Optical Access Solutions Beyond 10G-EPON/XG-PON

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Abstract: This paper discusses WDM-based optical access networks beyond 10G-EPON and XG-PON. It describes drivers and requirements. Challenges as well as possible solutions are outlined.

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1. Introduction

Point-to-point Ethernet (P2P Eth), Ethernet passive optical network (EPON) and Gigabit passive optical network (GPON) technologies are commonly used in today's optical access networks. Whilst P2P Eth solutions were dominant in the past, EPON and GPON systems are gaining market share worldwide [1]. EPON solutions are frequently found in Asia, whereas GPON solutions are more common in the US and Europe. EPON/GPON [2, 3] schemes can be classified as time-division multiple access (TDMA) PONs. They employ a burst-mode TDMA scheme for sharing a single 1.25 Gb/s upstream (US) wavelength amongst all PON subscribers. In downstream (DS) direction, a time-division multiplex (TDM) scheme splits an aggregate 1.25 Gb/s (GPON: 2.5 Gb/s) signal into individual user streams. A dedicated radio-frequency (RF) wavelength channel can be added for broadcast TV/video transmission.

Frequently cited arguments for EPONs and GPONs are: a power-splitter based optical distribution network (ODN), a single transceiver at the optical line terminal (OLT), and low-cost un-cooled sources with wide wavelength tolerance at the optical network termination (ONT). Whilst these arguments represent benefits in the near term, they can also become impediments if a further scaling in subscriber count, system reach and average user data rate is required [4]: The passive splitter architecture causes a large power loss. For a 32-channel class B+ GPON, ~17.5 dB of system budget is already consumed by the splitter. The attainable reach is therefore < 20 km. The shared transceiver at the GPON-OLT limits average DS and US subscriber rates to ~80 Mb/s and ~40 Mb/s, respectively. Dedicated solutions are thus required for higher bandwidth business and backhauling services. The GPON/EPON wavelength plan complicates a migration to significantly higher system capacities and causes operation at a relatively high fiber loss of ~0.5 dB/km.

2. Drivers and requirements

For some of these points, remedies have been or are being defined by ITU-T and IEEE: To increase the GPON reach to the protocol limit of 60 km, the ITU-T has defined a reach extender (RE) [3], a regenerator/amplifier unit typically residing mid-span in the ODN. Having active equipment there, however, is not always liked by network operators. To allow higher subscriber bandwidths and/or higher splitting ratios, XG-PON [5] and 10G-EPON [6] have been developed. They leverage the splitter-based ODN and allow co-existence of legacy GPON/EPON and new XG-PON/10G-EPON users on the same fiber infrastructure. The IEEE 802.3av 10G-EPON standard (10 Gb/s DS, 1 Gb/s or 10 Gb/s US) was ratified in September 2009. The ITU-T G.986.x XG-PON1 set of standards (10 Gb/s DS, 2.5 Gb/s US [10 Gb/s US in a future version]) is to be consented in 2010. Assuming a 32 channel split and 20 km reach, an XG-PON1 can attain ~320 Mb/s downstream and ~80 Mb/s upstream subscriber rates. Whilst XG-PON/10G-EPON can certainly help to increase the lifecycle of TDMA PON systems, a further scaling in reach, user count and per-used data rates will be difficult to achieve with a pure TDMA approach [7]. Wavelength enhancement bands are defined in the G.984.x and G.987.x standards to ease capacity extension. When a hybrid configuration with GPON/XGPON and RF-channel is deployed, however, neither the full C- nor the L-band is available for such extension. In addition, the ONTs may not have the right blocking filters in place to allow an upgrade with non-GPON/XGPON wavelengths.

Access solutions beyond XG-PON/10GEPON are driven by the steady traffic growth in residential, business and backhaul markets. The pervasiveness of high-quality multi-media applications paired with a shift from broadcast to a unicast services calls for future proof-solutions which are scalable to sustained per-user data rates of > 1 Gb/s. A single platform for residential/business/backhaul applications, the consolidation of local exchange offices, and the minimization of active field equipment are other drivers for next-generation access (NGA). Such an approach does not only lead to a simplified network planning and more integration but also to reduced energy costs [8].

NGA requirements beyond XG-PON/10G-EPON can be summarized by the simple formula "100 x 1000 x 1000": up to 100 km reach, up to 1000 users, and ≥ 1000 Mb/s per-user data rate. It is important to note that there is typically a correlation between user count and required reach: In dense urban scenarios the user count tends to be high but the distance to the next central office is relatively short, whereas in rural scenarios the distances can be high but the number of users is lower.

3. Challenges and possible solutions

With user data rates of 1 Gb/s and trunk fiber capacities > 10 Gb/s, a wavelength division multiplexing PON (WDM-PON) is a natural choice for NGA. It is also being discussed as base technology for the next-generation PON 2 (NGPON2) in the Full Service Access Network (FSAN) group [9]. WDM-PON provides logical point-to-point connectivity on physical tree or ring structures. WDM technology has been successfully deployed for many years in metro and core networks; it and provides practically unlimited system capacity and reach. Lately, service providers are deploying passive WDM technologies also for wireless/wireline backhauling, business connectivity, and fiber-to-the building (FTTB) applications. In residential fiber-to-the-home (FTTH) networks, WDM technology is not commonly used yet. This is caused by the relatively low per-user data rates at present but also due to missing solutions to these three challenges: 1) compact and cost-competitive access WDM components, 2) simple end-to-end operations/administrations/maintenance (OAM), and 3) a scalable concept for an aggregation of individual subscriber flows.

A WDM-PON ideally uses the C-/L-band, as this allows operation near the attenuation minimum of the transmission fiber and, where required, EDFA-based amplification (e.g. in the OLT). In conjunction with a 32-80 channel cyclic arrayed waveguide grating at the RN, a DWDM-PON with a 100/50 GHz spacing and a reach of ~60km (> 100km with amplification) is possible. Whilst a DWDM-PON OLT could be built from standard pluggable transceivers, a cost- and footprint optimized solution would use multi-channel transceivers in form of photonic integrated circuits (PICs). On the transmit side, either a directly modulated laser, reflective semiconductor optical amplifier (RSOA), or electro-absorption modulator (EAM) array (the latter two in conjunction with a shared multi-frequency source) could be used [10]. Employing a multi-channel SFP+ style electrical interface and electronic distortion compensation allows one universal PIC for 1G-10G services without requiring 10G bandwidth components [11]. At the ONT side, colorless or low-cost tunable transceivers are desirable to ease operations. Colorless sources based on RSOAs or EAMs have the advantage that they facilitate cooler-less operation. The necessity of a seeding source and the requirement of a separate feeder fiber in long reach applications, however, complicate the design. Tunable lasers at the ONT avoid these problems [12] and are as such more attractive. They require, though, some form of wavelength control.

To support an open access approach in which the passive infrastructure, the connectivity, and the service layer can be controlled by different providers, independent end-to-end OAM should be established for each layer. Monitoring of the passive infrastructure is facilitated by passive reflection devices [13] or OTDR techniques [14]. A supervision of the optical connectivity is possible by a remote retrieval of transceiver parameters [13]. Ethernet connectivity between ONT and OLT can be verified using IEEE 802.3ah (Ethernet in the first mile) [2]. For service level OAM, IEEE 802.1ag (connectivity fault monitoring) or ITU-T Y.1731 (Ethernet OAM) can be employed.

The biggest challenge of the 100 x 1000 x 1000 objective lies in achieving 1000 users at 1 Gb/s: The aggregate bandwidth of 1 Tb/s is more than what many metro and core networks provide today. Whilst statistical multiplexing down to 10..100 Gb/s may be employed at the OLT uplink, a Tb/s class aggregation switch is still required. Fulfilling the 1000 user requirement represents a formidable challenge also on the optical side. In principle, three solutions exist: The first option is to maintain an optical splitting ratio in the range of 32-80 channels as for the pure TDM(A) PONs. 1000 users are then obtained through multiple parallel trunk fibers (space division multiplex, SDM). This solution is often fully adequate as passive long-reach alternative to active reach-extended XG-PON/10GE-PON systems. It can be used for the delivery of business, backhaul and FTTB services. Disadvantage, however, is the large fiber count in the central office (albeit compact fiber management solutions exist). The second option is to employ 10 Gb/s wavelengths and share them amongst multiple users [15]. For multi-user wavelength sharing, TDM(A) or other techniques (e.g. electronic subcarriers [16]) can be used. The combination of WDM with any of these additional techniques leads to hybrid PON architectures which have been investigated for quite some time at lower speeds (see e.g. [17]). Terminating TDM(A) sub-wavelength channels not in the OLT but in an active RN brings the advantage that the ONTs can run with standard (grey) optics and that the domain conversion between WDM and TDM(A) automatically yields reach extension. The RN device in this case may consist of an XGPON/10GE-PON converter or a small Ethernet port-aggregator. With power-optimized designs, these devices could even be deployed in manholes (see e.g. [17]). The third option is ultra-dense WDM (UDWDM). Employing coherent reception in conjunction with a channel grid of a few GHz, this scheme offers the highest optical performance (> 45 dB power budget) of all alternatives discussed [18]. It requires, however, the most complex transmit/receive optics. Expecting that the cost of optics will always remain a dominant factor, the combination of low-cost optics with electronic processing seems a winning combination, irrespective of the option chosen.

OTuO1.pdf

4. Conclusion

This paper reviewed next-generation access solutions beyond 10G-EPON/XG-PON. WDM technology is always required as a basis for scalable, future-proof systems (100 km x 1000 users x 1000 Mb/s). To address 1000 users with a single system, three options exist: multiple feeder fibers, multi-user wavelength sharing and UDWDM. Irrespective of the option chosen, low-cost integrated optics with electronic signal processing seem to be a promising approach.

5. References

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