# *What Role for Photonics in Xhaul Networks of 5G Systems?*

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**Abstract:** This paper reviews key challenges in designing a transport network for 5G systems. Then it outlines how optics can contribute in solving some of them and which features the optical transport network shall be provided with.

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## 1. Introduction

Mobile networks are experiencing an exponential increase in the volume of data as a result not only of the increasing number of users and smart devices, but also of the enormous bandwidth required for novel applications. Smartphone subscriptions are set to more than double by 2020: by this time, 70 percent of the world´s population will have a smartphone [1]. Forecasts in [1] also indicate that there will be 26 billion connected devices by 2020. Along with the increase in capacity, users are expecting to count with real-time mobile applications with no delays and strong availability and reliability. The envisioned 5G cellular systems will need to provide very high data rates, as high as 10 Gbps per user and sub-ms latency, for time-critical applications as traffic safety and control of critical infrastructure and industry [2]. These objectives can be achieved by exploiting advanced Radio Access Technologies (RAT), such as Small Cells, Co-ordinated Multi Point (CoMP), massive Multiple-Input Multiple-Output (MIMO), and carrier aggregation **Errore. L'origine riferimento non è stata trovata.**. However advanced RAT technologies are not sufficient but shall be supported by novel reconfigurable optical transport networks interconnecting the Radio Access Network (RAN) nodes among themselves and with the 5G core network.

In this paper first the main aspects of the 5G scenario that affect the transport network will be outlined. Then specific requirements of the optical transport network for supporting the 5G scenario will be discussed.

## 2. Transport relevant trends in 5G

In contrast to earlier generations, 5G should not be seen as a specific radio access technology, targeting new radio spectrum, but as an overall access solution that will have an impact on the whole network architecture, including the fixed transport infrastructure interconnecting 5G architectural elements as depicted in *Figure 1*.

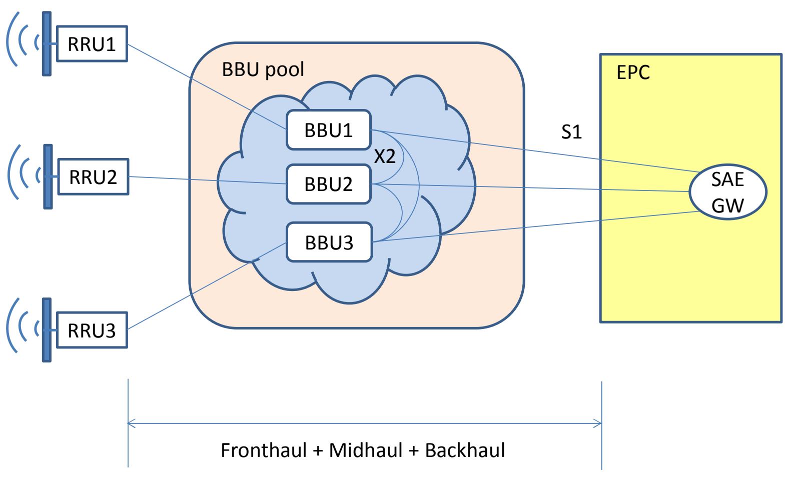


*Figure 1 – Xhaul general architecture for 5G networks*

In the 5G scenario, heterogeneous networks [3] will exploit a mix of radio technologies and cell types working together to seamlessly deliver additional capacity, coverage and speed. This will require to improve and densify the macro cellular layer for enhancing coverage and capacity, and to add integrated small cells in strategic locations, to offer cost-effective connections in traffic hotspots, fix coverage holes and serve demanding areas, such as enterprises and airports. *Improving* the macro layer requires an increase of capacity of the *backhaul* network:

considering that the data rate per user can be as high as 10Gbps, beyond 100 Gbps capacity will be required by the 5G backhaul network. *Densifying* macro cells and *adding* small cells will make topology and traffic distribution of the backhaul network more complex. Due to protocol transparency, energy efficiency and low latency, DWDM could be the candidate technology for the network upgrade, provided its current cost can be downscaled.
5G is expected to have a deep impact also on the *fronthaul* network segment, i.e. a RAN where the base station is split in a Remote Radio Unit (RRU), co-located with the antenna and in charge of radio frequency transmission, and a Base Band Unit (BBU), where the radio signal processing is performed. The most popular protocol utilized today for interconnecting RRU and BBU is the Common Packet Radio Interface (CPRI) [4] that carries, in a digitized format, in-phase and in-quadrature components of the radio signal. High resolution analog-to-digital conversion is necessary for interference coordination among interfering RRUs, leading to high excess bandwidth compared to the client radio signal. For similar reasons, CPRI has also strict link delay accuracy requirements between downstream and upstream transmission directions (in the order of nanoseconds) and tight latency and jitter specifications, in the order of tens of microseconds and a few parts per billion, respectively. In 5G fronthaul networks, CPRI could be replaced by a different, less bandwidth hungry protocol, moving back some processing functionalities to the RRU. However, the corresponding bandwidth gain will be compensated for by the higher data rate (10 Gbps per user) and delay and jitter requirements could still hold, depending on the protocol split choice.
Finally, Centralized-RAN (C-RAN) solutions [5] are expected to be introduced in 5G to increase the number of coordinated cells, improve their interaction, e.g. by means of local X2 interfaces, and reduce the Opex. In an extreme implementation, C-RAN could evolve toward a cloud based infrastructure (i.e., Cloud RANs) and Virtualized RAN (i.e., V-RAN) where BBUs based on Virtual Machines (VM) can be activated in general purpose servers. Centralization has deep consequences for the transport network: longer link distances (although latency limits the achievable distance to a few tens of kilometers), higher aggregate capacity per fiber (from several tens to several hundreds of Gbps, depending on the network segment and aggregation strategy) and, especially, the converge of fronthaul and backhaul in the same network, to actually exploit the Opex reduction originated by the reduction of points of presences and the possibility to seamlessly provision end-to-end services being unaware of the deployed infrastructure. Hereinafter we will refer to this new unified network segment as Xhaul [6].

## 3. Programmable Xhaul optical transport networks

A possible implementation of an Xhaul network is depicted in *Figure 2*. The depicted switches and the link interconnecting them represent generic elements performing switching and transport functions. Indeed, the aggregation of backhaul and fronthaul data can be performed at different layers. For example, a pure Layer 1 aggregation strategy could assign and route separate wavelengths dedicated to fronthaul and backhaul traffic data, with some flexibility guaranteed by wavelength assignment and path computation algorithms. However, this strategy is bandwidth inefficient when the backhaul traffic is generated by many, low bit rate sources, as can happen in the case of small cells and Wi-Fi terminals. Aggregation at sub-wavelength level can be envisaged to overcome this issue, providing the possibility to reconfigure amount of Ethernet and CPRI data carried by a shared optical channel, according to the actual traffic load. Sub-wavelength aggregation can follow two guidelines. A first method, e.g. followed at IEEE 802.1 TSN, extends the Ethernet framing protocols "packetizing" the fronthaul traffic, introducing an additional toolset (scheduling, pre-emption, buffering) to bound the latency, limit the packet delay variation and distribute synchronization information to the network elements. An alternative method is the protocol agnostic multiplexing of constant bit rate client signal, relying on accurate synchronization mechanisms to avoid jitter degradation and ensure deterministic latency. This approach is adopted by ITU-T G.709 but simpler and more performing framing protocol implementations are possible by considering that distances are quite limited in a fronthaul network (about 20 km), which also limits number of crossed network nodes and network topology complexity.
In a centralized network scenario, where a single based processing node (hub) serves several clusters of RRUs, multi-layer switches, capable to aggregate and route traffic at both wavelength and sub-wavelength levels, can be placed at the hub and at each cluster to dynamically allocate bandwidth resources. The switches will adopt one of the aforementioned multiplexing strategies.
A Xhaul Control Unit (CU) will be in charge of driving all the switches involved to provision the connections at the different supported granularities, in order to provide the best grooming and routing of fronthaul and backhaul data in the optical signal. The CU may receive inputs from external radio control or management systems to enforce policies and rules devoted to BBU power consumption optimization and load balancing. The CU can also handle recovery schemes at different granularities.
Assuming the hub hosts a pool of co-located BBUs, cooperation of BBUs shall be supported for load balancing purposes and to enable the switch-off of BBUs for energy consumption savings. Cooperation may also be exploited

for CoMP purposes. For example, turning off of BBUs could be advisable when small cells, associated to a macro cell, are switched off in low traffic conditions. In this case, the traffic handled by such small cells shall be rerouted to the BBU of the associated macro cell. It shall also be possible to dynamically swap the BBU which processes the traffic of an RRU; re-association can be pre-planned or un-predicted and driven by traffic forecasts or measurements. Finally, multi-tenant and multi-operator scenarios can be deployed by segregation of *both* computational and connectivity resources. This requires coordination between radio control and Xhaul CU that might be implemented by a hierarchical SDN architecture [7][8], where radio control and Xhaul CU respond to a common radio/Xhaul SDN orchestrator. Northbound, a second, upper level, orchestrator might be used to provide visibility and control of the end-to-end connection from the access to the core, across multiple domains.

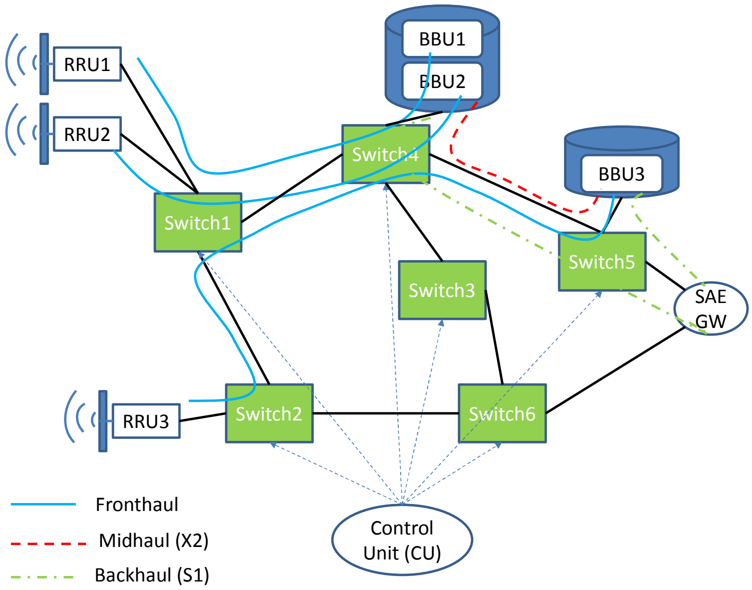


*Figure 2 – Possible Xhaul network architecture*

## 4. Conclusions

This study reviewed some of the key challenges 5G cellular systems will pose to the underlying transport network. Some of them are providing large capacity, low latency and reconfigurability. An optical transport network can play a key role in providing such 5G transport if it will be made programmable, that is, capable of providing the necessary resources where needed and when needed.

## 5. Acknowledgments


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