VIAVI Solutions

White Paper

Preparing Transport Networks for 5G

Emerging 5G services pose new requirements for transport networks. A drastic rise in demand for bandwidth and ultra-low latency constitute two of the more important of these requirements. Addressing them necessitates a new split of functions in radio access networks. CPRI/eCPRI, IEEE, and xRAN are among the organizations that have come up with new standards to design and characterize the new functional splits. This white paper will start by listing the new requirements and challenges of current transport technologies and focus on describing the split options and related service level agreements.

1. Introduction

Understanding the requirements for emerging 5G transport networks necessitates a deeper look at the service quality needs of emerging 5G services (Figure 1). They are broadly classified into three categories of service requirements:

- Enhanced massive broadband (eMBB) provides greater data-bandwidth services with peak data rates of 10 Gbps and beyond. This data rate will enable new use cases such as Augmented Reality/Virtual Reality or Ultra High Density UltrHD applications.
- ultra-Reliable Low Latency Communication (uRLLC) provides ultra-Reliable capabilities with availabilities in the range of 99.9999%, and extremely low latency features in milli second range. Vehicle to Vehicle communication (over 5G networks) is one prominent use case for this category.
- massive Machine Type Communication (mMTC) supports extremely large number of devices in the range of hundreds of thousands per square kilometer. For this application class, it is also essential to have battery life times in the range of 10 years.

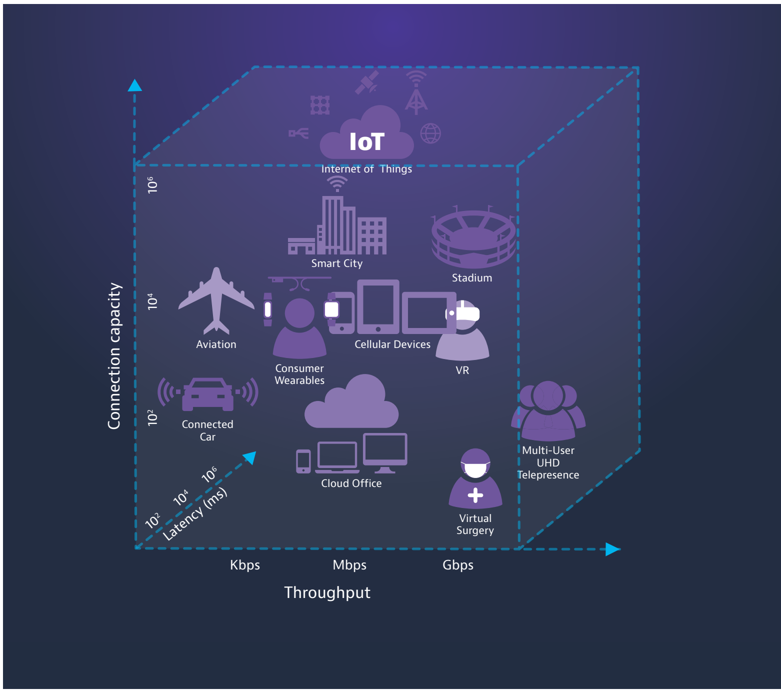

Figure 1: 5G applications

These three categories pose different requirements for the underlying networks and applications:

- eMBB demands much higher bandwidth availability from the network for the Ue
- uRLLC necessitates extremely low latency in the network design for the relevant network components and their interconnecting transport network
- mMTC requires networks that can serve very large number of end points in a power efficient manner
- The following sections describe the implications of the above orthogonal requirements for the transport network design

2. Fronthaul Challenges and Functional Split Options

Addressing the emerging 5G service requirements necessitated a new way of portioning the network functions in the radio access networks. To understand the reason for this portioning requires an understanding of the limitations of the current 4G network technology. We will start with fronthaul technology.

While CPRI continues to be a mainstream technology for fronthaul technology, it is bandwidth inefficient and cannot scale for 5G massive broadband services as the required bandwidth and antennas would push the CPRI bandwidth requirements above 100 Gbps (Table 1).

Antenna	10 MHz	20 MHz	100 MHz
1	0.49 Gbps	0.98 Gbps	4.9 Gbps
2	0.98 Gbps	1.96 Gbps	9.8 Gbps
4	1.96 Gbps	3.92 Gbps	19.6 Gbps
64	31.36 Gbps	62.72 Gbps	313.6 Gbps

Table 1: CPRI Bandwidth as a function of bandwidth and antenna ports

These bandwidth allocations would be extremely expensive for larger network rollouts. Developing an alternative solution necessitates an analysis of the key functional elements between a baseband unit and remote radio head (Figure 2). 4G Remote Radio units implement RF functions, while the other main functions are placed in the baseband unit. This functional distribution allows operators to centralize most of the functions at one location and have a basic lower cost radio at each end-point (option 8). This centralization also enables resource pooling which optimizes resource utilization. Furthermore, the architecture provides some key functions for advanced LTE technology. Being able to coordinate multiple radios from one location is a precursor to implementing features such as Coordinated Multipoint (CoMP), which helps increase user bandwidth by aggregating traffic sourced from multiple cells at the user terminal. All these advantages come with a massive disadvantage for emerging 5G service: inefficient bandwidth use.

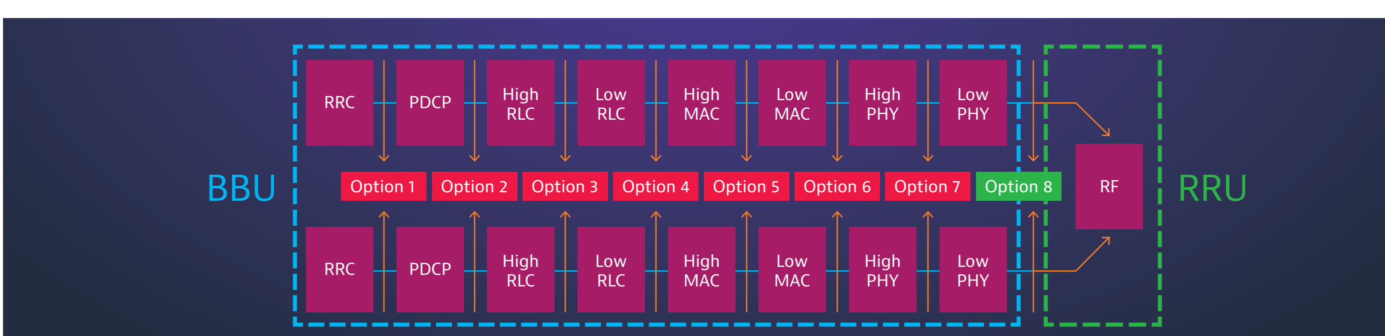

Figure 2: Functional Split Options

3. Higher Layer Split (HLS), Lower Layer Split (LLS) and eCPRI

Beyond the significant disadvantage of bandwidth inefficiency, there is another drawback for option 8: a very limited delay budget. In practice, it means that the distance between baseband units and remote radio heads will be very small. The distance is determined by the delay budget and the type of transport technology deployed in fronthaul. Using dark fiber is the simplest way to allow for maximum distance. Transport equipment that contains some processing elements reduce the delay budget, sometimes substantially as with Optical Transport Networking (OTN). As is often the case, one would need to look at the individual use case and conduct a trade-off analysis to determine the proper transport technology. Availability of fiber and equipment rooms, as well as the number and locations of radio end points are some key factors in this trade-off analysis.

One use case of emerging 5G networks is Fixed Wireless Access in which operators use 5G technology to deliver high bandwidth broadband services to customers in fixed locations. This use case can be considered an alternative to other fixed wireline applications such as Fiber to the Home (FTTH), or residential cable services. In this application, coordination of multiple radios is not a necessity. The priority is delivery of high capacity services that can require bandwidths in excess of 100MHz. For these applications, a Higher Layer Split (HLS) option is recommended (Figure 3). This option places most of the functions inside the radio unit and can also be considered as a Distributed Unit (DU)/Radio Unit (RU) functional element. This placement significantly reduces the bandwidth at the HLS option interface. 3GPP recommends option 2 for HLS. This interface is also known as the new F1 interface. Beyond significant reduction of the bandwidth, the delay budget is in the range of several milliseconds, much higher than CPRI (fronthaul) interfaces. This budget allows the Central Unit (CU) to be located dozens of miles away from the DU/RU element. This segment of the network is called midhaul as it sits between fronthaul and backhaul.

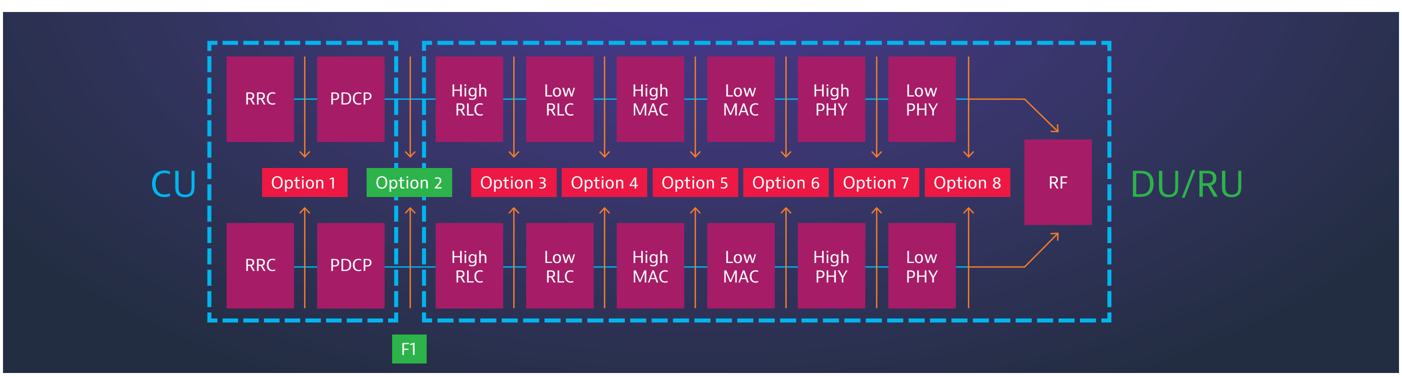

Figure 3: Higher Layer Split (HLS) Option

Beyond fixed broadband services, massive (mobile) broadband services are expected to take advantage of advanced mobility applications that require coordination of multiple radios. This capability requires a lower layer functional split option that leaves most of the functional elements (Figure 4) in a centralized location coordinating the radios. Options 6 and 7 are currently being considered for this use. For this same use case, the CPRI organization published the first eCPRI specification in 2017.

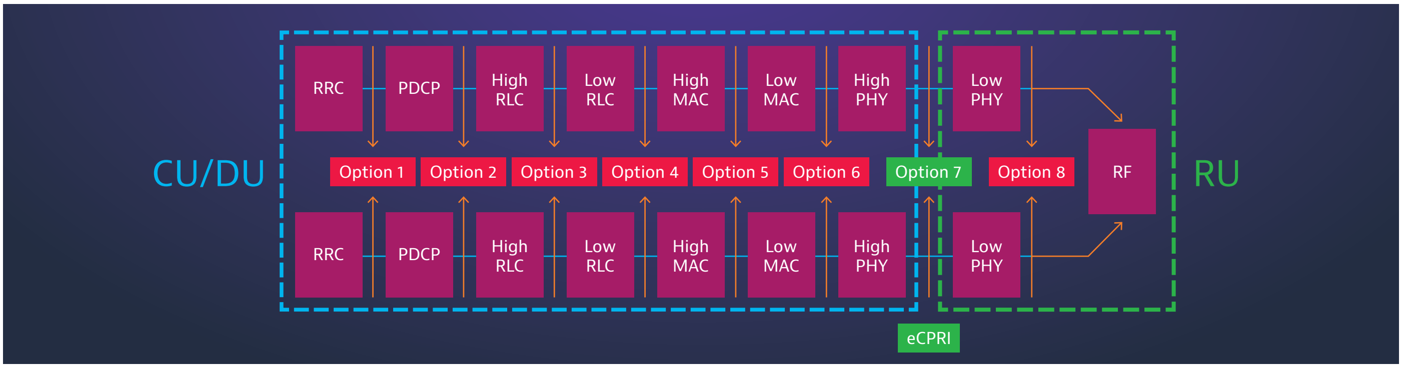

Figure 4: Lower Layer Split option

The eCPRI specification is based on a functional split in the PHY component. PHY includes several functions as depicted in Figure 5. The eCPRI specification recommends that the split option IU is used for uplink, and either IID or ID is deployed for downlink.

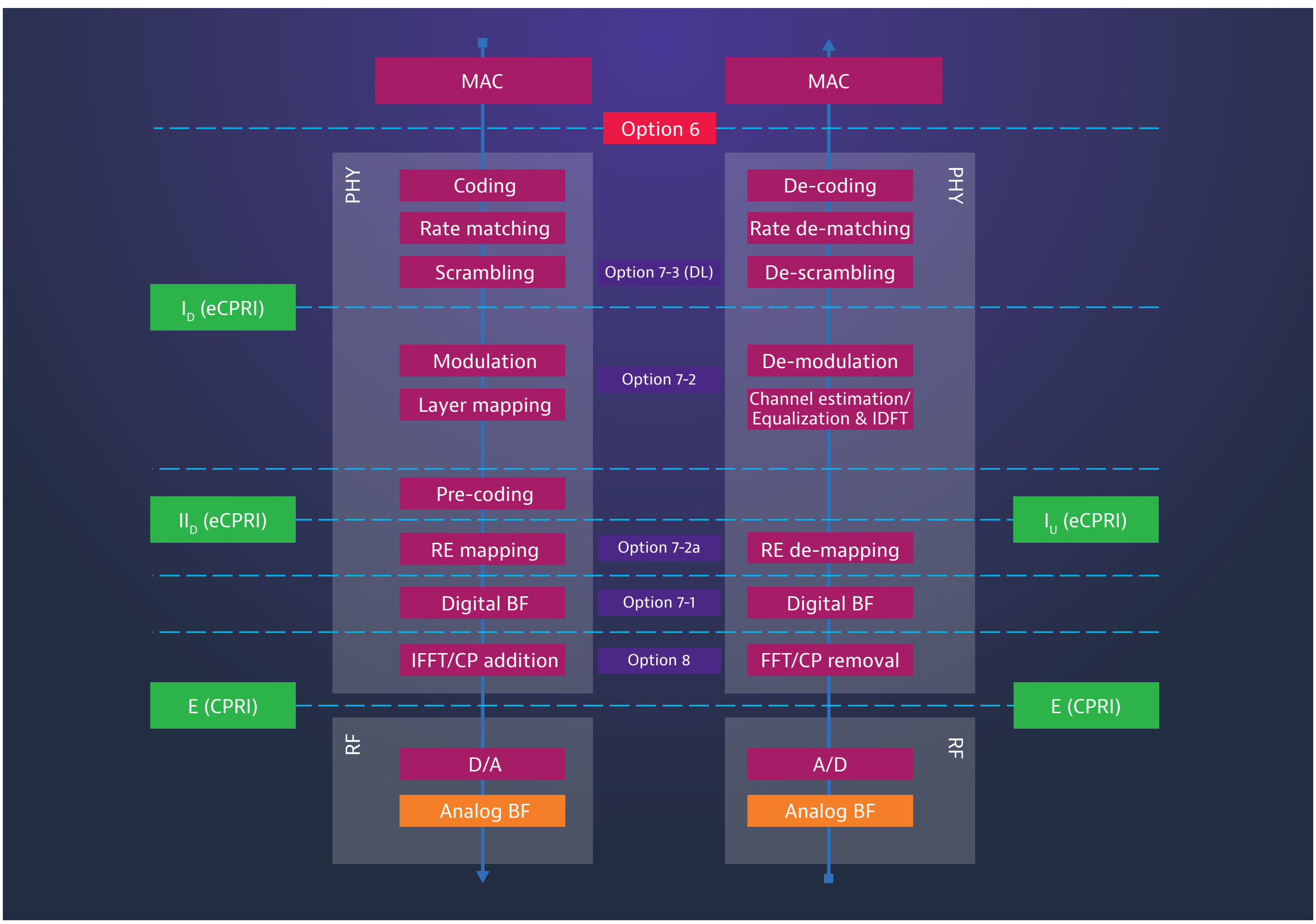

Figure 5: Functional Split in Phy (source: eCPRI specification)

In eCPRI, those entities are called eCPRI radio equipment control (eREC) and eCPRI radio equipment RE (eRE) as depicted in Figure 6.

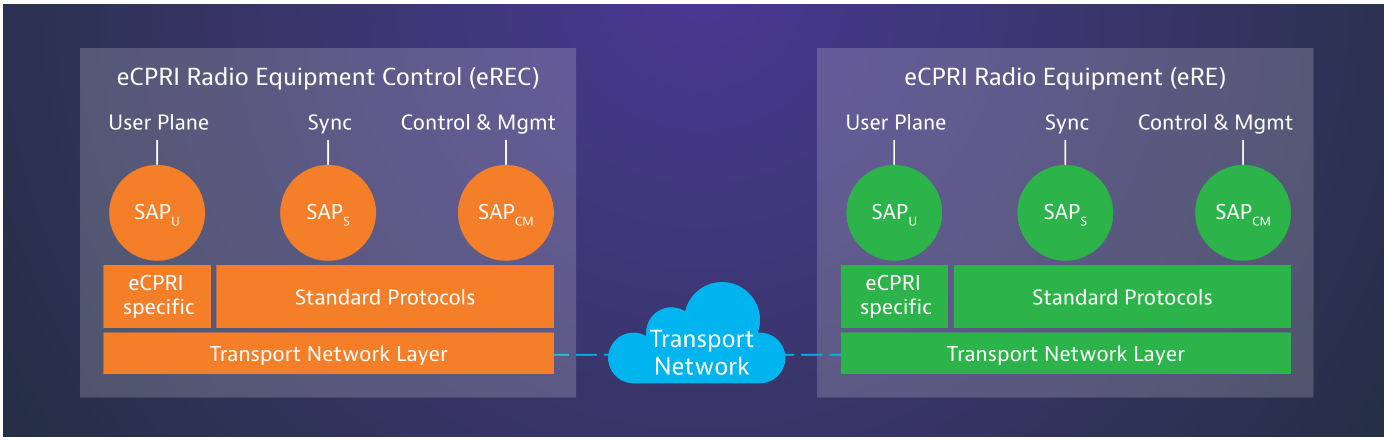

Figure 6: eCPRI Protocol Layers

Three planes are necessary for interaction between eREC and eRE: user plane, sync plane, and control and management (C&M) plane. The eCPRI standard defines the user plane and refers to other standards for the definition the other planes. For example, an operator is free to choose precision timing protocol (PTP), global positioning system (GPS) for synchronization, both in hybrid mode, or other synchronization methods.

eCPRI mentions packet-based technologies for the transport of user plane; both Ethernet (Layer 2) and Ethernet/IP/UDP (Layer 2/3/4) are possible. For the physical layer, eCPRI refers to Ethernet rates 10Gbps to 100Gbps. The frame format is based on using an Ethernet or Ethernet/IP/UDP frame that uses the unique Ethertype of AEFE16. The frame includes an eCPRI header that follows the layer 2 or layer 2/3/4 header and is followed by the eCPRI payload. eCPRI defines several message types for the payload listed in Table 2.

Message Type #	Name	Section
0	IQ Data	3.2.4.1
1	Bit Sequence	3.2.4.2
2	Real-Time Control Data	3.2.4.3
3	Generic Data Transfer	3.2.4.4
4	Remote Memory Access	3.2.4.5
5	One-way Delay Measurement	3.2.4.6
6	Remote Reset	3.2.4.7
7	Event Indication	3.2.4.8
8 - 63	Reserved	3.2.4.9
64 - 255	Vendor Specific	3.2.4.10

Table 2: eCPRI message types

The most significant part of the user plane is given by IQ data or bit sequence; the former for split options I_U/I_D, and the latter for split option II_D. Since split option E is very bandwidth intensive, most IQ data deployments are expected to be based on split option I_U/I_D. The IQ data or bit sequence are carried in association with their respective real-time control data that contains vendor specific information between PHY processing elements in eREC and eRE.

The above options rely on a single split configuration. There are also good reasons to have a double-split-option (Figure 7). Ultra-reliable low latency communication (URLLC) applications require extremely fast respond delay response from the network. Vehicle to Network (V2N) applications need response times in the range of a few milliseconds from vehicle to vehicle. This does not leave much budget for the cellular network, if the two vehicles communicate over two RU's. This use case is a good example of cases that would benefit from a double split design that separates the DU and CU. While the time critical functions in DU can be placed closely to the RU, and thereby help meet the low latency requirement, the non-time critical functions can be placed farther away in a central location.response from the network. Vehicle to Network (V2N) applications need response times in the range of a few milliseconds from vehicle to vehicle. This does not leave much budget for the cellular network, if the two vehicles communicate over two RU's. This use case is a good example of cases that would benefit from a double split design that separates the DU and CU. While the time critical functions in DU can be placed closely to the RU, and thereby help meet the low latency requirement, the non-time critical functions can be placed farther away in a central location.

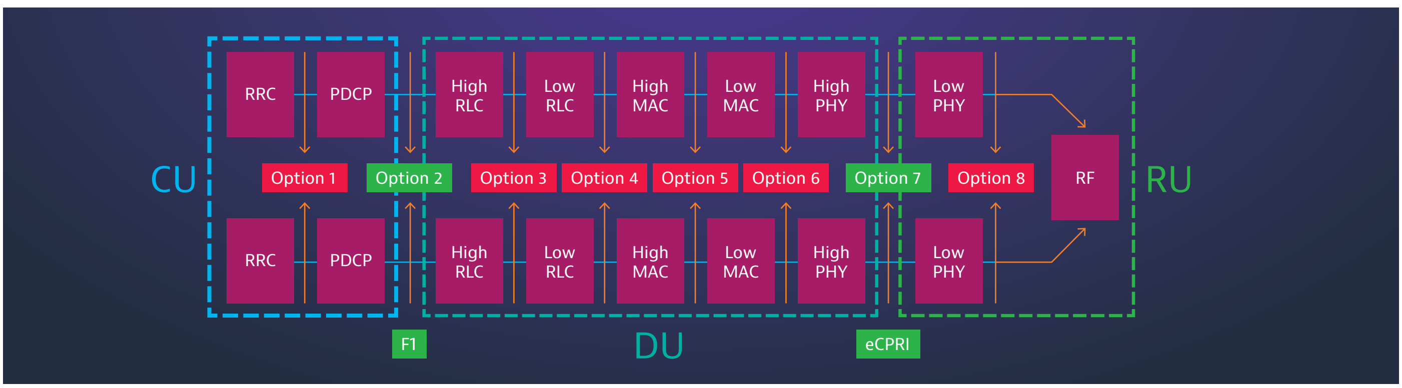

Figure 7: Double Split Option

4. Timing Sensitive Network (TSN)

While the initial deployments of 5G transport networks are expected to use dark fiber and WDM technologies, these technologies will not be scalable for large scale deployments. Given eCPRI's use of Ethernet transport layer, switched Ethernet technologies seem to be a logical way to increase efficiency and reach scalability. Conventional layer 2 or layer 3 switched technologies are, however, not appropriate for the transport of fronthaul traffic due to stringent quality of service requirements.

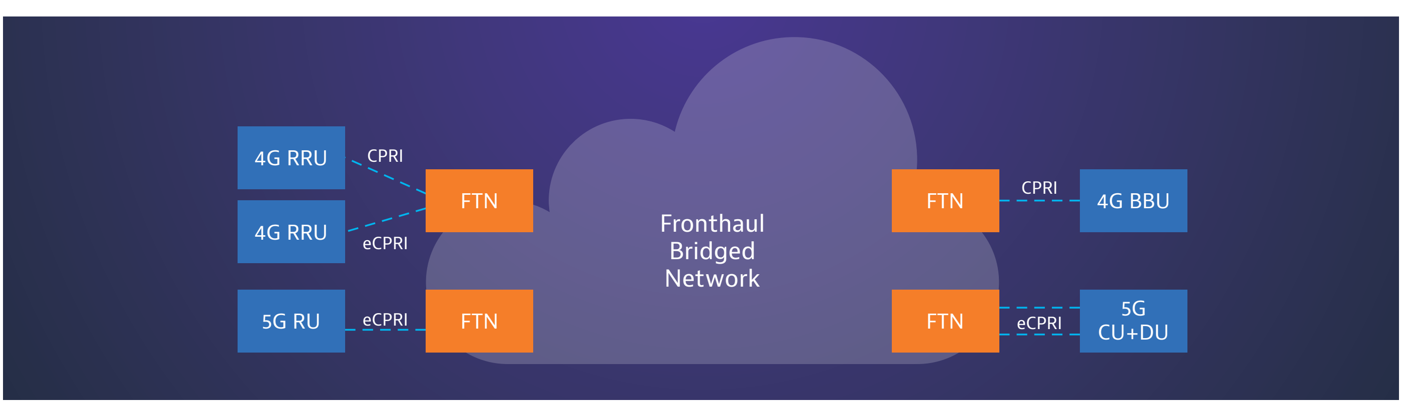

Figure 8: Fronthaul bridged network

To address these requirements, standards organizations have been developing standards for a fronthaul-friendly network design (Figure 8). IEEE 802.1cm selects features and options for fronthaul traffic by describing fronthaul requirements and synchronization requirements for two classes of networks that are distinguished by the functional split of the classes:

- Class 1: functional split 8 (CPRI)
- Class 2: functional split 7 (eCPRI)

Class 1 use cases revolve around transporting CPRI traffic. As we have seen in previous sections, CPRI traffic is composed of different flows such as IQ and C&M data. These flows have different quality of service requirements (Table 3) and can be prioritized and transported separately through a bridged network.

Flow	Latency	Frame Loss Ratio
IQ	100μs	10^{-7}
C&M	No requirement	10^{-6}

Table 3: Requirements for Class 1 (CPRI) traffic (IEEE 802.1cm)

Synchronization is always provided independent of IQ and C&M flows.

Class 2 refers to eCPRI (functional split 7) traffic. eCPRI specification lists two classes of user plane (Table 7). A subset of use cases may deploy the slow User Plane profile. However, the majority is expected to use the more stringent User Plane traffic profile. For Control and Management C&M, there are two categories; the fast category has more stringent requirements than the regular C&M category. For the three use cases mentioned above, three distinct Class of Service (CoS) categories Low, Medium and High are defined. These requirements are particularly listed for split options E, I_D, II_D, and I_U.

CoS Name	Flow	Latency	Frame Loss Ratio
High	User Plane (fast)	Table 5	10^{-7}
Medium	User Plane (slow) and, C&M Plane (fast)	1 ms	10^{-7}
Low	C&M	100 ms	10^{-6}

Table 4: Requirements for split options E, I_D, II_D, and I_U (eCPRI Transport Networks)

The High category is further refined in four latency classes High25 through High500 (Table 5). The traditional LTE (Evolved Universal Terrestrial Access E-UTRA) applications necessitate a tight budget for one-way delay in fronthaul networks as we saw in class 1 requirements above. The same is true for 5G NR radios. However, the transport networks are not necessarily only designed for mobile applications; High200 and High500 can be applied for those applications. For ultra-low latency applications, the delay budget is even stricter. And yet there are other applications that have less stringent requirements.

Flow	Latency	Use case
High25	25 μs	Ultra-low latency
High100	100 μs	E-UTRA and NR
High200	200 μs	For installation up to 40 km
High500	500 μs	Large latency installations

Table 5: CoS High Latency Requirements for split options E, I_D, II_D, and I_U (eCPRI Transport Networks)

5. Network Slicing

The previous section listed some of the critical network requirements for various applications. Network slicing allows operators to offer different categories of services with a wide range of service requirements on a common, shared physical network. Figure 9 illustrates the example of deploying one physical network to serve an eMBB and ultralow latency application at the same time. Whereas the former necessitates the use of a double split (options 2 and 7) architecture between the 5G core (NGC) and antenna, the later needs to place the core functions closer to the edge to meet the tight latency requirements.

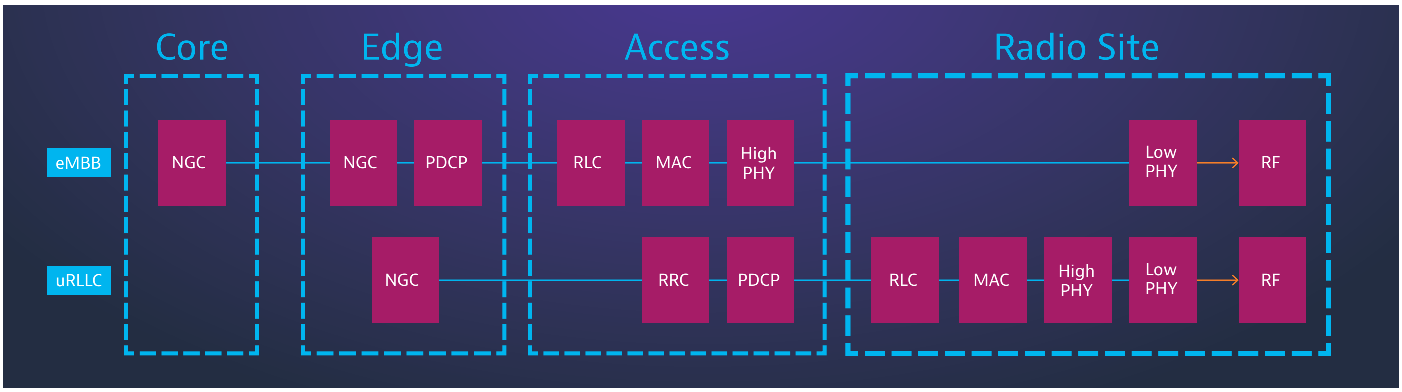

Figure 9: Network slicing for eMBB and uRLLC applications

6. Emerging 5G Synchronization Requirements

The synchronization requirements are derived from several bodies including the 3gpp in its technical specification series 36.xxx and 38.xxx for 4G and 5G services, respectively. The technical specifications 36.104/38.104 represent two key documents that describe base station radio transmission and reception requirements. More specifically, section 6.5 (Transmit signal quality) lists several requirements that are essential for synchronization network design including Time Alignment Error (TAE). TAE is defined as the largest timing difference between any two signals belonging to different antennas or transmitter groups. The requirements are categorized dependent on the wireless use case (Table 6). These use cases are assigned unique categories from A+ to A, B, and C. The use cases at the bottom of the table are being developed at this time and have not been assigned a category.

3GPP feature	**RAN**	
	LTE	**NR**
MIMO or TX-diversity transmission	Category A+	Category A+
Intra-band contiguous carrier aggregation	Category A	BS Type 1: Category B BS Type 2: Category A
Intra-band non-contiguous carrier aggregation	Category B	Category C
Inter-band carrier aggregation	Category B	Category C
TDD	Category C	Category C
Dual Connectivity	Category C	Category C
COMP	Not specified in 3GPP	Not ready in 3GPP
Supplementary Uplink	Not applicable for LTE	Not ready in 3GPP
In-band Spectrum Sharing	Not ready in 3GPP	Not ready in 3GPP
Positioning	Not specified in 3GPP	Not ready in 3GPP
MBSFN	Not specified in 3GPP	Not ready in 3GPP

Table 6: Timing Accuracy categories (eCPRI Transport Requirements)

Category A+ demands the most stringent synchronization requirements (Table 7); category C's requirement is in line with current LTE backhaul networks. The requirements are identified in terms of relative and absolute Time Error TE. The relative TE specifies the time error between any two RU (or eRE). Absolute TE is the time error against a reference PRTC. In most cases the absolute TE requirements are in addition to the one for respective relative TE requirements (categories A+, A, and B). There are some variations in the range of time error requirements; those are necessary to account for different implementations of the telecom time slave clock T-TSC. For example, if the T-TSC is integrated in an eRE/RU, then the time error limit is lower than the case of an external T-TSC function.

Category	Time Error
A+ (relative)	20-32 ns
A (relative)	60-70 ns
B (relative)	100-200 ns
C (absolute)	1100 ns

Table 7: Time Error requirements

7. RoE

As with previous generations of wireless networks, the introduction of 5G radio access networks will overlap with the continuous deployment of 4G RAN. This overlap certainly raises the need for a converged transport network that can address the needs of both RAN technologies. For example, the need to transport CPRI and eCPRI links over the same physical infrastructure (Figure 10). This example revolves around bringing together the 4G and 5G fronthaul networks together, but there is no reason why this convergence should only be limited to fronthaul networks. It is reasonable to expect a convergence of fronthaul, midhaul, and backhaul networks; and even beyond that in future a convergence with fixed wireline service. In its simplest form, this converged network can be based on WDM. Alternatively, Ethernet can be considered as a cost-effective. eCPRI is already based on Ethernet transport layer. To enable the transport of CPRI over Ethernet, the Radio over Ethernet (RoE) standard was developed in IEEE 1914.3/1914.1 working groups.

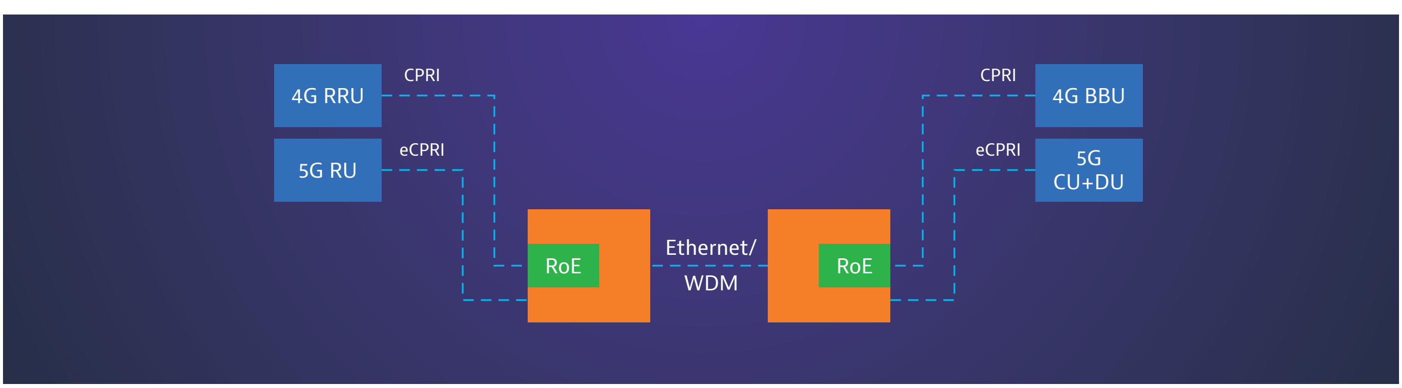

Figure 10: Converged Transport Network

RoE encapsulates CPRI signals into Ethernet frames. There are three variants of RoE:

- Structure agnostic
- Structure aware
- Native encapsulation

Structure agnostic is the simplest method. It has basic knowledge of the client signal. It includes the type of line coding used. Structure aware is partially aware of the protocol used and is more efficient than the previous method. The most efficient method is RoE with native encapsulation that only transfers the time or frequency domain IQ data, as well as, control and management data. In summary, the complexity and cost can increase from structure agnostic towards native encapsulation, but one gains more efficiency with the latter approaches.

8. Summary and Outlook

Emerging 5G services demand different SLA's for enhanced massive broadband eMBB, ultra-Reliable Low Latency Communication uRLLC, and massive machine type communication mMTC applications. While eMBB challenges the bandwidth inefficiency of existing fronthaul technologies, uRLLC applications require ultra-low latency networks, and yet the mMTC demands a network that can manage very large number of end points in a power efficient manner. These new challenges have led to consideration of new ways of splitting critical base band and radio functions.

Proper network design requires careful analysis of various SLA's associated with above functional split options and use cases. They are characterized by latency, frame loss ratio and time error metrics. Considering the diversity of the use cases and SLA's, 5G transport networks can only be economically viable if they can be designed on a single converged physical network. Network slicing enables the deployment of multiple services with distinct SLA's on a single physical network.

Initial converged networks are taking advantage of WDM technology. While sufficient for the initial deployment, massive deployment of 5G radios will necessitate an economic and ubiquitous technology such as Ethernet. To allow for the convergence of legacy CPRI based and new Ethernet based network technologies, RoE standard can be deployed in fronthaul networks. Finally, an Ethernet based technology can be most fruitful, if its statistical multiplexing gains are effectively used. Taking advantage of this multiplexing gain can only be realized with a careful analysis of 5G latency requirements. Timing Sensitive Networking is the ultimate goal of a cost effective and massively scalable converged access network.

Successful deployment of emerging 5G transport networks can only be accomplished if the respective SLAs are thoroughly verified in network design and field deployment phases. Throughput, frame loss ratio, latency and time error are some of the key metrics that have to be characterized with sufficient accuracy as determined by network limits listed in the paper.

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