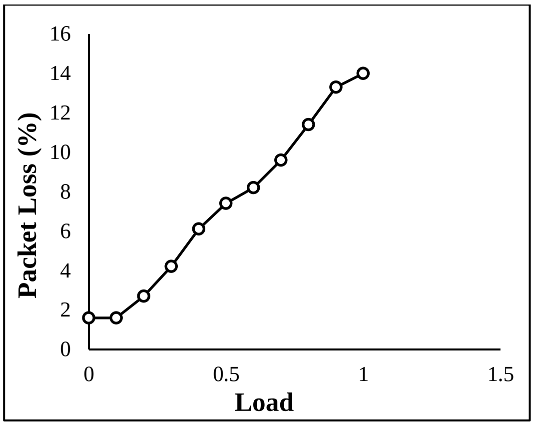

Fig.10. Packet Loss

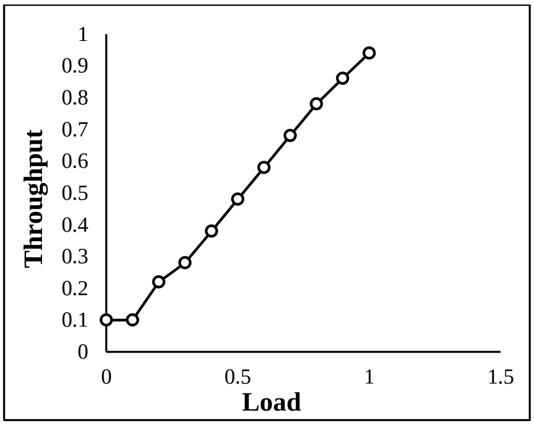

Fig.11. Throughput

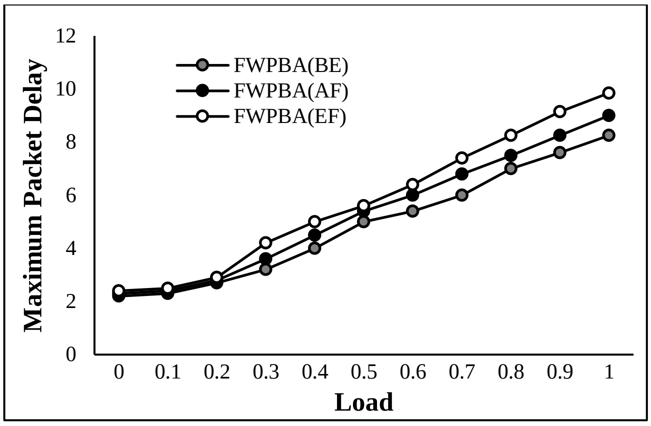

Fig.12. Maximum Packet Delay

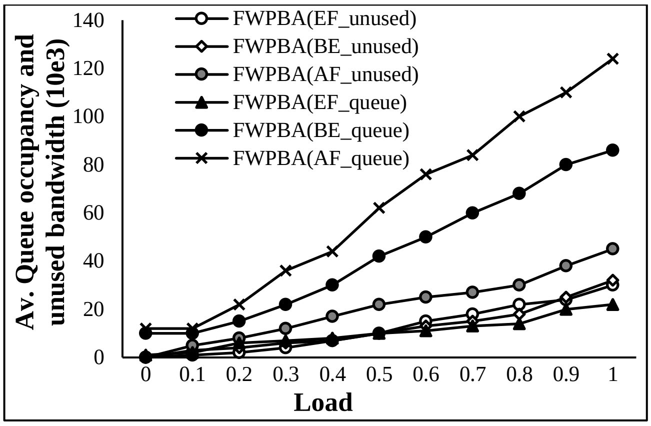

Fig.13. Average Queue Occupancy and Unused Bandwidth

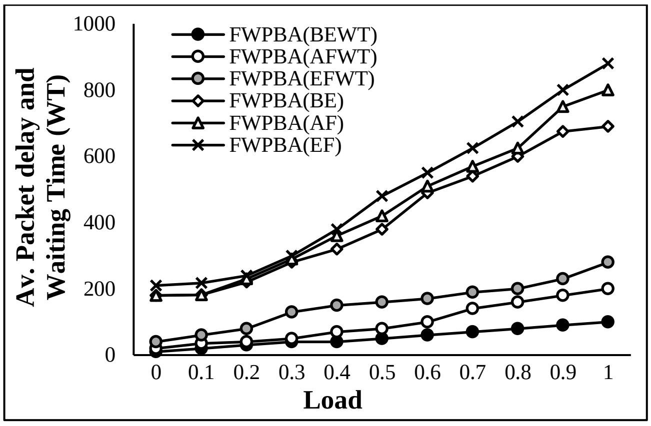

Fig.14. Average Packet Delay and Waiting Time

RRT is a uniformly distributed random variable U [50s, 200s] that corresponds to ONU distances of 15-30 km from OLT. Because EF traffic is narrowband, it is assumed that EF takes up 15% of the available bandwidth, AF takes up 50%, and BE takes up 35% of the available bandwidth.

The probability density function (pdf) of EF traffic class delay for a full loading condition is shown in Fig.9. The jitter is the difference in delay between two successive EF packets from the same ONU. The tail dispersion in the EF traffic class is up to 1.6ms, demonstrating the efficacy of the proposed approach in providing a certain degree of QoS to traffic with higher priority despite the existence of waiting time. Fig.10 displays the percentage of lost packets in the suggested model, which shows that as the load increases, the packet loss increases linearly, which is also too small. Fig.11 depicts the system's throughput, which reaches 87-95 percent under heavy load. Fig.12 illustrates that the EF traffic class has the longest delay in the proposed model since it is the least represented of the three traffic classes. Fig.13 indicates that the queue in which AF packets are placed is the busiest, compared to the other two traffic classes, which are dependent on the system's traffic distribution. We've also displayed the amount of idle or unutilized bandwidth that is allotted to each traffic class in the same diagram, which, according to the mathematical model, is dominated by EF. For each of the three traffic classes, Fig.14 illustrates a comparison of average packet delay and waiting time. The findings support the theoretical model analysis discussed in the preceding section.

7. CONCLUSIONS

In this paper, we have studied three traffic models of EPON, namely EF, AF, and BE, based on Differentiated Service (DiffServ). We have used MATLAB and NS2 software to simulate the bit rate performance of WDM EPON for all three traffic models. We observed that for all the models, the simulation results of MATLAB and NS2 follow the same trend. Further, the bit error rate in the AF model is more than the BE and EF model.

REFERENCES

[1] A.T. Liem, I.S. Hwang, A. Nikoukar and M.S. Ab-Rahman, "Distribution Drop Fiber In-Service Fault Management in Enhanced EPON System", *Optical Switching and Networking*, Vol. 17, pp. 52-63, 2015.

[2] C. Li, W. Guo, W. Hu and M. Xia, "Energy-Efficient Dynamic Bandwidth Allocation for EPON Networks with Sleep Mode Onus", *Optical Switching and Networking*, Vol. 15, pp. 121-133, 2015.

[3] C. Li, W. Guo, W. Wang, W. Hu and M. Xia, "Programmable Bandwidth Management in Software-Defined EPON Architecture", *Optics Communications*, Vol. 370, pp. 43-48, 2016.

[4] N.A.M. Radzi, N.M. Din, S.K. Sadon, M.H. Al-Mansoori and H.Z. Abidin, "Traffic Modelling for Ethernet Passive Optical Network using MATLAB", *Proceedings of IEEE Malaysia International Conference on Communications*, pp. 62-65, 2013.

[5] C. Sue and W. Sung, "Fitting Scheduling Timing–Elastic Weighted Granting (FST–EWG): An EPON DBA Algorithm", *Journal of Optical Communications and Networking*, Vol. 4, No. 6, pp. 468-479, 2012.

[6] V. Paxson and S. Floyd, "Wide Area Traffic: The Failure of Poisson Modeling", *IEEE/ACM Transactions on Networking*, Vol. 3, No. 3, pp. 226-244, 1995.

[7] W. Leland, M. Taqqu, W. Willinger and D. Wilson, "On the Self-Similar Nature of Ethernet Traffic (Extended Version)", *IEEE/ACM Transactions on Networking*, Vol. 2, No. 1, pp. 1-15, 1994.

[8] G. Kramer, B. Mukherjee and G. Pesavento, "Interleaved Polling with Adaptive Cycle Time (IPACT): A Dynamic Bandwidth Distribution Scheme in an Optical Access

Network", *Photonic Network Communications*, Vol. 4, No.1, pp. 89-107, 2002.

[9] M.H. Ali, "A Priority-Based Deficit Weighted Round Robin Queuing for Dynamic Bandwidth Allocation Algorithm in Gigabit Passive Optical Network", *Proceedings of International Conference on Intelligent Energy Management Technologies*, pp. 65-71, 2021.

[10] B.R. Rayapati and N. Rangaswamy, "Bridging Electrical Power and Entropy of ONU in EPON", *Optoelectronics Letters*, Vol. 17, pp. 102-106, 2021.

[11] E.E. Elsayed, "Modeling and Performance Enhancement of Hybrid Fiber Network-PON/DPPM-DWDM-FSO Communications under Atmospheric Turbulence Conditions", *Photonics*, Vol. 8, pp. 1-43, 2021.

[12] P. Parolari, A. Gatto, M. Rapisarda, F. Lipparini, C. Neumeyr, M.S. Moreolo and P. Boffi, "Transmitter and receiver solutions for VCSEL exploitation in access and metro networks", *Metro and Data Center Optical Networks and Short-Reach Links IV*, Vol. 11712, pp. 1-13, 2021.

[13] A. Singh, M. Sharma, R. Kumar, S.P. Singh and J.R. Madhesiya, "Modelling and Analysis of Polarization Noise in Vertical Cavity Surface Emitting LASERs", *Multiscale and Multidisciplinary Modeling, Experiments and Design*, Vol. 2, pp. 151-157, 2019.