Solutions for Extended Split PON

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High access bandwidths can be offered by deploying Fiber To The Home (FTTH) with Passive Optical Networks (PONs). This paper reports on the realisation of an extended split PON demonstrator that increases the split factor from the current 32 to 128 or 256. The solution improves the financial investments in several deployment scenarios.

Introduction

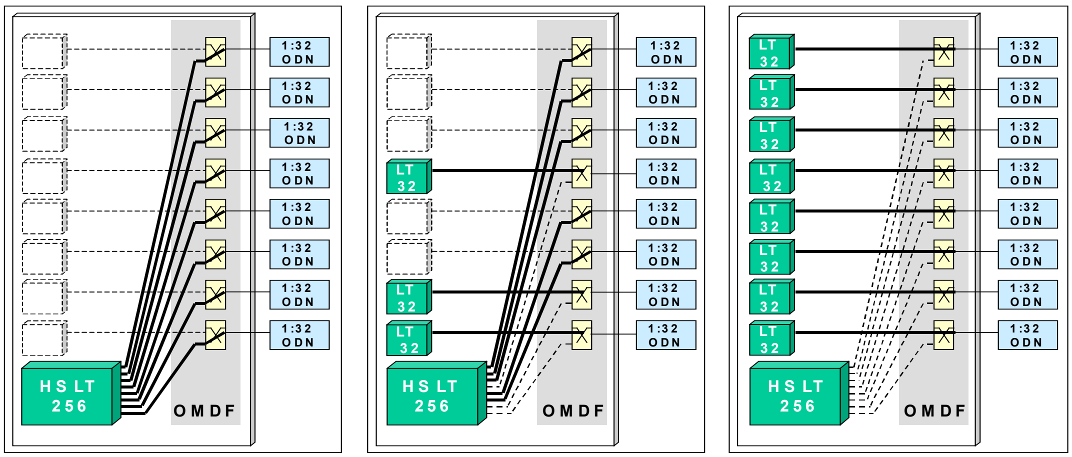
The ATM Passive Optical Network (APON) is generally accepted as a cost-effective Fiber To The Home (FTTH) solution well-suited to the future needs of broadband services. A major feature of the APON is that 32 customers can be concentrated on a single fiber to the central office using a simple passive optical splitter. The ITU G.983.1 APON standard [2] specifies a bit rate of 622 or 155 Mbit/s in the downstream direction and 155 Mbit/s in the upstream direction, shared by time division multiplexing.

Introducing FTTH by means of PONs represents a substantial initial investment for the operator. This investment is directly related to the amount of potential users in terms of passed premises (a fiber has to be foreseen for every possible connection to a PON Line Termination (LT)). In several situations, such as a broadband network in overlay to an existing narrowband network or an initial deployment, the penetration of connected users is much smaller than the number of homes passed (typically 25%). Given that the current maximal *optical* capacity of an LT is limited to 32 users (≠ from the logical capacity limited to 64 as defined in the standard [2]), the necessary amount of LTs can become quite large to serve every possible newly connected user, while the LT is inefficiently used. An extended split LT (128 or 256) PON may reduce financial investments in such cases. A switchover principle is required to offload the LT when the subscriber penetration increases, thereby exceeding the capacity of the LT in terms of number of users or bandwidth. The present paper reports on an extended split demonstrator realised in the frame of the Flemish IWT project ITA2-FTTH.

Switchover Principle

Increasing the optical split capacity per LT will reduce their necessary amount at the deployment phase when there are only few users connected. In practice, this means the ONUs from several different PONs are first grouped to High-Split LTs (See Figure 1.a). As more and more users are joining in, the logical capacity of these first High-Split LTs gets exhausted and extra Conventional-Split LTs can be gradually added in the access node, respecting the logical limit of the amount of connections for each LT (See Figure 1.b). So part of the optical connections have to be switched from the High-Split LT to some Conventional-Split LTs during the introduction process. An appropriate

switchover procedure is required to limit the interruption of the communications. This mechanism could operate optical switches located at an Optical Main Distribution Frame (OMDF) which is acting as a flexibility point.
This gradual switchover mechanism from a High-Split topology to a Conventional-Split topology will then finally result in all users being connected to Conventional-Split LTs. (See Figure 1.c). The High-Split LTs can then be reused at other nodes, or kept for protection purposes. When following this strategy, the operator can invest in equipment more gradually, as revenues grow [1].



a.) Initially, several PONs are grouped to a High-Split LT.

b.) More than 96 users have already joined. Three optical connections have been switched to Conventional-Split LT.

c.) Finally, all users are connected to Conventional-Split LT. The High-Split LT can be reused.

Fig 1 : Example of Split Ratio Switching scenario. 1 HS LT (256) is replaced by 8 CS LTs (32)

Implementations of extended split PON

Extending the splitting ratio from a typical value of 8, 16 or 32 to 128 or 256 requires increasing the optical power budget in both transmission directions. A cost-effective and reliable solution implies to keep the users' hardware unchanged and the fiber plant purely passive. Consequently, the optical power budget will have to be won at the CO side. The figure 2 presents the two demonstrators built to proof the feasibility of this extended split. Figure 2(a) illustrates a "Transparent solution" which does not require changes in existing hardware at the LT, but only insertion of extra components.
For the downstream path, the power is increased by amplifying the conventional DFB laser with a booster Erbium Doped Fiber Amplifier (EDFA). Analysis has shown that a pump module of 23 dBm could be shared over multiple high-split LTs in most cases, thereby reducing its relatively significant cost over a large amount of users. (See Table 1). Class B and Class C refer to the categories of optics suited for a standard APON with an insertion loss of respectively 10 - 25 dB and 15 - 30 dB as defined in [2].
In the upstream direction, a gain is achieved by using a Low Loss Combiner (LLC), guiding the power from eight Single Mode input to one Multi Mode output pig-tailed to the detector. This device can achieve a combination factor of 8 with an insertion loss (maximal 3.5 dB), which is far less than that of a conventional 1:8 combiner (maximal 11.5 dB).

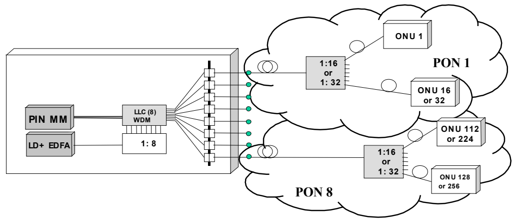


Fig 2 (a): “Transparent Implementation” of extended split PON : Low Loss Combiner and Erbium Doped Fiber Amplifier.

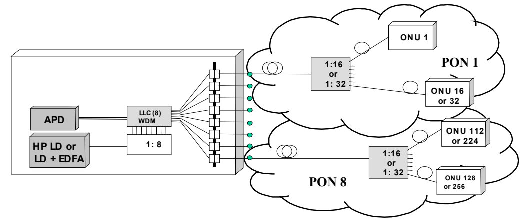


Fig 2 (b): “Hardware Upgrade Implementation” : Avalanche PhotoDiode (+LLC) and High Power Laser Diode or EDFA

Configuration	Class B		Class C	
	Required pump power (dB)	Pump sharing	Required Pump power (dB)	Pump sharing
1:128, 155 / 155 Mbps	13.42	4	11.76	8
1:128, 622 / 155 Mbps	15.44	3	11.76	8
1:256, 155 / 155 Mbps	17.40	2	14.77	3
1:256, 622 / 155 Mbps	19.54	1	14.77	3

Table 1 : Pump sharing capacity for the EDFA approach

In the second implementation, the “Hardware upgrade solution” depicted in Figure 2(b), one or both optoelectronic fronts-ends are replaced. The downstream 1.55 µm DFB laser can be exchanged by a directly modulated higher power version with 10 dBm average power. The upstream sensitivity can be improved by using an Avalanche Photo Diode (APD), the 1:8 Low Loss Combiner, or the combination of both.

Measured performances

The demonstrators were evaluated, measuring a Bit Error Ratio of 10^{-10} and using Class B ONUs. The measurements in downstream indicate that the HPLD can reach a power of 10 dBm as specified, and that the LD + EDFA complete a gain of 20 dBm, thereby covering all the topologies considered in [1].

In upstream, the BER measurements were compared in two different conditions. First, a single ONU while operating alone, having the full upstream bandwidth and secondly the same ONU, now with a second ONU also being active. This second ONU is operating near the optical overload point of the LT receiver. The upstream bandwidth is shared over both ONUs (60 Mbps traffic each), resulting in a succession of strong cells of ONU2, weak cells of ONU1, and empty cells. This represents a worst-case version of a real-life operation. In the first case with a single ONU, we have measured a sensitivity of –36.7 dBm with the APD. The second user introduces a small penalty of 0.6 dB and thereby reduces the sensitivity to –36.1 dBm, which is more than 6 dB of improvement compared to the G.983.1 requirement of –30 dBm. Furthermore, the insertion of a LLC in the upstream path will give an additional improvement of 8 dB as compared to a conventional 1:8 combiner.

Cost evaluation

An economic analysis has been carried out for several introduction cases. The investment was systematically estimated at the begin (no users) and the end (all users connected) of the subscription to FTTH. The investment estimation takes into account how many LTs are used (and hence the necessary amount of slots at the access nodes), the extra components needed to achieve high-split, the OMDF and optical switches for switchover, and the contribution of the necessary amount of access nodes. The cost results depend on the amount of conventional LTs that can be replaced by the High-Split LT at the start of the introduction and the impact on the necessary amount of access node slots at that time, and by the cost of the High-Split LT itself.

Regrouping factor	Class B			Class C		
	Initial Cost	Reference	Final cost	Initial Cost	Reference	Final cost
High Split Ratio of 128						
4 x (32 split)	0.65	1	1.53	0.60	1	1.49
8 x (16 split)	0.44	1	1.38	0.46	1	1.41
16 x (8 split)	0.35	1	1.32	0.31	1	1.29
High Split Ratio of 256						
8 x (32 split)	0.44	1	1.37	0.40	1	1.34
16 x (16 split)	0.38	1	1.34	0.32	1	1.29
32 x (8 split)	0.26	1	1.25	0.22	1	1.21

Table 3 : Cost comparison for a high split ratio of 128 (up) and 256 (below) – Reference is the cost of equivalent Conventional-Split configuration.

For small regrouping factors there is already a significant economy. When comparing equal regrouping factors for a split of 128 versus 256, the cost values are very similar. The advantage of the 256 version is of course the capacity of having higher regrouping factors. The difference between Class B and Class C is also limited, with a small benefit mostly for Class C. The investment in extra components like the EDFA and LLC can even be recuperated by reusing these components in other parts of the network after a complete switchover.

Conclusion

A fully operational extended split PON has been demonstrated for both "Transparent" and "Hardware Upgrade" implementations. The study has shown that a significant economy of initial investment can be achieved for regrouping factors of 4 or more. The splitting factor can be increased in a cost-effective way, without having to change the outside plant or user equipment. The gradual migration from High-Split LTs to Conventional LTs requires suitable switchover procedure. The technological choices in this study involved a booster EDFA with shared pumping or a high power laser, a power combiner, and an APD. The measurements show that the transparent solution can regroup PONs to a split of 128 and 256, under the condition that the ONUs have a limited distance of e.g. 10 km to the LT. We have also demonstrated that the hardware upgrade solution achieves PON topologies with an extended split of 128 and 256.

References

[1] F. Fredricx, B. De Vos, C. Bouchat, J. Watté, P. Van Overmeir, J. Vandewege, X.Z. Qiu, K. Noldus, "Solutions for Extended Split PON", IEEE / IEICE OHAN Workshop Proceedings, April 2001, 4.2.1 – 4.2.7.

[2] "Broadband Optical Access Systems Based On Passive Optical Networks (PON)", ITU-T Recommendation G.983.1 (1998).