5G & Optics in 2020 – Where are we now? What did we learn?

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Abstract *Optical networks requirements and solutions for 5G transport are discussed. Evolution of Point to Point, TDM PONs, and WDM networks are presented as candidates for fronthaul and mid or backhaul equipment.*

Introduction

Optical transport for Mobile technologies is often taken for granted as a limitless resource to connect Radio Access Network (RAN) equipment. However, legacy 4G networks have already supported serious evolutions with a generalization of Fiber To The Antenna[1],[2] and 5G induces even more challenging evolutions of the optical networks to deliver high throughput with low latency for enriched user services : enhanced Mobile BroadBand (eMBB); Ultra Reliable Low Latency Communications (URLLC); massive Machine Type Communications (mMTC)[3],[4]. With the new RAN technologies deployed for 4G and 5G, the optical transport network architecture now rely on backhaul, midhaul or fronthaul links according to the functional splits implemented in the RAN machines[5],[6]. The 3GPP 5GRAN architecture defined the 5G radio base stations (gNBs) that consist of 3 main functional modules: the Central Unit (CU), Distributed Unit (DU) and the Radio Unit (RU). Those modules can be deployed with different combinations according to the targeted services constraints, antenna site configuration and location: Distributed RAN (DRAN) and Centralized RAN (CRAN) are proposing contrasting architectures, depicted on Figure 1. DRAN is the most classic configuration when CU, DU and RU remain at the antenna site and a simple backhaul link is used to connect the 5G Network (5GC). CRAN allows reducing the footprint on antenna sites with the centralization of the CU and possibly the DU in a remote site (Central Office or Main Office). However, according to the chosen functional split[7], the transport networks will have different interfaces to carry different traffic types (CPRI, OBSAI, ORI or Ethernet based eCPRI and O-RAN 7.2x) with different transport requirements. The throughput is expected to be as high as 10Gbit/s to 100Gbit/s because of Analog to Digital Conversion. It can depend on the radio settings (Frequency, bandwidth, number of component carriers and MIMO configuration) and which high or low layer split is implemented[7]. Since 2018, the Open RAN (ORAN) Alliance intends to combine and develop the work of both centralized RAN alliance (C-RAN) and xRAN Forum[8]. Transport specifications are still discussed in Working Group 9 and 4 and first Fronthaul requirements are detailed in [9].

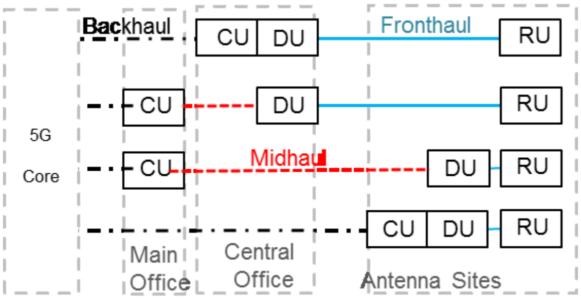

Fig. 1: Fronthaul, Midhaul and Backhaul for 5G

This wide range of constraints on the different Xhaul interfaces is not the only thing that encourages operators to push their optical networks beyond simple pipes with increased capacities. Different classes of services in the optical domain could already be implemented today with legacy equipment to accommodate varying bit-rates, latency/packet jitter needs and service availabilities of the many 5G verticals. However, the advent of network abstraction through software-defined networking (SDN) could be a game changer. At a first moment, it would make equipment configuration automation much easier thanks to vendor-agnostic solutions. Eventually, software based network abstraction and orchestration would allow practical implementations for multi-tenancy and multi-operator use-cases. It would equally enable optical solutions in-line with the different virtualization trends in the mobile domain for intelligent and cooperative fixed-mobile convergence. Finally, an intelligent and generic-hardware based optical node could enable coping with stringent latency requirements of different 5G services by hosting, for instance, virtualized RAN functionalities, content platforms or Mobile Edge Computing[10],[11]. In addition, independently of the functional split, new synchronization approaches (frequency, phase and time) will have to be adopted to allow both frequency and time division diplexing transmissions in the radio layer. Moreover, congestion in optical aggregation equipment will have to be managed to allow proper QoS of proprietary flows such as URLLC, which can be implemented thanks to different Time-Sensitive Network (TSN) strategies[12].

We propose in this paper to present optical solutions to support 5G access networks today and we will discuss about their possible future evolutions. Point to point transceivers, Time and Division Multiplexing Passive Optical Networks and Wavelength Division Multiplexing solutions are good candidates to support 5G networks.

Point to Point optical interfaces for 5G xHaul

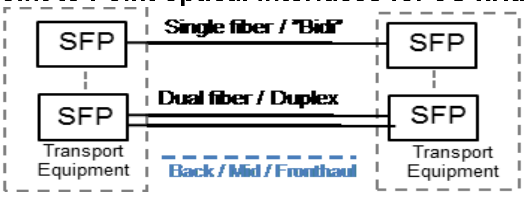

Fig. 2: Point to Point links for X-haul

As shown in Figure 2, PtP optical links rely mostly today on Dual fibre transceivers (Small Form Pluggables SFPs, SFP+ or SFP28) inserted in the RAN transport equipment which could be a RU, Base Band Unit (BBU), Optical Line Terminal (OLT), Open Transport Network (OTN), Switch or router depending on back-,mid- or front-haul links to be covered. For local links remaining on the same antenna site, multimode transceivers used to be deployed. For longer reach and higher bitrates needs, monomode fiber is necessary and PtP transceivers should rely on IEEE or ITU-T standard technologies with “grey” or “black and white” optics. Interoperability between those interfaces is not met today and complicates the operational engineering rules with different reaches, optical budgets and wavelengths to be managed at each end of the networks. A first evolution will be to swap the cell site switches to support 4 Gbit/s over 10GEth interface for backhaul and to carry natively 10G CPRI or eCPRI for fronthaul. A second simplification will be to generalize single fibre transceivers to reduce the number of deployed fibers and to ease installation.

For longer term issues (further deployment of Massive MIMO and FR2 5G), higher bitrates will be required and new standards have been discussed at IEEE and ITU-T for bidirectional PtP above 10Gbit/s. ITU-T proposed a solution for 10Gbit/s and 25Gbit/s “G.9806” and is preparing a 50Gbit/s amendment. IEEE is preparing the standard 802.3.cp expected in June 2021 and efforts are ongoing to propose aligned physical layer parameters. The technologies will rely on two different wavelength assigned for upstream and downstream transmissions with two main optical budget classes(BR20 or Class S [0-15dB] for 20km reach, BR40+ or Class B- [10-23dB] for 40km reach) to cover the needs for 5G x-haul. Non Return to Zero modulation format has been chosen for up to 25Gbit/s transceivers whereas a 4-level pulse amplitude modulation format (PAM4) has already been chosen for 50Gbit/s by IEEE to maintain lower bandwidth optical components. For 50Gbit/s, both NRZ and PAM4 are still discussed in ITU-T.

Those PtP transceivers can be used directly in 5G networks equipment (RU, DU or CU) that will ensure the management and monitoring of the PtP links, such as in RAN systems, BBU, RU switches, routers, OLTs hosting PtP cards. The major drawback of PtP connectivity remains the high number of interfaces and fibers to be deployed. The following optical solutions for 5G will resolve this issue sharing a single fiber in time or optical spectral domains.

TDM Passive Optical Networks for 5G

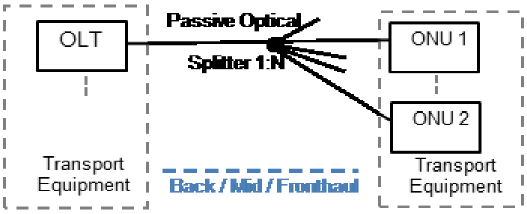

Fig. 3: TDM PON links for X-haul

TDM PONs are massively deployed for Fiber To The Home and Fiber To The Enterprise markets. PON Technologies are now reaching bitrates enabling the transport of 5G traffics[13]. XGS-PON offers 10Gbit/s symmetrical line rates and has been proposed as a serious candidate for 5G backhaul[14] and fronthaul[15]. Figure 3 depicts TDM PON links for X-haul. Sharing the optical fiber with passive optical splitters and with a single OLT port deployed for typically 64 ONUs, TDM PON are also optimum to support the increasing density of cells upcoming with 5G small cells[16]. A maximum 8.5GEth throughput capacity is shared for XGSPON. The OLT PON port can be hosted in regular OLT shelves but also in any RAN Transport Equipment with the development of SFP OLTs, given by the recent progress on virtualization and SDN at the OLT[17].

However, the use of TDM PONs remain limited mainly by the stringent latency constraints of 5G of 100µs (one way latency) for fronthaul and around 2ms for backhaul end to end latency. Specific Dynamic Bandwidth Allocation (DBA) (Cooperative DBA (coDBA), Fixed Bandwidth

Allocation) are proposed to cope with low latency objectives but the minimum latency achieved[18] still remains too important to meet fronthaul requirements for 20km fibre reach. TDM PONs could be still interesting to optimize the backhaul links though. They can also provide network slicing in order to deliver specific network resources and performances for different end user services with a guaranteed isolation from the other services[19]. Different classes of services are already handled via PON T-CONTs and VLAN tags. A physical layer slicing can also be introduced via WDM in addition or not to TDM PON (NGPON2 with 4x10Gbit/s TWDM[20]).

To transport the higher bandwidth required for 5G, Higher Speed PONs (HSP) discussed in ITU-T will offer 50Gbit/s line bite rates but high challenges rely on the optics to meet the optical budget of legacy PONs (at least N1 class with 14 to 29dB)[21],[22]. Digital Signal Processing will be unavoidable and will increase the complexity, cost and power consumption of the optics. Moreover, the maturity of commercial HSP will be slow and compete within a FTTH market which is still investing in GPON and XGS-PON, consequently a mature HSP will be behind 5G deployment schedule.

Wavelength Division Multiplexing for 5G

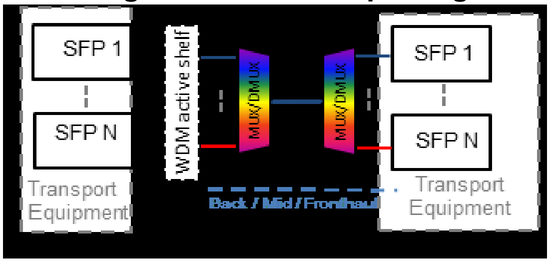

Fig. 4: WDM passive* or semi-active architecture for X-haul

Offering fiber sharing and point to point logical connectivity with wavelength slicing, WDM technologies have been proposed for mobile X-hauling for many years. New specifications are discussed in ORAN WG9 for fronthaul[23] and recent initiatives in ITU-T will lead to a WDM PON recommendation 'G.9802'. However, the management and cost of wavelength in access networks remained obstacles to reach massive deployments. Passive architectures are proposed to lower on site footprint: colored or colorless transceivers are inserted directly in RAN systems. But, semi-active or active architectures are also considered to provide RAN independent Operations Administration and Maintenance (OAM) features of the WDM transport, so at least one active WDM equipment must be introduced in the X-haul transport.

Fixed wavelength (colored) transceivers based on Coarse WDM (CWDM) has been deployed but operational installation and maintenance remained complex. Upgrading the throughput above 10Gbit/s for 5G is also challenging on the full spectrum of the 16 CWDM channels (from 1260nm to 1610nm). For 25Gbit/s, Medium WDM (MWDM) based on 12 CWDM sub-channels has been proposed in the O-band to avoid chromatic dispersion penalties[24],[25]. When more than 16 WDM links are required and to ease wavelength installation and management, the use of Tunable Dense WDM (DWDM) transceivers is needed. Many different colorless optics exist[25] and 25Gbit/s capable commercial transceivers were recently proposed with auto-tunable features[26]. In order to assure automatic wavelength pairing, once the transceivers are connected to the MUX/DMUX a wavelength management link is established via a pilot tone until the wavelengths reach their targeted channels. This makes it very convenient for operational installation. Further development of this technology will lead to bidirectional auto-tunable transceivers at 25Gbit/s for more than 10km reach.

Conclusions

5G requirements for enhanced services led to stringent constraints on the optical transport networks: high throughput, ultra-low latency, high reliability and synchronization accuracy. Distributed RAN will certainly remain the most popular architecture for 5G RAN and Point to Point connectivity will ensure the optical transport with TSN equipment, as long as fiber resources are available. Otherwise, TDM PON and WDM architectures are promising with new technologies reaching high bitrates and lower complexities: SFP OLTs with cooperative DBA for optimized latency of TDM PONs with specific services and X-Haul interfaces; Single wavelength auto-tunable DWDM and O-band MWDM transceivers are available with bitrate up to 25GBit/s for any X-haul traffic.

Particular attention should be given to virtualization trends and OAM features to ease end to end network slicing for multi-tenancy operated transport links. For URLLC and mMTC services, contents servers will go even closer to the RU. Consequently, the X-haul architectures should be adapted specifically and with redundancy of the optical links which is a new architecture for optical access networks. Finally, interoperability between the multiple interfaces to be deployed for 5G will be crucial to ensure the best functionalities at the lowest cost.

Acknowledgements

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