Towards a unified fronthaul-backhaul data plane for 5G

The 5G-Crosshaul project approach

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ABSTRACT

The paper presents a study of key aspects in the design of a flexible unified data plane capable of integrating both fronthaul and backhaul transport in future 5G systems. In this study, we first review candidate access and multiplexing technologies from the state of the art and assess their capability to support legacy and new fronthaul and backhaul traffic. We then propose a new design framework for the targeted flexible unified data plane, featuring a primary packet-switching path supported by an auxiliary circuit-switching for extreme low latency scenarios. This comprises a summary of the first results achieved in the 5G-Crosshaul EU project since its kick-off in July 2015.

Keywords—5G; backhaul; fronthaul; CPRI

I. INTRODUCTION

Roadmaps for the development of the next generation cellular communication system, also referred to as 5G, have been established by key international stakeholder organizations, such as ITU, 3GPP, IEEE, and IETF. Massive deployments of complete 5G systems are only expected after the landmark year 2020, following the ratification by ITU-R of the 5G air interface component. Advanced research, standardization, trials and pilot installations will therefore mark the next five years towards the target deadline of 2020. In Europe, this activity is being guided by the 5G Infrastructure Public Private Partnership created under the Horizon 2020 Framework Programme.

Although capabilities and technologies of the future 5G system are not firmly set yet, there is a global consensus emerging on the key capabilities targeted and enabling technology pillars. Taking as an example the radio access component, ITU-R WP5D [1] has already managed to reflect a global consensus on the key performance indicators (KPIs) targeted in 5G, such as 20 Gbit/s peak data rate, 1 ms air interface latency, 3x the spectral efficiency of IMT-Advanced, 100x the energy efficiency of IMT-Advanced, etc. Emerging enabling technologies to meet these ambitious KPIs at the access level include small cells, spectrum extension to millimeter-wave frequencies, massive multiplexing, flexible resource sharing, multi-technology support, etc.

However, this work is focused on the other fundamental element of the 5G system: the design of the future 5G transport network interconnecting access and core segments [1,12]. This vision sees 5G transport network to integrate the backhaul and fronthaul segments into a unified network substrate driven by software defined networks and network function virtualization (SDN and NFV)-based framework in order to deliver on the flexibility, scalability, efficiency, capacity, latency and cost reduction pursued for 5G.

Much of this work is dedicated to understanding the different mechanism that can be used for multiplexing fronthaul and backhaul traffic over a common transport network. Remark that fronthaul

[1] WP 5D is the working party responsible for the overall radio system aspects of International Mobile Telecommunications (IMT) systems, comprising the IMT-2000, IMT-Advanced and IMT for 2020 and beyond

refers to the fixed transport infrastructure communicating the Remote Radio Units (RRU) and the Base Band Unit (BBU), while backhaul is the portion of the network comprising the intermediate links in the core network, originating from BBUs. Several BBUs serving multiple RRUs sites might be pooled and, possibly, virtualized to implement the Cloud-Radio Access Network (C-RAN) concept.

Multiplexing backhaul and fronthaul traffic is highly advantageous since it enables the use of common infrastructure and control for multiple purposes, with a consequent decrease of the total cost of ownership due to the reutilization of hardware and management techniques. This holds even more in 5G, where new functional split schemes of the radio interface add a plethora of possible intermediate cases in between the pure fronthaul and backhaul scenarios, impossible to manage with dedicated infrastructures.

The applicability of three multiplexing strategies (at physical layer, time division multiplex (TDM) and packet based) is discussed in this article. For example, the high and constant bit rate (CBR) nature of Common Public Radio Interface (CPRI) traffic makes it difficult to justify a multiplexing method other than circuit-based (either time division or wavelength division multiplexing). However the advent of newer variable bit rate (e.g. due to compression) fronthaul streams defined in the Next-Generation Fronthaul Interface (NGFI) drives the interest in integrating fronthaul and backhaul traffic as much as possible in more cost-efficient packet switching schemes.

Towards this vision, the project consortium, composed of twenty-one partners among leading industry and academic organizations, is developing a solution called 5G-Crosshaul. Its key building blocks are: (1) a packetized common transport layer for multiplexing and switching legacy (e.g. CPRI [11]) or new fronthaul and backhaul traffic over the same medium, and (2) an SDN/NFV-based control infrastructure (i.e. XCI, Crosshaul Control Infrastructure) that opens up the transport network as a service for network applications such as multi-tenancy, mobile edge computing, energy optimizers, smart traffic engineering, etc.

The rest of the paper is organized as follows. In section II we present the technology map for the 5G-Crosshaul unified transport network. Section III discusses existing multiplexing strategies, and next section IV describes in detail our proposed design framework for the 5G-Crosshaul data plane. Finally we draw conclusions and present prospective future work in Section V.

II. 5G-CROSSHAUL TECHNOLOGY MAP

Figure 1 illustrates the two transport aggregation stages considered in the 5G-Crosshaul network. The high aggregation stage considers the metro and core transport network, while the low aggregation one refers mostly to the transport network that is closer to the edge, and so, to the RAN equipment (e.g., small cells, RRUs).

The high capacity targets set for 5G will require high transport capacity when aggregated. Optical transport technologies present the appropriate characteristics (notably in terms of capacity) to fulfill this demanding requirement. Therefore, optical transmission technologies based on Wavelength Division multiplexing (WDM) perfectly fit at the high aggregation region of the 5G-Crosshaul network.

As for the low aggregation stage, a variety of operator setups will be present due to both technical and economic reasons. In turn, such deployment constraints are eventually mapped to 5G KPIs (e.g., network density or cost-efficiency requirements). For these reasons, three different scenarios are considered (see Figure 1).

In Scenario no. 1, wireless links (microwave, mmWave, or optical wireless) are used when wired options are not feasible, or in cases where deployment flexibility or extra capillarity is needed. Some examples are rural deployments in which laying fiber is not economically feasible or dense urban scenarios for which deployment flexibility and capillarity are required to offer a high areal capacity density.

When a fixed access network (copper or optical) is already in place (Scenario no. 2), operators may want to reuse it also for carrying mobile fronthaul and backhaul. This will provide the transmission medium, but fulfilling the 5G requirements like low latency and symmetric downstream/upstream delay planned for future 5G real-time services, let alone synchronization requirements to support handovers, may require some effort.

In the proposed migration path, cables, fibers and distribution nodes are reused, while the fixed access central office (CO) can either be fully replaced by a general-purpose data center or seamlessly upgraded by adding new mobile BBUs by means of coexistence-enabling devices (e.g., optical band-split filters).

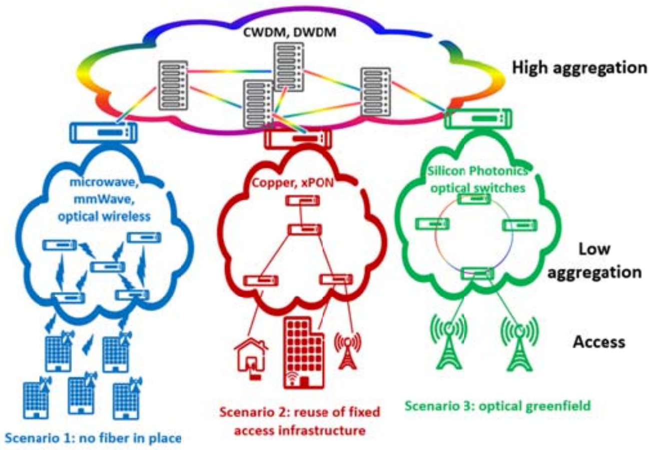

Figure 1: 5G-Crosshaul deployment scenarios

Finally, Scenario no. 3 represents greenfield optical installations, i.e., those planned from scratch. In the absence of legacy constraints, this enables the introduction of the latest optical architectural concepts and novel transmission technologies (e.g., WDM 100 Gbit/s transceivers and low-cost silicon photonic optical switches) to increase the network capacity while minimizing the cost per Gbit/s. In this way, the operator may select the most recent set of technologies to deploy without any economic or technical constraint beyond those imposed by the 5G KPIs. That is, there would be no infrastructure reuse constraints (e.g., cable plant), as it is the case for other scenarios.

Regardless of the deployment scenario (including greenfield deployments), bandwidth and connectivity resources must be programmable and dynamically allocable during network operation to avoid overprovisioning or bottlenecks. This flexibility is offered through the combination of 1) a unified 5G-Crosshaul Control Infrastructure (XCI), which enables dynamic reconfiguration of network paths over 2) a unified multi-layer data plane (Section IV) featuring 5G-Crosshaul Forwarding Entities (XFE) that embed the appropriate multiplexing and switching capabilities.

The remainder of this section discusses about the potential that wireless, fixed access, and optical transport technologies have in the context of a 5G transport network.

A. *Wireless technologies*

Most existing wireless backhaul networks are designed for macrocells and typically use point-to-point line-of-sight (LoS) links. This approach may not scale for the dense small cell deployment case, which is of particular relevance to 5G due to the increase in the network capacity these deployments imply. The 5G-Crosshaul network integrates mmWave technology in the V-band (57 to 66 GHz) for small-cell point-to-multipoint backhaul links with rates of a few Gbit/s over a few hundred meters (~200 meters) of inter-site distance [2]. mmWave technology in the E-band (71-76 to 81-86 GHz) is also considered in 5G-Crosshaul for providing cost-effective Gbit/s wireless fronthaul links over a few kilometers [4].

Optical wireless systems (OWC), either LED- or laser-based, are also envisaged in 5G-Crosshaul as an attractive alternative due to the use of unlicensed spectrum, large bandwidth and immunity to electromagnetic interference. Measurements of LED-based systems show rates of up to hundreds of Mbit/s over distances of tens of meters [5], making this technology an appropriate and cost effective solution for backhauling where fiber is not deployed. More costly laser-based systems available on the market may reach several kilometers and support rates of up to 10 Gbit/s, aligned with fronthaul needs. OWC can be used in conjunction with radio systems, to improve the link availability and capacity, or as gap filler in fiber links.

B. *Copper access technologies*

Copper-based access is widely deployed as Ethernet LANs, DSL or telephony local loops, and Cable-TV coax networks. It is thus often available for carrying backhaul and fronthaul over short distances, say a few hundred meters. The recently standardized G.fast (ITU-T G.9701) operates over short copper lines, 20-450 meters, and can deliver up to 1 Gbit/s. Non-standardized technologies such as the NOKIA-prototype XG-fast can reach up to 10

Gbit/s over a few tens of meters. These rates could support 5G-Crosshaul needs.

Ethernet cabling is abundant in enterprise and commercial buildings. With over a hundred meter reach there are consolidated standards for 1 Gbit/s (1000BASE-T) and 10 Gbit/s (10GBASE-T). Higher rates of 25 and 40 Gbit/s are being standardized but mainly for data center applications with a maximum reach of 30 meters. The prospect of a massive deployment of 5G indoor small cells makes Ethernet a suitable technology for 5G-Crosshaul, both for fronthaul and backhaul.

C. *Optical fiber access and transport technologies*

The deployment of fiber to the premises based on Passive Optical Network (PON) technology has experienced a rapid growth in the last decade. However the reuse of installed fiber access infrastructure for 5G is challenging. While standards like GPON (ITU-T G.984, Gigabit-capable PON) may be sufficient for residential users (bandwidth is 2.5/1.25 Gbit/s shared by up to 128 subscribers), it is clearly insufficient for the transport of fronthaul traffic due to its high data rates requirements [11]. Upcoming XGS-PON (symmetrical 10 Gbit/s) and TWDM PON (ITU-T G.989, Time and Wavelength Division Multiplexing PON 40 Gbit/s and 80 Gbit/s capable based on 10 Gbit/s carriers) should meet the bandwidth and latency requirements of NGFI traffic. However the latency induced by TDM access makes the transport of legacy CPRI complex and dependent on an appropriate QoS mechanism. An alternative option is point-to-point (PtP) WDM PON (ITU-T G.698.3), which easily provides virtual 10 Gbit/s PtP links making it suitable for legacy fronthaul, NGFI and backhaul traffic.

In the long term, the advent of elastic optical networks featuring flexible channel allocations (ITU-T G.694.1), together with a flexible modulation format and programmable transceivers open the door to a fine-grained and truly dynamic capacity allocation, both, in the access and in the transport segment of 5G-Crosshaul network. Programmable sliceable bandwidth-variable transceivers can be used at the optical line terminal to concurrently serve different Optical Network Units (ONUs) for delivering different services [7]. At the ONUs, bandwidth-variable transceivers can be remotely configured by the control and management plane for flexible spectrum assignment purposes.

For the transport segment, optical technologies based on WDM provide the required capacity at the high aggregation stage considered in Figure 1. Coarse WDM (CWDM) can provide a total capacity of about 219 Gbit/s using two fibers for uplink and downlink, enough to transport up to 18 channels of the most demanding CPRI configuration (Option-9). Moreover, CWDM technology allows cost effective deployments achieving link distances around 20 km and transceivers support outdoor operation conditions (-40/+70°C). Recent bidirectional solutions exploit sub-wavelength multiplexing over the CWDM grid, doubling the bit rate to 438 Gbit/s.

Dense WDM (DWDM) supports a higher number of channels (e.g. 48 channels, 100 GHz spaced) with a channel bit rate up to 100 Gbit/s. 1 Tbit/s super-channels in a single line card will soon be commercially available due to advanced transmission techniques used in future elastic optical networks, as explained previously. The transmission distance ranges from tens to thousands of kilometers (with optical amplification). Furthermore, DWDM allows to realize energy efficient network designs thanks to the use of reconfigurable optical add drop multiplexers (ROADMs), which consume much less power compared to capacity-equivalent electrical switches. The ability to support multiple physical topologies (bus, ring, point-to-multipoint) while keeping a PtP logical connectivity is another big advantage of DWDM, allowing it to fit a variety of 5G-Crosshaul deployment scenarios. The main drawback of DWDM is the current cost of the optical devices. Nevertheless, research and industry are both active in studying new cost-effective solutions based on silicon integrated photonics.

Finally, it must be noted that analog radio over fiber (RoF) is an interesting alternative to digital radio transmission to reduce bandwidth and latency in short fronthaul links, while increasing their energy efficiency. RoF just requires electrical-to-optical conversion and radio frequency circuits, which may also lead to cost savings compared to digital systems [8]. RoF can be used in combination with WDM to achieve high aggregate capacity. In 5G-Crosshaul, RoF is considered to be deployed inside tunnels along high speed train rails to extend the coverage of base stations.

III. Multiplexing Strategies for a Unified Fronthaul and Backhaul Transport

A. *Physical layer Multiplexing*

Physical layer multiplexing makes sense especially in those centralized RAN deployments where many RRUs need to be connected to the same baseband processing site and fibers are not available or expensive to lease. In these cases, it is useful to mix heterogeneous traffic on the same fiber, for example backhaul traffic from non-split radio base stations and fronthaul traffic from RRHs.

Physical layer multiplexing can be achieved by means of WDM, dedicating each wavelength either to backhaul or fronthaul. WDM is also useful to multiplex traffic of different-vendor radio systems that need to share the transport infrastructure. In both cases, the usual design practices of WDM systems guarantee that the wavelengths do not interact during propagation over the fiber, ensuring the segregation of traffic with heterogeneous performance specifications or generated by different operators.

Bidirectional transmission on a single fiber, as in the access network, helps to simplify the operation in field, avoiding wrong way connections, and natively solving the issue of unbalanced downstream and upstream trip times, which is an issue in fronthaul links that require equal propagation times in the two directions.

B. *Time Division Multiplexing*

When the demand for links increases dramatically, further multiplexing levels must be considered. TDM mechanisms are natively defined in fronthaul interfaces like CPRI but, to further increase the bandwidth efficiency, it may be useful to mix fronthaul and backhaul traffic on the same wavelength channel.

Circuit or packet based techniques can be used for this purpose: the Optical Transport Network (OTN) standard (G.709) is an example of the first class of techniques. CPRI mapping over OTN was recently introduced and analyzed at ITU-T [3], and can be extended to any time-sensitive fronthaul interface. However, the introduced frequency noise and delay asymmetry might not fulfill the CPRI specifications. As a consequence, the practical use of CPRI over OTN today is limited to the case of synchronous mapping of CPRI signals having the same clock reference, in contrast with the 5G-Crosshaul paradigm of fronthaul and backhaul coexistence.

To overcome this issue, 5G-Crosshaul proposes a new, simplified and less time-sensitive circuit multiplexing approach, where the multiplexed frame is synchronous to the fronthaul client signal, on attempts to avoid any degradation of the synchronization accuracy. Multiplexing of Ethernet with a fronthaul client signal (e.g. CPRI) is performed by using a buffer for clock adaptation before the Ethernet line (Figure 2). The field for Operation, Administration and Management (OAM) in Figure 2 contains pointer to the CPRI and Ethernet frame portions.

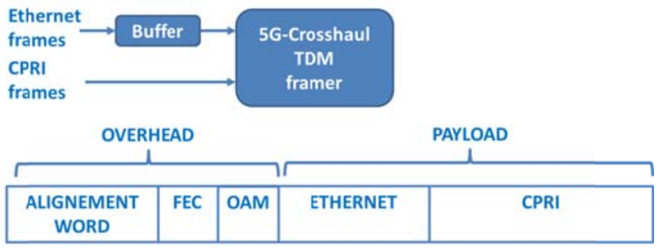

Figure 2: Simple TDM scheme for fronthaul and backhaul multiplexing

An example of frame structure is illustrated in Figure 3. The frame is 2390 octets long (239 rows by 10 columns). Columns 1 to 9 are for payload while column 0 is reserved for overhead, including frame alignment word (rows 0-5), forward error correction (FEC) code for payload (rows 10-153), bit interleaved parity, BIP (rows 6-8), generic communication channel, GCC (row 9), OAM channel (rows 154-222), and FEC code for protected overhead (rows 223-238). For example, in a 10 Gbit/s wavelength channel, each payload column can be used to accommodate a Gigabit Ethernet data service or one CPRI Option-2 client (1.2288 Gbit/s). Higher bit rate CPRI options can be carried using more columns.

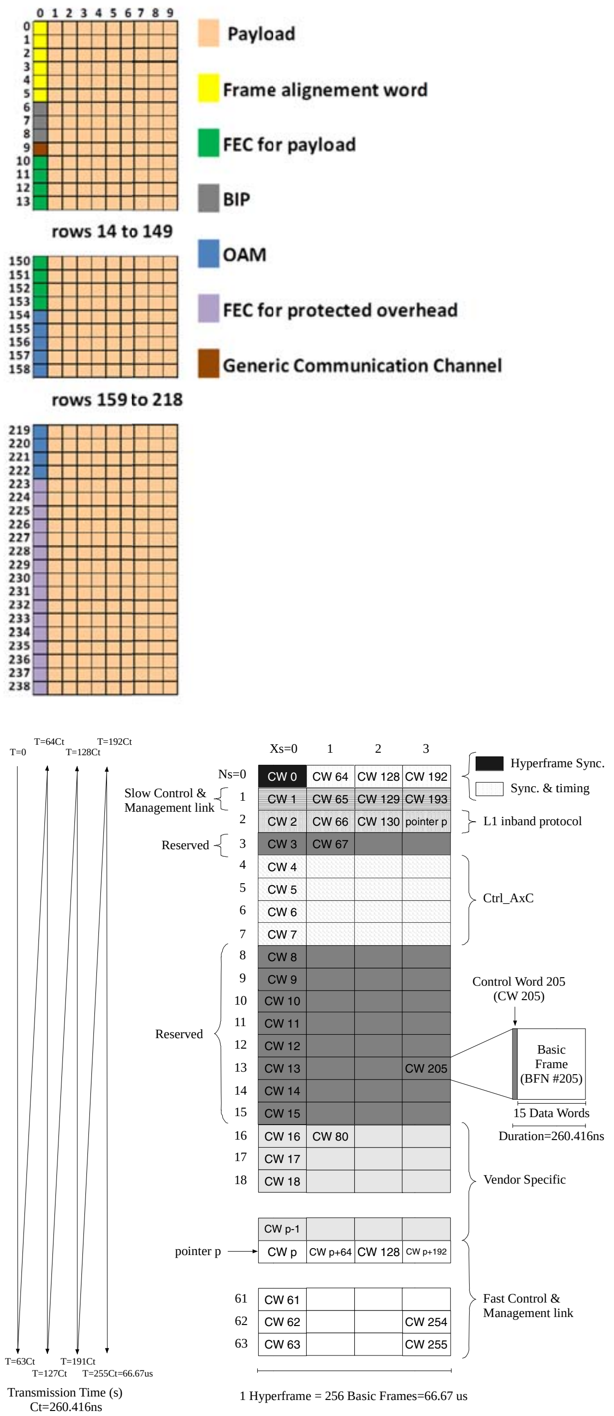

Figure 3: A simple TDM frame structure to multiplex fronthaul and backhaul traffic

C. *Packet based multiplexing*

Packet based multiplexing makes sense especially in the presence of multiple sources with load dependent data rate on attempts to exploit the advantages of statistical multiplexing gain. Such a load dependency, inherent to backhaul, may also apply to new packet based fronthaul interfaces coming from a redefinition of the functional split between remote and digital units. Motivations for new packed based fronthaul interfaces also come from the need to overcome CPRI demanding requirements, especially in terms of bandwidth.

As an example of the extremely high requirements imposed by CPRI fronthaul traffic, the bit rate for a 2x2 MIMO 20 MHz LTE system is 9.83 Gbit/s and it goes up to 162.2 Gbit/s for an 8x8 MIMO 100 MHz LTE-Advanced system [11]. Strict link delay accuracy of ±8 ns is required between master and slave ports, and 2 parts per billion (ppb) frequency deviation from the CPRI link to the radio base station [9]. Therefore, if we aim to transport CPRI streams over a packet-switched network such as Ethernet or IP-MPLS, a) a jitter compensation buffer is necessary to match the delay accuracy requirements, and b) a careful QoS engineering design must be used to limit the packet delay variation through the network. This could be accomplished with current high-end switches but subject to a careful engineering of the latency budget (estimated in 100 µs one-way) with, for instance priority queuing.

Given the challenges of capacity, latency and scalability that remain with CPRI traffic, the research community has started to explore new directions. First, new mechanisms for compression of the fronthaul signal are being studied as an initial alternative to reduce the requirements of the fronthaul transport. Lossless compression mechanisms are preferred by mobile operators because no waveform degradation is generated but achievable compression ratios are low. Lossy compression creates distortion but achieves compression rates higher than 50%. With new approaches [6], the added latency as a result of the compression process can be as high as 10.5 µs for any compression ratio.

Second, for the multiplexing of backhaul and fronthaul traffic on the same physical link while dealing at the same time with the synchronization requirements of mobility, there exist a number of proposals towards taking advantage of new link-level features being introduced to the Ethernet standard to support a more deterministic timing. The Time-Sensitive Networking (TSN) Task Group in

IEEE 802.1 is developing a set of standards addressing transmission of time-sensitive data over Ethernet, with very low latency and high availability. The mobile industry is paying attention to the TSN Working Group since it may provide the means to transport digitized radio over packets, enabling the C-RAN concept in a cost-effective manner. The recently created IEEE 802.1CM “Time-Sensitive Networking for Fronthaul” will define a standard network profile for fronthaul. IEEE 1904.3 addresses instead Radio over Ethernet encapsulation and mappings between the BBU pools and the RRHs. This standard will enable the transfer of user-plane, vendor-specific data and OAM information across an Ethernet-based packet-switched network. The IEEE 1914.1 group goes one step beyond the 1904.3 standard by addressing new functional splits compared to conventional CPRI.

Next, we present our design framework integrating all these into a common data plane architecture for 5G-Crosshaul.

IV. 5G-Crosshaul data plane architecture

A multi-layer network architecture, where both circuit and packet switches are present (Figure 4), is the most suitable data plane architecture for the transport and switching of radio client signals with heterogeneous characteristics and requirements. Indeed, a packet interface may not always fit the requirements of latency critical services. Therefore adopting a layered architecture, the circuit switch can be used to limit the occurrence of overload situations or long queueing times in the packet switch, aggregating packets that have the same destination in guaranteed bitrate pipes that can be managed by the circuit switch. In a real network, not all the layers might be present. For instance, a mesh of Ethernet switches connected by point-to-point fiber links is an example where only the packet layer is present. However, in the most general implementation, the fundamental block of the 5G-Crosshaul data plane architecture (Figure 4) is the Crosshaul Forwarding element (XFE) made up of both a packet switch (Crosshaul Packet Forwarding Element, XPFE) and a circuit switch (Crosshaul Circuit Switching Element, XCSE), while the latter can be implemented in the wavelength and/or the time domain.

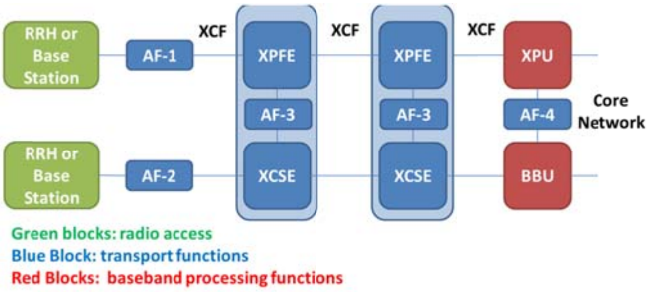

Figure 4: 5G-Crosshaul data plane architecture

The radio units (green blocks in Figure 4) are connected to the XFE by means of adaptation functions (AF). AF-1 performs media adaptation (e.g. from air to fiber) and translation of vendor specific radio interfaces into a Crosshaul Common Frame (XCF), to interface the packet switch. The XCF is a packet interface that evolves the Ethernet standard, adding mechanisms to deal with time-sensitive applications, as mentioned in Section III.C. AF-2 applies instead to constant bit rate links, like CPRI, which can be cross-connected by the circuit switch without intermediate packet conversion. It performs media adaptation functions and maps the radio interface into the protocol used by the circuit switch, as detailed in Section III.B.

The packet switch communicates to the circuit switch through the node internal adaptation function AF-3. The XCF is also used as interface between the packet switch and the Crosshaul Processing Unit (XPU), the virtualized unit in charge of hosting baseband processing. The XPU can be interfaced to pre-existing BBUs by means of another adaptation function, AF-4.

Both XFE and XPU are controlled by a common Crosshaul Control Interface for the optimization of transmission bandwidth and switching resources. An example of resources optimization is the possibility to route the packets in the packet switches of a 5G-Crosshaul network to minimize the number of involved baseband processing units, as well as their energy consumption.

A. *The 5G-Crosshaul multi-layer switch, XFE*

As shown in Figure 4, the XFE includes a packet switch (XPFE) on top of a circuit switch (XCSE) in a multi-layer node architecture.

1) *The packet forwarding element, XPFE*

Packet switching is particularly suitable for NGFI protocol split options where media access control (MAC) and, partly, radio link control (RLC) are moved back to the remote radio head, so that hybrid automatic repeat request (HARQ) re-transmission, which is a major source of latency, is performed locally.

In the XPFE a common switching layer is implemented through the XCF for enabling a unified traffic management across various types of traffic and link technologies. The XCF does not impose any constraint on the payload protocol carried within it, for example using MAC-in-MAC Ethernet encapsulation [13], which presents good scalability properties and the possibility to isolate traffic from different tenants of the network.

The XPFE is based on a common switching layer that works on XCF frames. An Ethernet-based XCF allows the XPFE switching mechanisms to inherit all the work that has been done in the IEEE 802.1 Working Group regarding the optimized transmission of fronthaul traffic (802.1TSN and 802.1CM). Adaptation functions transform the media dependent frames into the XCF and provide an abstraction level for mapping technology-specific capabilities to data-plane and device agent interfaces, hiding the low-level details of interfaces and peripherals. For example, a mapper layer may abstract the status of the physical channel in more generic terms like available bandwidth, bit error rate, jitter, etc. The XCI will use a view, detailed as defined by the abstraction level, of the traffic resources that will be exposed to the orchestration to enable intelligent management of resources and network functions across the fronthaul and backhaul domains.

2) *The circuit switching element, XCSE*

In the most generic implementation, the XCSE can be split into two sub-switches, acting at different traffic granularity. In optical networks, the coarsest sub-switch could be a ROADM while the finest one could be an OTN switch.

Figure 5 suggests an alternative XCSE implementation based on the TDM frame presented in Section III.B.

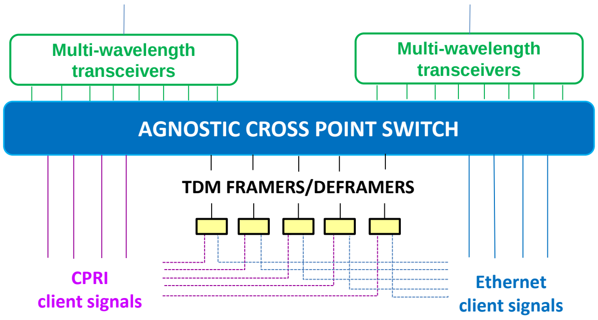

Figure 5: XCSE implementation

Wavelength channels, generated and received by multi-wavelengths integrated transceivers, are first optical-to-electrical converted and then cross-connected by a protocol agnostic cross-point switch. Wavelengths that carry only CPRI or Ethernet signals undergo no further processing. Wavelengths where CPRI and Ethernet are multiplexed together are instead sent to de-framers. The de-framers use pointers in the frame header to separate CPRI and Ethernet CBR client signals. Using the pointers, slots size and position of the client signals can be programmable, depending on network configuration and planned traffic load. This implementation relies on cost effective devices, as integrated multi-wavelength transceivers and high capacity cross-point switches (e.g. 160x160 ports), to achieve modularity and enhanced flexibility, offering the possibility of wavelength reuse over multiple ports.

V. Conclusions

The 5G-Crosshaul network vision [12] provides a holistic approach to address the formidable challenges that the advent of the new 5G mobile generation systems poses to the transport network. This work focused on the data plane, which provides the first fundamental level of flexibility and programmability in the network. This is achieved by multi-layer switches, combining packet and circuit switching features. Packet switching enables statistical multiplexing suitable for the high 5G peak to average access traffic load. Circuit switching allows the best latency performance. For the packet switching, a unified framing format based on MAC-in-MAC Ethernet is proposed for the transport of various types of fronthaul and backhaul traffic over various data link technologies (optical, wireless, copper). Such a new data plane paradigm poses new challenges to the control plane, whose level of dynamicity and flexibility, and then complexity, increases according to the enhanced level of configurability that the data plane is capable to provide.

ACKNOWLEDGEMENT

This work has been partially funded by the EU H2020 5G-Crosshaul project (grant no. 671598).

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