Optical Technologies in Support of 5G

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Abstract: Increased traffic in 5G networks is supported by passive optical networks between base band units and remote radio heads. Wavelength control is centralized at the optical line termination. Various network architectures, partly allowing protection, are reported.
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1. Introduction

With the transition from 3G over LTE, LTE-A to 5G, mobile data rates have grown from a few hundred kbps to several Gbps. At the same time, the number of users as well as the number of antennas and base stations is growing exponentially. This growth in the mobile network needs to be supported by the optical backhaul network connecting the baseband unit (BBU) with the data center. In addition, the current trend goes towards separating the BBU, in which the signal processing for multiple antennas (or remote radio heads - RRHs) is performed, from the antenna itself, where the radio frequency processing takes place. In the mobile backhaul section, mostly Ethernet protocol data are transmitted between the data centers and the BBUs. The data rates currently required here are around one Gbps. In the mobile front-haul section, the BBU is connected to the radio heads over direct fiber links, currently mostly running the Common Public Radio Interface (CPRI) protocol with stricter timing requirements than Ethernet. Since the CPRI frames contain the raw IQ data flow for upconverting to the actual analogue radio signal, the CPRI data rate is usually 16 times higher than the IP rate at the end user. While for 5G different functional splits of the processing in the BBU and the radio heads are discussed, still a very high-capacity connection between the BBU and the radio heads will be required. The current optical transport technologies may support such a bandwidth demand, but unfortunately are far too expensive and thus no longer feasible for the mobile network.

To reduce the cost of the optical infrastructure, the wavelength division multiplexing passive optical network (WDM-PON) can be used for fronthaul as well as for backhaul applications. ITU-T SG15 is currently working on the standardization of a hubbed system with wavelength-agnostic spoke interfaces, in which those interfaces can be remotely controlled.

In this paper, features of the remote tunability will be explained, and we will discuss architectures of the passive distribution network, including variants with protection against fiber cuts.

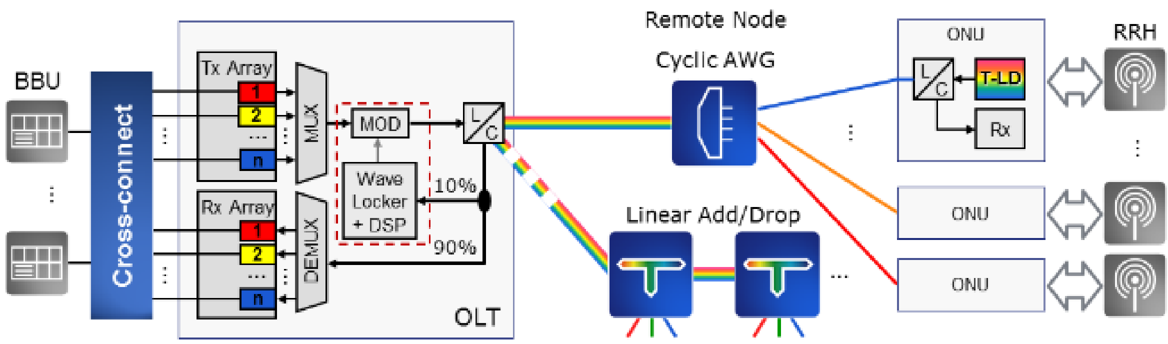

Fig. 1: WDM-PON system architecture for mobile fronthaul

2. Remotely tunable transceivers

To support a widespread deployment of the 5G-infrastructure, a low-cost optical fronthaul and backhaul system is required. Figure 1 shows a possible realization, where tunable ONUs are connected to a central OLT over a single, bi-directional fiber link. The OLT, in turn, is connected to an array of BBUs via a cross-connect. This enables a flexible association of between BBUs and RRHs.

Currently, standardization in the ITU-T SG15 is under way, specifying an optical WDM-PON system to support mobile fronthaul applications. A central point to reduce the system cost is the reduction of functionality placed in the distributed terminals (ONUs) and concentrating the necessary functions in the central OLT. Especially, the central control of the individual wavelengths of the ONU transmitters can help to reduce cost. Not only a reduction of components in the ONU will result from centralizing the wavelength control, but the tunable transmitter lasers will also require less calibration effort, only requiring a generic tuning table, as was demonstrated in [1].

In general, the remote tuning of the ONU laser is based on a message channel that conveys the tuning information from the OLT to the ONU. When an ONU is connected to a port of the remote node filter in the distribution network, it starts sweeping over the full band of allowed frequencies. Only when its frequency coincides with the passband frequency of the remote filter, the signal from the ONU is detected at the OLT and the OLT sends a command to the ONU to stop sweeping and initiate fine tuning. The fine tuning is based on a wavelength locker (e.g. Etalon) located at the OLT. The periodic wavelength response of the wavelength locker allows sharing the device between all ONUs.

To avoid cross talk onto active channels during the tuning phase, sufficient suppression of the tuning wavelength in the add/drop filter or AWG is required [2]. To allow the use of standard filters with limited isolation, however, the transmit power of a tuning ONU still needs to be reduced to avoid interferences, especially as the received power at the OLT might differ strongly between channels added at different distances from the OLT. To still ensure the proper detection of a tuning channel and to distinguish this channel from a strong neighbor channel, the developing standard defines dedicated pilot tones modulated onto the optical signal.

3. Network architectures

In general, the distribution network connects the OLT with each ONU using an individual wavelength pair. The network architecture can be based on a tree structure, where the trunk fiber transports all wavelengths between the OLT and the remote node and the filter in the remote node separates or combines the wavelengths, as shown in Figure 2. It is essential that each drop line between the remote node and an ONU carries two distinct wavelengths, which are then both routed from or to the common port. A cyclic AWG can be used to realize such a remote node filter. Here, in each order of the AWG, based on the internal delay paths, one wavelength is routed between the common port and a drop port. This allows upstream and downstream wavelengths to be located in different orders of the AWG. However, it should be noticed that the frequency spacing in different orders of the AWG does not stay constant. For instance, a frequency grid of 100 GHz in the downstream order might correspond to a 98-GHz grid of the AWG used for the upstream direction. An alternative implementation of the remote node filter would be using 2 x N AWG with an additional band splitter towards the common port. The design can be chosen such that the frequency grid in both directions is identical. Of course, this comes at the cost of an additional band splitter, introducing additional insertion loss of approximately 0.5 dB.

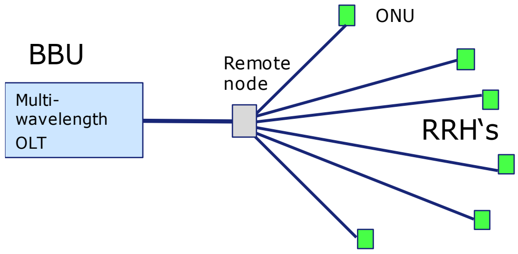

Fig. 2: Star network architecture

An architecture more often used in fronthaul systems is a linear add/drop, where filters along the trunk line add or drop single wavelengths or a group of wavelengths towards individual or a group of ONUs, as shown in Figure 3. The filters in this system would typically be thin-film filters. As in each filter location at least one wavelength would be added and dropped, a more complicated filter structure would be required, assuring sufficient isolation for the added wavelength. Also, the loss budget of the system needs to take into account the concatenated filter loss of approximately 0.5 – 1 dB per filter.

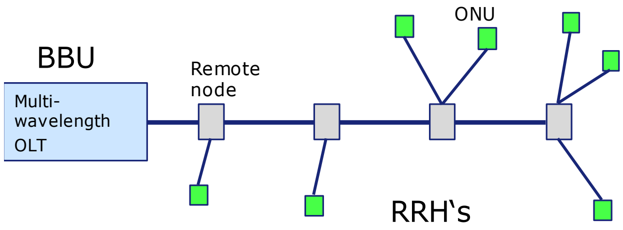

Fig. 3: Linear add/drop architecture

As increasing data traffic is transported over the passive optical network, protection of the physical link becomes necessary. For dual-homing protection, the linear add/drop architecture can be extended such that OLTs are provided on both sides of the line, as shown in Figure 4. If one line end is folded back such that both OLTs are in the same location, the architecture is sometimes referred to as a horseshoe.

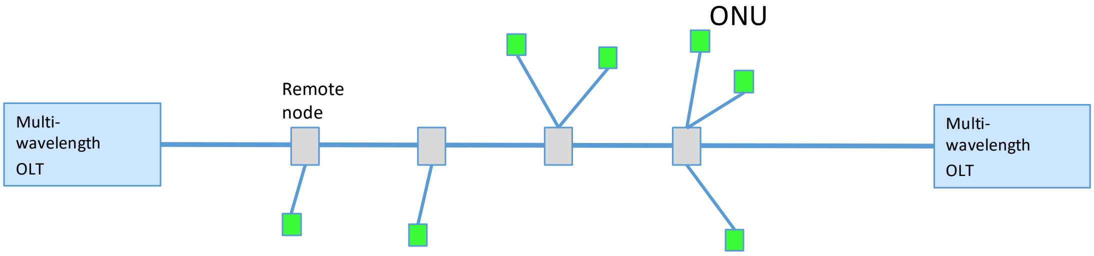

Fig. 4: Linear add/drop architecture with protection

In ONU receiving direction, each filter drops the same wavelength from both directions onto separate fibers towards the ONU. At the ONU, a switch is required to select the one of the two downstream signals to be received. In transmitting direction, the signal can be split and, in the add filter, be sent towards different OLTs. It should be noted that, while an ONU is connected to both OLTs with the same wavelength pair, no two signals with the same wavelength are travelling over any section of the linear add/drop architecture.

4. Conclusion

The growing capacity of mobile networks can be supported by high-performance passive optical networks. Cost reduction in these systems is achieved by moving wavelength control functionality from the ONU to the OLT. Several architectures of the passive networks are facilitated by the centrally wavelength tuned system, including a linear add/drop and a star variant. Protection against fiber cuts can be provided by terminating both ends of the linear add/drop structure.

5. Acknowledgement

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6. References

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[2] C. Wagner et al., "Impairment Analysis of WDM-PON Based on Low-Cost Tunable Lasers,", IEEE J. of Lightw. Technol., **34**(2016)22, pp. 5300-5307.