Efficient Transport of eCPRI Fronthaul over PON

Jochen Maes[(1)], Sarvesh Bidkar[(2)], Michael Straub[(2)], Thomas Pfeiffer[(2)], Rene Bonk[(2)]
[(1)] *Nokia Bell Labs, Copernicuslaan 50, 2018 Antwerp, Belgium, jochen.maes@nokia-bell-labs.com*
[(2)]*Nokia Bell Labs, Magirusstrasse 8, 70469 Stuttgart, Germany*

Abstract: Passive optical networks (PONs) facilitate small cell deployments. Back- and midhaul already make efficient use of PON. We explain the steps taken in mobile and in PON industries to enable efficient eCPRI fronthaul over PON.

1. Introduction

The ongoing massive fiberization of the access networks globally is spurred by fiber-to-the-home (FTTH) broadband connectivity. Economic viability is enabled by selection of point-to-multipoint (P2MP) passive optical network (PON) technology, in which the feeder fiber and line termination port is amortized over several tens to a hundred subscribers and by the massive volume of the residential market. Current roll outs are dominated by XGS-PON that can deliver up to 10 Gbit/s symmetrically. Besides homes, the FTTH network passes schools, local shops, and small and medium enterprises. Business parks, shopping areas, airports and industrial zones are also being fiberized. They demand a service level agreement (SLA) tier, as provided by the latest commercially available 25GS-PON. The ability to deliver all these services over a single high performance fiber network generates more revenues, reduces power consumption, lowers the total cost of ownership (TCO), and allows to rapidly introduce new services. Mobile transport is one such service that can synergistically benefit from the massive availability of fiber. A fiber transport network dedicated to mobile transport is scalable for macro cells, where the cell area is measured in units of km^2. On the other hand, the introduction of small cells is enabled by the availability of the FTTH network on the corner of every street, leading to a reduction in time-to-market and TCO [1]. Small cell densification is a gradual process. It starts with the deployment of few small cells on selected hot spots. Initially, we may see just one or few small cells per PON optical distribution network (ODN) that covers a service area of about 64 FTTH customers. While early small cells deployments may favor backhauled all-in-one radio access points, future deployment may require fronthaul solutions to support uplink distributed massive multiple-input-multiple-output (MIMO). Both the future densification and the shift towards fronthaul pose increased requirements on the transport network. In this paper, we clarify how back- and midhaul transport networks are being dimensioned and provide an overview of technical and standardization developments in the mobile and fixed access industries to improve scalability towards future densified and fronthauled small cell networks.

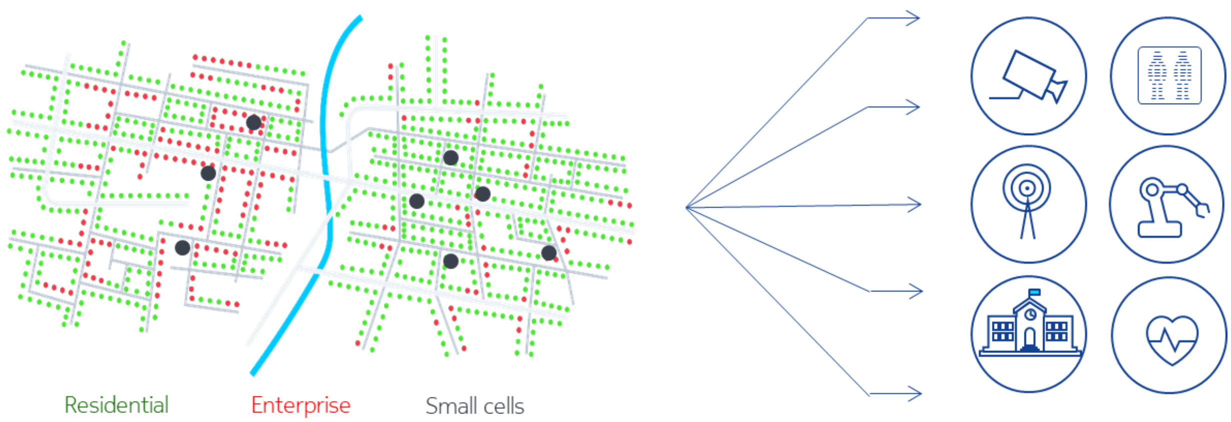

Fig. 1. The ubiquitousness of the PON fiber infrastructure, amortized over multiple services, provides a small cell transport network with short time to market and low TCO.

2. Mobile back- and midhaul over PON

Mobile backhaul transport is characterized by moderate requirements on data rate and latency. The data rate over the backhaul link is directly proportional to the instantaneous air interface throughput of a cell. Consequently, the backhaul data rate varies over time and between cells. The Next Generation Mobile Networks Alliance (NGMN) has formulated dimensioning guidelines that mobile networks operators (MNOs) globally have adopted to dimension their transport network for 4G [2]. These well-established dimensioning guidelines are continued to be used for 5G deployments. In essence, the guidelines stipulate that the backhaul data rate during busy hour is on average between ¼ and 1/6 of the peak cell throughput. This data rate is referred to as the busy hour average (BHA). The transport network can be dimensioned accordingly, provided that the number of aggregated cells is sufficiently large. At the expense of slightly higher transport rates, the same dimensioning applies to midhaul that provides connectivity between distributed units that perform layer 2 medium access control (MAC) and a centralized unit that performs layer 3 radio resource control (RRC).

One benefit of PON is that it allows to extend aggregation gains over the full transport network (see Fig.2). With point-to-point (P2P) optics, each cell site needs to be dimensioned for the peak cell throughput. Instead, PON allows to aggregate over a shared fiber connected to a single Optical Line Termination (OLT) on the network side. This is illustrated in Fig. 2 with the numerical example of midhaul for cell sites with three sectors for omnidirectional coverage. Each sector employs 100 MHz spectrum and 4x4 MIMO. The peak midhaul data rate requirement is 1.9 Gbps per sector [3]. This occurs when there is a single user equipment (UE) (the red UE in Fig. 2) in the cell consuming all air interface resources at maximum modulation and coding scheme (MCS). With a point-to-point fiber to each cell site, the fiber capacity needs to be 3x this number, requiring 10 Gbps P2P optics to each cell. However, this peak occurs rarely, let alone concurrently over sectors. In practice, MNOs dimension the transport link for the BHA, i.e. the transport rate required when 100% of the air interface is utilized by numerous UEs dispersed geographically over the area covered by the cell. In our numerical example, the BHA is 400 Mbps (assuming the BHA is 1/5 of the absolute peak data rate) per sector, or 1.2 Gbps per cell site [3]. This means that about 8 cell sites can be supported on a single XGS-PON, leading to a vast efficiency increase compared to using 8x 10G P2P optics.

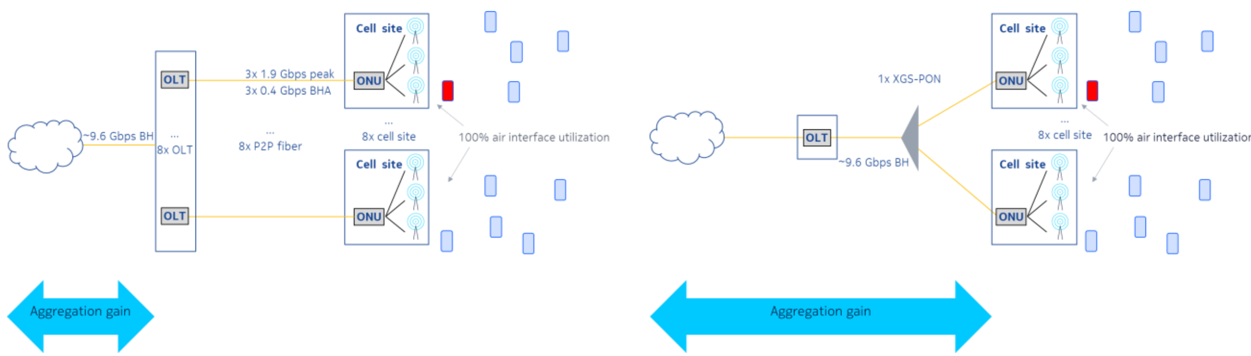

Fig. 2. PON allows to dimension for busy hour average, and for excess bandwidth up to a single absolute peak rate.

3. Mobile fronthaul over PON

Early digital fronthaul solutions in 4G employed the common public radio interface (CPRI) to transport the time domain IQ stream. CPRI leads to a high and static transport bandwidth requirement [4]. There will be no aggregation gain for CPRI over PON. Hence, only a limited number of low-capacity cells can be CPRI fronthauled over a single PON. This may be fine for initially sparse small cell deployments. CPRI has a stringent latency requirement. It has been demonstrated in [5] that PON meets those latency requirements by allocating a constant bitrate to the CPRI service with an upstream delay tolerance configured at ¼ of the 125 µs PON frame duration.

In more recent fronthaul architectures, radio units can perform some of the lower physical layer (PHY). This reduces transport bandwidth. Multiple functional splits exist. Notably, 3GPP split option 7-2 has been moved forward by the O-RAN alliance as an open interface for multi-vendor interoperability. Split option 7-3, in which layer mapping is performed in the radio unit (RU), is more bandwidth efficient. Consequently, a larger number of cells can be aggregated with split option 7-3 [3].

Since the mobile scheduler is centralized in the Distributed Unit (DU) (Fig. 3), the eCPRI fronthaul does require low latency. In downstream PON, this comes naturally through proper prioritization of eCPRI over potentially other services on the PON. In upstream, low latency can be guaranteed through proper configuration of the delay tolerance, as in the CPRI case [5]. However, the PON scheduler is traditionally reactive since it bases itself on observed traffic and queue filling in the Optical Network Unit (ONU), and will react too slow relative to the fronthaul latency requirement. The same solution as for CPRI can be used, i.e., to allocate a constant bit rate that can support the peak transport. But then no aggregation gain is achieved. Another solution is to coordinate the PON scheduler with the mobile scheduler (Fig. 3). Since the mobile scheduler informs the UEs of their future allocations, the mobile system is knowledgeable about future upstream transport requirements for each radio unit. The mobile scheduler then informs the PON scheduler on the amount of bandwidth. For this purpose, O-RAN has defined a Cooperative Transport Interface (CTI) to exchange control messages between the mobile and the PON system [6]. Similarly, ITU-T has created a supplemental document describing the use of these CTI messages by the PON system [7]. Using CTI, PON transport can maintain low latency while achieving aggregation gain [8].

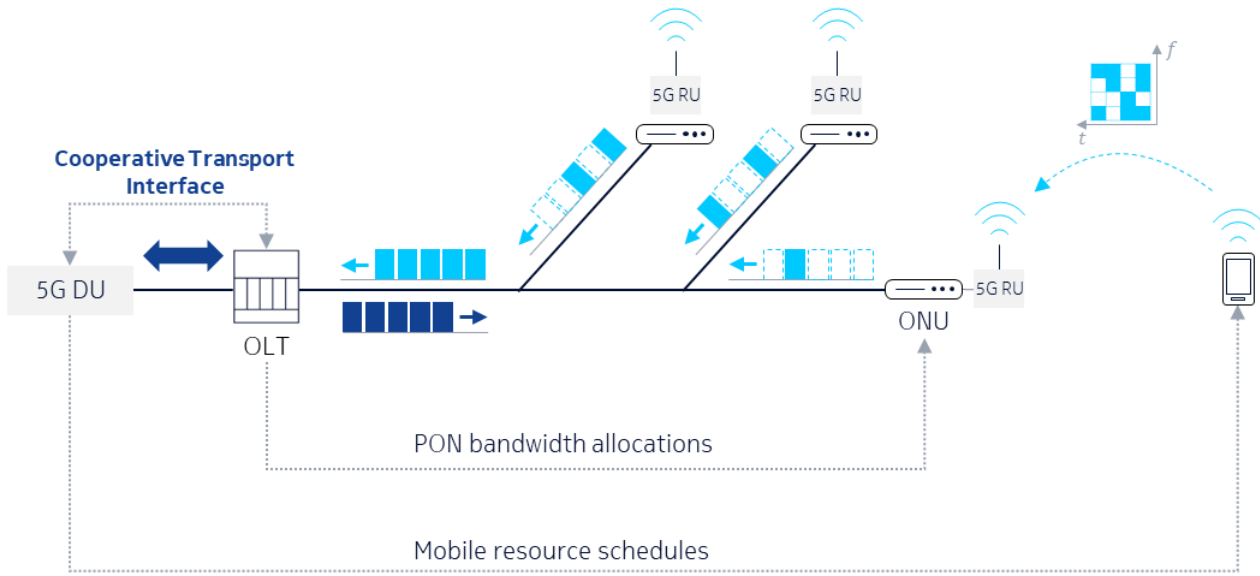

Fig. 3. Coordinated scheduling enables aggregation gains for eCPRI fronthaul over PON while respecting low latency transport requirements

4. Neutral host

A converged operator that provides both fixed and mobile services in the same geographic area can readily use its own PON network for mobile transport. Other MNOs may seek fiber access through a PON infrastructure provider that acts as a neutral host. The neutral host will typically provide access for multiple service providers, potentially multiple MNOs. It operates and monitors its fiber network independently from the systems of the service providers. [9].

5. Conclusions

PONs facilitate small cell deployments. The main benefit is total cost of ownership and time to market. As opposed to a new fiber network to be built solely for small cells transport, the already available PON infrastructure is amortized over multiple services including residential and enterprise access. Initial small cell deployments on sparse hot spots are readily achievable over PON. Back- and midhaul architectures scale well to future small cell densification. Solutions to make fronthaul scale well to future small cell densifications are underway in the mobile industry as well as in the PON industry.

6. References

[1] A. Rafel, and J. Maes, “Comparing Optical Transport Technologies for X-Hauling 5G Small Cells in the Sub-6GHz”, in *Journal of Optical Communications and Networking* 14 (4), pp. 204-210 (2022)
[2] NGMN Alliance, “Guidelines for LTE Backhaul Traffic Estimation”, ngmn.org/publications, (2011)
[3] S. Bidkar, P. Dom, R. Bonk, and Th. Pfeiffer, “Mobile Xhaul Traffic Modelling for High-Speed TDM-PON,” in proceedings of ECOC (2020) paper We2J.5
[4] A. de la Oliva, J. A. Hernandez, D. Larrabeiti, and A. Azcorra, “An overview of the CPRI specification and its application to C-RAN-based LTE scenarios,” in *IEEE Communications Magazine* 54(2), 152–159 (2016)
[5] S. Bidkar, J. Galaro, and Th. Pfeiffer, “First Demonstration of an Ultra-Low-Latency Fronthaul Transport Over a Commercial TDM-PON Platform”, in proceedings of OFC (2018) paper Tu2K.3
[6] O-RAN Working Group 4, “Cooperative Transport Interface Transport Control Plane Specification”, O-RAN.WG4.CTI-TCP.0-v03.00, (2022)
[7] ITU Study Group 15 Question 2, “OLT Capabilities for Supporting CO DBA”, ITU-T G.sup.71 (2021)
[8] S. Bidkar, K. Christodoulopoulos, Th. Pfeiffer, and R. Bonk, “Evaluation of Burst Scheduling Schemes for Cooperative DBA enabled TDM-PON for 5G Fronthaul” in proceedings of ECOC (2022) paper Mo3C.2
[9] M. Straub, V. Hückstädt, M. Ulrich, Th. Pfeiffer, and R. Bonk, "Field Trial of a System-Independent Infrastructure Monitoring System for Access Networks," in proceedings of OFC (2021) paper M3F.3