Assessment of Coherent 100G PON Architectures

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***Abstract*—Coherent technology in Optical Access Network (OAN) promises a wide range of benefits over the legacy IM-DD Passive Optical Network (PON) architectures, including enhanced Receiver Sensitivity (RxS). This enables extended differential reach in PONs and supports higher Splitting Ratios (SRs). The higher RxS facilitates node consolidation within OANs. This work investigates several aggregation schemes, targeting the migration from legacy XGS-PON to 100G Coherent PON (CPON), with a focus on power consumption. In particular, an architecture based on a coherent backbone Optical Distribution Network (ODN) interconnecting a main Central Office (CO) with multiple peripheral COs, referred to as 100G-CPON Remote Optical Line Terminal (OLT) (R-OLT) scheme, is shown to provide both cost-, and power-efficient intermediate step towards the ultimate all-100G-Optical Network Units (ONUs) deployment. The evaluation is conducted over a network comprising 73500 ONUs covering a geographical region of 610.27km^2. The 100G-CPON R-OLT scheme results into 20.71% increase in connected ONUs and a 41.84% reduction in CapEx per connected ONU, while incurring only a marginal 1.14% ($\sim$2.1mW) increase in power consumption per connected ONU.**

***Index Terms*—Passive Optical Network, Energy Consumption, Optical Access Network, Coherent Optical Access**

I. Introduction

Coherent technologies have been widely adapted in metro, and core networks, while their application in Optical Access Network (OAN) became a prominent research area in the past decade, especially while approaching Very High Speed PON (VHSP) datarates, 100G/200G [1], [2]. The key advantages include a higher Receiver Sensitivity (RxS), which entails higher Splitting Ratio (SR) for urban regions, and longer differential reach for sub-urban cases, thereby relaxing legacy IM-DD ODN reach constraints. For delivering 100G or beyond, IM-DD solutions are approaching their RxS limits [3], [4]. With the higher RxS advantage of coherent, a path towards the deployment of 100G PON emerges, via Node Consolidation. By leveraging the existing, and/or currently being deployed, XGS-PON fiber layouts in individual regions, an aggregated PON infrastructure can be planned that lays the foundation for an all-100G-ONUs goal in Fiber to the Building (FttB), while minimizing additional cost and energy consumption.

This work discusses multiple aggregation schemes, combining several 'local' PONs through a selected 'backbone' infrastructure. A 'local' PON resides in individual regions, with OLTs placed at the Central Office (CO), ONU at the Customer Premises (CP), and a passive ODN in-between. Several of the surrounding (here, peripheral sub-urban) COs are aggregated together with an architecture, called the 'backbone', keeping the main CO at the main urban location. The 'backbone' can either be a Point-to-Point (P2P), or an ODN. In P2P backbone, the feeder fibers are spliced with the backbone fibers at the peripheral COs location, making them passive, as all the OLTs are moved to the main CO location; while in the ODN backbone, peripheral COs remain active, with the placement of R-OLTs with embedded Coherent ONU (C-ONU), as proposed by [5] for a mixed use case scenario.

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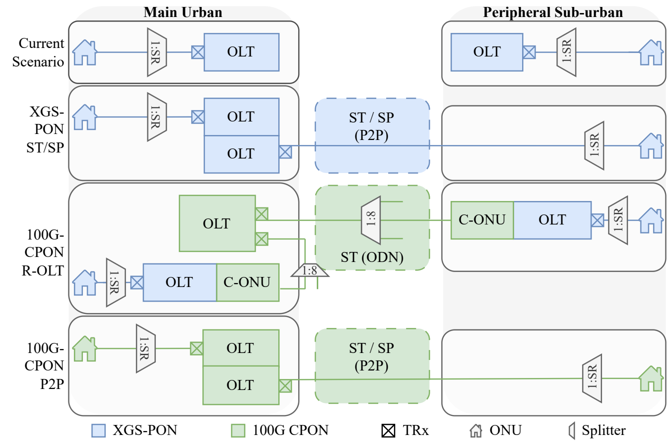

Fig. 1. Migration/Aggregation Schemes: Main urban (left) is surrounded by several Peripheral sub-urban (right) PON networks. Backbone (dotted-center) aggregates the peripheral OLTs, using Steiner Tree (ST), or Shortest Path (SP). Legacy XGS-PON (blue), and 100G-CPON (green) technologies are depicted for backbone and local PON.

In PON, there are only two active units: CO and CP. This work only focuses on the CO's power consumption because of the significant backbone architecture-based variation. The active components at the CO are OLT line cards (say, OLT), Transceiver (TRx), and secondary facilities like air conditioning and power supply efficiency. For 100G with ODN backbone, the energy consumed by embedded C-ONU, along with the remote XGS-PON OLT units with XGS-PON TRxs is also considered. The work concludes with the overall system performance assessment for the aggregated scenarios, in Fig. 1, in terms of ONU connectivity, cost of aggregation, and power consumption.

II. Methodology

With node consolidation, the target is connect as many ONUs as possible over a broader distance. The crucial pa-

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rameter about the longer layouts in OAN is the Optical Path Loss (OPL), which increases with the distance, and/or with the SR. Each PON standard [2] complies with different attenuation categories, also known as ODN classes, of the physical network infrastructure. Since XGS-PON [6], the necessary condition for OPL stays at 29dB, also called N1 ODN class. Other attenuation categories include N2 (31dB), E1 (33dB), E2 (35dB), and B+ (28dB)/C+ (32dB) for backward compatibility with GPON solutions. Here, the network planning is done with N1 and C+ ODN classes.

Fig. 1 illustrates the proposed aggregation-based migration schemes for the PON deployment towards 100G-Coherent:

(i) *XGS-PON ST/SP*: Where all the peripheral OLTs are moved to the main CO, via a P2P backbone in either Steiner Tree (ST) or Shortest Path (SP) infrastructure layout. In this scenario, an additional backbone OPL is introduced per PON connection, and some ONUs might become 'disconnected' based on the RxS range of XGS-PON for the given ODN class.

(ii) *100G-Coherent PON (CPON) R-OLT*: A backbone ODN is introduced among all the COs with SR=1:8, where peripheral CO locations remain active, having R-OLTs placement with embedded C-ONU. This architecture has shown remarkable results in terms of CapEx for performing aggregation, and ONU connectivity [7], however, the overall power consumption might have some negative implications because of having additional active units.

(iii) *100G-CPON P2P-ST/SP*: Similar to *XGS-PON ST/SP*, however the entire network from main CO to the end-user ONU in each region is driven by 100G-Coherent technology, using either ST or SP backbone layout. The P2P here refers to the interconnection between the main CO and all the peripheral OLTs.

With these architectures in mind, a power consumption at the operator's side, i.e., at the COs is evaluated and compared.

III. Performance Evaluation

The proposed schemes are planned for the city of Ulm (Germany), having 20880 ONUs, which is then consolidated with surrounding 11 sub-urban regions, giving rise to a total of 73500 ONUs. The local PON planning in individual regions are done with the SR=128 (also for 64 and 32 for comparative purposes). Table I shows the maximum power consumed by every active component at the COs, for the discussed PON technology. For 100G-CPON, OLT per port power is determined by the difference in the trends for IM-DD and Coherent technologies in terms of energy consumed per bit [10]. The assumption for C-ONU's power is based on the simplified design by [12], [13].

TABLE I
Power consumption per active component

	Component	Power [W]
XGS-PON	OLT per port	10.313 [8]
	TRx N1	2.599 [8]
	TRx C+	3.3 [9]
100G-CPON	OLT per port	3.208 [10] times XGS-PON's OLT per port = 33.08
	TRx	5.5 [11]
	C-ONU	10 (deduced from [12])

Fig. 2 depicts a thorough power analysis, based on different SRs for all aggregation schemes. On the x-axis, six different schemes are shown: (1) Using only N1 ODN class components for XGS-PON in an ST layout; (2) Using both N1 and C+ components based on each ONU's OPL requirement for XGS-PON in the same ST layout; (3) Using both N1 and C+ components for XGS-PON in SP layout; (4) proposed *100G-CPON R-OLT* scheme with active peripheral COs; finally (5) and (6) aggregated 100G-CPON network with P2P backbone in ST and SP layout, respectively. Fig. 2(a) denotes the total power consumption with segregated active components' consumption (main OLT and main TRx (say OLT, TRx), peripheral OLT and peripheral TRx, and C-ONU at peripheral CO location), for SR=1:128. Having additional active units in *100G-CPON R-OLT* scenario results into a marginal 3.24% higher power consumption than the best XGS-PON scenario, i.e., *XGS-PON SP (N1/C+)*, which formulates a gradual migration step towards the $\sim$35kW consuming *100G-CPON P2P* scenario. However, 100G-CPON can also supports SR>128, i.e., 256, 512, even 1024 in very dense regions [5], which would minimize the required active components at the main CO.

Looking towards the power per connected ONU, Fig. 2(b) gives a comparison in terms of different SR. A lower SR constitutes to lower splitter loss, hence have a higher number of connected ONUs, but then also deals with a major amount of active OLTs requirement at the CO. The relative difference between *XGS-PON SP (N1/C+)* and *100G-CPON R-OLT* varies from 2.52%$\uparrow$ for SR=1:32, to 1.14%$\uparrow$ for SR=1:128, which means the higher SR eases the migration towards 100G-Coherent, in terms of power consumption. The same can also be said for power per delivered datarate, shown in Fig. 2(c). For *100G-CPON P2P* scenarios, the delivered datarate is 781.25Mbps for SR=1:128, ten times than the other schemes for the same SR, hence consuming only 0.6W/Gbps-ONU.

To summarize the impact of each aggregation scheme, in terms of aggregation CapEx, power, and connectivity, a spider-plot is shown in Fig. 3. The CapEx model, from [7], is combined with the power consumption model of this work, along with the number of disconnected ONUs. The motive is to have a migration scheme which covers the least area in the plot. Only N1 ODN class for aggregation is unrealistic due to 43.8% of disconnected ONUs, hence not discussed further. The 'blue' (XGS-PON ST) and 'yellow' (100G-CPON R-OLT) curve has the same backbone's physical layout, i.e., Steiner Tree (ST), hence when focuses only on power, then 'yellow' consumes 8.86% less than that with aggregated XGS-PON, while delivering the same 78.125Mbps per connected ONU. As expected, the 'extreme' scenario of *100G-CPON ST/SP* requires the highest CapEx and power.

IV. Conclusion

The work investigates the idea of aggregation/node consolidation, aiming the future deployment of 100G PON everywhere, thanks to the high Receiver Sensitivity (RxS)

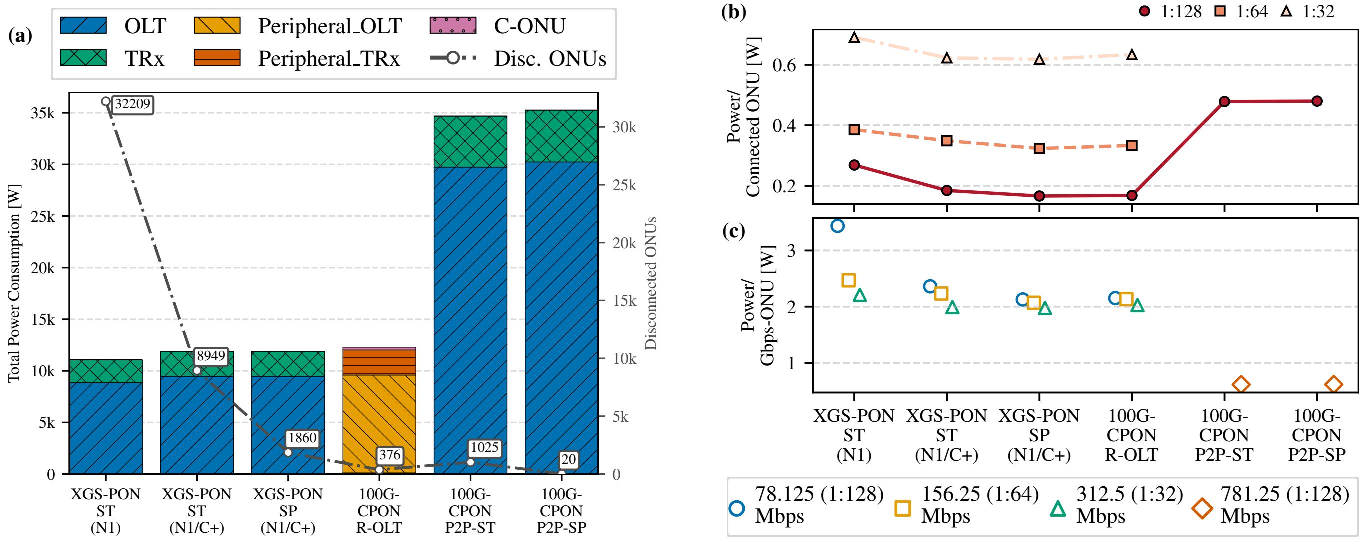

Fig. 2. (a) Total power consumption (left-bar) for the operator's COs for every aggregation scheme; and the number of disconnected ONUs (right-line). (b) Power consumption per connected ONU for given SR. (c) Power consumption per delivered datarate for each connected ONU (operator side only).

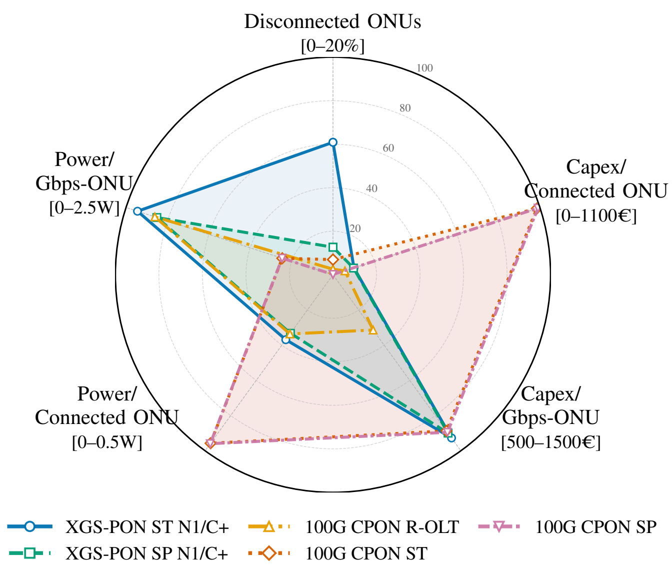

Fig. 3. Normalized overall performance comparison of the discussed aggregation schemes. Metric ranges (in square brackets) are adjusted for a distinguishable analysis.

of coherent technologies. Before moving to 100G-Coherent deployment, first the aggregation using the existing XGS-PON technologies is implemented with both ODN classes upto 32dB. However, the lower RxS of XGS-PON limits the extending reach of the main CO, leading to a higher number of disconnected ONUs (in thousands). The cost- and energy-effective method to begin the future-proof 100G deployment starts with introducing a coherent backbone ODN among all the neighboring COs, keeping the central location as the main CO, i.e., Ulm. This ends up having potentially more active units, however, leading to an increase of only 1.14% higher power consumption per connected ONU, 2.1mW. On CapEx front, this method already proved itself to be highly cost-efficient, with 41.84% lesser cost/connected ONU, in comparison with the aggregated XGS-PON schemes. This work initiates a techno-economic migration towards the '100G in access' goal, using the benefits of longer differential reach with coherent technology.

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