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Encapsulation Techniques and Traffic Characterisation of an Ethernet-based 5G Fronthaul

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ABSTRACT
This paper first overviews how, in the 5G Next Generation Radio Access Network (NG-RAN), the Next generation NodeB (gNB) functions are split into Distributed Unit (DU) and Central Unit (CU). Then it describes the proposed *fronthaul* transport solutions, such as Common Packet Radio Interface (CPRI), eCPRI, IEEE P1914.3 and their relationship with the Ethernet protocol. Finally, a characterisation of the traffic generated by the fronthaul is presented. Such characterisation may guide in the selection of the right network for fronthaul transport.

Keywords: Ethernet, Encapsualtion, Fronthaul, 5G, functional split.

1. INTRODUCTION

The fifth generation (5G) mobile networks features several highly differentiated services to address the requirements of the ever-growing network market. Key performance indicators (KPIs) that 5G targets are, for example, very low latency (milliseconds range) and large capacity [1]. Moreover, the 5G Radio Access Network (RAN) needs to support new technologies, such as small cells for a better coverage area and the use of new spectrum with higher channel bandwidth to support low latency services. Thus, new techniques, such as massive MIMO and coordinated multipoint (COMP) are adopted in Next Generation RAN (NG-RAN) with attention also to cost-effectiveness to reduce capital and operating expenditures (CAPEX and OPEX) [2].
To combine the support for low latency and high capacity applications with cost reduction, a popular approach in the 5G Next Generation RAN (NG-RAN) is to split the functionality of a base station (i.e., next generation eNB, gNB) into two different network entities: a Central Unit (CU), deployed in a centralized location, and a Distributed Unit (DU), deployed near the antenna. The connection between CU and DU is known as fronthaul, which has the role to permit the communication without adversely affecting the radio performance. The connection between CU and Evolved Packet Core (EPC) is known as *backhau*l, which enables the communication from CUs with geographically dispersed core network. The DU-CU functional splits can occur at different 5G protocol stack layers. The chosen split impacts not only the capacity and latency requirements, as specified in 3GPP TR 38.801 standard [3], but also the characteristics of the fronthaul traffic.
This paper characterises experimentally the fronthaul traffic by considering different eNB functional splits (i.e., Option 8, Option 7-1, and Option 2) and differently proposed fronthaul traffic transport. In particular, the paper evaluates the impact of the user traffic injected on fronthaul with different inter-departure time distributions. Results show that the fronthaul traffic is independent on the user traffic profile when the lower layer functional splits (i.e., Option 8 and Option 7-1) are considered. Whereas, the fronthaul traffic is dependent on the user traffic when upper layer functional splits (i.e., Option 2) are considered.

2. OVERVIEW OF SOLUTIONS FOR FRONTHAUL TRANSPORT

Different functional splits and fronthaul transport have been defined by both research papers and Standard Developing Organisations (SDOs). This section provides an overview of them.
The lower layer functional splits (i.e., PHY-RF split or Option 8 and intra-PHY split or Option 7) transport baseband signal I/Q samples either in the time or in the frequency domain, thus requiring constant high-speed connections between the CU and the DU and strict latency requirements (due to the Hybrid ARQ --- HARQ --- protocol constraints). The higher layer functional splits, instead, need lower bandwidth and looser latency requirements since the processing of the I/Q samples is performed inside the DU before sending data through the fronthaul towards the CU. In *Table 1* the requirements for each functional split are listed [3].

Table 1: Bandwidth and latency requirements for each functional split

Protocol split Option	Required Bandwidth		Max allowed one-way latency
Option 1	DL: 4Gb/s	UL: 3Gb/s	10ms
Option 2	DL: 4016Mb/s	UL:3024 Mb/s	1.5~10ms
Option 3	lower than option 2 for UL/DL		1.5~10ms
Option 4	DL:4000Mb/s	UL:3000Mb/s	approximate 100µs
Option 5	DL: 4000Mb/s	UL: 3000 Mb/s	hundreds of microseconds
Option 6	DL: 4133Mb/s	UL:5640 Mb/s	250µs
Option 7-1	DL:10.1~22.2Gb/s	UL:16.6~21.6Gb/s	250µs
Option 7-2	DL:37.8~86.1Gb/s	UL:53.8~86.1 Gb/s	250µs
Option 7-3	DL:10.1~22.2Gb/s	UL:53.8~86.1Gb/s	250µs
Option 8	DL:157.3Gb/s	UL: 157.3Gb/s	250µs

2.1 CPRI

Common Public Radio Interface (CPRI) is a radio interface developed by several leading telecom vendors to transport sampled RF data between the DU and the CU. In *Figure 1a*, the option 1 CPRI frame format is reported as an example. Here, the IQ samples are encapsulated inside a frame which lasts 260 ns (1/3.84MHz). Each IQ sample is encoded with 8-bit word and 16 words are transmitted in a single frame. Thus, the transmission throughput can be calculated as follow:

$$1\ chip * 16\ words * 8\ bit * 3.84\ MHz * \frac{10}{8} = 614.4\ Mb/s \quad , \qquad (1)$$

where $\frac{10}{8}$ is the factor due to the 8B/10B line coding for the error correction/detection used in CPRI option 1 [4].

2.2 eCPRI

The utilization of native CPRI in networks, instead of point-to-point connections only, implies the development of dedicated hardware not compatible with current MAC and PHY standard protocols, potentially causing cost inefficiency. Thus, transporting CPRI frame over Ethernet-based fronthaul (eCPRI) has recently increased interest because of its flexible, cost-effective deployment, easy integration with the current high speed ethernet based optical networks.

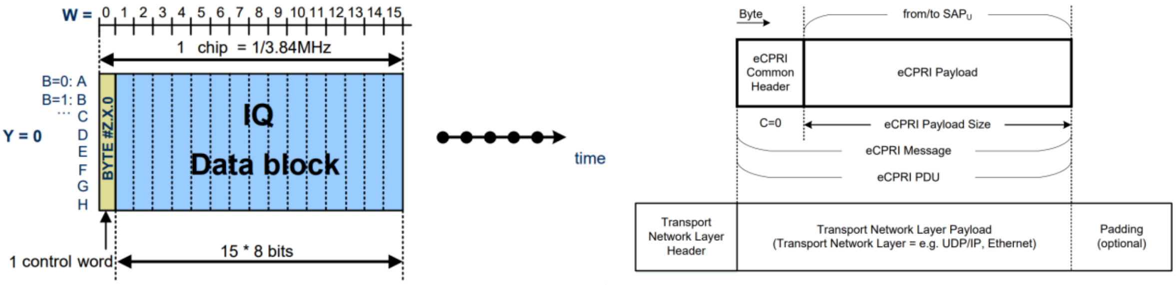
Figure 1b shows how eCPRI message is mapped into transport network layer payload (e.g. UDP/IP or Ethernet) [5]. In [6] the impact of different encapsulation techniques between the DU and CU functional splits have been described for the use of Ethernet based fronthaul.

2.3 NGFI

The bandwidth requirements for CPRI are high and the link rates are currently limited without the possibility to scale up. Bandwidth is not the only restrictive aspect, in fact CPRI also requires very strict latency constrains that does not permit to transport data for long distance [7].

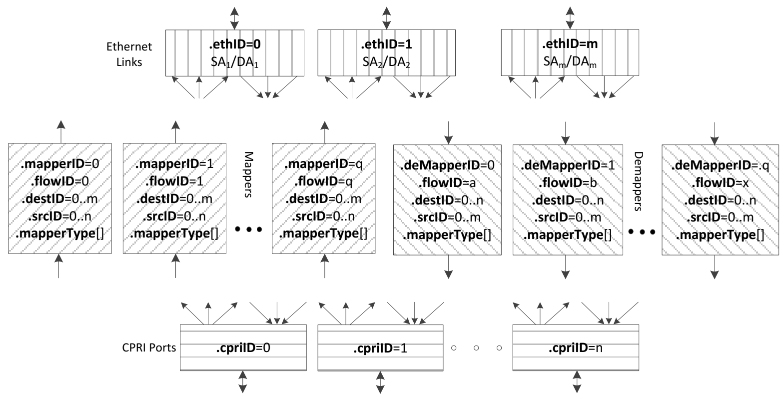
Several other ongoing efforts are investigating fronthaul solutions such as the Institute of Electrical and Electronics Engineers (IEEE) 1914 Working Group with the Next Generation fronthaul Interface (NGFI). In NGFI the fronthaul traffic depends on the functional split implemented and bandwidth and latency constrained may vary according to the functional split used [8]. NGFI has identified both lower and higher possible functional splits, and it is claiming to be the technology that supports key technologies for 5G such as statistical multiplexing and have radio interface technological neutrality.

The NGFI is based on Radio over Ethernet (RoE) encapsulation, which is summarized in *Figure 2* where both hierarchy and RoE encapsulation format are presented. The RoE node maps the CPRI ports into Ethernet links exploiting the mapper/de-mapper process blocks (*Figure 2a*). The packet that is sent over the Ethernet link is depicted in *Figure 2b* and the RoE payload contains a flow of IQ samples for a single antenna carrier of a group of antenna carriers [9].

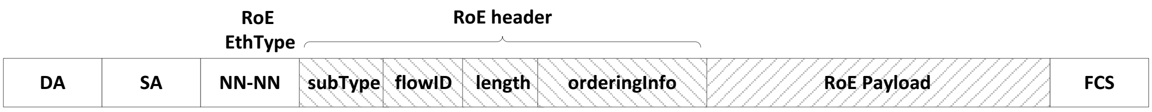


(a) (b)

Figure 1: CPRI (a) and eCPRI message format (b)



(a)



(b)

Figure 2: RoE node hierarchy (a) and RoE message format (b)

3. EVALUATION SCENARIO

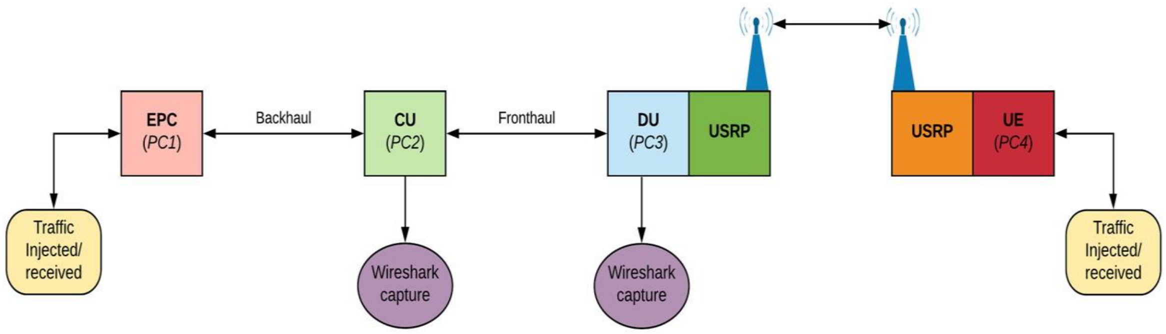


Figure 3: 5G Experimental Scenario

This section presents the characterisation of the traffic carried by the fronthaul for different eNB functional splits. The considered setup is depicted in *Figure 3*. The utilized mobile network software is OpenAirInterface (OAI) whose fronthaul transport technology is based on NGFI [10]. Here, the OAI-based User Element (UE) is used as an end user device connected to Universal Software Radio Peripheral (USRP) to exploit wireless communication. The USRP represents the physical front end radio based on Field Programmable Gate Array (FPGA), since it has the role to acquire/send samples from UEs at very high rate. Considering, for example, the uplink direction to describe the communication flow, the data are sent from UE to USRP which is connected to the DU through a USB3.0 connection. Then, the DU receives the data and performs several elaborations on them, depending on the

implemented functional split, before encapsulating and sending the packets towards to the CU via fronthaul (e.g., 1 Gbps Ethernet link). The CU receives the packets from fronthaul, decapsulates them and completes the tasks according to the used functional split and, finally, sends the traffic to the *backhaul* towards the EPC. Note that the OAI core is utilised for implementing the EPC functions.
The functional splits implemented by the OAI platform are the IF5 and IF4.5 also known as Option 8 and Option 7-1 in the 3GPP terminology [3]. In this study, a signal bandwidth equal to 5 MHz, corresponding to 25 Physical Resource Blocks (PRBs) with the Option 8 and Option 7-1 scenario is considered. *Table 2* summarizes the characteristics of physical machines that are used in the experimental setup.
Regarding the test, the inter-departure time at both sending side (e.g., EPC in downlink direction and UE in uplink direction) and receiver side (e.g., UE in downlink direction and EPC in uplink direction) is measured. As shown in *Figure 3*, a Wireshark probe is placed at the DU and at the CU to capture the traffic. The DU probe is used to monitor the data for Option 8 and Option 7 -1 functional split while the CU probe is necessary to capture packets related to Option 2 functional split. In this scenario, it is possible to understand if the fronthaul traffic is dependent on user traffic for the considered functional splits.

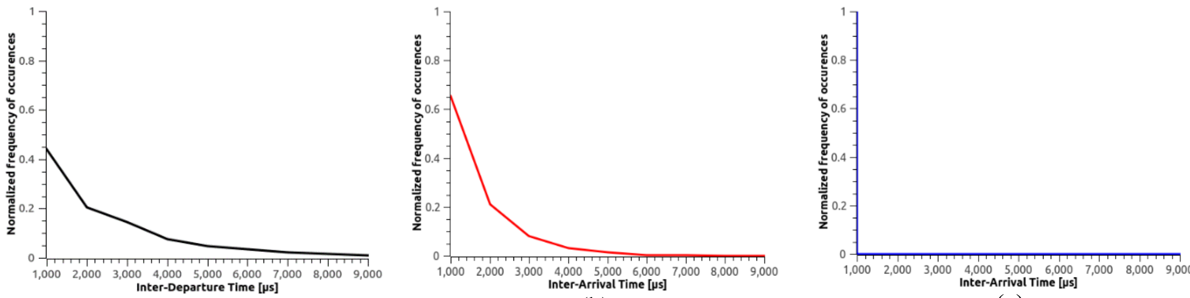
Table 2: 5G experiment physical characteristics components

Device Name	5G Component	Processor Type	Operating System
PC1	EPC	Intel Atom x5-Z8350 Quad Core Processor	Ubuntu 14.04 (4.7 kernel)
PC2	CU	Intel Xeon E5620	Ubuntu 14.04 (3.19 low-latency kernel)
PC3	DU	Intel I7 7700 Quad Core (@ 4.0GHz)	Ubuntu 14.04 (3.19 low-latency kernel)
PC4	UE	Intel I7 7700 Quad Core (@ 4.0GHz)	Ubuntu 14.04 (3.19 low-latency kernel)

To characterise the behaviour of the fronthaul traffic, packets are injected at EPC and UE and monitored as described above. *Distributed Internet Traffic Generator (D-ITG)* tool [11] is used to produce traffic with distributions that accurately follows patterns defined by the Inter-Departure Time (IDT) between packets. Here, negative exponential IDT traffic distribution is considered with Option 8, Option 7-1, and Option 2 functional splits. The considered evaluation parameter is the *normalized frequency of occurrences,* which represents the probability density function, of the IDT at EPC side and of the Inter-Arrival Time (IAT) at CU or DU side.
In all the considered functional splits, the *sender* component of D-ITG tool (*ITGSend*) is running at EPC to generate downstream UDP traffic, and the receiver component of D-ITG tool (*ITGRecv*) is running at OAI UE to receive UDP traffic and vice versa in the uplink direction.

4. RESULTS

This section presents the traffic characterisation experimental. *Figure 4* shows the normalized frequency of occurrences of the IDT and IAT of the user traffic generated by following negative exponential distribution from EPC to UE and of the fronthaul traffic, respectively. In particular, *Figure 4a* refers to the EPC side while *Figure 4b* is related to the CU for Option 2 functional splits and *Figure 4c* represents the traffic behaviour at DU for Option 7-1 functional split. The results show that upper layer functional split (i.e., Option 2) fronthaul traffic depends on the user traffic, whereas the lower layer functional split (i.e., Option 7-1) is independent of the user traffic. Moreover, by comparing the results depicted in *Figure 4b* of *Figure 4a*, the fronthaul traffic does not have the same behaviour as the user traffic. Indeed, the normalized level of occurrences curve values for the frontaul are more clustered toward similar IAT. The reason lies in the buffering necessary for packet encapsulation at CU. Note that the experiments for uplink communication and with Option 8 were performed, but not presented because they follow the same behaviour of downlink communication and Option 7-1.



(a) (b) (c)

Figure 4: Downstream User traffic generated with Exponential Inter-Departure Time between the packets a) Source of the traffic generated at EPC b) the fronthaul traffic captured at the CU with Option 2 functional split c) the fronthaul traffic captured at the DU with Option 7 functional split

5. CONCLUSIONS

This paper presented the next generation eNB (gNB) functional split analysis and fronthaul transport solutions, such as Common Packet Radio Interface (CPRI), eCPRI, NGFI and their relationship with the Ethernet protocol. It analysed the impact of the negative exponential IDT user traffic profile on fronthaul with different functional splits. Based on the obtained results, the fronthaul traffic is independent on the user traffic profile when lower layer functional splits (i.e., Option 8, and Option 7-1) are considered. Whereas, the fronthaul traffic is dependent on the user traffic when the higher functional split (i.e., Option 2) is considered.

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