

New Use Cases for PONs Beyond Residential Services

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Abstract: New use cases for PON are highlighted in critical network infrastructures and industrial factories. Introduction of more flexibility and increased determinism including bounded latency, low jitter, highly secure and available connectivity over PON is addressed.

1. From FTTH-centric to new use cases for PON

Passive optical network (PON) systems are a low-cost and mature technology that is the predominantly used solution in fiber-to-the-x (home, building, curb, …) deployments today. More than 70 million optical line terminals (OLT) and more than 900 million optical networks units (ONU) have been shipped worldwide in the past ~13 years. All PON systems up to the 10 Gbit/s-capable PON generations have been driven by the objective to increase peak broadband capacity for the last mile to satisfy the growing demand over the years originating from e.g., triple play, IP TV and OTT video [1]. Beside throughput in recent years also the user experience has gained significant importance and is addressed by applying methods such as "quality of attenuation measurement" [2] that consider beside throughput also the application latency and end-to-end reliability. The interest especially from business users in true symmetrical 10 Gbit/s services is driving the introduction of higher-speed time division multiplexed (TDM)-PON solutions, like the 25 GS-PON [3]. This recent PON deployment option coincides as well with the expected demand for affordable optical transport solutions as part of the 5G radio access network (RAN) densification applying many small cells, and disaggregation of RAN functions for centralized or Cloud-RAN realizations. To fulfil the requirements for mobile transport, PON systems have been designed beside taking care of the peak capacity especially on the following: a) a reduced PON system latency, especially in upstream (US) direction, by inventing low latency medium access control (MAC) mechanism allowing for reduced inter-burst gap waiting time, thus allowing for a roundtrip PON system latency below 100 µs [4, 5], b) defining a common transport interface (CTI) by ORAN, enabling the distributed unit (DU) to signal upfront the uplink capacity requirement of the radio unit (RU) for the subsequent radio slots towards the OLT, thus allowing the PON system by using cooperative dynamic bandwidth assignment (co-DBA) to timely accommodate to the RAN capacity needs and to offer this way a combination of lowest US latency with statistical multiplexing gains allowing for a larger number of cell aggregation over PON [6], c) enabling the synchronization over PON needed in the 5G RAN networks [7], and d) development of radio unit (RU)-pluggable ONUs for simplicity.

In this paper, we highlight new use cases for PON in critical network applications, e.g., for automated driving services [8, 9], and for industrial factory environments [7]. These scenarios extend beyond the residential and optical transport for RAN applications, thus, desire for more determinism, like enhanced secure and available connectivity, bounded latency, and low jitter. How future PON systems [10] can benefit from more flexibility is outlined as well.

2. Flexibility as a new PON paradigm

Today's PON generations apply for each OLT-ONU connection the same modulation format (NRZ-OOK) and forward error correction (FEC) code rate, e.g., in G.9804.2 (50 G-PON) a punctured form of the low-density parity check code (LDPC) from IEEE 802.3ca with 0.8444 code rate. Thus, there are no degrees of freedom for throughput or power budget margin enhancement on top of the nominal line rate or nominal power budget.

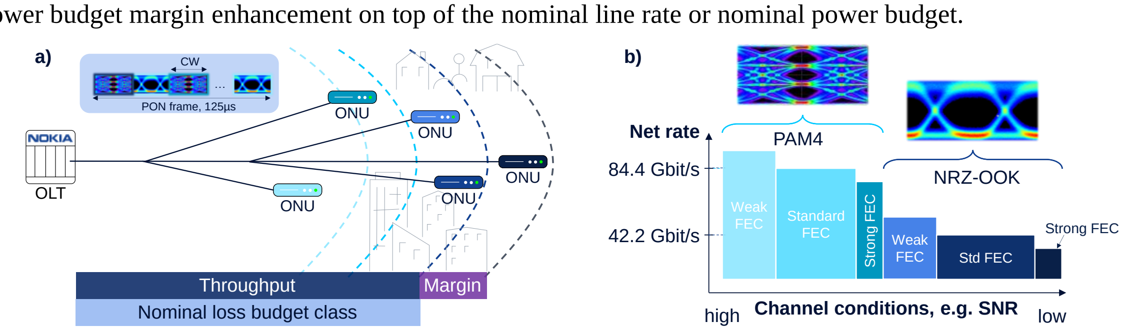

Fig 1. Flexibility in PON can enable new features, like throughput increase and increased power budget margins, see (a). In (b), it is shown how the flexible modulation format and flexible FEC can be allocated according to channel conditions, (cw codeword).

However, in the amendment phase of the 50 Gbit/s TDM-PON standardization in ITU-T (SG15/Q2) an analysis to adopt a first wave of flexibility in the US directions by applying different FEC code variants to support higher throughput or increased power budget margins is ongoing [11]. A similar approach has also already been applied in a proof-of-concept (PoC) operator trial realizing a 100 Gbit/s TDM-PON [12] in the downstream direction. In this PoC the channel capacity can be maximized for groups of OLT-ONU connections that experience similar signal-to-noise ratio (SNR) capabilities. The modulation format can be adjusted applying the same 50 GBd symbol rate, e.g., NRZ-OOK and PAM4, and different FEC codes, see Fig. 1, as well as probabilistic shaping [13] can be allocated. The throughput can also be traded off with the optical power budget, i.e., even extensions to the nominal power budget classes using a stronger FEC code, i.e., using a lower FEC code rate, are possible.

Some key benefits of this flexible-PON approach are: 1) building on top of the digital signal processing toolboxes introduced for the 50 G-PON solution and reusing the same 25 GHz opto-electronic receiver components and similar equalization techniques and FEC code variants, 2) doubling of net rate for majority of ONUs can be possible, however, depending upon the actual operator optical distribution network designs and 3) increased margins for robustness. All of that can extend not only the lifetime for applying intensity modulation and direct detection in PONs towards 100 Gbit/s peak capacities, but it can also be used to accelerate use cases. For example, the Cloud RAN-over-PON solutions typically come with demands of maximum 10 km fibre reach and a deployment density that is lower than for residential scenarios. This can leave margins in the power budget that can be exploited to increase the throughout per group of OLT-ONU connections and support satisfying the peak capacity demands, especially present in the fronthaul transport segment.

3. PON as part of the critical network infrastructure use case

Smart city networks require cost-efficient fiber connectivity for a variety of services ranging from massive IoT to sustainable transportation systems [8, 9]. Especially the evolution towards automated shuttle busses demands for communication network connectivity to enable these vehicles to exchange transport information with the environment or for entertainment. The German Government has released a law for automated driving that allows for limited regular operation of autonomous vehicles that do not require human interaction in their operations, i.e., SAE level 4, starting from 2022 onwards. This law demands the vehicles to have at any point in time a communication network connectivity as well as the opportunity to establish a secure connection with a remote assistance (RA). The role of the RA is to provide teleguidance for automated vehicles in the rare cases that vehicles are stuck in a traffic condition. To enable the RA to offer a proposal for the movement of the vehicle, it is beneficial to provide the RA with all necessary information of the scene, e.g., 360° video, lidar and radar information as well as information from transport infrastructure. This scenario indicates that the RA demands not only for a secure and trusted, but also for an available and robust end-to-end network connectivity. This use case is an example for making the PON part of a critical network infrastructure, see Fig. 2. Other use cases in this field could be power grid or water network control.

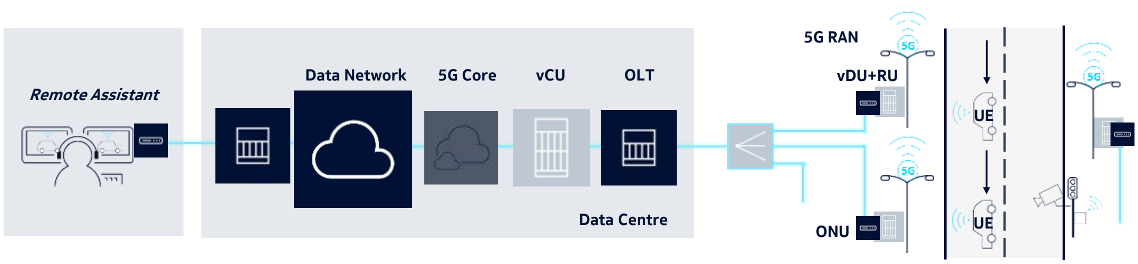

Fig. 2: PON as part of a critical network infrastructure use case.

PONs are already designed for point-to-multipoint operation, thus authentication and encryption, like AES-256 as per latest PON standard G.9804.2, can be applied to offer secure connectivity. Further, the availability of the PON link connection can be enhanced by monitoring, resilience, and protection of optical distribution network and PON endpoints. Contrary, there is a debate on the required level of security and availability and the general demand to further strengthen implemented techniques. An increased level of isolation as well as of prioritization of services for critical applications seems desirable for the logical and physical connections. The partitioning of a single PON network function or service into multiple instances of that function or service is under discussion by G.sup.PONslicing in SG15/Q2 to realize access network slicing. The PON slicing features can be combined with the available methods of translating 5G RAN slices into VLAN traffic descriptors and DBA priority levels. In addition, the “PON flexibility” can be utilized to generate virtually separated physical channels within the same system by corresponding assignments per codeword. This concept is extendable into areas of security and availability as well.

4. PON as part of the Industry 4.0 factory use case

The development towards flexible factory floors for smart production connected with providing augmented reality for support of the fabrication processes let the manufacturing industry consider the convergence of the operation technologies (OT) with the information technologies (IT). Thus, the extreme requirements on latency and jitter (i.e., packet delay variations, PDV) for time critical machine operations in OT coexist with the demands from best effort IT traffic, e.g., from video cameras. In the industrial environment, time-critical data flows are typically cyclic with fixed size packets repeated every period. The maturity and cost efficiency of PON systems make them very attractive for this non-telecom application in the Industrial 4.0 environment [7]. Here, a challenge for the PON is to satisfy the demand of time-critical applications and/or of time sensitive networking (TSN). Mismatches between OT cycles (hundreds of µsec to few msec) and PON reservation cycles, as well as uncontrolled offsets would create latency variations, jitter, which could disrupt the time-critical applications. Thus, the traditional PON must be augmented to achieve industrial-grade performance by adding a jitter compensation (JC) functionality and modifying the conventional DBA process for US transmission using multiple bursts per 125 µs PON frame [14].

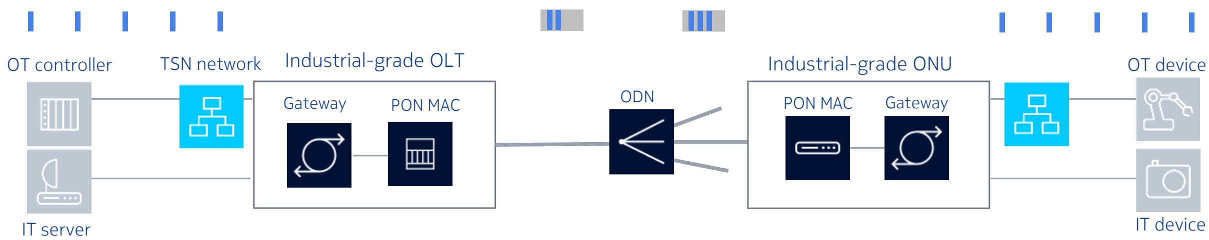

Fig. 3: Industry-PON use case.

In general, in PON systems beside burst reservation cycle in US direction and phase of these bursts inside the frame, jitter contributions from Ethernet switching fabrics and rate conversions need to be considered. In [14, 15], we address these challenges and demonstrate an industrial-grade PON operation allowing transport of time-critical flows and interworking with TSN. In our PoC, a commercial TDM-PON system with a low-latency MAC is augmented with JC modules that connect as gateways to the ONU and to the OLT, see Fig. 3, as well as to TSN switches. IEEE 802.1AS precision time protocol (PTP) is used for synchronization. The JC includes a gateway (GW) at the ONU side that for every PON reservation cycle of 31.25 µs encapsulates the time-critical bitstream, including idles, into an Ethernet frame. The frame is carried in PON bursts to the OLT where it is forwarded to the egress JC-GW for decapsulation and directing the data to the dedicated OLT output port, i.e., forming a tunnel for the ONU-OLT connection. In the PoC, we measure jitter of time-critical flows over the industrial-grade PON of < 1 µs irrespective of the mismatch in cycle times and background IT traffic demands.

5. Summary

We have introduced new PON use cases in critical network applications and industrial factory environments and have shortly discussed flexibility in PONs. More details will be provided in the conference talk.

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