Performance Assessment of Multiband OADM in Metro-Access Network for Converged Xhaul Traffic

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Abstract *We experimentally assess a flexible SOA-based multiband (MB-OADM) node in the Metro-Access Network for supporting beyond 5G mobile communication Xhaul. Three use cases, Split 5/7.2/8, are considering and experimental results show error-free with power penalty of 1.3dB, 4dB, and 1.6dB at 25Gbps NRZ, respectively. ©2023 The Author(s)*

Introduction

The 5.5G and 6G technologies promise to deliver extremely high data rates (Virtual/Augmented Reality 25 Mbps~ 5G bps), low latency(Tactile <1ms), and massive connectivity, enabling a wide range of new applications and services that were previously impossible. In order to satisfy the different requirements, mobile standards have come up with different functional splitting schemes for radio access network (RAN) [1], where the protocol stack for 5G is grouped into different nodes, Radio Unit (RU), Distributed Unit (DU), Central Unit (CU) and different DU/RU, CU/DU divisions, generically referred as Xhaul [2]. As shown in Table 1, it list the requirements of three representative split functions, namely Split 5, 7.2, and 8. Split 8 uses centralized virtual BBUs at the edge computing node to enable optimum resource utilization [3]. Each RU generates peak data rate of 200Gbps to 850 Gbps at Xhaul [4]. Additionally, the data is accessible when Hybrid-Automatic Repeat reQuest (HARQ) retransmissions are used. The one-way delay must be under 200 us for retransmissions for Ultra-Reliable and Low Latency Communications (URLLC) application [5], which limits the maximum transmission distance to less than 20 km. By sinking the iFFT, beamforming calculations into the RU, in the Split 7.2, the bandwidth requirements will be reduced, and each RU generates a peak data rate of 38 Gbps~142.8 Gbps, but the one-way latency is still limited by HARQ [6]. Split 5 combines the RU/DU together, and thus the RU produces 21.4 Gbps ~ 40.3 Gbps data. As drawback, it is difficult in defining scheduling operations over CU and DU. It can be used particularly well in scenarios where distances greater than 20km between DU and CU need to be bridged. Assuming that each access node can aggregate 8 RUs traffic, for Split 8, the maximum peak data rate can reach 6.8 Tbps. Even at Split 7.2 with reduced bandwidth constraints, each node still needs to handle 1.1 Tbps. After cascading multiple nodes, it exhausts the entire C-band. Therefore, it is attractive to exploit another band to load more data traffic. O-band is a good candidate as the low dispersion is beneficial for efficient high data rate transmission.

Table 1 Requirement for Different Splitting Functions

Splitting Functions	Capacity/RU [Gbps]	Distance [km]
5	21.4-40.3	<100km
7.2	38-142.8	<20km
8	200-850	<20km

A new optical transport network infrastructure for converged Xhaul traffic exploiting flexible, high capacity, fast reconfigurable, and low cost multiband OADM (O- and C-band) should be investigated that simultaneously satisfy the exploding bandwidth demands, network densification, and the low-latency needs of new applications, while efficiently use the network resources.

Horseshoe networks have been demonstrated to be highly effective, particularly in the metro-access network [7]. Previous studies have focused on the use of discussed the use of DWDM in the C and L bands for converged Xhaul traffic, which often results in higher costs [6], [8]. The utilization of multi-band is a simple and efficient solution. Nevertheless, there remains a research gap in the area of multi-band OADM for Xhaul optical transport network.

In this work, we demonstrate a loss-less flexible O- and C-band OADM node with fast reconfiguration in a metro-access network scenario to support Xhaul traffic with different Split 5, 7.2, and 8. The experimental results show that the MB-OADM can support different splitting functions and data rates while maintaining low power penalty. Specifically, for Split 8 the MB-

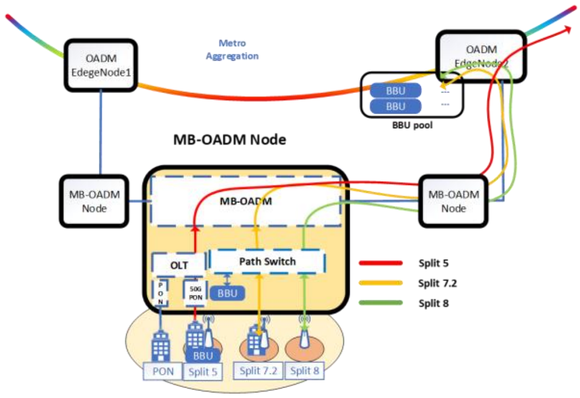

Fig.1 Optical network architecture for converged Xhaul

OADM can achieve BER < 10^{-9} with a power penalty of less than 1.6 dB. For Split 7.2, the BER < 10^{-9} with a power penalty of less than 4 dB after passing through two medium distance nodes. For Split 5, the BER < 10^{-9} with a power penalty of less than 5dB in O-band and less than 1.3dB in C-band after passing through three nodes in the access network.

Optical network architecture for converged Xhaul traffic

The optical network architecture for the converged Xhaul traffic that support the above three typical split function options is shown in Fig. 1. This network is based on a horseshoe topology that utilizes flexible MB-OADM technology. Each MB-OADM node is equipped with an MB-OADM for adding or dropping wavelength channels, while the node control utilizes a fixed wavelength for carrying the SDN control. The OLT aggregates Split5 and PON traffic, and a path switch is employed to flexibly allocate Split7.2 and 8 high-speed data flows, either bypassing them to the BBU pool or processing them at local BBU, depending on their latency requirements. The OADM Node supports data streams with different capacity and latency requirements, which benefit from multi-band operation and the fast switching speed of the node [9].

As shown in the Fig.2 the MB-OADM comprises a band mux/ demux, a C-band and corresponding in-band mux/demux, several different band SOAs, and a 3dB coupler. The band mux/demux functions to separate the C-and O-band, while the in-band mux/demux, usually constructed using an arrayed-waveguide gratings (AWGs) structure, is employed to divide/combine the channels of each band. The input and output 1x2 coupler is utilized to drop and add signals, respectively. Once a wavelength is dropped, the SOA of the corresponding channel in the OADM is closed. The downstream RU is then notified that the corresponding wavelength is reusable.

It is important to note that Split 8 and 7.2 are subject to the latency requirements that arise from HARQ processing, with maximum distance to the edge computing node limited to 20 km. For example, the Split 8 green flow in Fig 1, it can just by pass the nodes with shorter path and terminates the nearest edge computing node for physical layer computation. It is similar with the yellow flow in Split 7.2 with less bandwidth. Furthermore, the red data flow corresponds to Split 5 data, which has the least demanding bandwidth and latency requirements. As this flow has direct access to the core network, it is practical to utilize C-band for transmitting Split 5 backhaul data and PON .

Experimental setup and results

The experimental setup to assess the MB-OADM based network is shown in Fig. 2. Commercial pluggable O-band LAN WDM (LWDM) transceivers with four 25Gbps NRZ channels (CH) at 1295.5 nm, 1300.5 nm, 1304.5 nm and 1309.5 nm were only available and employed for the experiments. For C-band we employed 2 CH at 1549.32 nm and 1550.92 nm. The bit error rate (BER) was measured under the 25 Gbps and 10 Gbps NRZ data streams with a pseudorandom bit sequence (PRBS) length of $2^{15} - 1$. The initial OADM node is located after a span of 10km single mode fibre (SMF), followed by the second node after 15km, and the third node placed after a distance of 3.4 km. The final Edge node is in proximity to the third node, with their distance being less than 1 km.

As possible example we considered three distinct scenarios, denoted as Split5, Split7.2,

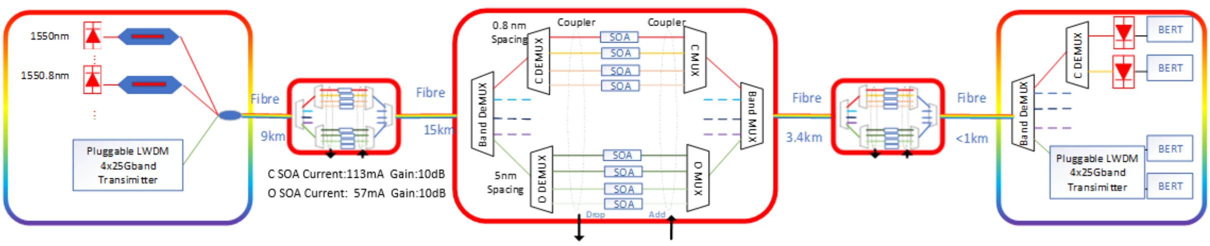

Fig.2 Experimental setup for the MB-OADM in horseshoe access network

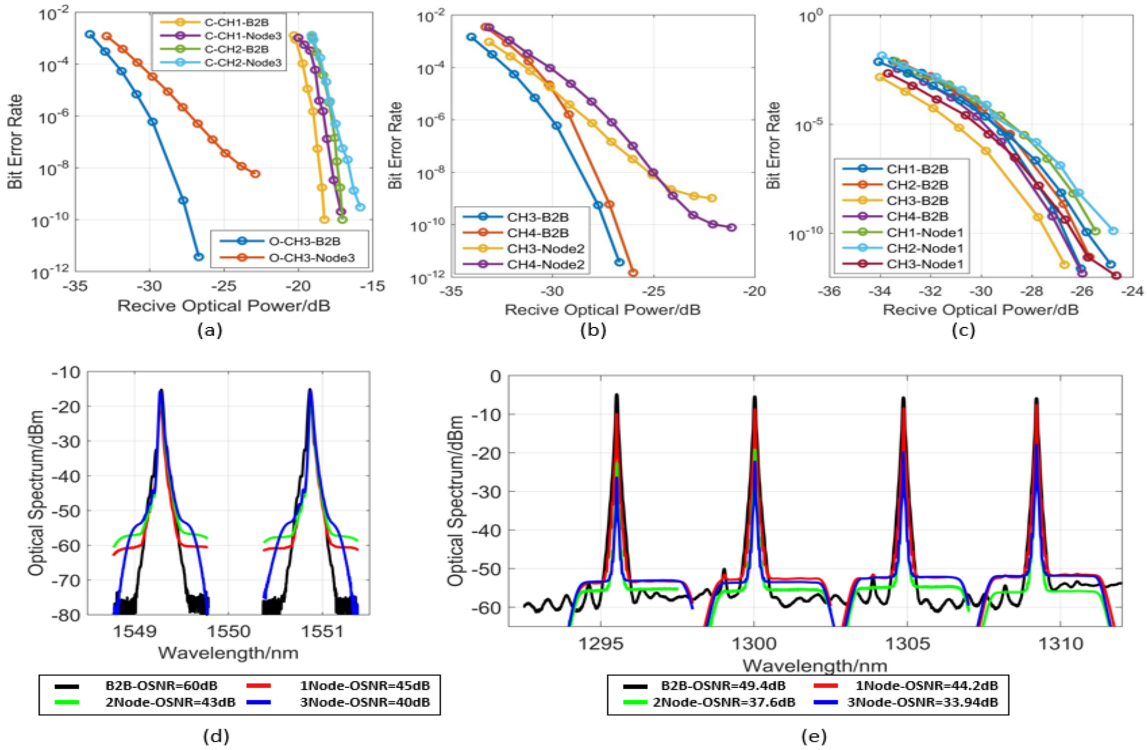

Fig.3 BER results: a) Split 5; b)Split 7.2; c)Split 8. OSA: d) O-band receive optical spectra e) C-band receive optical spectra

and Split8. For the Split 7.2 and Split 8 scenarios, we employed O-band transmission 50 Gbps (2x25 Gbps, employ CH3 and 4) and 100 Gbps (4x25 Gbps, employ CH1-4), respectively. The former scenario traversed two nodes (total link of 19.4 km), while the latter configuration traversed one nodes, spanning a distance of 4.4 km. The O-band SOAs were biased at 57 mA and provide a gain of 10 dB. For the Split 5 scenario, we employed C-band 20 Gbps link (2x10 Gbps or O-band 1x25 Gbps) crossing three nodes (total link of 28.4 km) to connect to the edge node and entering the cloud. The O-band SOA was biased at 57 mA and provides a gain of 10 dB, while the C-band SOAs were biased at 113 mA and provide a gain of 10 dB.

Fig. 3 depicts the experimental results for the different scenarios. In the Split 5 scenario, O-band 25Gbps CH3 or alternatively two C-band 10Gbps CH1 and CH2 were utilized for transmission. In Fig. 3(a), the power penalty of CH3 was less than 5 dB after 3 nodes, mainly caused by the reduced SNR. As shown in Fig. 3(e) the OSNR after 3 nodes is around 24 dB for this channel. For the transmitted Split 5 flow on C-band the power penalty of CH1 and CH2 after 3 nodes is only 1.2 dB. For the Split 7.2 scenario, CH3 and CH4 were utilized for transmission. Fig. 3(b) indicates that after passing through two nodes, CH3 and CH4 exhibited power penalties of 4 dB and 3.69 dB, respectively. The OSNR after 3 nodes is around 28 dB. For the Split 8, CH 1-4 were utilized for 4X25 Gbps signal transmission. As illustrated in Fig. 3(c), the power penalty of CH 1-4 after traversing a node were found to be 1.14 dB, 1.11 dB, 0.95 dB, and 1.6 dB, respectively. The OSNR decreases from 49.4dB in the B2B to 42 dB. Moreover, Fig.3(d-e) report the optical spectra at different nodes. It can be seen that the SOAs in the nodes compensate the MB-OADM losses and fiber link losses in the horseshoe network.

Conclusions

We propose and demonstrate a flexible MB OADM node to support Xhaul with different split function options. The network has been assessed with three use cases Split 5, 7.2, and 8, traversing multiple nodes and with different capacity according to the splitting function to be served. The MB-OADM demonstrates excellent performance in Split 8 with a BER < 10^{-9} and < 1.6 dB power penalty after traversing one node. Split 7.2 yields a BER < 10^{-9} and < 4 dB power penalty after passing through two nodes. In Split 5, the BER is < 10^{-9} with < 5 dB power penalty in O-band and < 1.2 dB in C-band after traversing three nodes in the access network.

Acknowledgements

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References

[1] L. M. P. Larsen, A. Checko, and H. L. Christiansen, “A Survey of the Functional Splits Proposed for 5G Mobile Crosshaul Networks,” *IEEE Communications Surveys & Tutorials*, vol. 21, no. 1, pp. 146–172, 2019, doi: 10.1109/COMST.2018.2868805.

[2] S. Bidkar, P. Dom, R. Bonk, and T. Pfeiffer, “Mobile Xhaul Traffic Modelling for High-Speed TDM-PON,” in *2020 European Conference on Optical Communications (ECOC)*, Dec. 2020, pp. 1–4. doi: 10.1109/ECOC48923.2020.9333350.

[3] 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,” *IEEE Communications Magazine*, vol. 54, no. 2, pp. 152–159, Feb. 2016, doi: 10.1109/MCOM.2016.7402275.

[4] M. U. Sheikh, K. Ruttik, E. Mutafungwa, R. Jäntti, J. Hamalainen, and E. Yusta Padilla, “X-Haul Solutions for Different Functional Split Options Using THz and Sub-THz Bands,” in *Proceedings of the 20th ACM International Symposium on Mobility Management and Wireless Access on 20th ACM International Symposium on Mobility Management and Wireless Access*, Montreal Quebec Canada: ACM, Oct. 2022, pp. 47–53. doi: 10.1145/3551660.3560921.

[5] S. Bidkar, R. Bonk, and T. Pfeiffer, “Low-Latency TDM-PON for 5G Xhaul,” in *2020 22nd International Conference on Transparent Optical Networks (ICTON)*, Jul. 2020, pp. 1–4. doi: 10.1109/ICTON51198.2020.9203123.

[6] T. Sizer *et al.*, “Integrated Solutions for Deployment of 6G Mobile Networks,” *Journal of Lightwave Technology*, vol. 40, no. 2, pp. 346–357, Jan. 2022, doi: 10.1109/JLT.2021.3110436.

[7] L. S. de Sousa and A. C. Drummond, “Metropolitan Optical Networks: A Survey on New Architectures and Future Trends.” arXiv, Apr. 06, 2022. Accessed: May 04, 2023. [Online]. Available: http://arxiv.org/abs/2201.10709

[8] J. Gutiérrez *et al.*, “5G-XHaul: a converged optical and wireless solution for 5G transport networks,” *Transactions on Emerging Telecommunications Technologies*, vol. 27, no. 9, pp. 1187–1195, 2016, doi: 10.1002/ett.3063.

[9] X. Xue and N. Calabretta, “Nanosecond optical switching and control system for data center networks,” *Nat Commun*, vol. 13, no. 1, Art. no. 1, Apr. 2022, doi: 10.1038/s41467-022-29913-1.