Performance Evaluation of Integrated XG-PON and IEEE 802.11ac based EDCA Networks

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***Abstract*—**
The increase in demand for multimedia services and real-time applications has led to the increasing deployment of telecommunication services all over the world. However, this also necessitates the requirement for the enhanced performance in the quality of service (QoS) parameters of the network, such as throughput, packet loss rate (PLR), and end-to-end delay. In this paper, we investigate an integrated fiber-wireless (FiWi) network composed of a 10-Gigabit-capable passive optical network (XG-PON) and IEEE 802.11ac based wireless local area network (WLAN). The paper aims to enhance the throughput of the FiWi network such that each user is granted an uplink bandwidth of 100 Mbps. At the optical line terminal (OLT), the deficit dynamic bandwidth allocation (DBA) algorithm is incorporated to provide the necessary QoS at the users. It has been shown through intensive simulations that the proposed work is able to achieve an improvement in the QoS parameters like average throughput, end-to-end delay, PLR, and aggregate throughput within an acceptable range of International Telecom Union-Telecommunication Standardization Sector (ITU-T) standards.

***Index Terms*—FiWi, EDCA, XG-PON, IEEE 802.11ac, WLAN**

I. Introduction

The universal access to web-based information has driven the need to analyze and enhance the performance of access networks. The confluence of optical networks with wireless networks has recently gained a lot of attention. Such networks are known as Fiber-wireless (FiWi) networks. FiWi networks accelerated the performance of access networks as it combines the high capacity of the optical networks with the amenities of wireless networks such as ubiquity and flexibility. The study in [1] shows that the major amount of traffic is due to best effort (BE) traffic, such as web-browsing, email services, whatsapp, and text messages, though voice and video traffic are also increasingly contributing to the overall data traffic. Fig. 1 shows the global forecast for the number of internet users as a percentage of the regional population [1].

IEEE 802.11 which is also known as wireless fidelity (WiFi), offers enhanced distributed channel access (EDCA), i.e., IEEE 802.11e [2] and distributed coordination function (DCF), i.e., IEEE 802.11b [3] mechanisms at the medium access control (MAC) layer to enhance the WLAN performance. The main difference between EDCA and DCF lies in the fact that DCF does not provide any service differentiation and treats all the traffics with equal priority. In contrast, EDCA consists of four access categories (AC) – background (BK), voice (VO), best effort (BE), and video (VI). It provides QoS differentiation by adjusting various parameters for each kind of AC, namely, transmission opportunity (TXOP), contention window size (CWmin and CWmax), arbitrary inter-frame space number (AIFSN). By having control over these parameters, EDCA assigns priority to the packets of access categories (ACs) to facilitate channel access.

Fiber optic networks such as a passive optical network (PON) provides high bandwidth allocation, which enhances the network capacity as well as improves the QoS parameters. It is required to analyze the various PON standards to achieve affordable and worldwide coverage that can meet the requirements of plenty of subscribers. The upgraded version of Gigabit PON (GPON), i.e., 10-Gigabit-capable PON (XG-PON), provides a bandwidth of 10 Gbps for the downstream traffic and 2.5 Gbps for the upstream traffic. However, the nominal line rate is slightly less than specified, i.e., 9.95328 Gbps for downstream and 2.48832 Gbps upstream [4]. The XG-PON uses time-division multiple access (TDMA) and time-division multiplexing (TDM) for the upstream and downstream flow, respectively [4]. Due to the difference in the upstream and downstream bandwidth, the XG-PONs are also called asymmetric PONs. Compared to the above, 10-gigabit symmetric PON (XGS-PON) grants 10 Gbps bandwidth at the optical line terminal (OLT) for both upstream and downstream traffic flow [5].

FiWi networks integrate XG-PON as a backhaul network with various wireless networks such as long term evolution(LTE) [6], wireless mesh networks (WMNs) [7] or WLANs [8], [9]. There are various challenges that are generally encountered while integrating these networks, for instance, designing a simple and cost-effective integrated architecture, optimal resource allocation mechanism as well as enhancing the QoS service parameters of the integrated architecture. The major part stands in designing the dynamic bandwidth allocation (DBA) mechanism, which will provide services to various aggregated applications in the upstream link, i.e., from the users to optical network units (ONUs), and finally to optical line termination (OLT). Though several DBAs exist for standalone XG-PON networks, however, for the integrated network in which XG-PON is a backhaul, very few resource allocation mechanisms exist. For instance, authors in [6] focused on two XG-PON standard-compliant DBAs, namely XGIANT and efficient bandwidth utilization (EBU). The author tested

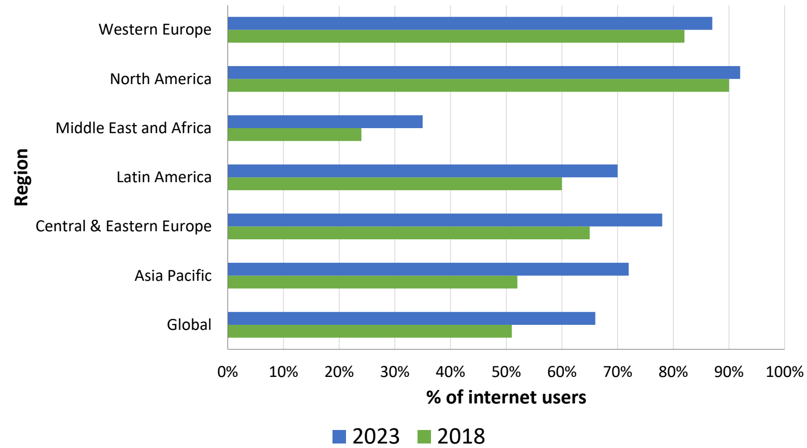

Fig. 1. Number of internet users as a percentage of regional population [1]

the existing XG-PON module in network simulator (NS-3) with the LTE backhaul network, evaluated XGIANT and EBU DBAs, and concluded that none provided XG-PON standard-compliant mean queuing delay, improved fairness index, and throughput. However, these algorithms proved essential for standalone XG-PON architecture with aggregated application traffic, such as real-time voice, video, and best effort. Hence, they proposed two DBA algorithms, proportional XGIANT (XGIANT-P) and deficit XGIANT (XGIANT-D), which provided promising results for the mean-queuing delay, fairness index, and throughput of XG-PON.

This paper considers the integration of XG-PON with IEEE 802.11ac based WLAN network using deficit DBA at OLT. Each user is assumed to transmit three kinds of traffics, i.e., VO, VI, and BE. The voice traffic is given the highest priority, followed by video and best effort. The aggregated traffic from each user is 100 Mbps. Deficit DBA makes effective use of channel bandwidth and allocates the unused bandwidth of the higher prioritized services to low priority service transmission container (T-CONTs) dynamically. In order to incorporate the real-time burst nature of the traffic, we use the Poisson Pareto Burst Process (PPBP) to model the upcoming traffic from the users.

The rest of the paper is organized as follows. The considered system for the FiWi network is described in Section II. The system parameters and the simulation environment are presented in Section III. In Section IV, the performance evaluation for the implemented FiWi network in NS-3 is presented. The results are evaluated in terms of end-to-end delay, PLR, average throughput, and aggregate throughput. Section V finally concludes the work done.

II. System Description

The integrated FiWi architecture is shown in Fig. 2. The FiWi network consists of XG-PON as the backend network and IEEE 802.11ac based WLAN network at the frontend. The XG-PON consists of OLT located at the central office, which is connected to multiple optical network units (ONUs) through a passive splitter. Since the splitter in the network is a passive component, hence, these networks are known as PONs. The function of the passive splitter is to combine the end-users to OLT by distributing the signal from OLT to the user and vice versa. Further, OLT is connected to an internet server via a point-to-point ethernet link. ONUs receive packets of different traffic types and queues them in T-CONTs maintained by each such ONU. As mentioned in [10], the data packets generated by the users are marked with differentiated services code point (DSCP) based on user priority (UP) to get classified on determined services network. Based on DSCP, they are queued in T-CONTs to be able to receive by OLT. Since each ONU is connected to OLT via the passive splitter, uninterrupted time slots are awarded to each ONU in which they can de-queue the containers. Time slots are granted to each ONU based on the DBA algorithm. The DBA is very crucial to avoid collision of packets sent by multiple ONUs. After assigning the TXOP and CW values, the packets are ready to be sent to ONUs. The deficit DBA is applied to allow each T-CONT to use the shared medium by assigning sufficient bandwidth to maximize the bandwidth utilization. In [8], the authors compared the performance of deficit DBA with the existing X-GIANT algorithm. The authors concluded that with the use of deficit DBA the authors were able to get performance improvement in terms of average delay and fairness index of the FiWi network.

Algorithm 1 illustrates the bandwidth allocation to each T-CONT using deficit DBA. It can be observed that after serving the users with voice and video traffic i.e., users in T-CONT 2 and T-CONT 3, the remaining bandwidth is used to serve the unserved users of T-CONT 4. Table I briefs about the type of bandwidth allocated to each T-CONT type and the corresponding served AC in the deficit DBA algorithm [6]. It can be seen that fixed bandwidth is allocated to T-CONT 1 of 128 Kbps. T-CONT 2 and 3 are reserved for voice and video traffic, respectively. The guaranteed bandwidth allocated to T-CONT 2 and 3 depends on the guaranteed data rate (GDR) and the number of users generating voice and video traffic,

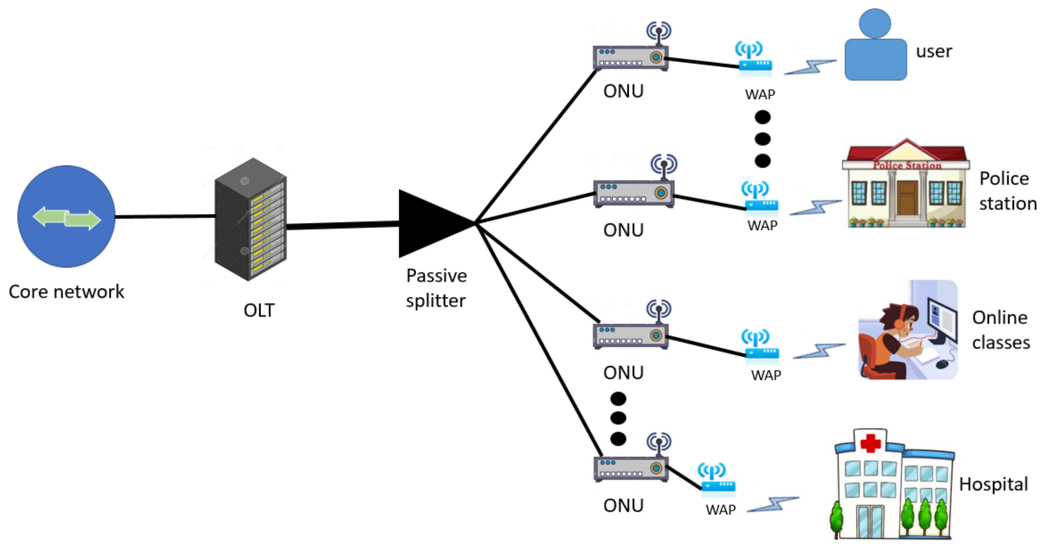

Fig. 2. System architecture for the considered FiWi network.

i.e., N_2 and N_3, respectively. The surplus bandwidth assigned to T-CONT 2 and 3 depends on the maximum data rate for the voice and video traffic, i.e., MDR_2 and MDR_3, respectively. The bandwidth allocated to T-CONT 3 is further divided into non-assured and assured bandwidth. Assured bandwidth is allocated to real-time services such as real-time video streaming, while non-assure bandwidth is allocated to non-real-time videos such as downloadable video. The bandwidth remaining (Remaining-BW) after serving T-CONT 2 and 3 is allocated to BE traffic according to the number of users sending BE traffic, i.e., N_4.

III. Simulation Environment

For the simulation of FiWi network architecture, we used pre-existing XG-PON and IEEE 802.11ac wireless network features in network simulator (NS-3) software. The FiWi network consists of 4 ONUs, and each ONU is connected to a WiFi access point (WAP) to receive WiFi packets from the clients. The ONUs are served by a single OLT via a passive splitter. The distance between ONU and OLT is considered to be 60 kms [10]. The queue size for each T-CONT is taken as 1 MB [11]. For the integrated network, we have used point to point protocol between WAPs and ONUs so that traffic received by the AP gets forwarded to the corresponding ONU without collision. The distance between the WiFi APs is considered to be 0.5 km. We used IEEE 802.11ac based WLAN with the maximum bandwidth of the channel as 160 MHz. For the wireless network, a 4×4 MIMO system is considered. Table II shows the incoming traffic parameters for a user. In PPBP distribution, the bursts arrive according to poission point process. The length of each burst follows a Pareto distribution with hurst parameter (H), such that 1/2 $< H < 1$ [12]. The voice and video traffic are bursty in the real-world, therefore, PPBP distribution is used to model these traffic. Further, the proportion of BE traffic such as over-the-top (OTT) messages and email services is higher compared to voice and video traffic, hence, the data rate for the best effort is the highest, followed by video and voice. The data rate for voice is the minimum, which is in accordance with the traffic distribution in [10]. It can be observed from Table II that the sum of traffic coming from the users is more than 100 Mbps, thus, through extensive simulations, we are able to provide a data rate of 100 Mbps to each users. Each simulation was run for 15 seconds. The parameters for the different ACs such as $CW_{\max}$, $CW_{\min}$, AIFSN and TXOP are taken according to the standard IEEE 802.11e parameters. Table III summarises the values for the standard EDCA parameters.

TABLE I
Deficit DBA bandwidth allocation

T-CONT type	Bandwidth type	Guaranteed data rate (GDR)‘	Surplus data rate (SDR)
T-CONT 1	Fixed bandwidth	128 Kbps	-
T-CONT 2	Assured bandwidth	GDR_2/N_2	$(MDR_2 - GDR_2)/N_2$
T-CONT 3	Non-assured & assured bandwidth	GDR_3/N_3	$(MDR_3 - GDR_3)/N_3$
T-CONT 4	Best effort bandwith	$BW_{remaning}/N_4$	-

Algorithm 1 The deficit DBA algorithm

Inputs:
$AB_{\min}$:Minimum allocation bytes
Required-BW: Bandwidth required by the users.
FB: Number of bytes in a frame.
$AB_{\max}$:Maximum allocation bytes
N_2: Number of users with voice traffic.
N_3: Number of users with video traffic.
N_4: Number of users with BE traffic.
λ: Assured:Non-assured bandwidth for T-CONT 3.
$\bar{\lambda}$: $1 - \lambda$.
$XG - PON_{upstream}$:upstream bandwidth of XG-PON 2.488 Gbps.
$r_{traffic}$: Incoming traffic for voice:video:BE.
Remaining-BW: Remaining BW after granting bandwidth to voice and video traffic.
Threshold-BW: Threshold bandwidth, Remaining-BW / N_4.
Grant-size: Granted bandwidth.
Total Deficit-BW: total deficit bandwidth.
Deficit-BW: Deficit bandwidth.

1: **T-CONT 1**: Grants 128 kbps of fixed bandwidth.
2: **T-CONT 2**: Grants bandwidth $BW_{T-CONT2}$ = minimum of {Required-BW, $AB_{\min}$, FB}.
2: **T-CONT 3:** Grants bandwidth $BW_{T-CONT3}$ = minimum of {Required-BW, $AB_{\max}$}
- For assured round, $AB_{\max}$ = (Unused-$BW_{T-CONT2}$ + $\lambda \times r_{traffic} \times XG - PON_{upstream}$)/$N_3$ corresponding to each T-CONT 3 user.
- For non-assured round, $AB_{\max}$ = (Unused-$BW_{T-CONT2}$ + $\bar{\lambda}$ $r_{traffic}$ $XG - PON_{upstream}$)/N_3 for each of T-CONT 3 user.
- Go to Step 4.

3: **T-CONT 4:**
- Deficit-BW = Threshold-BW - Required-BW.
- Total Deficit-BW = Total Deficit-BW + Deficit-BW

4: **if** Deficit-$BW > 0$ **then**
5: Threshold-BW = [Remaining-BW + Total Deficit-BW]/N_4
Grant-size = minimum of {Required-BW, Threshold-BW}
6: **end if**

TABLE II
INCOMING TRAFFIC PARAMETERS

AC	Data Packet Size	Encoding bit rate	Traffic Model
Voice	160 Bytes	5 Mbps	ON-OFF model with ON duration is exponential with a mean of 0.35s and OFF duration is exponential with mean of 0.65s
Video	795 Bytes	40 Mbps	PPBP with hurst parameter, H=0.9
BE	1472 Bytes	64 Mbps	PPBP with hurst parameter, H=0.5

TABLE III
STANDARD EDCA PARAMETERS FOR IEEE 802.11E

AC	TXOP	AIFSN	$CW_{\min}$	$CW_{\max}$
Voice	1504μs	2	3	7
Video	3008μs	2	7	15
BE	0μs	3	15	1023

IV. PERFORMANCE EVALUATION

In this section, the performance of the considered FiWi network is presented. The performance is analyzed in terms of average throughput, end-to-end delay, packet loss rate (PLR) for each AC. Moreover, the performance of aggregate throughput with respect to the variation of the load is also shown. It has been shown that for the standard EDCA parameters [2], namely, CW, TXOP, and AIFSN, we are able to achieve the system performance near to the QoS specified in the ITU-T standard.

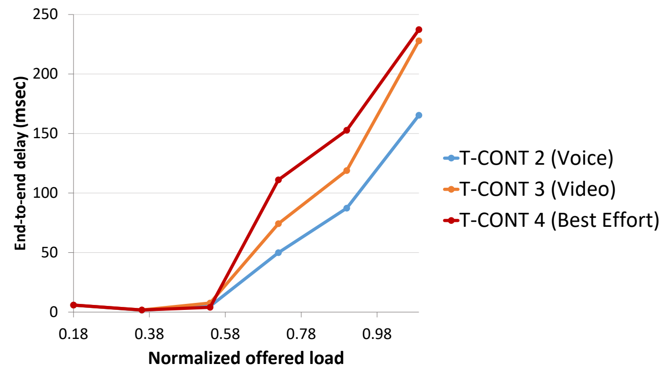

Fig. 3. End-to-end delay vs Normalized offered load using deficit DBA algorithm.

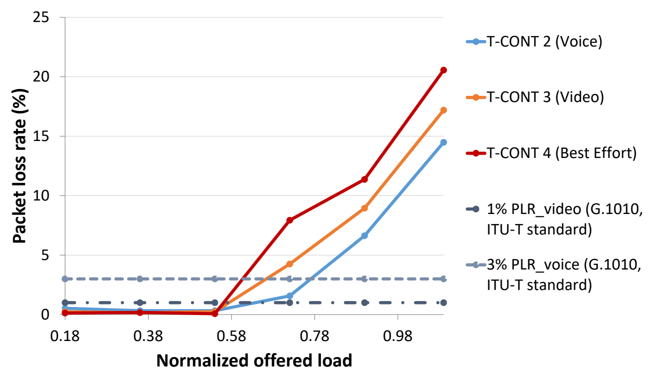

Fig. 4. Packet loss rate vs Normalized offered load using deficit DBA algorithm.

Fig. 3 shows the variation of end-to-end delay for T-CONT 2 (voice), T-CONT 3 (video), and T-CONT 4 (BE). It can be observed that the end-to-end delay for the integrated FiWi network increases as the network load increases. Further, for voice traffic, the end-to-end delay is the least, while for BE traffic, the end-to-end delay is the highest. Moreover, it could also be observed that for low traffic load, the end-to-end delay performance for voice, video, and BE is similar, but as the traffic load increases, the end-to-end delay performance varies according to the priorities of the ACs, i.e., as voice traffic has the highest priority, therefore, the end-to-end delay for the voice traffic is the least. Similarly, BE traffic has the least priority and the end-to-end delay for BE is the highest.

In Fig. 4, the variation of the packet loss rate is shown with respect to normalized traffic load is shown for voice, video, and BE. As the network load increases, the PLR increases. This can be explained by the fact that collisions in the network will increase as the traffic load increases. Further, it can also

TABLE IV
SIMULATION RESULTS FOR FIWI NETWORK AT 100 MBPS DATA RATE

Number of ONUs=4											
No. of clients per ONU	Normalized offered load	Average throughput (Mbps)			End-to-end delay (msec)			Packet loss rate (%)			Aggregate through-put (Mbps)
		T-CONT 2 (Voice)	T-CONT 3 (Video)	T-CONT 4 (BE)	T-CONT 2 (Voice)	T-CONT 3 (Video)	T-CONT 4 (BE)	T-CONT 2 (Voice)	T-CONT 3 (Video)	T-CONT 3 (BE)	
1	0.18	5.59	76.04	244.27	5.86	5.87	5.88	0.52	0.234	0.126	318.35
2	0.36	12.31	177.69	352.79	1.644	1.731	1.73	0.324	0.145	0.173	523.96
3	0.54	20.34	152.6	609.13	4.92	7,562	3.98	0.324	0.244	0.073	776.98
4	0.72	25.52	257.733	975.41	49.9	74.3	111.11	1.569	4.25	7.93	1243
5	0.90	32,27	298.84	984.00	87.31	118.92	152.75	6.63	8.95	11.37	1315
6	1.09	30.91	377.3	1044.25	165.38	227.88	237.30	14.49	17.2	20.56	1446.39

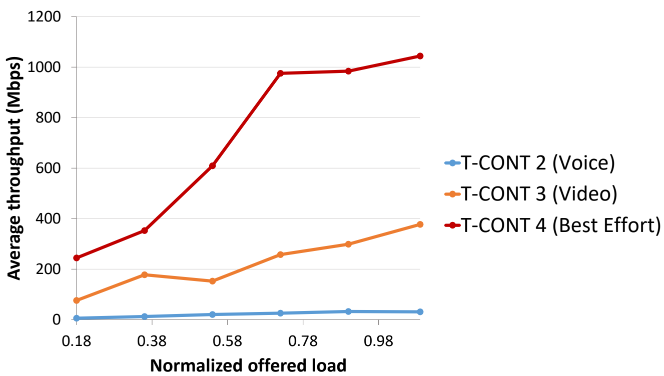

Fig. 5. Average throughput vs Normalized offered load

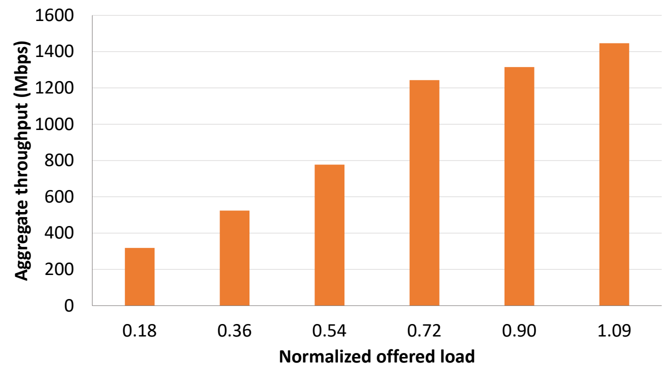

Fig. 6. Aggregate throughput vs Normalized offered load using deficit DBA algorithm.

be observed that for voice, the PLR is in the acceptable range of ITU-T standard up to a network load of 80%. Also, for video traffic, the network performance is within the acceptable range of ITU-T standard for 60% network load. Fig. 5 shows the variation of average throughput for voice, video, and BE. It can be observed that the throughput of the network increases as the network load increases. Further, it can be observed that for BE traffic, the throughput increases as the network load increases to 92%. As the network load increases beyond 92%, there is no significant change in the throughput of the network. Although, for voice and video traffic a significant change can be seen. This is because voice and video traffic have higher priority over BE traffic; therefore, as the network becomes fully loaded, the BE traffic average throughput decreases while the average throughput of voice and video increases.

In Fig. 6, the variation of aggregate throughput with respect to normalized offered load. It can be observed that as the normalized offered load increases, the aggregate throughput of the network also increases. Further, it can be observed that for a fully loaded network, we are able to achieve an aggregate throughput of around 1.5 Gbps, which is 62.5% of $XG - PON_{upstream}$. Table IV summarises the performance analysis results for T-CONT 2, T-CONT 3 and T-CONT 4 for average throughout, end-to-end delay, PLR, and aggregate throughput.

V. CONCLUSION

In this paper, we use the deficit DBA algorithm to enhance the throughput of the FiWi network. Specifically, we are able to achieve a throughput of 100 Mbps per user for an integrated network. The use of high-end wireless standards such as IEEE 802.11ac based WLAN helps in achieving the QoS parameters within the tolerable range of ITU-T standards. The simulations results show the performance of the FiWi network for end-to-end delay, average throughput, PLR, and aggregate throughput. The results demonstrate that for voice, we are able to achieve the PLR within a tolerable range of ITU standard for a network load of 80%, and for video, the PLR is maintained within a tolerable range for a network load up to 60%. Moreover, the results demonstrate that for a fully loaded network, we are able to achieve an aggregate throughput of 62.5% of the XG-PON upstream capacity.

ACKNOWLEDGEMENT

This work is partially supported by a project titled "Designing a cost efficient and optimised Green Broadband Access Network for Rural India using Fiber Wireless (FiWi) Access Network Architecture appropriate for NOFN", funded by the Ministry of Electronics and Information Technology (MeitY), Govt of India, Reference : Administrative approval No. GG-11/1/2018-EMCD-MeitY dated 4^{th} December 2018.

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