Improving Power Efficiency and Reliability for Passive Optical Access Networks in GPON and XG-PON coexistence

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Passive optical access networks have been adopted to solve bandwidth bottle-neck in the last mile. In this paper, we propose a solution to improve their power efficiency and reliability by dual-homing in GPON and XG-PON coexistence. The dual-homing ONU, which have both GPON and XG-PON functionality, is proposed in order to be able to communicate with both GPON and XG-PON OLT. During light-load hours, the ONU can switch from XG-PON mode to GPON mode to save the power consumption. Our analysis shows that the scheme can potentially save up to 31.8% for the overall network consumption.

1. Introduction

Internet has transformed human life enormously. According to ITU statistics, 29.7 % world population in 2010 has become Internet users (68.8 % in developed countries) [1]. Nowadays, the online life spans from tax declarations and shopping to watching a high quality movie and following your friend daily activities on a social network. There are thousands of enabling technologies behind this and among them optical communications is among the most important ones. Starting from core networks, optical communications has expanded to the access segment and even steps beyond the door of homes.

In the access, the most widely deployed standard is gigabit-capable passive optical network (GPON) specified by ITU-T G.984.x series as depicted by white blocks in Fig. 1. GPON optical line terminal (OLT) transmits a downstream data at a wavelength located in 1480nm to 1500nm region to the feeder fibre. The downstream wavelength is branched in the field by power splitter(s) to reach the optical network units (ONUs) through the distribution fibres. GPON class B+ optics allows 28 dB loss budget, which determined the reach and the splitting ratio. Typical deployment configurations are 1:32

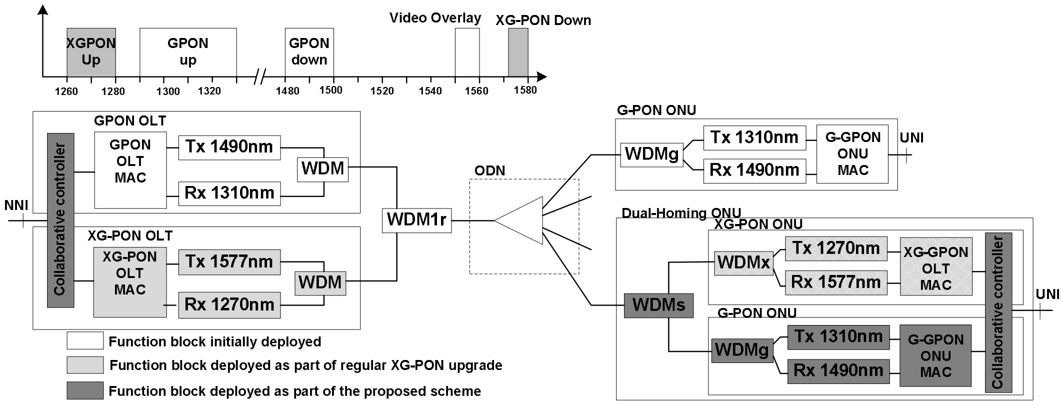

Fig.1. GPON and XG-PON coexistence as recommended by ITU-T (excluding dark blocks) and the dual-homing scheme. WDMs, WDMx, and WDMg are not nescessarily discrete devices.

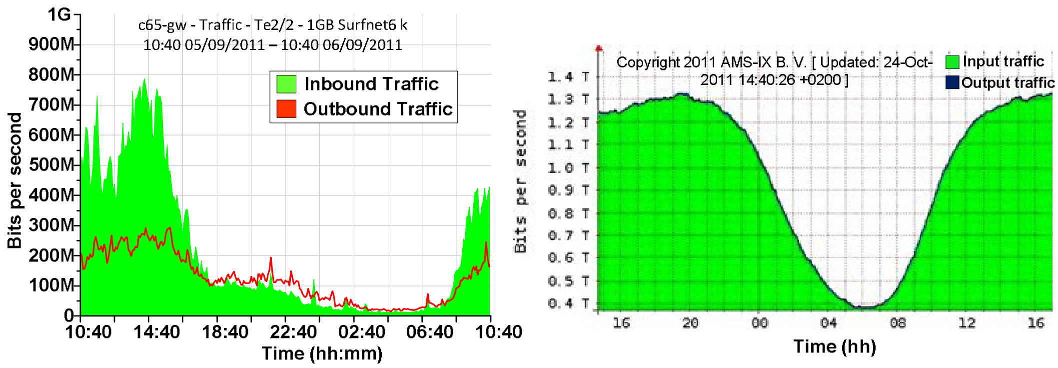

Fig.2. Daily Internet traffic traces at TU/e gateway (left) and at Amsterdam Internet Exchange (right)

or 1:64 splitting with the reach of 20 km or 10 km. Similar to downstream, each user in upstream is assigned a time slot in a 125 μs cycle to transmit the data at 1290 nm to 1330 nm region. The most important bit rate is 2.4 Gbps down and 1.2 Gbps up constituting nearly all of deployments. Therefore, GPON offers sustainable bit rate per ONU of 75 Mbps down and 37.5 Mbps up (1:32 splitting). These bit rates are too tight or not enough for emerging applications such as HDTV requiring from 32 Mbps (2160i format) to 480 Mbps (4230i format) per stream [2], cloud computing from 2 Mbps to 38 Mbps [3]. Therefore, the optical access network has to continue evolving to match future needs.

To address the issue, ITU-T released new standard called XG-PON in 2010, where X is the Roman sign for 10. As the name suggested, XG-PON increases downstream transmission bit rate to 10 Gbps. There are two flavours for upstream: 2.5 Gbps and 10 Gbps called XG-PON1 and XG-PON2, respectively. Due to the current technology challenges for a low cost 10 Gbps upstream burst mode receivers, XG-PON1 is the choice for this moment although the 4:1 asymmetrical down-up bandwidth can pose a problem. The coexistence with GPON in the same optical distribution network (ODN) is the primary requirement for XG-PON. Therefore, XG-PON wavelength spectrum is specified in different regions as shown in the inset of Fig. 1.

Although optical fibre based access networks have been proved to be more power efficient than copper based local loops, the access segment is still foreseen to have largest share of the power consumption in telecommunication networks [4]. Therefore, many efforts have been carried out to reduce the consumption ranging from low-power electronics and optics to power-aware protocols and energy-efficient architectures [5, 6]. In this paper, we propose an architecture for GPON and XG-PON coexistence to reduce power consumption by switching XG-PON to stand-by mode in light-load hours. Basically, conventional GPON and XG-PON ONU are collocated in an ONU called dual-homing ONU, which can operate in GPON-mode or in XG-PON mode or even in both at the same time. In light-load hours, the dual-homing ONUs switch to GPON-mode allowing XG-PON OLT and XG-PON part in the ONU stay in the standby mode.

2. Dual-homing GPON and XG-PON coexistence architecture

The proposed architecture is shown in Fig. 1 that includes the initial deployment of GPON indicated by white blocks and the XG-PON coexistence recommended by ITU-T indicated by while and gray blocks. Many GPON deployments already have WDMr1

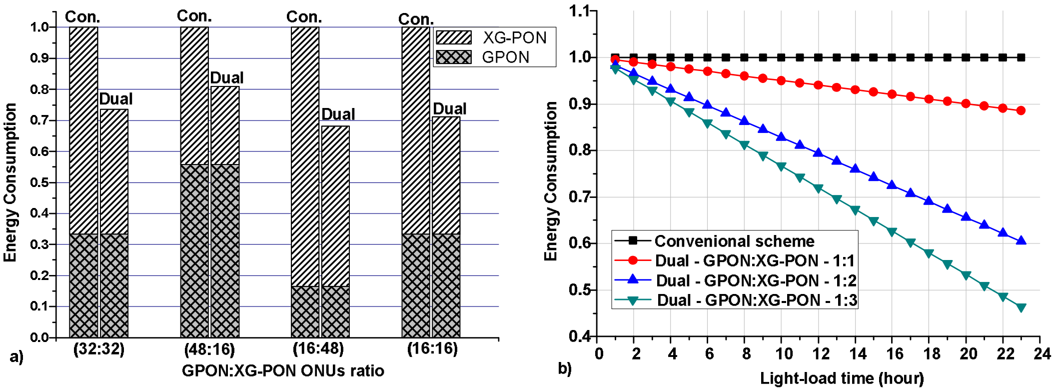

Fig.3. Energy consumption comparision between conventional scheme and dual-homing scheme. a) the comparion based on TU/e traffic for different GPON:XG-PON number of ONUs ratio. b) Energy consumption as a function of light-load hours in case of 16:16 ONU ratio

installed as the foreseen of XGPON upgrade. Because of broadcasting nature of the power splitter, the GPON and XG-PON signals reach every ONU regardless of its type. Leveraging this fact, the proposed dual-homing ONU receives both signals instead of cancelling GPON signal like in the conventional XG-PON ONU. In light-load hours as shown in Fig.2, the dual homing can save power by switching XG-PON parts in both central office (CO) and user side. In peak-load hours, the dual homing also can reduce congestion since dual-homing ONU can work in both GPON and XG-PON channel. The down-up bandwidth is less asymmetric by 20 % from by 4:1 in XGPON1 and 4:1.2 in the dual homing.

On the other hand, the dual homing may increase the ONU cost because the ONU also includes GPON functionality. In the worst case, the dual-homing ONU cost is the cost of XG-PON ONU plus the cost of GPON ONU. However, GPON and XG-PON MAC logic can share the same hardware to help to reduce cost figure. That is expected because the large part of XG-PON MAC is inherited from GPON MAC. In the OLT side, the collaboration controller can be seen as an additional feature of XG-PON OLT which may also increase the XG-PON OLT cost. Therefore, it is necessary to evaluate the merits of the proposed architecture. The following section will analyze and compare the power consumption of conventional GPON and XGPON coexistence and the dual homing proposal.

3. Power consumption reduction in light-load hours

When the network traffic both in GPON and XG-PON is lower than a certain threshold L_a, the dual-homing ONU can switch to GPON mode and the traffic is carried using only GPON. L_a is 20 % of network capacity that obtained based on GPON down of 2.5 Gbps and XG-PON down of 10 Gbps. Let m_a denotes the time per day (in hours) in which network traffic is lower than L_a. Then, we have the energy consumption of the dynamic dual-homing in one day:

$$E_{Dyn} = 24(e_{OLT} + Ne_{ONU}) + (24 - m_a)(e^*_{OLT} + Me^*_{ONU}) + m_a Me_{ONU} \tag{1}$$

Where e_{OLT} *and* e^*_{OLT} denote the power consumption of GPON and XG-PON OLT, respectively. e_{ONU} and e^*_{ONU} denote the power consumption of the GPON part and the XG-PON part of the dual-homing ONU, respectively. We assume that the GPON ONU and the GPON part of the dual-homing ONU consume the same amount of power. N is the number of GPON ONU and M is the number of dual-homing ONUs.

The energy consumption of conventional scheme remains the same regardless of load level. Therefore, we have

$$E_{Con} = 24\left(e_{OLT} + e^{*}_{OLT} + Ne_{ONU} + Me^{*}_{ONU}\right) \quad (2)$$

The energy consumption for conventional and dual-homing scheme with different $N:M$ combinations are computed based on the daily traffic trace from Eindhoven University of Technology (TU/e) Internet gateway shown in Fig.2. The consumption is normalized by the maximum consumption which is in Eq.(2). Although XG-PON speed is four times higher than GPON, we assumes that the power consumption of XG-PON parts (e^{*}_{OLT}, e^{*}_{ONU}) is double of G-PON parts (e_{OLT}, e_{ONU}). The light-load time in the trace is 16.75 hours resulting significant savings in all $N:M$ combinations. A higher saving is observed when the proportion of number of super ONU is high. This is expected because the power saving is yielded by switching dual-homing ONUs to GPON mode and XG-PON OLT to standby mode. We saves maximum of 31.8% in case of 16 GPON ONUs and 48 XG-PON ONUs in the system and minimum of 19.1%. Assume that e_{ONU} is 10 W and e_{OLT} is 100 W, we potentially save minimum of 9636 kWh per year.

The amount of saving depends on the light-load hours per day. Fig. 3 (right) shows the energy consumption per day as a function of light-load hours for different proportions consumption between GPON and XGPON. As expected, the less light-load hours is the less saving is observed. However, we can save 8.6% when the light-load hours are reduced to 5 hours in case of consumption GPON:XGPON 1:2. The saving percentage seem not high but providing that it is the percentage of overall GPON and XG-PON systems.

4. Conclusion

In this paper, we have proposed a dual-homing architecture for GPON and XG-PON coexistence. The architecture reduces down-up bandwidth asymmetric from 4:1 in XGPON1 to 4:1.2. The power consumption is also can be reduced given that the network traffic varies greatly in a day. Based on a real traffic trace, we have shown that the proposed architecture can potentially save 9636 kWh per year in comparison to the conventional architecture.

5. References

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