To 5G with O-RAN

White paper

Bittium

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Published January 2022

Abstract

The 5G system is yet another leap forward in the decades long progression of cellular systems. A diverse set of requirements, including Enhanced Mobile Broadband (eMMB), Ultra-Reliable Low Latency Communication (URLLC) and Massive Machine Type Communication (mMTC) have been defined. The wide RF frequency range with bands ranging from 400 MHz to the millimeter wave lengths at tens of gigahertz bring new challenges for RF and massive MIMO antenna design. Low latency performance drives the efficient integration of hardware and software processing elements, and efficient interfaces between network nodes. The security aspects of the network nodes are also of special concern. The mMTC requires supporting many simultaneous connections, while allowing for an ultra-low power consumption of the radio interface. A one-size fits all is hardly able to address all the requirements, opening the market for diverse solutions. O-RAN with its open interfaces, allows for network nodes and design units from third party providers to be integrated into the networks, to address a given set of requirements. The diverse requirements also open the market for new business models utilizing network sharing, efficient network slicing and neutral host network providers. This white paper provides a high-level view of the 5G architecture and the 5G New Radio (NR) air interface, also highlighting the different deployment scenarios, which may utilize varied business models. A high-level view of O-RAN including selected design challenges is also included. The proven track record over the past decades makes Bittium an ideal R&D partner that can help customers with development of O-RAN hardware and software implementations for 5G RAN (Radio Access Network).

Background

Defining a next generation wireless telecommunication system is never an easy task, especially when requirements ten to twenty years into the future need to be accounted for. The requirements have typically been underestimated, and the most prominent applications used on the system in the future have not been estimated correctly. The applications used on the system may not even exist yet at the time of system specification. What has become evident based on the past, is that all the bandwidth and capacity made available by the system will eventually be utilized, with the market continually craving for more. This is true, even though WiFi technology has dominated the indoor data market. Even the most optimistic estimates of cellular data usage have been too small in the past, as can be seen from the ITU-R data shown in **Figure 1**. The trend has continued with the early deployments of 5G.

On the high-level, the 5G system is intended to address the requirements of eMBB, mMTC and URLLC. Fulfilling any of these requirements will require making a set of trade-offs, which are often contradictory. For example, supporting the peak data rates requires a very different set of trade-offs than is required for the support of many connected users.

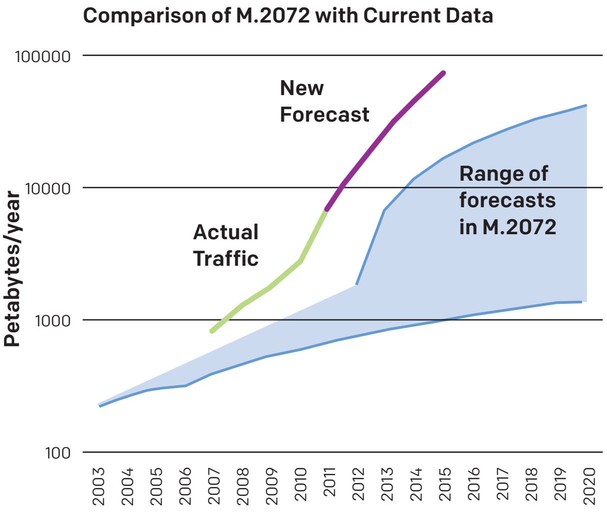


Figure 1: Comparison of data traffic predictions and actual values (Modified from source: ITU-R).

The main technology for achieving significantly higher data capacity is the usage of wider RF bandwidths. As the available bandwidth is limited at lower frequencies, a wide range of radio bands from 410 MHz to 71 GHz are defined for 5G. These are divided into Frequency Range 1 (FR1) from 410 MHz to 7125 MHz and Frequency Range 2 (FR2) from 24.25 GHz to 52.6 GHz. Newer versions of the standard are also going beyond 52.6 GHz. The different frequency bands have different physical characteristics. The frequencies below 1 GHz provide wide coverage areas and deep indoor penetration, as required by the URLLC and mMTC but provide limited bandwidth and data capacity. The higher frequencies of the FR1 can be used for deploying wide area data coverage, as more bandwidth is available there. The FR2 band has limited coverage and poor indoor penetration and is typically used for data hot spots either indoor or outdoor, as the largest bandwidth and data capacity are available with this band. The current ITU band allocations in the FR1 and FR2 frequency bands are shown in **Figure 2**. The actual frequency bands used by 5G in different geographical regions can be found in 3GPP Technical Specification 38.101.

The data traffic in a cellular network is typically very asymmetric, with users downloading 10 to 20 times more data than uploading. This asymmetry favors Time Division Duplex (TDD) band allocations, with most of the time provided for the downlink. Link imbalance due to TDD, smaller User Equipment (UE) transmission power, high downlink data rates and the relatively high frequencies all drive the base station (gNB) towards beamforming type antennas with high gain.

Each consecutive generation of cellular standards has also worked towards reducing the end-to-end communication latency. This has improved the perceived quality of the different services and applications operated over the network. For 5G, a major step in reducing the latency has been taken to facilitate applications such as factory automation, remote medical treatment, mission critical communications and self-driving cars. In the end, the applications requiring low latency may be something different, but the past has shown, that once low latency is available, applications utilizing it will be created.

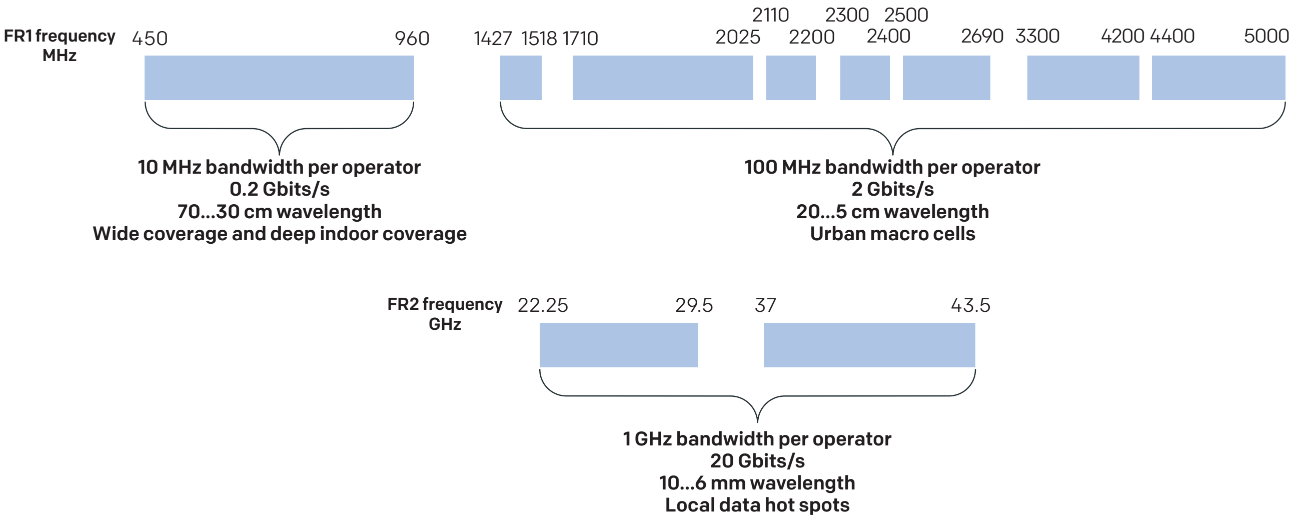
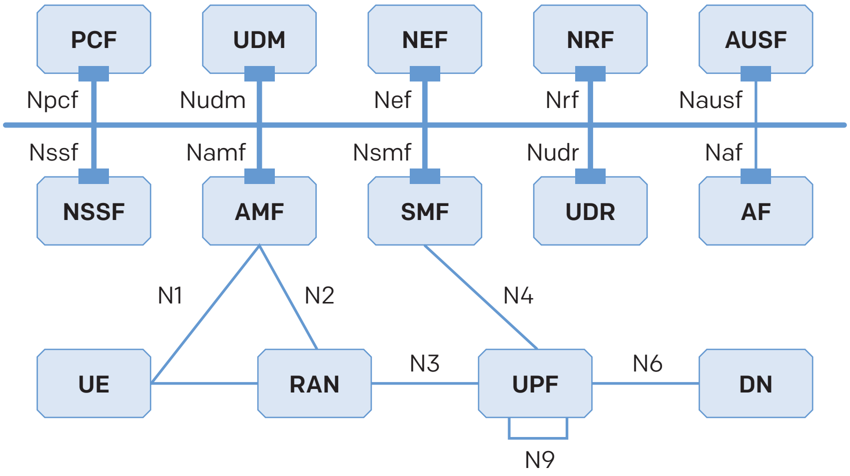


Figure 2: ITU frequency band allocations in the FR1 and FR2 frequency bands.

5G Architecture

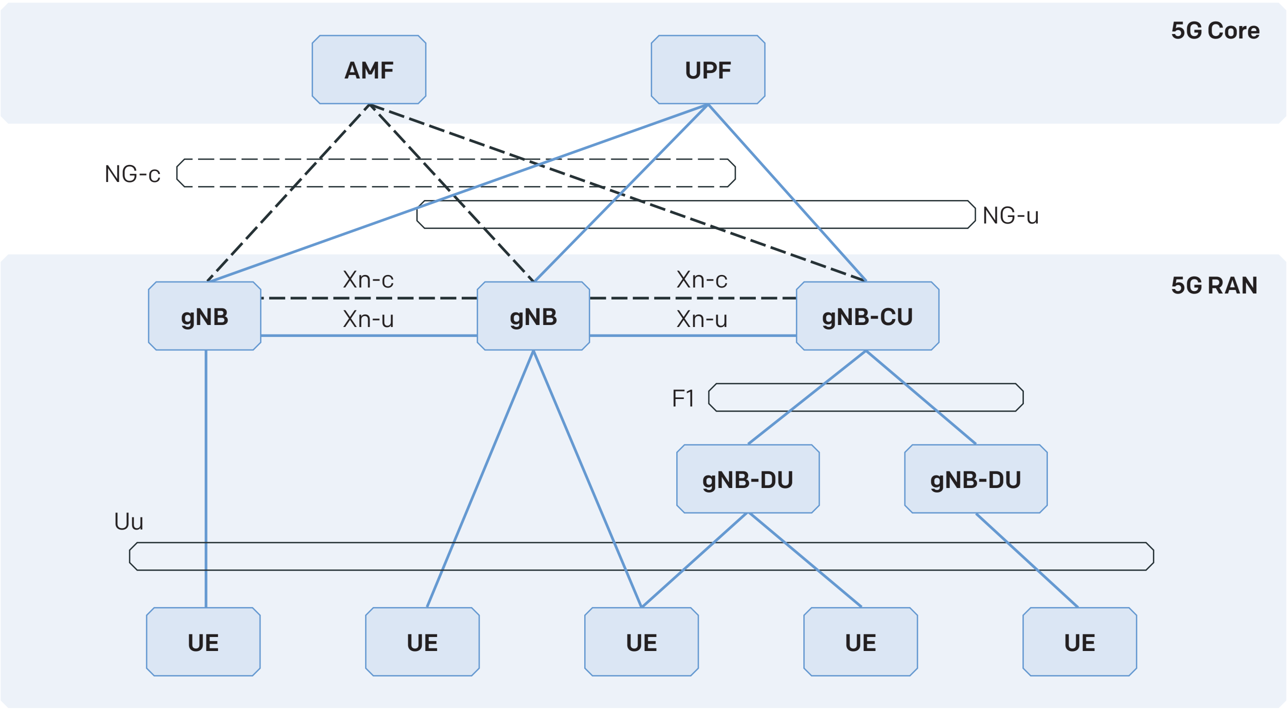
The 5G core network builds upon the 4G Enhanced Packet Core (EPC), while making enhancements towards a service-based architecture, enabling network slicing at several levels and providing an independent scaling of resources through the control and user plane split. **Figure 3** shows the top level 5G system architecture including the Service Based Core (SBC) network functions, the Radio Access Network (RAN) top level and the interfaces between them.

The RAN architecture is further detailed in **Figure 4**, including the interfaces between the network elements. The separation of the control plane interfaces, indicated with -c, and the user plane interfaces, indicated with -u, are shown.



UPF	User Plane Function gateway
SMF	Session Management Function
AMF	Access Management Function
PCF	Policy Control Function
UDM	Unified Data Management
NEF	Network Exposure Function
NRF	New Radio (NR) Repository Function
AUSF	Authentication Server Function
NSSF	Network Slice Selection Function
UDR	Unified Data Repository
AF	Application Function
UE	User Equipment
RAN	Radio Access Network
DN	Data Network

Figure 3: 5G system architecture



gNB-CU	g Node B Central Unit	**gNB-DU**	g Node B Distributed Unit

Figure 4: 5G RAN architecture.

A similar protocol stack is used in the different control and user plane portions of the NG, Xn and F1 interfaces. The control and user plane protocol stacks are shown in **Figure 5**.

The main functions of the NG-c interface are
- Paging
- UE context management
- UE mobility management
- PDU session management
- AMF load balancing

The NG-u interface is used to transport the user plane data Protocol Data Units (PDUs) between the NG RAN and the Data Network.

The Xn interface connects gNBs to each other, or in some cases to LTE eNBs, and the main functions are

- UE mobility control
- UE data forwarding for lossless mobility
- Resource coordination
- Network energy saving
- Dual and multi-connectivity support

The Xn-c main functions are Xn interface management, UE mobility control and management of dual and multi-connectivity. The Xn-u primary functions are data transfer, flow control, retransmissions and transfer of radio related assistance information.

The Uu interface is the NR air interface. The protocol stack for the Uu user and control planes are shown in **Figure 6**. As can be seen, both the user and control planes utilize much of the same protocols.

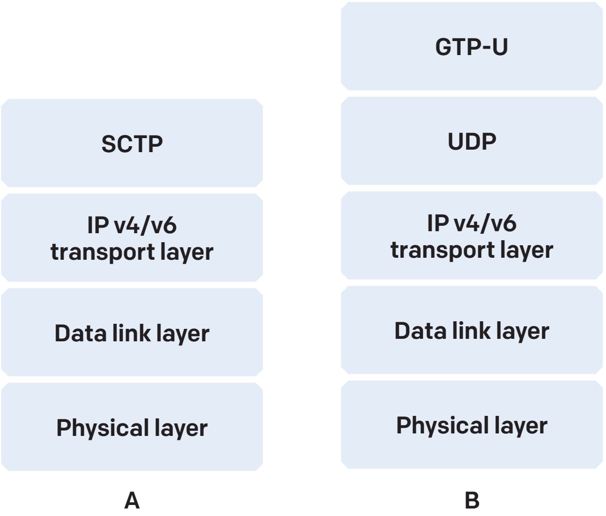


Figure 5: Protocol stack of
A) control plane and B) user plane interfaces

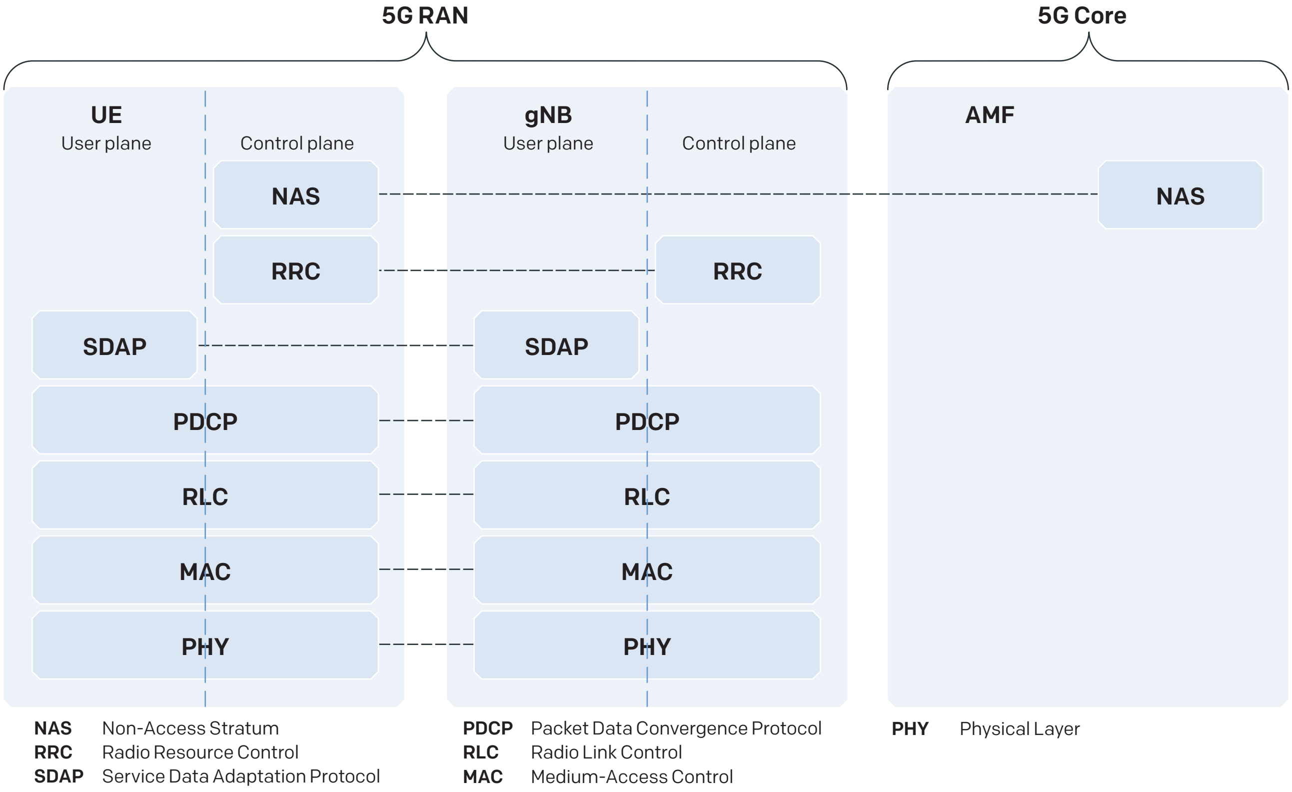


Figure 6: The NR air interface protocol stack.

NR Interface

The New Radio (NR) interface is used as the protocol stack in the 5G air interface. The NR downlink user plane protocol stack is shown in **Figure 7**. The uplink stack includes similar components.

The main functions of the different protocol layers are depicted in the figure.

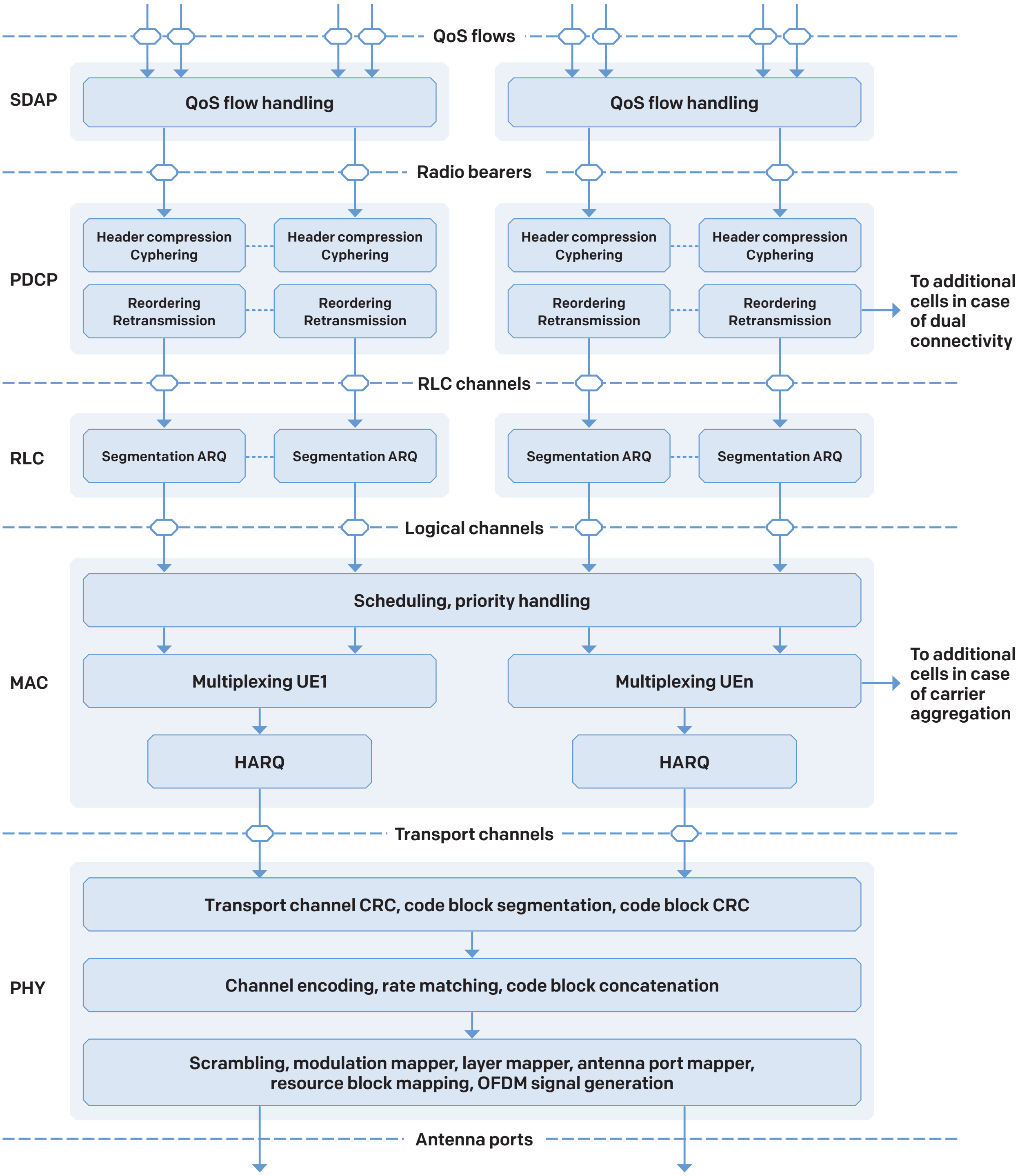


Figure 7: NR downlink user plane protocol stack.

Subcarrier spacing KHz	Symbol time µs	Cyclic prefix time µs	Max carrier bandwidth MHz (275*12 subcarriers)	Minimum scheduling interval ms
15	66.7	4.7	49.5	1.0
30	33.3	2.3	99	0.5
60	16.7	1.2	198	0.25
120	8.33	0.59	396	0.125
240	4.17	0.29	-	0.0625

Table 1: NR subcarrier spacings.

The NR control plane stack includes the Radio Resource Control (RRC) functionality, as shown in **Figure 6**. The main functions of the RRC are

- Broadcast of system information
- Core network-initiated paging
- Connection management
- Mobility functions like cell selection
- Measurement configuration and reporting
- Handling of device capabilities

The NR devices can be in one of three states as shown in **Figure 8**. The RRC_INACTIVE state has been added to NR to enable a fast transition to RRC_CONNECTED state for an inactive device. This is useful in order to minimize the control plane latency.

Achieving a large part of the requirements set for the NR interface are due to improvements in the physical layer. The NR physical layer uses primarily the OFDM waveform in both the uplink and downlink. The option of using the DFT-coded OFDM, similarly to LTE, in the uplink for NR is available, to achieve higher power amplifier efficiency in the UE.

The OFDM numerology including the subcarrier spacing and cyclic prefix length are important for addressing the wide radio frequency range of the NR. A larger subcarrier spacing provides robustness against frequency error and the phase noise more prevalent at higher frequencies, for example. Support of large cell sizes with frequencies below 1 GHz and small cell sizes at the mm-wave frequencies, require different numerologies, as addressed by NR. The NR numerology utilizes as a basic time unit T_c=1/(480000*4096), to determine the sampling time. The symbol times and cyclic prefix lengths for the different subcarrier spacings used by NR are shown in **Table 1**. The larger subcarrier spacings are used at the higher frequencies. The frame, subframe and slot structure of NR is shown in **Figure 9.** NR utilizes a resource block, which is 12 subcarriers in frequency and one symbol in time.

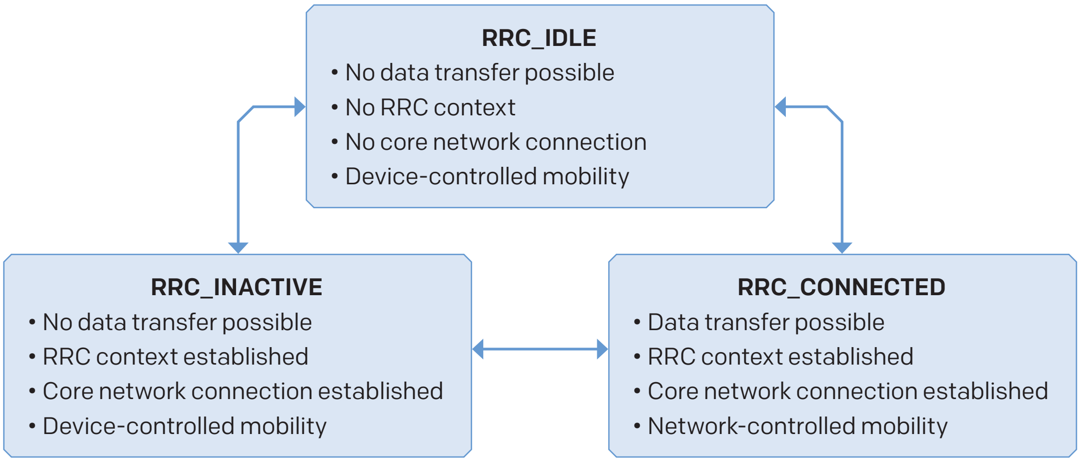


Figure 8: Different RRC states for a NR UE.

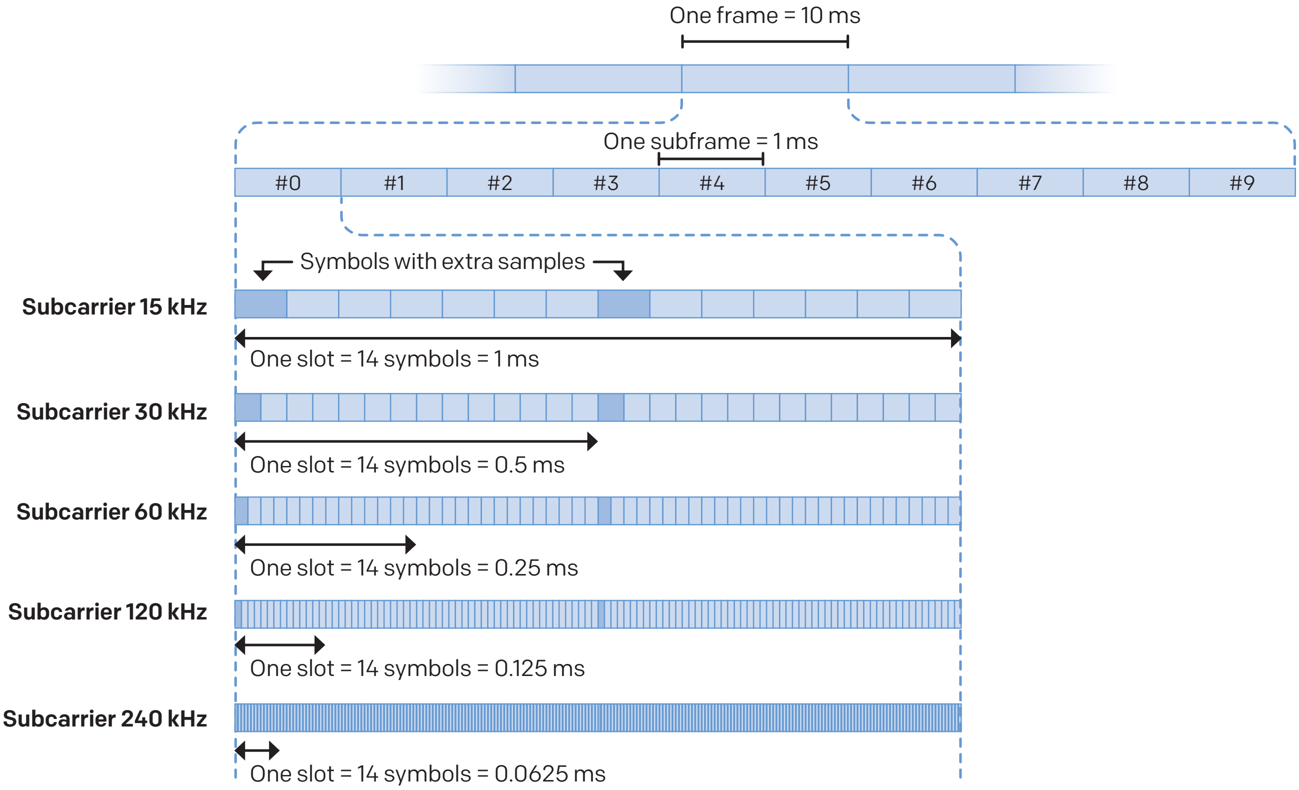


Figure 9: Frames, subframes and slots in NR.

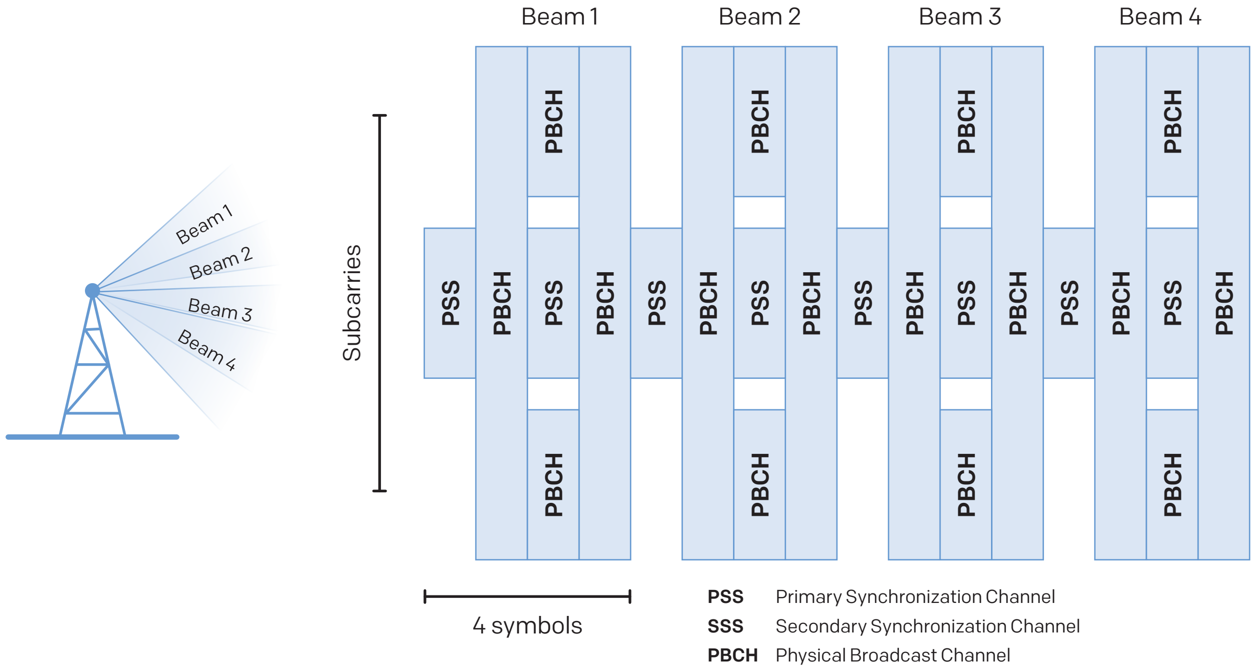


Figure 10: Sequence to transmit control channels over different beams.

Beamforming is an inherent part of NR, which defines usage of beamforming also for the cell specific control channels. An example of the sequence of transmitting control channels through several beams is shown in **Figure 10**.

Yet another key element of the NR physical layer is dynamic usage of duplexing. The NR structure supports separation of uplink and downlink in time and/or frequency subject to either half-duplex or full-duplex operation, all using the same single frame structure. An example of using flexible cell and device specific uplink-downlink patterns is shown in **Figure 11**.

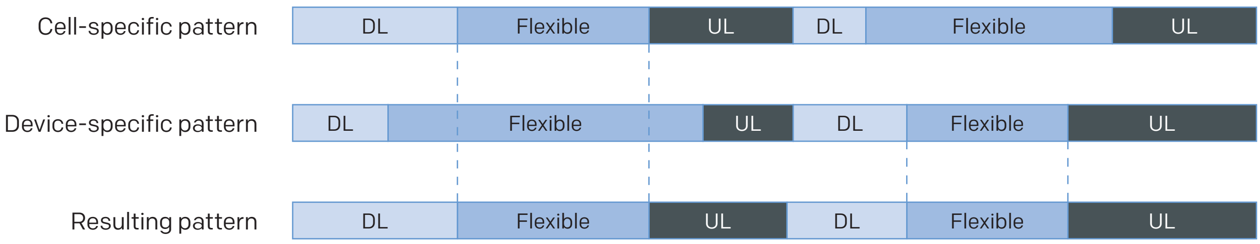


Figure 11: Cell and device specific uplink-downlink pattern example.

Deployment Examples

The most of the current 5G deployments are traditional Mobile Network Operator (MNO) operated macro-cell networks. 5G also provides inherent support for several other deployment models. Several alternatives for network sharing between MNOs are possible as shown in **Figure 12**. Slicing the network into virtual network slices to support different business verticals is also defined for 5G.

A neutral host deployment model is additionally defined for 5G. A neutral host can build and maintain the 5G network within a residential, office or shopping complex and provide the 5G service for customers of different MNOs. This scenario is especially relevant for frequencies in the FR2 region, where building indoor coverage through macro cells from the outside is difficult. **The Figure 13** depicts the neutral host scenario.

The radio propagation of the FR2 frequency range prohibits large cell sizes. On the other hand, the largest user throughputs are available in that frequency range, leading to hot-spot small cells. One of the major challenges for deploying small cells is

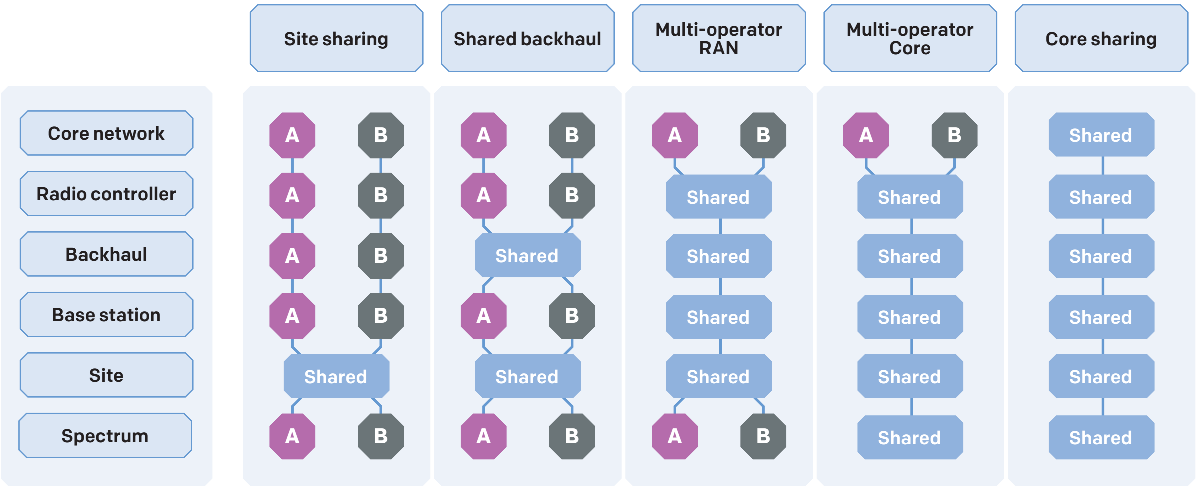


Figure 12: Network sharing alternatives.

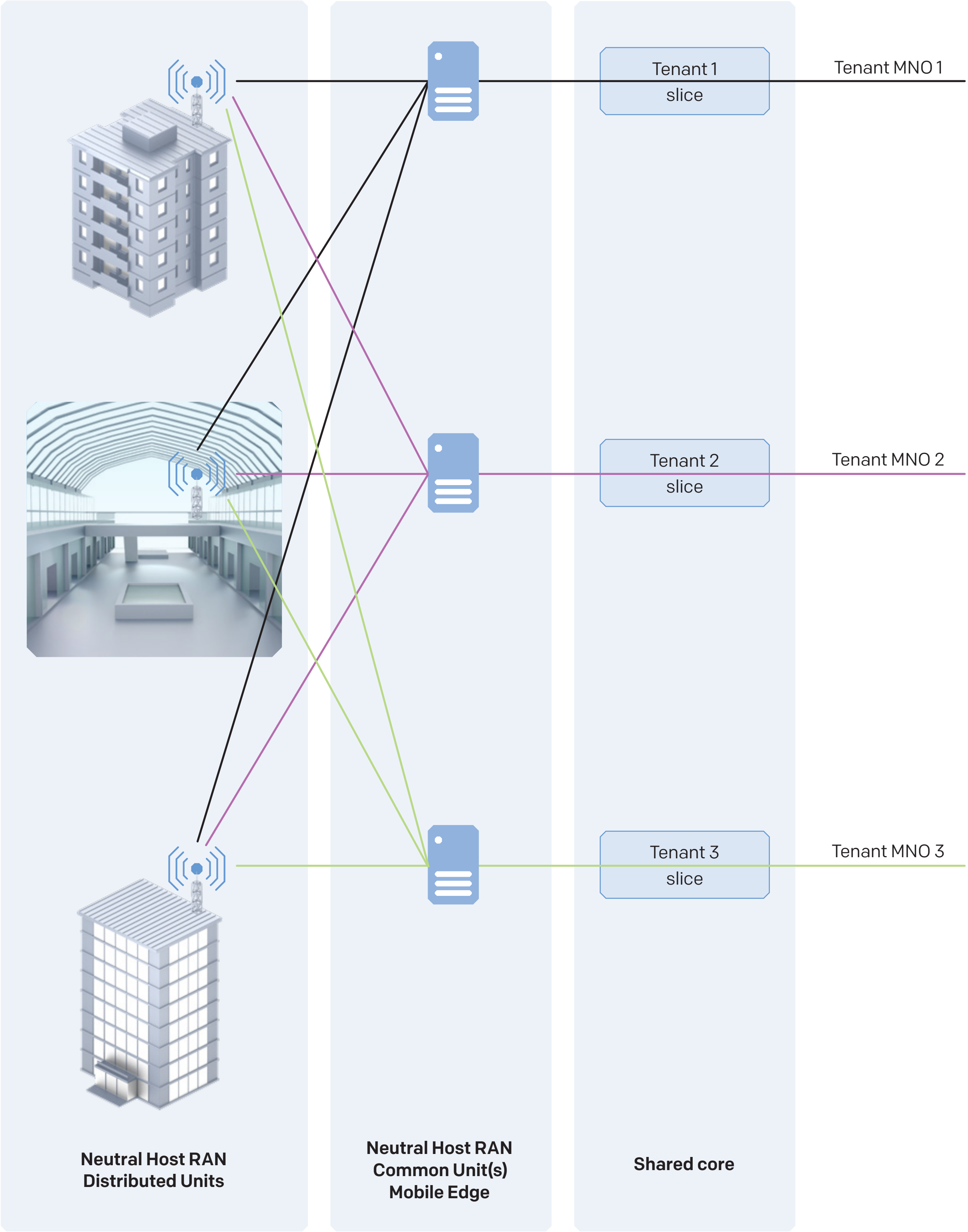


Figure 13: Neutral host deployment.

arranging of the transport, however. The 5G system has defined Integrated Access Backhaul (IAB) for wireless backhaul to address the issue. The **Figure 14** shows an example of a multi-hop backhaul network. MT depicts the mobile functionality required by the IAB.

As a special deployment, the 5G also defines a Non-Terrestrial Network alternative utilizing either Low Earth or Geostationary Orbit satellite systems. The aim has been to provide support for flying platforms in general, like High-Altitude Platform Systems. Special consideration to account for the large propagation delay and rapid speed of the satellite is needed.

An additional deployment scenario is the usage of sidelink communication. Sidelink communication is utilized in 5G for device-to-device communication, V2V or V2X communication supporting unicast, multicast or broadcast transmission. Two resource allocation modes are defined. In mode 1, an overlay network schedules the sidelink communication. In mode 2, the device decides on the resource to use for sidelink transmission based on a sensing and resource-selection procedure, allowing for autonomous operation, without support of an overlay network.

Improvements for IoT energy efficiency have been made for 5G, to address battery consumption of IoT devices. This is important, because, for example, the LTE modem of a biosensor consumes up to 10x more energy from the battery compared to the sensor itself. Several improvements in energy efficiency have been made for 5G. Idle mode consumption and network access procedures have been optimized, so that less activity is needed while the sensor device is not actually transmitting and that also initiating the transmission consumes less energy. During transmission, the device bandwidth adaptation feature allowed by 5G brings several orders of magnitude reduction to energy consumption compared to LTE.

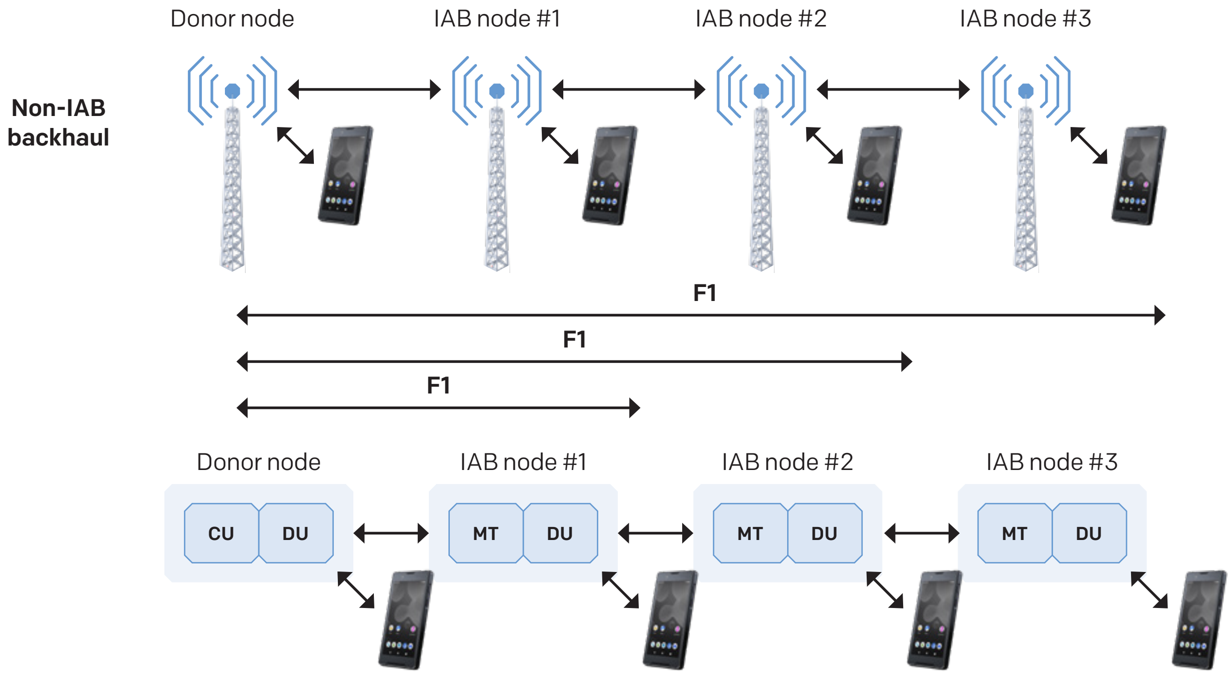


Figure 14: Multi-hop IAB network.

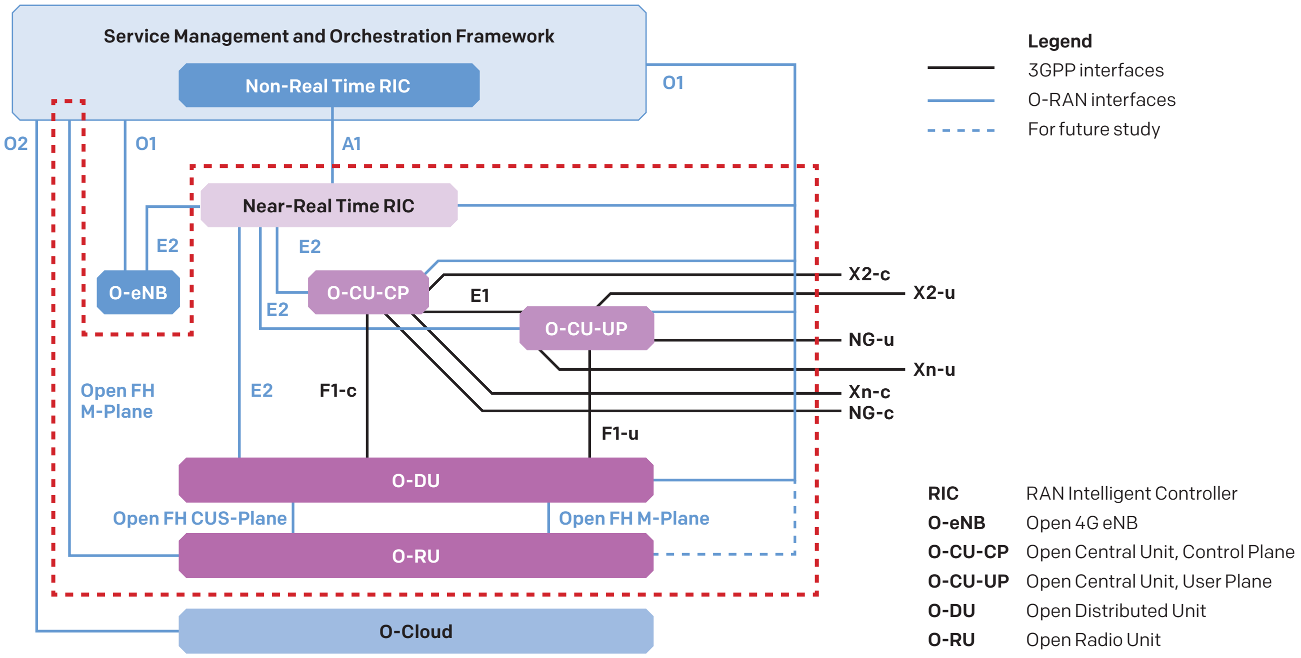
O-RAN

The O-RAN Alliance is an industry alliance, driving the virtualization/cloudification, openness, interoperable interfaces and intelligent, AI driven management of the RAN architecture. The **Figure 15** shows the O-RAN logical overall architecture, showing the O-RAN and 3GPP interfaces between logical nodes. The dashed red line encapsulates the functionality of a gNB, but as the figure implies, several physical splits are possible, with O-RAN ensuring open interfaces.

The Non-Real Time RIC provides non-real time policy-based management using data analytics and machine learning. The Near-Real Time RIC enables near real-time control and optimization of O-RAN (O-CU, O-DU and O-RU) nodes and resources. Managing traffic steering, QoE (Quality of Experience) optimization, QoS based resource optimization and massive MIMO optimization are possible use cases.

The O-RAN Alliance has put a significant effort into the definition of open interfaces, enabling of virtualization and providing the framework for intelligent control of the RAN. For the purposes of this paper, only a small part is elaborated further. A closer look at the synchronization issues and the O-DU/O-RU functional split is warranted.

Several alternatives for making a functional split between the Distributed and Radio Units exist. Trade-offs between unit complexity, achievable interface latency and the interface throughput requirement need to be made. The **Figure 16** shows different split alternatives, with also the 7.2x used by O-RAN highlighted. The option of using data compression to reduce the interface bit rate exists.



RIC	RAN Intelligent Controller
O-eNB	Open 4G eNB
O-CU-CP	Open Central Unit, Control Plane
O-CU-UP	Open Central Unit, User Plane
O-DU	Open Distributed Unit
O-RU	Open Radio Unit

Figure 15: O-RAN overall logical architecture.
(Modified from source: O-RAN Alliance, O-RAN Use Cases and Deployment Scenarios, White paper.)

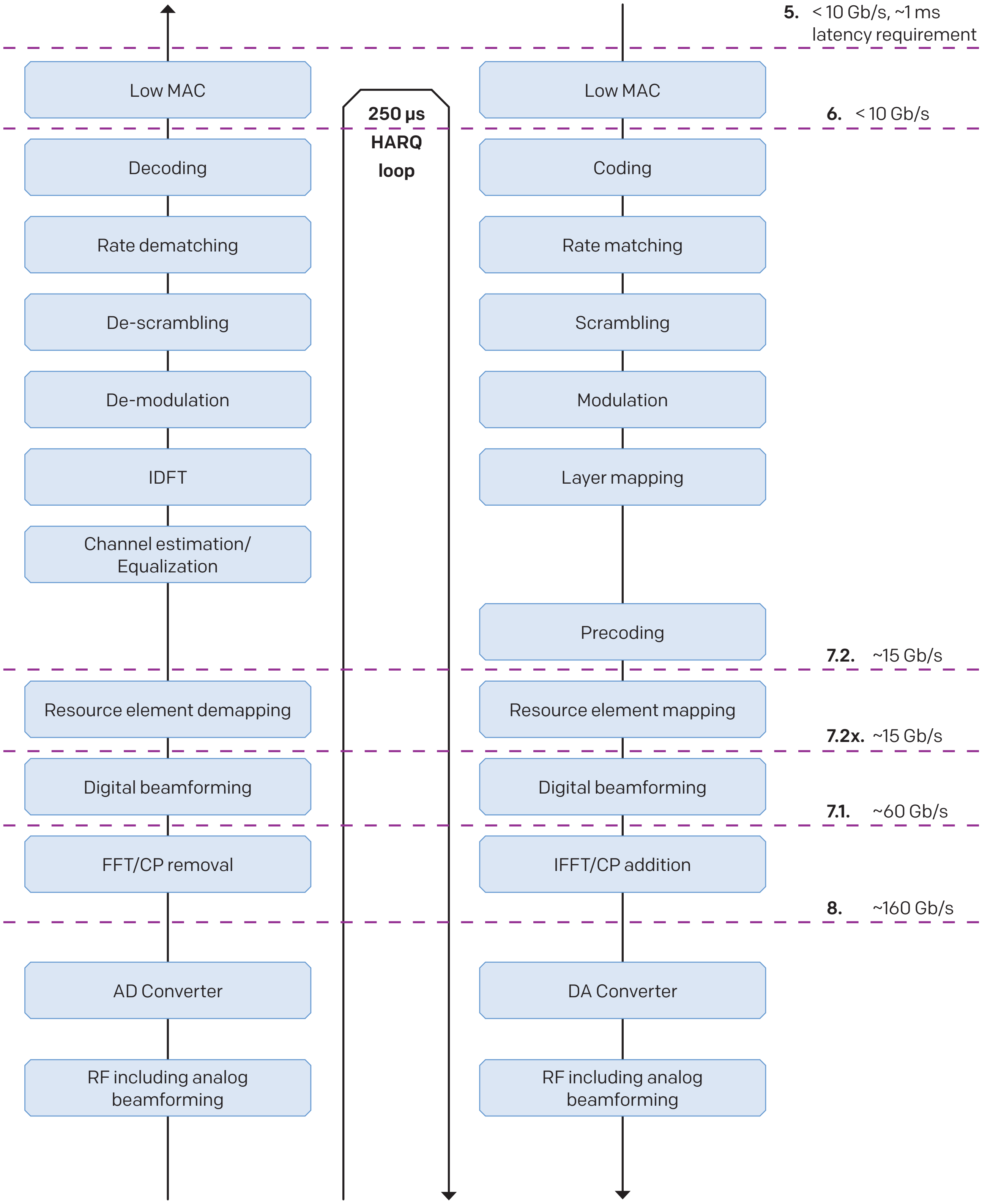


Figure 16: DU/RU functional split alternatives.

The interface between the DU and RU Units is often referred to as the fronthaul interface. The base station vendor industry has defined the eCPRI specification for this interface. It leaves many things open, however, which are then further specified by O-RAN. A view of the eCPRI protocol stack when operating over IP is shown in **Figure 17**.

The NR radio requires both frequency and phase or timing synchronization between MIMO layers of the same gNB as well as between gNBs. The eCPRI protocol stack shows the Precision Time Protocol (PTP) and Synchronous Ethernet (SyncE) to support these requirements, also over the fronthaul network. The 3GPP requirements for frequency and timing synchronization are given in **Table 2** and an example of the RAN synchronization architecture shown in **Figure 18** including PTP and SyncE. As the PTP time stamps may traverse over several hops, jitter and other anomalies may occur, which need to be handled with proper algorithms in order to reach the 3GPP requirements.

Base station class	Frequency accuracy
Wide area BS	± 0.05 ppm
Medium range BS	± 0.1 ppm
Local area BS	± 0.1 ppm
Configuration	**Timing accuracy**
MIMO	65 ns
Intra-band carrier aggregation	260 ns
Intra-band non-contiguous carrier aggregation	3 μs
Inter-band carrier aggregation	3 μs

Table 2: NR frequency and timing accuracy requirements.

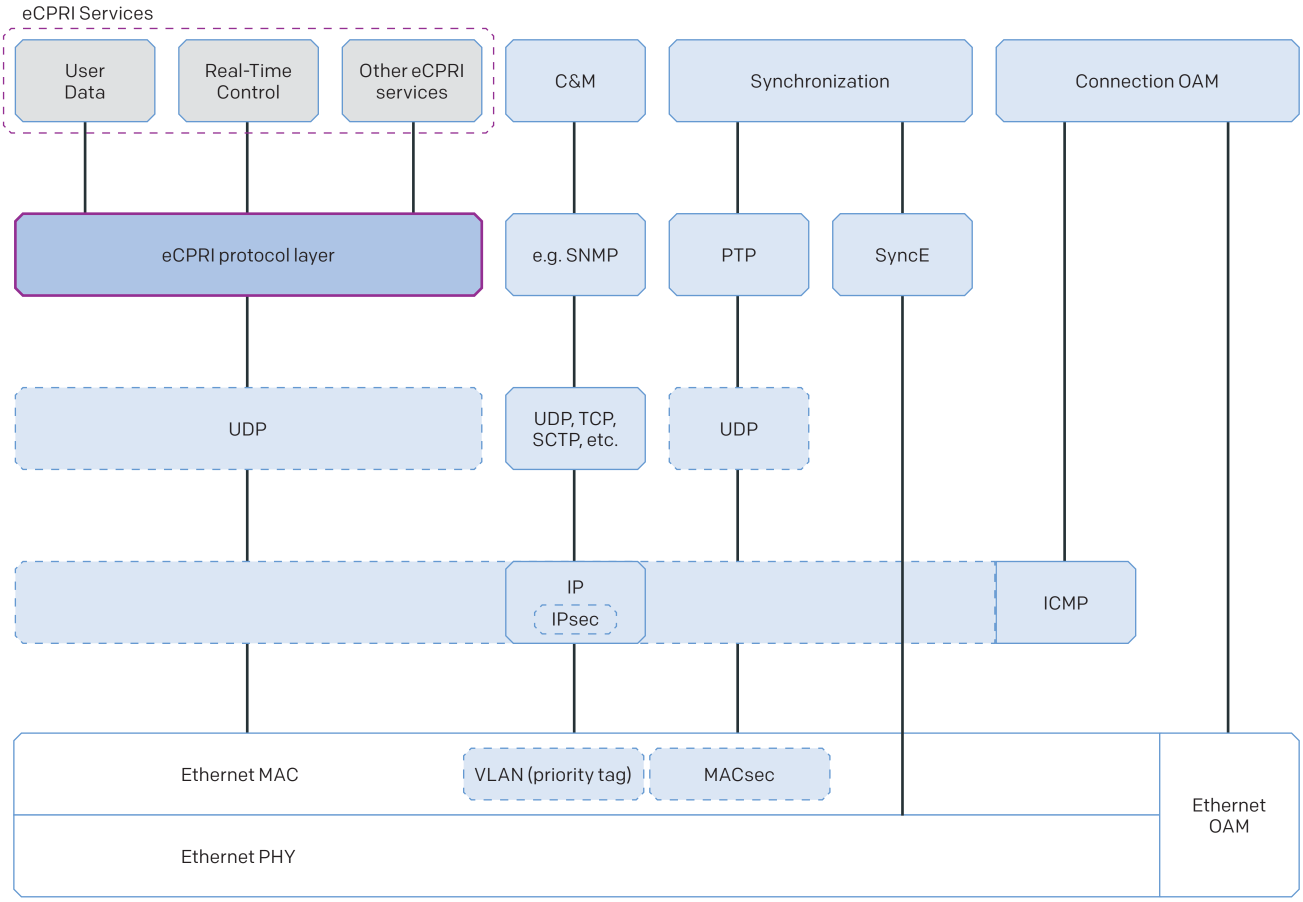


Figure 17: eCPRI protocol stack over IP. (Modified from source: eCPRI Specification V2.0)

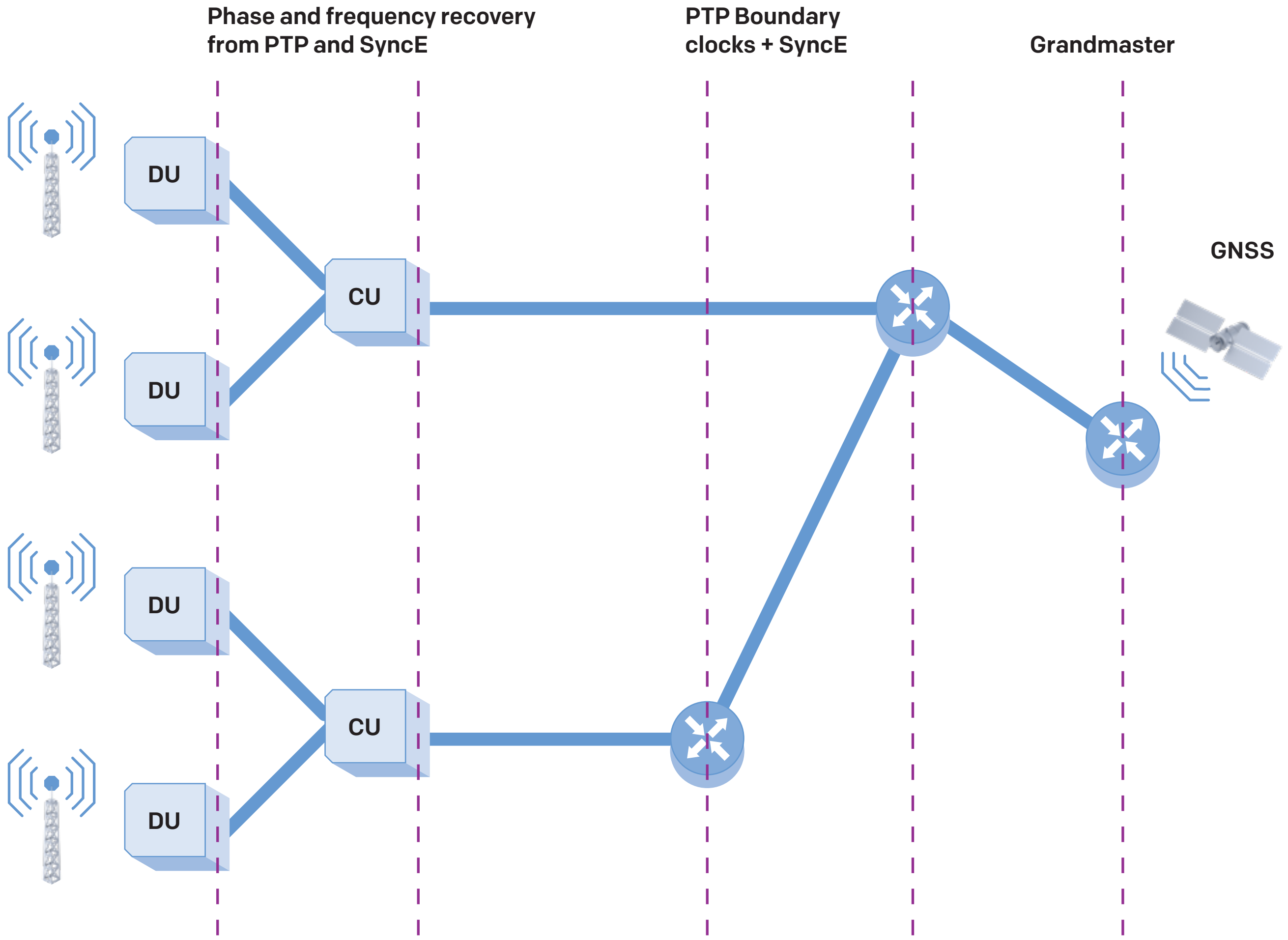


Figure 18: An example RAN synchronization architecture using PTP and SyncE.

Conclusions

A high-level view of the 5G architecture and the 5G New Radio (NR) air interface has been provided, also highlighting the different deployment scenarios, which may utilize varied business models. Also, a high-level view of O-RAN including selected design challenges has been included. The diverse requirements of 5G and the different business models enabled by 5G provide new opportunities for different players in the market. Further opportunities can be found through adoption of O-RAN technology. Bittium has been an active player in the field for decades. Our proven track record is based on 35 years of experience in product and solution development for secure network infrastructure and OEM's. We are forerunners in telecom technology development also providing our expertise for open and virtualized RAN development.

The 5G wide RF operating range, with bands ranging from 400 MHz to the millimeter wavelengths, bring new challenges for RF design including support for massive MIMO. Also, the ever-increasing demand for smaller and energy efficient radios is important from the customer standpoint. Our long and successful track record implementing radios from small form factor base stations (small cells, pico and micro) to macro solutions, makes us an ideal partner for addressing the challenges for 5G radio implementations.

In addition to RF design, we have R&D teams for mechanics, hardware and software development, providing a complete skill-set to develop radios with optimal performance in an environmentally friendly form factor.

Our good long-term relationships with key component and test equipment vendors help to further enhance the development efficiency. We also have strong experience of transferring designs into the customer's own or partner manufacturing sites.