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Study and Emulation of 10G-EPON Access Network

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Abstract

Background/Objectives: Significant amount of research and development has been made in the field of core network and it operates in hundreds Gigabits per second (Gbps) speed currently. But on seeing the growth in bandwidth demand in the access network which is exploding day by day, the only promising solution is to upgrade the access network. So it is essential to have an efficient access network that can operate at high functional speeds to support differentiated services. **Methods:** This paper proposes a novel TD_Optimum for improve the network performance and compares it with a DBA_GATE algorithm. The algorithm is employed by emulating an access network with the use of two 10G transceivers for 10G-EPON. The algorithm is tested for Triple Play services that include emulated voice, video and data packets. **Findings:** The algorithm is found to maintain a better tradeoff between throughput and delay as well as QOS, than the existing DBA_GATE algorithm. **Application/Improvement:** The 10G-EPON is a great boom in the optical technology and provides a great support to Video on Demand, High Definition TV (HDTV), Online gaming, Telemedicine, Video Conferencing. The ardent task of this research is to implement in this algorithm using 40Gbps supported NIC cards (next generation optical networks) and measure the variation of throughput and the average delay with an efficient network monitoring tool. The purpose is to provide huge bandwidth for packet transfer without dropping of voice, video and data packets. The emulation of this scenario in future can be switch over to Labview or Opnet software for further improvements.

Keywords: Average Delay, Gate, NIC Cards, OLT, ONU, Offer Load, Report, Throughput

1. Introduction

The current data communication networks especially the Internet is a result of unprecedented technical changes that has been taken place in the last few years. Whether it is in the case of communication or business, all the cases have seen significant changes evolving in the last few years. The conventional objective of having internet connectivity has been changed dramatically from just having a provision of data transfer between universities or organizations to real time technologies and real time transactions, including Video Conferencing, High Definition Video On Demand, Telemedicine, Voice over IP, Uploading and Downloading jumbo files. All these applications or services, demand crucial resources, which is bandwidth. Whereas, the earlier peer to peer communication traffic is expected to decrease in next few years. The audio and video communication is expected to have an annual growth of 65%[1,2]. Real broadband access to the users, which supports hundred megabits of data, is relying on optical transport. In the current scenarios many of the users are connected by twisted pair coppercable to the central offices like BSNL, MTNL, TATA etc. These wires have their own shortcomings. The only way to overcome these problems is to replace fiber in place of traditional copper cables. Most of the intense bandwidth applications have pushed the service providers to look for different alternatives. But in most of the cases the solution to the issues is, either increase in CAPEX or OPEX or at times even both. Thus to keep pace with the need of the hour, solutions are being studied, to come up with technologies either in existence or enhanced versions, that keep the expenses under control and also provide a real broadband experience to the users. The simplest approach is Point-to-Point network such as SONET, SDH and Ethernet.

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These approaches are being replaced with passive optical network concepts. Even though the network architecture is simpler and less cluttered, the control schemes deployed are more complex. In late 1990's, immense traffic growth has been observed, (more than 95% per year) for all kinds of traffic. To augment it, there are hundred thousand devices that are being linked to the internet every single day, which again increases the chance of bottlenecks at the edges of the access networks. Other than the enterprises network which are operating at 10Gbps, we have also an increasing number of home-based devices that share a single internet connection. The latest development in the area of optical communication augmented the quantum of bandwidth available to access networks or last mile network. The last hop between the internet service provider's backbone and the users is referred as Last Mile network. Due to the reduced costs users are spending more time in using internet. Moreover, they are also using bandwidth intense applications and exchanging huge files. A similar trend is being observed in the field of mobile domain where the technology is providing quicker and quicker internet connections over phones. So the complete process results in increase in the traffic in the access networks. The subsequent plots demonstrate the progress that has taken place in the number of internet users worldwide over the last 20 years[3,4].

Since the last mile network has remained concealed and unattended, some of the organizations involved in data communication had renamed it as the First Mile network, to signify the prominence and its priority. Some of them denote as the First mile. Thus both the words First Mile and Last Mile are used interchangeably. The First Mile was also denoted as subscriber access network. The core of the network has always been growing but the access network has remained stagnant. The up gradation of core network has enabled the network to have more capacity of data being transported. As a consequence, the access network technologies have only advanced slightly over the years. DSL's and cable technologies were also deployed but not able to meet the pleas that have been increasing continuously. Highly intense bandwidth applications require improved upload to download ratio which has been missing in the conventional technologies. Symmetric upload and download speeds are highly essential. The access network has been sensitive to costs and the geographical region of coverage. Network service providers and operators will have to make a trade-off between the CAPEX, OPEX and geographical region of coverage. DSL, ADSL, CATV, Enhanced HFC has been for considered and arrayed at various levels and have never able to provide long term solutions. Service such as Video on Demand, Interactive Gaming, two ways Video Conferencing, and Triple Play are all intense bandwidth applications. Having all these restrictions, PON was chosen as best contender that can provide high bandwidth with reasonable costs. This implies that the optical fiber technology is moving deeper into the First Mile to improve the bottlenecks[5,6].

2. Active Optical Network

Active Optical Networks have a router or a simple switch to route the traffic. These devices are electrically powered and also may require a backup power to avoid failures. The equipment that does the job of signal allotment is called an Optical Distribution Network. In an ODN the incoming optical signals are converted into electrical and then back to optical signal. Buffers are provided to avoid the data loss during conversion. This is the one reason for ODN being very expensive. Ethernet is widely used as a popular means of delivering the data to the First Mile. No other technology is popular as Ethernet. Owing to these attributes the Ethernet was used to connect small enterprises, educational institutions, and residential homes in the first mile. This was realized by incorporating Ethernet switches and the access network into single Ethernet network. The functionality of switches was to provide L2 – L3 operations such as switching, routing etc. With rapid developments, Metro Ethernet also gained admiration and nowadays the CAT 6 Ethernet cable can handle data rates up to 10Gbps[7,8]. AON needs electrical power for the Ethernet switch and for optical distribution in the network we need to do the electrical- optical- electrical conversion. This gives rise to propagation delays. So just by deploying a PON we can get out of these problems and make our access network more electrically efficient.

3. Passive Optical Network

The elementary principle of PON is to share the Optical Line Terminal (OLT) and the feeder fiber over as many Optical Network Units (ONUs) as practical. In comparison to the point-to-point architectures the PON consumes minimum resources. The amount of fiber required and the amount of equipment to be installed are much lesser than the other configurations. In the true sense, PON is a fiber- optic access network. A central office accommodates the OLT. An OLT forms the service provider's endpoint of a PON. Multiple OLT of the same central office can be connected with a switch or a cross-connect to the core network on one side and to the access network at the other. The interface between the OLT and the core network is called service network interfaces. An OLT can support 128 ONUs. The ONU is located either at the nearby customer premises or at the curb. Each ONU further can furnish to multiple number of end users. The section between the OLT and the ONU is referred as PON. The edge between the client node and the ONU is called as the end user interface. Signals broadcasting from OLT to ONU are called as downstream signals, while the signals from the opposite direction are called as upstream signals. Downstream signals are broadcasted to all the end nodes linked to the ONU. Since the mode of transmission is broadcast in nature, there is a high vulnerability of data being snuffled and meddled with. To prevent signal from eavesdropping, the signals must be encrypted. Upstream signals are multiplexed using TDMA method or using Wavelength Division Multiplexing. The idea of WDM exploits the nature of PON having an optical splitter which has low back scattering and internal reflections. In such instance even a single fiber can be used for downstream and upstream transmission. Therefore in the upstream transmission PON functions as point -to-point connection whereas downstream transmission PON roles as point- to multi-point connection. PON are classified into various types and compared in the Table 1.

In early 90, passive optical network was introduced as the path breaking technology for the telecommunication industry. The fiber was considered as replacement for hybrid coax as well as the traditional copper connections that were sluggish. The core network was definitely shifting towards the fiber optics technology. The mid 90's saw the deployment of fiber in Last Mile i.e. access network also. In the year 1995 the Full Service Access Network (FSAN) consortium was founded[10,11]. This consortium intended in developing the standards of the PON. This was a consortium consisting of telecom service providers from all around the world. They aimed in making relatively new optical technology feasible for all and also having a set of standards. The DSL and PON were the key agenda. Initially Time Division Multiplexing was the choice for which many standards and specification were developed, but later the FSAN consortium came into an agreement on encapsulating the ATM data. This steered to the development of first Passive Optical Network standard and became ITU-T G.938.1 also recognized as ATM PON. USA too experimented with PON in Bell South testing center, to find whether it was ready for global installation. The test enabled the service providers to come to a conclusion that PON is the future. But still PON had lost the battle due to various reasons. The CAPEX was very high due to expensive optics. There was no demand for higher bandwidth. The internet service providers were keen to work on XDSL and for other alternatives. XDSL was also very limited by speed but there weren't any bandwidth intense application and also they were economical to deploy. In APON connections between the ONU and the OLT are connection oriented and are established by ATM virtual circuits. Related to ATM, virtual path identifiers (VPI) are used to identify the virtual circuits with virtual circuit identifiers (VCI) in the ATM cells[12-14]. It is VCI/VPI pairs that pinpoint the ATM connections. The wavelength assigned per users as per ITU-T G.983.3 is as follows. The 1260 nm to 1360 nm is assigned for APON upstream data, 1480 nm to 1500 nm for APON downstream data and 1550 nm to 1560 nm is assigned for video sharing. Two more bands 1360 nm to 1480 nm and

Table 1. Comparison between various PON architecture

Features	APON/BPON	GPON	EPON	10G-EPON
Defined by	FSAN and ITU-T G.983	ITU-T G.984	IEEE 802.3ah	IEEE 802.3av
Upstream Rate	155 Mbps	622 Mbps	1 Gbps /1.25 Mbps	1 Gbps/10 Gbps
Downstream Rate	155 Mbps/622 Mbps	1 Gbps/1.25 Gbps	1 Gbps/1.25 Gbps	10 Gbps
Payload Encapsulation	ATM Payload	GPON Encapsulation Payload	Ethernet Payload	Ethernet Payload
Control Unit	T-CONT	T-CONT	Logical Link Identifier	Logical Link Identifier
Link Speed	Average Speed	Faster than EPON	Slower than GPON	Fast Speed
Splitting Ratio	1:32	1:64	1:32	1:32/1:64

1560 nm and beyond were earmarked for future studies. BPON supports a wide range of narrowband and broadband services like POTS, ISDN, Data, CATV, VOD etc[15]. The 21st century saw APON going forward into BPON. ITU approved FSAN and new standards that were developed. The downstream data was specified to be 622 Mbps with upstream of 155 Mbps or aggregate of 622 Mbps. The distance between the OLT to ONU was about 20 Km with a maximum of 32 ONU's connecting to single OLT[16,17]. Wavelength Division Duplex was specified with 1300 nm constituting the upstream mode of traffic, 1490 nm with downstream mode of traffic and 1550 nm for TV overlay. Apart from Bell South and NTT, Verizon and SBC also started showing interest in BPON. But neither APON nor BPON was able to deliver the expectation of becoming the universal network protocol. It was possible for only Ethernet and IP to fulfill the expectations for becoming universal and also could cater to increase the bandwidth demands. Thus PON standards were made to cater the gigabits demand. Thus the ITU-T created and standardized the G.984 series. Apart from ITU-T even IEEE had its own share of contribution to PON. The IEEE 802.3ah Ethernet First Mile task force was instrumental in developing EPON. In the year 2004 the IEEE conceptualized the idea of EPON. Initially when EPON was designed the charters were that the single fiber network operates at 1490 nm downstream and 1310 nm upstream with 1550 nm for extra value added services CATV and private WDM networks. Different from the other standards the EPON never had any standardized algorithms specified for DBA. The obligation of selecting the algorithm is on the equipment manufacturer. Over 90% of the data in the access network is carried over Ethernet[18-20]. This is another added advantage for EPON. It does provide passable bandwidth for small scale organization and residential users. Since Ethernet is packet based transport, it is only the IP packets that are transported. Thus EPON has the ability to support heterogeneous networks. The EPON has its own downsides. GPON and BPON support packet fragmentation while EPON doesn't. To make the PON carrying efficient data, other options were also considered. One was the ATM, Ethernet framing system and a method is similar to SONET/SDH and GFP[21-23]. This was modified to support all kind of services. GPON was more stimulating as the transmitting lasers had to have lower delay, lower power consumption and higher speed while the receivers had to be highly sensitive for covering low budgets requirements. This means that the GPON would cater to long distance transmission. Commercial availability of GPON was delayed due to the deployment of optics and electronics counterparts supplying the needs and demands. Only after the improvement of hardware GPON instilled the faith on the telecom service providers that it was worth the test. GPON uses the Generic Encapsulation Method or the GPON Encapsulation mode and has increased the transmission rate to 2.5Gbps downstream and 1.25Gbps upstream[25-27]. GPON has better performance than EPON. It is also complex, thereby adding to the OPEX. GFP based adaptation layers support any services i.e. packet based or circuit based oriented. While Japan has been keen on deploying EPON, the European countries have shown their curiosity in GPON. Since more than 90% of today's traffic is only IP packet with Ethernet frames being used for generation and termination. It was very vital to handle the Ethernet traffic efficiently. But still the presence of IEEE and ITU-T has added more problems for the vendors. The IEEE 802.3 project scope was limited to the physical layer, not on DBA algorithms, security and ONU management. The ITU-T had failed to arrive at consensus on these issues too. So in the next generation PON both the IEEE and ITU-T have functioned together to complement their efforts. IEEE has enabled interfaces to interact with ITU-T devices in 10 GEPON[28,29].

4. Simulation and Modules of 10G-EPON

The project aims at emulating a real time access network that is capable of working at a speed of 10 Gbps. The setup used for the project is actually not real time traffic setup. It has certain assumptions that have been taking into consideration.

The set-up uses a full functional 10G Ethernet server adapter which is very well capable of handling data speed upto 10 Gbps. This setup gives the real time functionality. The networking setup uses optical patch cords which are again used in the field of optical communication. That why the setup is called as semi real traffic network because the ONUs were simulated at varying distances and has not been emulated properly. In order to achieve the goal of emulating passive optical network with just two machines with Linux OS loaded in the networking lab. One machine was considered as OLT (Server Side) and the other machine was considered as ONU. Since, this resemblance as point-to-point network connection rather than a PON shown in the figure 1. The ONUs and the end nodes are to be simulated so as to follow the passive optical network architecture. The simulation was done by creating multiple processes which behave as ONUs and each process running multiple threads which acts end nodes. The multiple threads will acts as traffic generator which will generate random traffic. This similar to the end nodes, that generates real time traffic for real system. To realize the PON, C programming has been used, which interacts with hardware. The entire setup of a passive splitter and the ONUs at different distances has been simulated on a single system and the OLT simulated on the other system. Even though the two system can behaves as OLT and ONU give rise to real time scenarios, the setup lack of some functional features that makes the setup as a prototype of passive optical network.

4.1 Traffic Generation Modules

Another factor that makes the network semi real is that there is no actual traffic used to measure the throughput and network efficiency. Instead of that I simulated a traffic generator that generates packets size and pump it to the NIC card. But the size of the packets that was generated is from 64-9000 bytes. The rate at which packets are generated is kept random so as to achieve the closest approximation to the real time scenarios.

The mathematical equation followed for generation of random numbers is given below as

$$X = -\log(1-\mu) \div \beta \quad (1)$$

Where β_1 is the parameter with exponential distribution and rand ( ) is system call that generates random numbers. The second traffic generation module implemented is based on Pareto Distribution that generates ON - OFF periods. The Pareto distribution is a heavy tailed distribution with a probability density function. In mathematically it can be represented as

$$F(x) = \beta_2 * b^{\beta} \div Y^{\beta+1} \quad (2)$$

Where β_2 is the shape parameter and b is the location parameter, the packets that are generating from the traffic generator for transmission, the number of packets per second (ON period) follows the Pareto Distribution with the rate factor from 0.2 to 0.8. The OFF period also follows Pareto Distribution. Using the above mathematical equations the packet size can be varied using the RATE factorsβ_1 and β_2. Similarly packets of random lengths are generated in the range of 64 and 9000 bytes. Therefore each simulated thread generates packets of random length at random intervals of time. At the ONU all the packets were collected and encapsulated into a packet of size 9000 bytes and sent to the OLT. We have used the MTU (Minimum Transfer Unit) to be 9000 in my case. This presumes to aid the transfer of packet at higher rates.

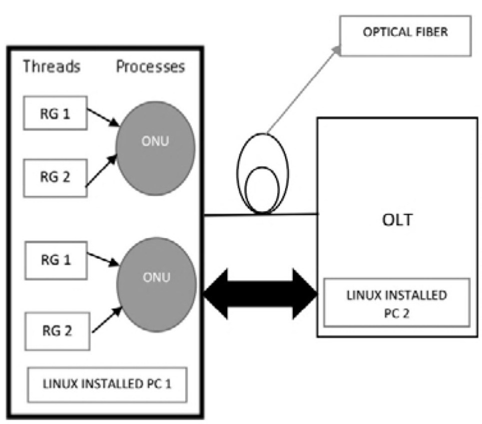

Figure 1. Traffic Generation Module Emulation.

4.2 Planning of the Access Network implemented

In this project the OLT and ONU discovery gate message behaves differently during the testing condition. There are five types messages that will propagate across the channel. They are Register message, Gate message, Acknowledgement message, Report message and Data. The ONU initially sends its LLID with a register message to OLT. The OLT sends the Register_AcK and the initial Gate message. Upon receiving the Gate message, the ONU checks the queue in its buffer which is filled with data, pumped by the random traffic generator and sends the Report message, contains the size of the buffer and its corresponding LLID(Logical link ID)[30]. The OLT on receiving the Gate computes the channel idle time and chooses the DBA algorithms appropriate for the effective transmission. The OLT sends the Gate message back with the time after which ONU should transmit and the amount of data it can transmit. Once the data is transmitted by the ONU, it empties the queue partially or completely depending on the request and fills it up with new data generated by the traffic generators from the end users. Once the queue in the buffer is full, the data is dropped until transmission occurs. The OLT continues the process of accepting the data from different ONUs.

4.3 Channel Idle Time

In high speed access network, channel idle time lead to wastage of resources. If there is no idle time between the transmissions of ONUs, then there will be a condition of packet collision. There arise the needs to have a trade-off that will take care of idle time for the transmission to achieve high data throughput and efficiency. This is a consequences where multiple ONUs trying to strive for the bandwidth. The need of any ONU is to transfer as much data it can for a given bandwidth available for transmission. Unlike CSMA there is no way that OLT can snort for collision and also the optical fiber can spread over a large distance. In case multiple Register messages from different ONUs arrive at the same time, the OLT intelligently allocate the transmission window for data transfer. Hence, considering two cases that arises due to this shown in figure 2.

- If the downstream channel is idle, when the Report message is arrived
- If the downstream channel is busy, when the Report message is arrived

In the first circumstance, if the downstream channel is idle, when the Report message arrives then the Gate assigns the delay after which the ONU has to transmit zero, which implies that ONU must start the transmission as soon as it receives the Gate message[31,32].

In the second circumstance, if the downstream channel is busy, when the Report message arrives then the OLT calculates the expected time the channel will be free. For the calculation of channel idle time in future, it takes

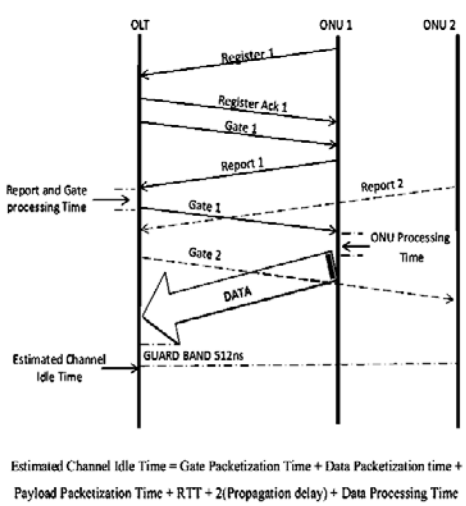

Figure 2. Channel Idle Calculation and Establishment.

into consideration of RTT between the OLT and ONU which is made constant in my case, the simulated propagation parameter, the ONU processing time after receiving the Gate message, the payload packetization time and the gate packetization time of the current transmission. Once the next Report message from another ONU arrives, the OLT already computed the channel idle time and subtract with RTT (Round Trip Time). It also had a small guard band of 512 ns between the two data reception also shown in figure 2. If the future calculated idle time is negative, then it again transmit a Gate message with a delay of zero asking the ONU to start the transmission immediately, else Gate message will be replaced by the computed time. The mechanism which I discussed enhances maximum utilization of bandwidth with minimum delay[33,34]

4.4 Network architecture for minimizing packet drops

In the project the exchanging of control messages between OLT and ONU plays an important role for synchronization and ranging. As per the code written the efficiency and network performances should increase but due to some problem it got decreased. After a thorough analysis I found that the low priority control messages are getting dropped at the socket level of OLT and ONU. This has occurred because OLT when ready to send data, at that particular moment the control message from another ONU arrived, then OLT dropped the control message in its buffer and send the data to the corresponding ONU. As a result the other ONU was keep on waiting for the reply and at the same time OLT waits for the control message from the other ONU which had sent already. So this gave to confusion, where OLT and ONU were keep on waiting for each other responses. So to tackle this problem, we modified the communication between OLT and ONU at their socket level shown in figure 3. OLT used two sockets of different port number to communicate to particular ONU[35]. Where, one socket deals with control message exchanging and the other port deals with data transfer shown in figure 3. ONU uses the same socket for control message and data.

5. Proposed DBA Algorithms for 10G-EPON

In DBA_GATE algorithm, the OLT grants the preferred window size to each ONU. Further, if the same ONU has to send more data, it has to send another request

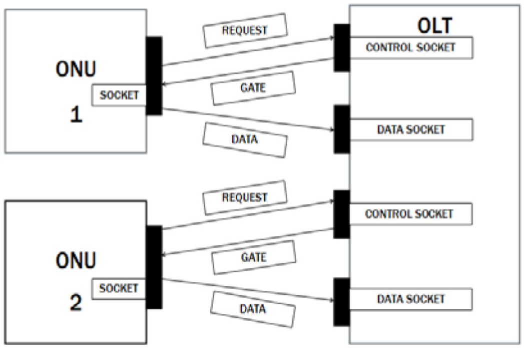

Figure 3. Network Design for minimizing packet drops.

to OLT. Though this algorithm provides a high level of QOS, the drawback is that an ONU with more data will block the other ONU with less data. This means ONU with fewer amounts of data has to wait for a long time until the ONU with more data completes its transmission. So in DBA_GATE algorithm, a single user is allowed to meet his demands and standard of service at the cost of other users, which is inequitable. In DBA_GATE Algorithm all the traffics are taken equally with considering it as delay and non-delay sensitive traffic. The dynamic bandwidth allocation for different traffics is considered equally to improve the throughput shown in figure 5. But when it comes for differentiated services that include simulated voice, video and data, the QOS drastically reduced due to drop of packets.

The newest algorithm "TD_Optimum algorithm" which has been proposed to eradicate the drawback faced in DBA_GATE algorithm is implement in the project. This algorithm was used to see the performance of the network in terms of variation of both throughput and delay. This algorithm is proposed to implement the Triple Play, where both delay sensitive and non-delay sensitive application exists. In the simulation of project, the Delay sensitive application like voice over IP, video over IP and other multimedia are basically from 64 bytes-2500 bytes denoted as Type 0 traffic and the non- delay sensitive application like huge video transfer and data transfer (downloading and uploading) are basically from 5000 bytes-9000 bytes denoted as Type 1 traffic. In this algorithm the report message of all corresponding users stored inside the buffers of the ONUs. The report message may be delay sensitive or non-delay sensitive.

Let us consider an example where there are 4 ONUs connecting to the OLT, and each ONU having 4 end users. The ONU1 in its buffer having both Type 0 and

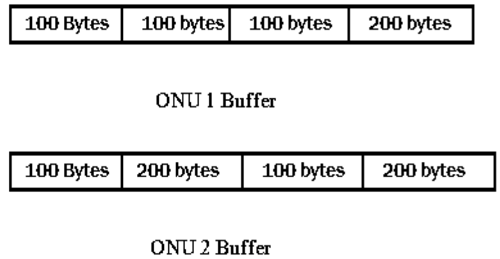

Figure 4. ONU1 and ONU2 Buffers.

Type 1 traffic shown in figure 4. The ONU2 is having Type 1 traffic only which has shown in the figure 4.

Let us now calculate the free time or channel idle time which is measures as the difference between the ends of first report message (Report 1) to the start of the second report message (Report2) with guard time.

$Time_1$= It is the time where ONU 1 sends Report1 to the OLT

$Time_2$ = It is the time where Report 1 received at the OLT side.

μ = guard time

Time (0) = The Report length of the delay sensitive traffic in bytes or Type 0 traffic

Time (1) = the Report length of the non-delay sensitive traffic in bytes or Type 1 traffic

- Let us calculate the channel free time which is defined as below

Channel Free Time = $Time_2 - Time_1$ in bytes

- In this case four possibilities are coming which are as follows

Case 1: When Time (0) > Time2 – Time1, then Time (0) will be scheduled and Time (1) will not be scheduled

This condition indicates that delay sensitive traffic should be scheduled immediately and keeps the non-delay sensitive in buffer to be scheduled in the next cycle.

Case 2: When Time (0) < Time2 – Time1, then Time (0) will be scheduled and Time (1) will be scheduled at the channel free time. By elaborating in a detail manner, suppose Time (0) is 100 bytes and Time2 – Time1 is 600 bytes. Then if in the first cycle Time (0) is buffered as 100, 100, 100, 200 and then combinations of all is less than the channel free time. So we can start scheduling Time (1) of 200 bytes during at 600 bytes.

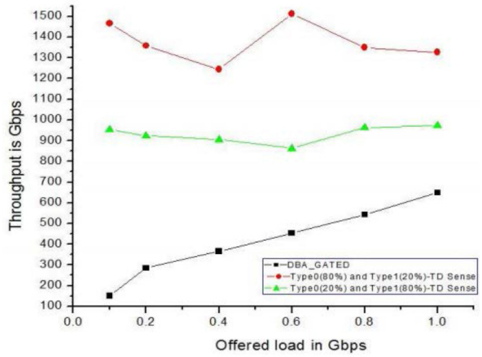

Figure 5. Throughput (Gbps) vs. Offered Load (Gbps).

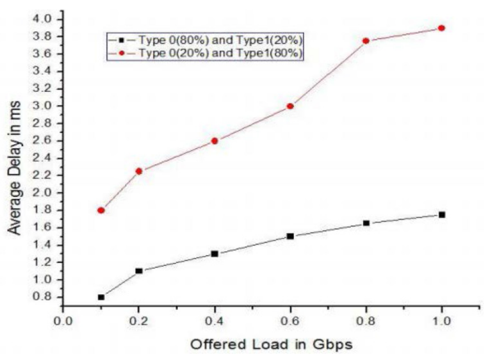

Figure 6. Average Delay (ms) vs. Load (Gbps).

Case 3: When Time (0) + Time (1) < $Time_2$ – $Time_1$, then scheduled both Time (0) and Time (1)

Case 4: When Time (0) + Time (1) > Time2 – Time1 and Time (0) < Time2 – Time1, then scheduled both Time (0) and Time (1) but cut down the report length of Time (1) so that it can be accommodated in the channel free time.

With different offered load containing 80% traffic from delay sensitive application and 20% traffic from non-delay sensitive application and vice versa, the throughput and average delay has been measured shown in figure 5 and figure 6.

6. Conclusion

This paper presents a novel 'TD-Optimum algorithm' for Triple Play by emulating a semi real access networks with the use of two 10G NIC cards and simulating OLT and ONUs in two different systems. It is found that this algorithm maintains a tradeoff between throughput and delay as compared with the existing DBA_GATE algorithm. Bandwidth starvation is overcome in this algorithm.

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