Optical Fronthauling for 5G Mobile: A Perspective of Passive Metro WDM Technology

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Abstract: We discuss the necessity of passive WDM technology in the 5G fronthaul application. The proof-of-concept field trial showed that the proposed system integrated seamlessly with the current wireless equipment and had no impact on services.
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1. Introduction

The upcoming 5G evolution, as well as the higher data rate demand and the multi-service convergence, impose an imminent reformation on the radio access network (RAN) infrastructure. In the 5G era, most radio signal processing in the baseband unit (BBU) will be centralized, in order to ease the implementation of the advanced 5G radio access technologies (RATs), and also to reduce the CAPEX and OPEX of the remote radio head (RRH), which only performs the RF-band/baseband conversion. However, such a functional split between the BBU and RRH might provoke a much higher line rate than the actual data rate in the transport link, commonly known as the fronthaul. In addition, the use cases of 5G are very diverse in terms of the throughput, latency, jitter, device density, etc. this heterogeneity will lead to the coexistence of different RATs. Therefore, the 5G fronthauling will also require more flexible topologies and improved performance [1].

To meet the aforementioned requirements, in the ongoing 5G-PPP project 5G-XHaul [2], we propose a passive metro wavelength division multiplexing (WDM) technology to flexibly provision the optical fronthaul between the RRH at the antenna tower and the BBU at the central office (CO), as illustrated in Fig. 1. The idea is to leverage the passive optical network (PON) in order to cost-effectively deliver the fronthaul data (e.g. CPRI) for massive radio cells, while the baseband processing is centralized and shared at the CO. Given the fact of the practical operations, typically the operators demand for an autonomous wavelength configuration of the remote optical network unit (ONU). Therefore, a centralized wavelength locker is implemented in the optical line terminal (OLT), which is able to set the ONU wavelength automatically according to the connected port at the remote node (RN). More importantly, such an implementation will also significantly reduce the cost of the tunable ONU laser.

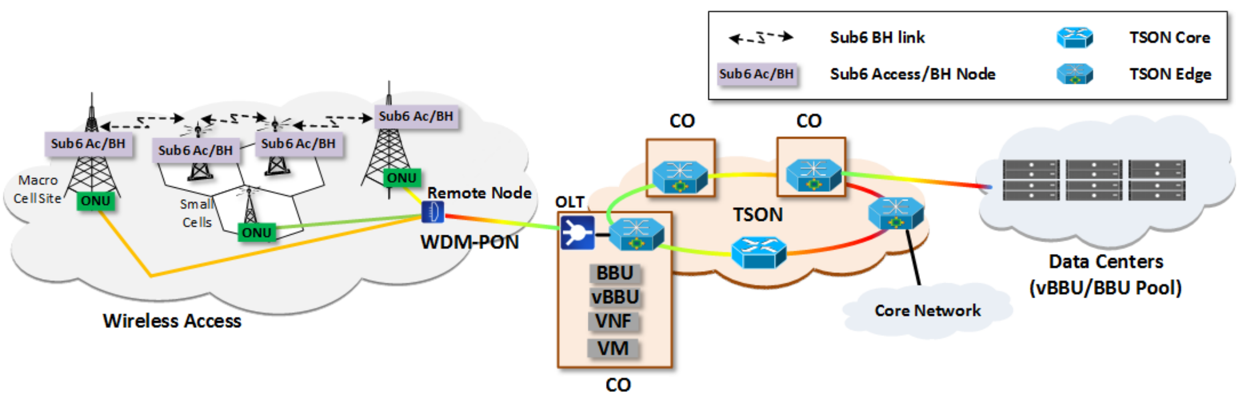

Fig. 1: The key role of the WDM-PON system in the 5G-XHaul project [2]

In this paper, we will elaborate a flexible fronthaul architecture based on the wavelength-agnostic WDM-PON, in which different resources can be assigned on demand from the BBU to the RRH. As a successful showcase, we will also report our recent fronthaul field trial in collaboration with China Unicom, presenting the feasibility of the proposed technology in a real network.

2. Flexible fronthaul architecture

The WDM-PON is designed to deliver a wavelength-based point-to-point (P2P) connectivity between BBUs and RRHs. Each WDM wavelength is currently able to achieve bit rates up to 10 Gbit/s bidirectionally, over a transmission distance of 20 km. For the purpose of single fiber working, the downlink operates at the L-band while the uplink operates at the C-band.

Current Cloud-RAN architectures (e.g. LTE) connect at any given moment one BBU to one RRH, which is suboptimal from an energy-consumption point of view, but in some cases it may be also suboptimal in terms of performance. For instance, some of the new RATs like fractional frequency reuse (FFR) or coordinated multipoint (CoMP) require the transmission of different radio frames from different RRHs [2]. Therefore, we introduce a cross-connect between the BBUs and the client side of the OLT, as depicted in Fig. 2. The WDM-PON system serves for fronthaul transmission by connecting the BBUs at the OLT to the RRHs attached to the ONUs, where the traffic flow of each RRH can be flexibly connected to a different BBU by changing the BBU-OLT transceiver connection in the cross-connect.

To realize the cross-connect a transparent solution can be provided, for instance, by an optical fiber switch. This type of switch is available with the size of up to 384 × 384 ports. The advantage of an optical switch is data rate and format transparency, such that the CPRI, Ethernet or Optical Transport Network (OTN) signal of any rates can be switched. Also, the switching power is typically low and does not depend on the rate of the signal. Alternatively, electrical switches can be utilized in the cross-connect. However, these switches are often rate or format specific, or they might terminate the protocol of the Layer-2 signal. On the other hand, they provide a lower cost solution and can be implemented with a smaller footprint.

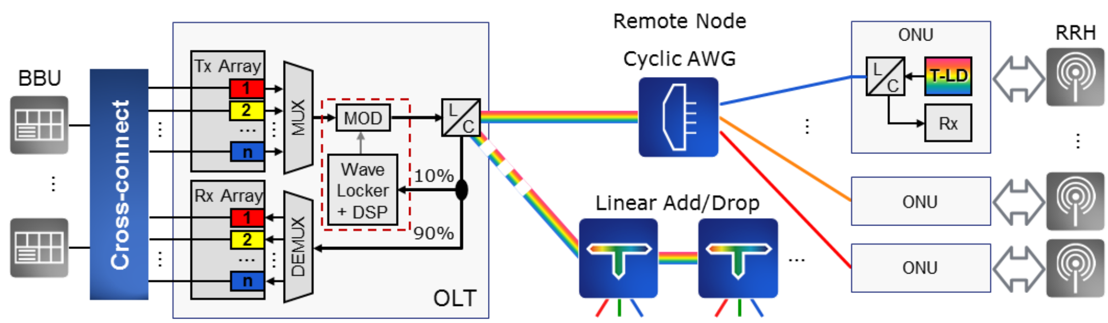

Fig. 2: WDM-PON system architecture flexibly connecting RRHs with BBUs

Ideally, the arrayed waveguide grating (AWG), as the RN that splits and routes the wavelengths, should be located in the field close to all the RRHs, namely in a tree structure. In some cases, however, installing the RN in an optimal location is quite difficult in practice. Alternatively, the add/drop line structure can be adopted, where the individual wavelength or group of wavelengths is added and dropped at the distributed filter nodes along the trunk line. Both structures are depicted in Fig. 2. The add/drop line structure could also add fiber protection by terminating both ends of the line at the CO. In both cases, a single centralized wavelength locker at the OLT communicates with each ONU on a specific wavelength, such that each ONU is able to adaptively select its transmission wavelength to fit the connected filter port by employing an out-of-band communication channel [3]. Thus, instead of the individual wavelength locker in each tunable laser, all the attached ONUs share only one locker, which significantly saves the overall ONU cost.

Currently the ITU-T Study Group 15, Question 6 (Q.6/15) is drafting a new recommendation G.metro, proposing the next-generation WDM access facilitated by such a wavelength-agnostic concept for the ONU devices (called tail-end in the Q.6/15 terms). The communication channel between the tail-end and the central side (called head-end in the Q.6/15 terms) is also being defined as an auxiliary management and communication channel (AMCC) in the G.metro draft.

It is also worth pointing out that the WDM-PON can be in principle used not only for the fronthaul but also for the backhaul application, because both applications can benefit from the transparency of the system.

3. Preliminary field trial

We have been developing the WDM-PON prototype in line with the G.metro draft, and also keep contributing the inputs to this standardization. Recently we collaborated with China Unicom to carry out a successful field trial in Tianjin, China, evaluating ADVA's WDM-PON prototype for the mobile fronthaul application. Fig. 3 shows pictures of the system deployed in the field. The OLT was installed next to the BBU hotel in one of China Unicom's

COs, which serves many public LTE antennas in that area. We then disconnected one of the in-service LTE transmission links running at CPRI option 7 (i.e. bit rate of 9830.4 Mbit/s), and connected that link directly from the BBU to the cross-connect. The cross-connect also converted the grey light to the WDM wavelength in the WDM-PON system, which transmitted the CPRI data to the RRH over the original fiber link. At the remote side, since only one LTE link was tested, we put both the cyclic AWG and one ONU together in the location of the RRH. The ONU was connected to the RRH via an optical transponder, in order to convert the wavelength back to the grey light. Once the system was switched on, the ONU was simply connected to the corresponding port of the cyclic AWG, and the wavelength of the ONU laser was automatically adjusted. The centralized wavelength locker keeps tracking and stabilizing each wavelength as long as the system is in operation.

Fig. 3: WDM-PON prototype installed in the fronthaul field trial

During the field trial, the one-way intrinsic delay of the prototype system (i.e. excluding the fiber transmission) was only 130 ns, and in a 15-hour long-term test, the maximal round-trip jitter was around 2 ns. No data error was observed in all the measurements. Furthermore, we also analyzed the wireless data throughput at the LTE antenna side in a normal smartphone, and the result is shown in Fig. 4. Compared with the LTE throughput without the WDM-PON link, the result with the WDM-PON showed absolutely no degradation in the wireless performance, and also proved that the system is fully compatible with current wireless technology.

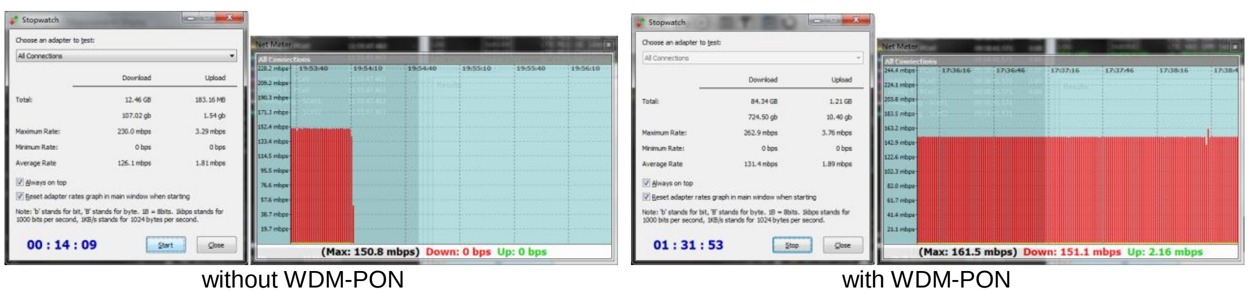

Fig. 4: Measured LTE throughput at the antenna side

4. Conclusions

We believe that the WDM-PON is the most promising solution to the 5G fronthaul, and the proposed system can be flexibly adopted for the heterogeneous wireless applications. With a centralized wavelength locker at the OLT, the ONUs are capable of adapting the wavelength autonomously. This enhanced efficiency will be the key to reducing the overall cost and complexity. The prototype has been trialed successfully in a live network, moving a big step closer to the real-world deployment.

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