Mobile Fronthaul Architecture and Technologies: a RAN Equipment Assessment

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Abstract: Optical fiber is the required technology for Radio Access Network (RAN) backhaul and fronthaul. We report the evolution of RAN equipment including the advent of virtualization and an investigation of the required architecture and optical access technologies.
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1. Introduction

Optical access systems have seen a widespread deployment over a decade or more. Gigabit capable Passive Optical Network (G-PON) was introduced in the field by several operators, with at first aim to provide up to 100 Mbit/s rate to the customer. Currently commercial offers with more than 100 Mbit/s are possible on G-PON and even 1 Gbit/s commercial offers are now available. After the legacy G-PON, XG-PON (PON working at 10Gbit/s) is recognized as the next deployable solution for an enriched fixed broadband. Following XG-PON, the present standardization working topics on 25 Gbit/s line rates for PON add solutions to secure the fixed access roadmap over the deployed Optical Distribution Network (ODN). Parallel to the optical fiber roll out for Fiber To The Home (FTTH), mobile access has achieved multiple progress by proposing several radio access technology generations. The promises of the coming 5G could be resumed as a fiber-like user experience (cf. required capabilities: low latency, massive capacity). In order to support such mobile network evolution, the optical fiber is or will be the predominant support for the mobile backhaul. Rather than the backhaul, Radio Access Network (RAN) introduces a new kind of network segment where optical fiber is essential also known as fronthaul. Fronthaul concerns the connection from the radio Digital Unit (DU also named BaseBand Unit - BBU) to a remote Radio Unit (RU also named Radio Head - RH).

For existing and previous mobile generation, the fronthaul [1] was first defined as a digital backplane extension based on either Common Public Radio Interface (CPRI), or Open Base Station Architecture Initiative (OBSAI) or Open Radio equipment Interface (ORI). Over the last few years, lots of optical technologies and standardization initiatives have been considered to support the multiple links (one fronthaul link per RF (Radio Frequency) carrier, cell sector, radio access technology), very high bitrate interfaces (up to 25Gbit/s) and time sensitive parameters (latency, unbalance latency, physical layer jitter and wander) in an efficient way by saving the number of required optical fibers. All these technical challenges are due to the fact that from a functional point of view, the RAN equipment is defined as a single entity from the DU to the RU. In other words, the existing fronthaul is not designed as a network interface but as a backplane extension of the RAN.

In order to cope with the fronthaul challenges for the new optical access for the 5G, we assess in this invited paper the evolution of RAN interfaces. We will discuss some new architectures and technologies made possible thanks to the introduction of new RAN functional splits and their impact on the fronthaul [2].

2. Functional split of RAN equipment in a nutshell

In order to introduce the evolution of fronthaul, Figures 1 concisely describes the footprint and functional block arrangements of the RAN equipment:

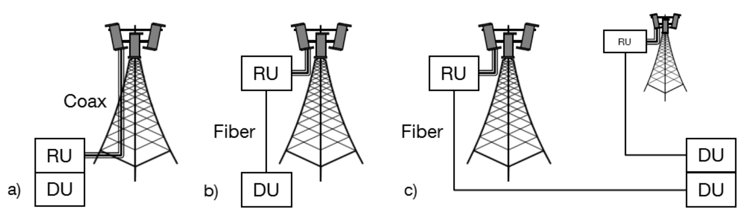


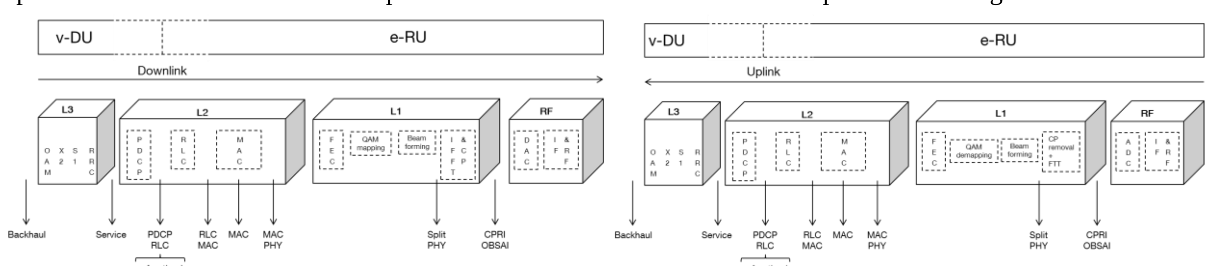
Fig. 1. First three steps of mobile equipment evolution

a. The most common implementation of the base transceiver station (BTS) for 2G and partially for 3G was a single unit based on a radio signal communication block for transmission and reception connected via coaxial cable to a RF power amplifier block which is also connected by a coaxial cable to the antenna (cf. Figure 1a).

b. Due to the progress of chipset processing capabilities, it was possible to implement several radio signal communication blocks inside one single unit. This signal processing evolution allowed a rearrangement of the functional blocks and was designed “distributed” RAN. Typically, one radio processing unit can operate with several amplifier blocks. The technologies needed in the radio signal processing and RF amplifier are significantly different one from the other. Thus, an arrangement based on two different form factors was proposed. The signal processing functions are commonly supported by regular slot on a 19’’ rack. Concerning the RF amplifier form factor, we note that its performance (power consumption and cost) is dependent on the RF attenuation of the coaxial cable reaching the antenna (named remote RU). An outdoor form factor was proposed to be close to the antenna. As far as the links between the multiple ports of radio signal processing slot and the outdoor RF amplifiers are concerned, the main requirements were to allow for the lowest RF signal degradation and to reach several tens of meters of propagation. The combination of DAC & ADC (Digital to Analog Converter and vice versa) and digital transmission over fiber with regular pluggable optoelectronic transceivers allowed meeting these requirements. It is interesting to highlight that this digital backplane extension consists on the lowest layer functional split fronthaul (eg. CPRI, OBSAI, ORI) between the DU and RU. Each fronthaul link between DU and RU is based on a constant and symmetrical high bit rate serial digital interface. Typically, 2.5 Gbit/s are needed to transport a 20 MHz 2x2 Multiple Input Multiple Output (MIMO) radio signal whose maximum mobile peak bit rate is limited to about 150 Mbit/s. The reason behind such poor spectral efficiency can be straightforwardly explained by the quantization and coding operations needed to convert the radio signals into non-return-to-zero (NRZ) sequences used in the optical link [1]. Also, the clock of this NRZ signal serves as a reference for mobile RF generation inside the RU. Figure 1 b) shows such RAN evolution with separated RU and DU communicating using digital interfaces.

c. Since commercial optical transceivers are available and can reach several tens of kilometers at the required bitrates, the reach extension of the fronthaul becomes possible (cf. Figure 1 c)). At the same time, the data processing capacity of DUs increases and allows thus to design equipment which processes an increasing number of DU functions and even allows for cooperation between them. The “cloud” RAN (C-RAN) term refers to this evolution. This radio signal processing stack or pool is localized in a DU (BBU) hotel inside a Central Office. Optical fibers are used to reach the antenna sites within the limit of the maximum round trip time allocated to fronthaul (typ. 20 km for one way, given that this value depends on the RAN implementation). Nevertheless, the feasibility to transport this backplane extension over network equipment (such as OTN - Optical Transport Network or Ethernet [3] over PON or Point to Point - PtP systems) remains a challenge due the amount of bit rate and timing requirements.

Three drivers are now considered for the coming evolution of RAN equipment. The first one could be tagged as “Ethernet fronthaul” which has the goal to transform this digital backplane extension using the most common access network protocol. The second driver is the capacity crunch and the time sensitivities of the existing fronthaul interface (also related to the transceiver cost) to support radio technologies with high level of MIMO and large RF bandwidth foreseen in 5G. A last driver concerns the real-time dependence of the radio signal processing. The feasibility to implement some of the DU functions (L3 and a part of L2) by means of software enables the use of agnostic server to host them. This evolution is known as “virtual DU” (v-DU) [4]. As a consequence, putting together these drivers, a solution appears based on new functional distributions between the regular DU and RU with visualization capabilities. Different functional splits have been discussed so far (cf. Figure 2) but in this invited paper we focus on the PDCP/RLC split. This choice allows the v-DU to be placed in an edge node and connected



PDCP: packet data convergence protocol
RLC: radio link control
MAC: medium access and control
CP: cyclic prefix
OAM: operation, administration and management
(I)FFT: (Inverse) Fast Fourier Transform
IF: intermediate frequency
L1 (PHY): physical layer
L2: data link layer
RRC: radio resource control
L3: network layer
v-DU: virtual Digital Unit
e-RU: evolved/Ethernet Radio Unit
QAM: quadrature amplitude modulation
X2, S1: application protocols

Fig. 2. Several functional splits based on simplified block diagram of the signal processing in a RAN for downlink and uplink

via Ethernet (access and aggregation network segments) to e-RUs (“e” for evolved/Ethernet RU). The low RAN layer parts (L1 and a part of L2) of the previous DU are more real-time hardware-dependent. That is the main reason why e-RU hosts the RF amplifier and those low layer RAN parts. The link between v-DU and e-RU is now named e-fronthaul and can be transmitted with asymmetric and lower bit rates (now dependent on the end-user traffic load).

It also allows for more relaxed latency requirements. These requirements converge to the ones of previous backhaul networks.

3. Architecture and technology for e-fronthaul

The e-fronthaul (PDCP/RLC split) will require a one-way latency of typically 30 ms and an Ethernet throughput 20% higher than the (asymmetric) backhaul traffic. This bit-rate estimate includes the summation of end user-dependent traffic load and extra traffic dedicated to the control, scheduling and RAN security mechanisms. If synchronization and Ethernet security features are required over this link, extra overhead must be considered. In the end, the expected traffic and the latency of the e-fronthaul link are so relaxed that the existing Ethernet equipment dedicated to backhaul could be re-used as far as the amount (asymmetric) of peak traffic capacity required by 5G is taken into account. Figure 3 shows the evolution of access and aggregation network architectures and their possible implementations, namely 1) the regular backhaul based on PtP or PON technologies for access network, 2) the backplane extension based on low layer RAN functional split (CPRI or OBSAI) from the antenna site through dark fibers or WDM equipment to achieve fiber sharing up to the access node and finally 3) the e-fronthaul based on PtP or PON (working at 10 Gbit/s or at the coming 25 Gbit/s line rate) technologies for the access network segment. The e-fronthaul architecture of v-RAN must also coexist with legacy 2G, 3G and 4G backhaul and optionally with low layer fronthaul links of C-RAN. Wavelength overlay could play thus an important role to achieve coexistence over the existing backhaul fiber or in synergy with the FTTH roll out.

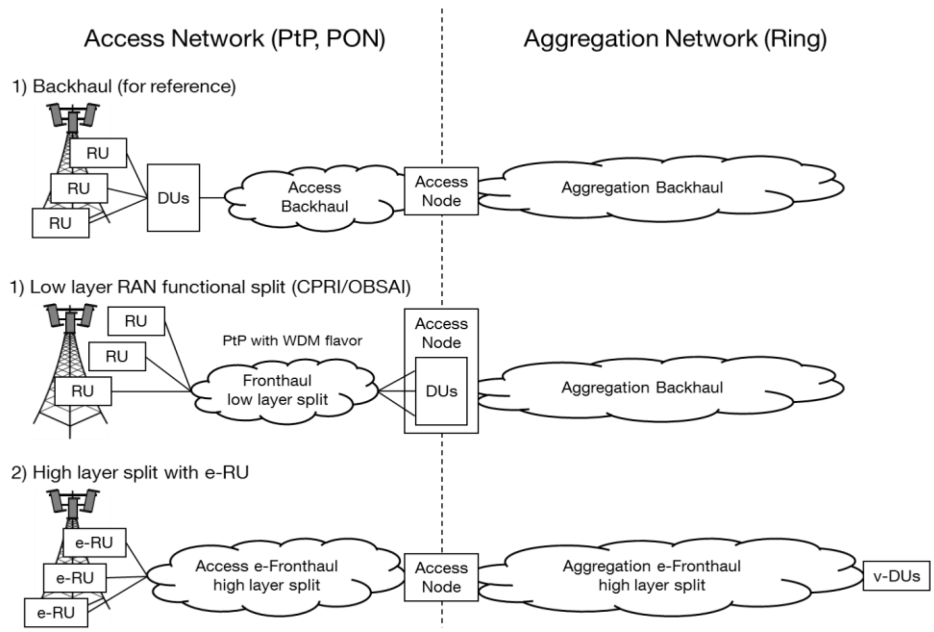


Fig. 3. Architecture evolution from backhaul to e-fronthaul

4. Conclusion

The motivation of mobile architectures and technological evolutions are driven by form factor implementation feasibilities and a pursuit of several advantages of a centralized architecture such as power consumption efficiency and throughput performances. In a context of the coming RAN virtualization for the 5G (fiber-like mobile user experience), optical fiber technology will play an important role for e-fronthaul. This multi-segment (access and aggregation) and the multi-point interfaces requirements still need advanced studies regarding bandwidth allocation and statistical multiplexing in order to guarantee low latency and high peak rate for 5G. The wavelength should be the key enabler technology in optical access network allowing sharing fiber infrastructure in synergy with FTTx and by supporting the legacy mobile backhaul and the "pay as 5G grows" investment.

Acknowledgements

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