O-RAN.WG9.XTRP-REQ-v01.00

*Technical Specification*

# O-RAN Open Xhaul Transport Working Group 9

# Xhaul Transport Requirements

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# Xhaul Transport Requirements



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# 1 Revision History

| Date | Revision | Author | Description |
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# 2 Contents



 

# 3 Scope

This document defines the requirements for an Open Xhaul transport infrastructure. As far as possible it tries to make no assumptions about the underlying transport technology, rather define a set of requirements about the overall capabilities of an Open Xhaul transport infrastructure that can support different 5G services, different radio architectures and is multi-service in nature. This document refers to 5G services, but the transport requirements also apply to O-RAN networks deploying 4G services.

Following introductory sections 1 through 5, section 6 concentrates on a general description of Open Xhaul transport and high-level requirements. The next three sections concentrate on the transport networking requirements needed to support the different radio architectures identified in 5G, namely, Fronthaul, Midhaul and Backhaul. The aim is to provide the reader specific information about the transport infrastructure in order to support different radio splits. Section 11 provides requirement for ease of operability of transport networks. The last two main sections revolve around requirements for synchronization and legacy services.

This document uses information published by O-RAN, 3GPP, IEEE, ITU-T, IETF, CableLabs, NGMN and several other relevant standard bodies and industry associations. It contains educational, informative, and normative content.

What is not covered in this document:

- As stated above, the document makes no assumption about transport technologies to be used. Technology specific architectural considerations shall be covered in other -possibly WG9- documents and will be referenced in this document as soon as published. Examples include DOCSIS, PON, WDM, Ethernet/IP based implementations, as well as, architectures that may deploy Fronthaul gateways, Fronthaul muxes or other types of CPRI/eCPRI aggregation technologies.
- The document doesn’t cover the synchronization architectural options. These aspects will be covered in an upcoming WG9 Synchronization Solution document.
- Finally, this document provides no requirements on synchronization requirements at an O-RU output. They are stated in WG4 CUS Specification document [74].

 

# 4 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, the latest version applies. In the case of a reference to a 3GPP document (including a GSM document), a non-specific reference implicitly refers to the latest version of that document in Release 15.


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# 5 Definitions and abbreviations

## 5.1 Definitions

The key words "**SHALL**", "**SHALL NOT**", "**SHOULD**", "**SHOULD NOT**", "**MAY**", and "**OPTIONAL**" in this document are to be interpreted as described in IETF RFC 2119 [25]. All key words must be in upper case, bold text.
Items that are **REQUIRED** (contain the words **SHALL** or **SHALL NOT**) will be labelled as **[Rx]** for required. Items that are **RECOMMENDED** (contain the words **SHOULD** or **SHOULD NOT**) will be labelled as **[Dx]** for desirable. Items that are **OPTIONAL** (contain the words **MAY** or **OPTIONAL**) will be labelled as **[Ox]** for optional**.**
Items, if supported, are not meant to be active at all times, but should be available for use. Their state (active or not active) should be based on configuration.

## 5.2 Abbreviations

Abbreviations defined in this document take precedence over the definition of 3GPP

| | | | |
|---|---|---|---|
| AF | Application Function | ITU-T | International Telecom Union-Telecom |
| AMF | Access and Mobility Management Function | LAN | Local Area Network |
| AN | Access Node | LLS | Lower Layer Split |
| ARP | Address Resolution Protocol | LTE | Long Term Evolution |
| ABW | Antenna Bandwidth | MAC | Medium Access Layer |
| BBU | Baseband Unit | MBSFN | Multimedia Broadcast multicast service Single Frequency Network |
| BH | Backhaul | MPLS | Multi-Protocol Label Switching |
| BiDi | Bidirectional | MIMO | Multiple Inputs Multiple Outputs |
| BS | Base Station | MNO | Mobile Network Operator |
| BW | Bandwidth | MRTD | Maximum Receive Time Difference |
| CAPEX | Capital Expense | NGMN | Next Generation Mobile Network |
| CBS | Committed Burst Size | NR | New Radio |
| CFP | Common Form factor Pluggable | NSA | Non-Stand Alone |
| CIR | Committed Information Rate | NSSI | Subnet Networking Slices Instance |
| CN | Core Network | OAM | Operation Administration Maintenance |
| CoMP | Coordinated Multipoint | O-CU | O-RAN Central Unit |
| CP | Control Plane | O-DU | O-RAN Distributed Unit |
| CPRI | Common Public Radio Interface | OPEX | Operation Expense |
| CU | Central Unit | O-RU | O-RAN Radio Unit |
| DC | Data Center | PCF | Policy Control Function |
| DL | Downlink | PDCP | Packet Data Convergence Protocol |
| DN | Data Network | ppb | Parts per billion |
| DHCP | Dynamic Host Configuration Protocol | PRB | Physical Resource Block |
| DSCP | Differentiated Services Codepoint | PRTC | Primary Reference Telecom Clock |
| $dTE_H$ | Dynamic Time Error High | PTP | Precision Time Protocol |
| $dTE_L$ | Dynamic Time Error Low | OFDM | Orthogonal Frequency Division Multiplexing |
| DU | Distributed Unit | QAM | Quadrature Amplitude Modulation |
| eCPRI | evolved Common Public Radio Interface | QoS | Quality of Service |
| eMBB | enhanced Mobile Broadband | QSFP | Quad SFP |
| eNB | Evolved NodeB | RB | Resource Block |
| EP | Ethernet Private | RRH | Remote Radio Head |
| EPC | Evolved Packet Core | RU | Radio Unit |
| EPL | Ethernet Private Line | SCS | Sub Carrier Spacing |
| ePRC | Enhanced Primary Reference Clock | SCTP | Stream Control Transmission Protocol |
| ePRTC | Enhanced Primary Reference Telecom Clock | SFF | Small Form Factor |
| E-UTRA | evolved UMTS Terrestrial Radio Access | SFP | Small Form factor Pluggable |

| | | | |
|---|---|---|---|
| EVP | Ethernet Virtual Private | SLA | Service Level Agreement |
| EVPL | Ethernet Virtual Private Line | TAE | Time Alignment Error |
| FDD | Frequency Division Duplex | T-BC | Telecom Boundary Clock |
| FFO | Fractional Frequency Offset | TDD | Time Division Duplex |
| FFS | For Further Study | TE | Time Error (in the context of synchronization) |
| FH | Fronthaul | T-GM | Telecom Ground Master |
| FLR | Frame Loss Ratio | TN | Transport Node |
| FR1 | Frequency Range 1 | TNE | Transport Network Equipment |
| FR2 | Frequency Range 2 | T-TSC | Telecom Time Slave Clock |
| FTTH | Fiber To The Home | TX | Transmit |
| gNB | gNodeB | UDP | User Datagram Protocol |
| GNSS | Global Navigation Satellite System | UE | User equipment |
| GPRS | General Packet Radio Service | UL | Uplink |
| GTP | GPRS Tunnelling Protocol | UNI | Universal Network Interface |
| ICMP | Internet Control Message Protocol | UNI-C | UNI-Customer edge |
| IoT | Internet of Things | UPF | User Plane Function |
| IP | Internet Protocol | URLLC | Ultra Reliable Low Latency Communication |
| IQ | In phase Quadrature | VPN | Virtual Private Network |

# 6 Open Xhaul Transport infrastructure

This section provides a definition of Open Xhaul transport, some of the key characteristics and high-level requirements associated with Open Xhaul transport.

## 6.1 Xhaul transport network details

At the highest-level the Open Xhaul transport network provides the connectivity from the Radio Access Network (RAN) to the mobile packet core, which subsequently makes the connection to the application function. These could reside in a public network infrastructure, such as the Internet, a walled garden or a completely private network. For details of future developments envisaged in services / spectrum and timelines please see the "International Mobile Telecommunications (IMT) 2020 and beyond" [73].

Below are some of the key considerations

### 6.1.1 5G services and vertical markets

5G networks are expected to enable a new range of services that can be categorized in three classes:

- enhanced Mobile Broadband (eMBB)
- Ultra Reliable Low Latency Communications (URLLC)
- massive Machine Type Communications (mMTC)

These services will drive the need for new or enhanced classes of RAN and transport networks.

### 6.1.2 Network Scale and capacity

Whereas eMBB services demand more capacity in transport networks, URLLC applications will pose new challenges for the design of Xhaul networks in terms of low latency and increased reliability. Finally, mMTC necessitate a network that can efficiently manage huge number of devices such as intelligent devices in utility meters or house appliances.

### 6.1.3 5G RAN Architectures

As illustrated in Figure 1, in a traditional D-RAN (distributed RAN) architecture, the O-DU and O-CU are integrated as a BBU, collocated with the O-RU (Radio) at cell site. When evolving to the C-RAN (centralized RAN) architecture, the O-CU, which contains the higher layer of the RAN processing stacks, is centralized in a Hub. Depending on Operator's deployment needs, the O-DU may remain at cell site, or be centralized. The Xhaul transport (Fronthaul, Midhaul, and Backhaul) serve as connections among the 3GPP RAN and core components. Transport Network Equipment (TNE) represents the transport functions necessary in Xhaul networks. Specifics of TE are outside of the scope of this document and will be covered in WG9 solution documents:

D-RAN:
(O-RU+O-DU+O-CU)← Backhaul → (5GC)

C-RAN:
(O-RU) ←Fronthaul→ (O-DU+O-CU) ← Backhaul → (5GC)

(O-RU) ←Fronthaul→ (O-DU) ← Midhaul → (O-CU) ← Backhaul → (5GC)

(O-RU+O-DU) ←Midhaul→ (O-CU) ← Backhaul → (5GC)

The X2/Xn interfaces that provide logical connection between O-CUs (or to LTE eNBs) are also depicted in Figure 1 to support the inter site coordination such as EN-DC.

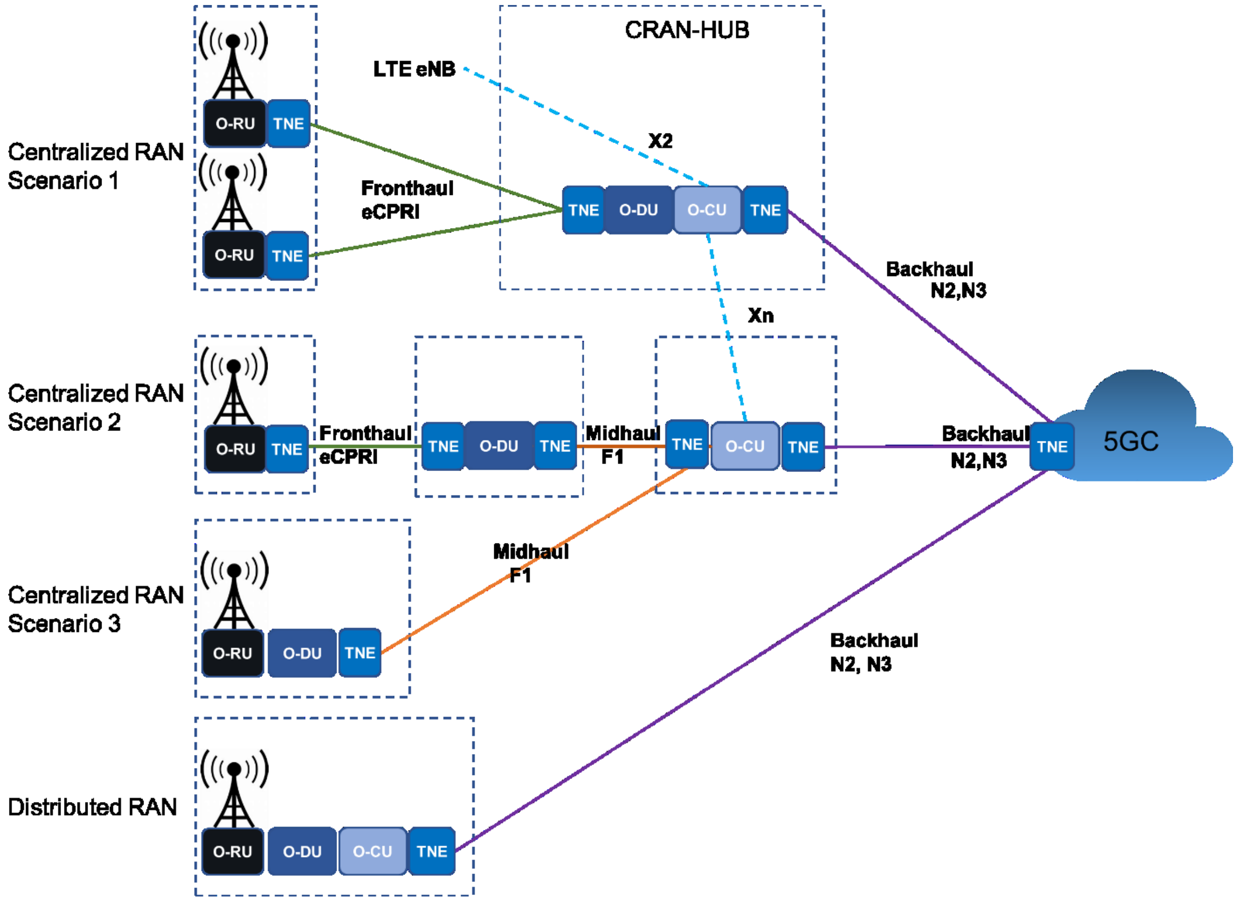



**Figure 1: RAN reference architecture**

## 6.1.4 Network DCs, MEC and NFV

Beyond the abovementioned evolution of wireless access networks with D-RAN and C-RAN, wireless operators started to take advantage of Network Function Virtualization NFV technologies to scale and control the CAPEX. Introduction of 5G creates new opportunities to use these technologies to scale functions and manage low latency in radio access networks.

## 6.1.5 Flexible Xhaul transport infrastructure

As outlined 5G defines different services and RAN architectures. Figure 2 is adapted from NGMN [56] and illustrates how different RAN components may be placed in different locations within the same Mobile Network Operator's (MNO) infrastructure to meet the delay and reliability requirements of a 5G service or vertical market.

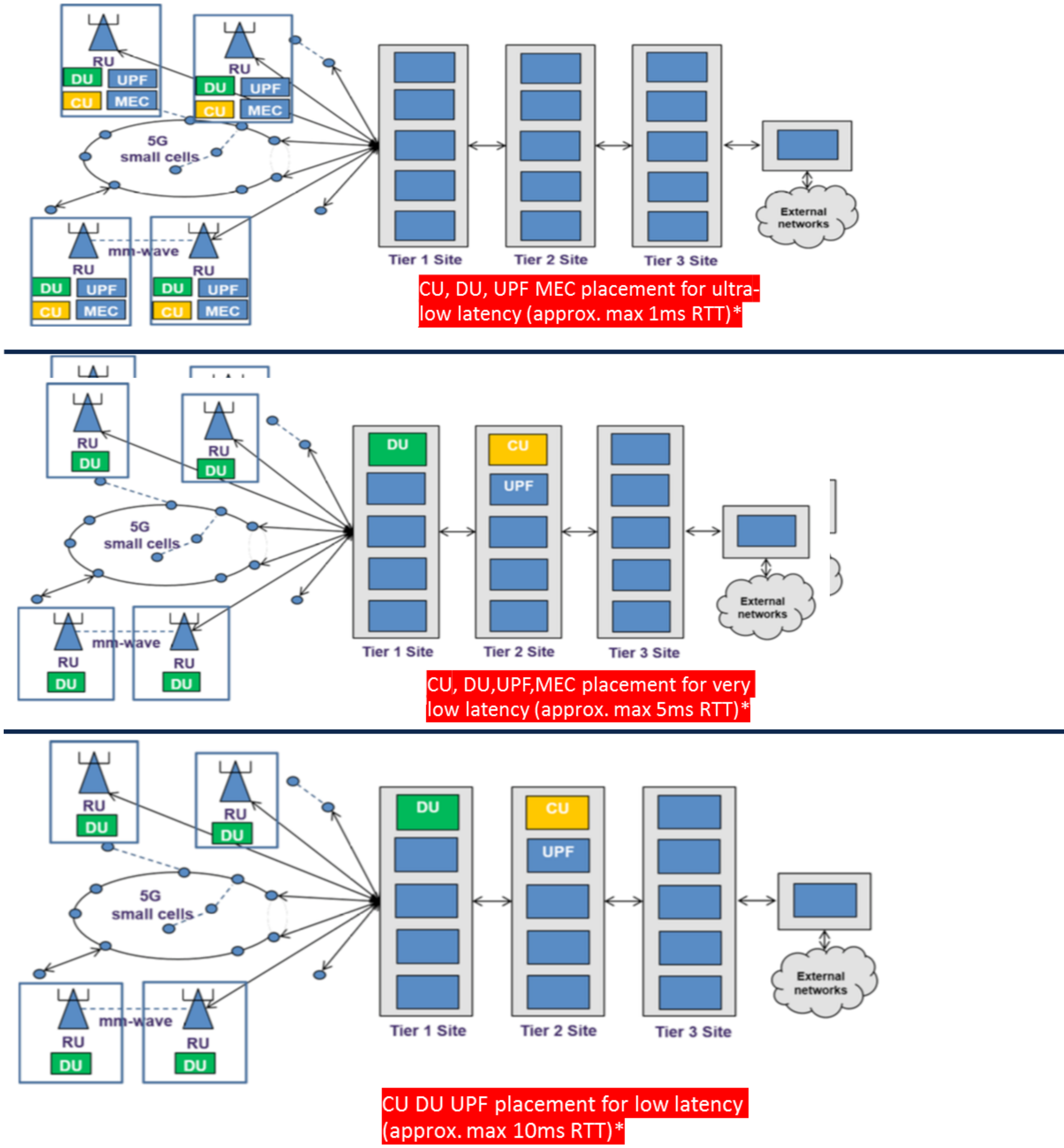



**Figure 2: End to end Xhaul transport – adapted from text and diagrams in "NGMN: Overview on 5G RAN Function Decomposition" [84]**

These different RAN deployment models impact on where the Fronthaul, Midhaul and Backhaul overlay the Xhaul transport infrastructure or even if they are all required. Beyond these deployment models, the choice of radio technology/spectrum can impact the architectural split. Low-/mid-/high band radios may require different choice of functional split or Fronthaul (CPRI/eCPRI) technology. The number of antenna ports/layers (spatial multiplexing) is another factor to be considered.

Ideally the Xhaul transport infrastructure and its design need to be flexible enough to accommodate Backhaul, Midhaul and Fronthaul and even the N6 portions of the 5G infrastructure running in the same part of the physical infrastructure. There will be exceptions to this requirement, for example some MNOs may wish to treat the transport infrastructure supporting the Fronthaul in isolation to the Midhaul and Backhaul but given the similarities and potential overlap between Backhaul/Midhaul/N6 (GiLAN) the Xhaul transport infrastructure must be able to accommodate all these capabilities running in the same portion of the physical transport infrastructure.

### 6.1.6 Xhaul multi-service capability

NGMN identifies the need for X-haul transport to be multi-service capable. Depending on the type of service provider the following capabilities MAY need to be supported on the X-haul transport infrastructure:

- Non-stand Alone (NSA) and Stand-Alone deployment of 5G wireless services including eMBB, mMTC and URLLC defined by 3GPP
- Mobile vertical market solutions
- Legacy 2G/3G/4G wireless services
- Enterprise services
- Residential broadband services
- Data center interconnection

This paper focuses on mobile deployment cases as listed in the first three bullets above.

## 6.2 Xhaul Functional Split

The introduction of 5G services necessitates a new look at the distribution of functions between 4G BBU and RRH (Figure 3). 4G BBU hosts the majority of functional elements with the exception of RF functions. Also known as option 8, CPRI technology provides a simple synchronous interface that allows for a low-cost design of the RRH. It also permits the introduction of advanced mobility functions such as carrier aggregation and CoMP. This simplicity comes at a cost; the CPRI interface transports time domain IQ data whose bandwidth is proportional to the bandwidth of the baseband signal and the number of antennas or more generally the number of spatial streams. Higher bandwidth and massive MIMO requirements of 5G cause an explosive growth of this interface option.

A review of the functional split options (Figure 3) led to several new options (Options 1 through 7) that can be theoretically considered for solving the challenges raised by emerging 5G services. These options were ultimately narrowed down to three prominent options 2, 6 and 7.

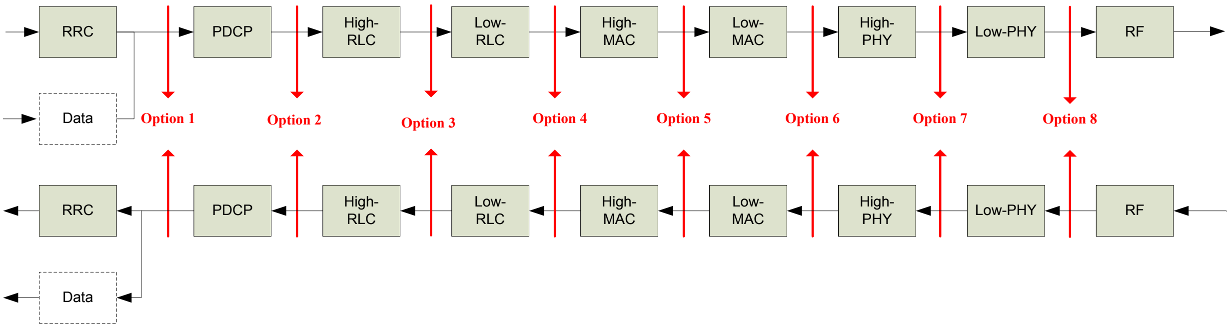



**Figure 3: Functional Split Options [83]**

Furthermore, the option 7 also presents different choices in terms of splitting the functions of the PHY layer such as options 7-1, 7-2x, and 7-3 for the Fronthaul interface. This document only focuses on option 7-2x (Figure 4) as the interface for open Fronthaul chosen by O-RAN. However, the document also considers the option 8 for the definition of Fronthaul transport requirement as this interface is widely used in 4G networks and will be presented in future networks not only for 4G services, but also as an option for carrying low bandwidth 5G services.

## 6.3 High-level Xhaul Transport requirements

**[R1]: MUST** support the mandatory transport capabilities outlined by WG5 in the "O-RAN Open F1/W1/E1/X2/Xn Interfaces working group transport specification". [60]

**[R2]: MUST** support the mandatory transport capabilities outlined by WG4 Open Fronthaul Interfaces Workgroup [74].

**[R3]:** Mobile components reside in the WAN and the DC. It **MUST** be possible to build L2 and L3 services where mobile components reside in both domains

**[R4]: MAY** need to be multiservice in nature. Refer to 6.1.6 for examples of the type of services that may need to be supported on the Xhaul transport network

**[R5]: SHOULD** support flexible placement of front / mid / Backhaul / N6 on Xhaul transport.

**[R6]: MUST** support flexible placement of Mid/Backhaul / N6 on Xhaul transport.

**[R7]: MUST** support L2 and L3 Virtual Private Networks (VPNs).

**[R8]: MUST** support multi-point VPNs.

**[R9]: MUST** support point to point VPNs.

**[R10]: MUST** support 5G network slicing.

# 7 Fronthaul

Fronthaul in O-RAN is defined as the connectivity in the RAN infrastructure between the Distributed Unit (O-DU) and Radio Unit (O-RU).

## 7.1 Fronthaul details

As explained in section 6.2, the herein presented Fronthaul requirements focus on split options 7-2x, as shown in Figure 4 [74]. Option 8 will be addressed in chapter 13.

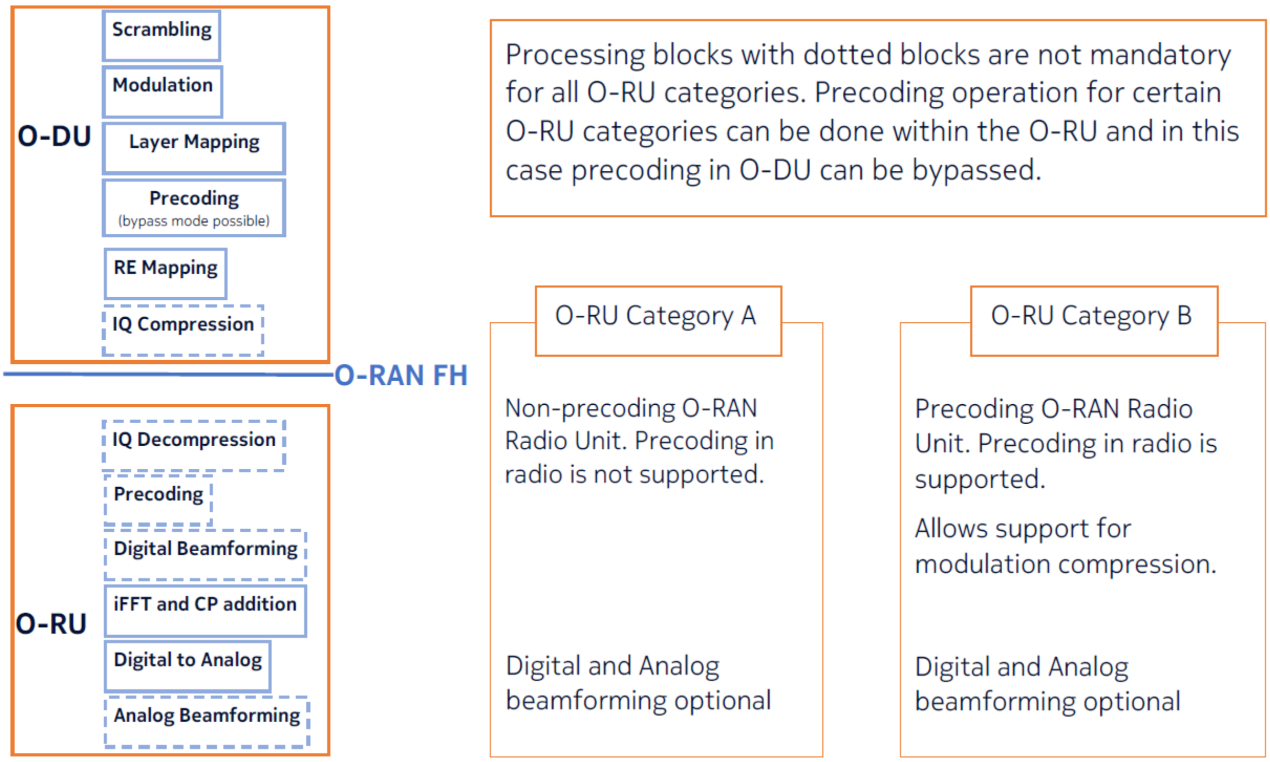



**Figure 4: O-RAN WG4 functional split 7-2x (Figure 2-2 in [74])**

The use cases revolve around 4G/5G mobility services and URLLC. The presented requirements take advantage of documents already available by other standard bodies such CPRI (eCPRI Transport Requirements; [51]), IEEE 802.1CMde [52], and IEEE 1914.1 [53].

## 7.2 Fronthaul specific requirements

| Category | Comments |
|---|---|
| Interfaces | O-RAN 7.2x, 1914.3, eCPRI, CPRI, |
| Protocols | O-RAN 7.2x: Ethernet VLAN based or IP/UDP |
| Logical connectivity requirements | |
| Bandwidth per O-RU and O-DU | Listed in this chapter below |
| Transport delay (one way) O-RU to O-DU | Listed in this chapter below |
| Transport delay asymmetry | Annex C (For Further Study) |
| Synchronization / timing requirements | Listed in synchronization chapter of this document |

**Table 1: High level Fronthaul requirements**

The primary reference for Frame Loss Ratio and Latency proposed in this document is the eCPRI Transport Requirement V1.2 [51]. IEEE 802.1CMde [52] also refers to the eCPRI Transport Requirements V1.2 for latency and frame loss ratio, and therefore is not referenced for the purpose of latency and frame loss ratio requirements in this document. Further information on delay parameters can be found in WG4 CUS specification, Annex B [74].

IEEE 1914.1 [53] uses a different terminology for the identification of Fronthaul (NGFI-I) and Midhaul (NGFI-II). It does not include any requirements on frame loss ratio. However, it provides a table for latency requirements that distinguishes the requirements by different use cases. While there is some overlap with the limits provided in eCPRI Transport Requirements document, there are also some differences. To avoid any confusion, we are not presenting the IEEE 1914.1 requirements in this document and are proposing that it only refers to eCPRI Transport Requirement V1.2 document for latency.

The Frame Loss Ratio and Latency requirements are summarized in Table 2 and Table 3, respectively.

| CoS Name | Example use | Maxim One-way Frame Loss Ratio Performance |
|---|---|---|
| High | User Plane (fast) | $10^{-7}$ |
| Medium | User Plane (slow), C&M Plane (fast) | $10^{-7}$ |
| Low | C&M Plane | $10^{-6}$ |

**Table 2: Frame loss ratio requirements**

| Latency Class | Max. One-way Frame Delay Performance | Use case |
|---|---|---|
| High25 | 25 µs | Ultra-low latency performance |
| High75[1] | 75 µs | For full NR performance with fiber lengths in 10km range |

| | | |
|---|---|---|
| High100 | 100 µs | For standard NR performance with fiber lengths in 10km range |
| High200 | 200 µs | For installations with fiber lengths in 30km range |
| High500 | 500 µs | Large latency installations > 30 km |
| Medium | User Plane (slow) & C&M Plane (fast) | 1 ms |
| Low | C&M Plane | 100 ms |

1. New requirement category added based on deployment needs.

**Table 3: One-way Delay requirements**

Fronthaul bandwidth is dimensioned per cell site, where a number of carriers are deployed at different frequency bands (Low/mid bands in Sub 6 and mm wave in high band), and at different sectors. The Fronthaul bandwidth for a cell site depends on following key parameters

- Number of sectors
- Radio channel bandwidth of each carrier
- MIMO order of each carrier

Various sizes of site configuration may be considered for the eCPRI Fronthaul traffic:

- Small: single sector, carriers in either mmWave or Sub 6 with low MIMO order
- Medium: multiple sectors, carriers in both Sub 6 and mmWave with medium MIMO order
- Large: multiple sectors, carriers in both mmWave and Sub 6 band with Massive MIMO

Table 4 provides "typical" peak Fronthaul bandwidth "cases" in such site configurations:

| | | Sub6 | | | | mmWave | | | | Total FH BW (Gbps) |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number of sectors | Total CBW[1] (MHz) | MIMO layers | ABW[2] (MHz) | FH BW[3] (Gbps) | Total CBW (MHz) | MIMO layers | ABW (MHz) | FH BW (Gbps) | |
| Small | 1 | | | | 0 | 400 | 2 | 800 | 15 | 15 |
| Medium | 3 | 100 | 4 | 1200 | 23 | 400 | 4 | 4800 | 87 | 110 |
| Large | 3 | 100 | 16 | 4800 | 90 | 800 | 4 | 9600 | 175 | 265 |

1. CBW: Aggregated Channel Bandwidth of all carriers in a sector
2. ABW: Antenna Bandwidth = number of sectors X number MIMO layers X CBW
3. FH BW: Fronthaul Bandwidth for functional split 7-2x (transport protocol overhead not included)

**Table 4: Fronthaul Bandwidth Reference for eCPRI traffic**

The FH BW in Table 4 is calculated for functional split 7-2x and block floating point compression specified in O-RAN WG 4 CUS plane specification [74]. The formula used for the calculation is given as follows:

$$\text{FH BW} = 2 \times 10^{-9}(1+c)\frac{v_{layer}N_{PRB}(12N_{mantissa}+N_{exponent})}{T_s^{\mu}}\ \text{(Gbps)}$$

Where

- $v_{layer}$ is the maximum number of supported layers
- $N_{PRB}$ is the maximum RB allocation for a given channel bandwidth and numerology $\mu$.
- $N_{mantissa}$ is the number of mantissa bits. $N_{mantissa}$= 9 used in Table 4.
- $N_{exponent}$ is the number of the exponent bits. $N_{exponent}$= 4 used in Table 4.
- $T_s^{\mu}$is the average OFDM symbol duration in a subframe for a given numerology, i.e., $T_s^{\mu} = \frac{10^{-3}}{14 \times 2^{\mu}}$ (second)
- $c$ is the overhead from the control-plane. For downlink, $c \approx 10\%$ and for uplink $c \approx 0$, as the control-plane is primarily the downlink traffic in O-RAN specification[74]. The overhead may also take different value depending on vender specific implementation.

The relation of $N_{PRB}$ to the channel bandwidth and numerology is defined in 3GPP specification [64] that applies to both FDD and TDD. There is no need for any additional scaling by downlink/uplink ratio for TDD because full $N_{PRB}$ is always made available at the time of transmission in one direction (downlink or uplink).

The Fronthaul bandwidth calculation equation does not include the protocol encapsulation overhead (e.g., eCPRI header, Ethernet header, and IP header, etc.). At an assumption of average packet size equal to 1000, an additional 3.6% overhead needs be added for L2 Ethernet Encapsulation, and 6.4% for L3 IPv4 Encapsulation.

Note that the Fronthaul traffic from the 7-2x Lower Layer Split is user data dependent. The actual real time Fronthaul bandwidth is expected lower than its peak depending on traffic payload in the deployment. Hence certain level of over subscription to transport network with Fronthaul statistical multiplexing is allowed at operator's decision on the cell site dimensioning, user traffic profiling, and reliability requirement. More accurate calculation of such use of the Fronthaul transport is complex and is for further study.

Examples of the site carrier configuration related to the Fronthaul bandwidth calculation are provided in Annex A, together with some possible eCPRI or CPRI interface configurations associated with the carriers.

# 8 Midhaul

There are many similarities between Midhaul and Backhaul components of a 5G RAN infrastructure and the transport infrastructure needed to support it. In order to avoid duplication this document has dedicated chapters covering Midhaul and Backhaul. These contain descriptions of the component and a requirements table. For requirements that are common for both Midhaul and Backhaul they are held in the Backhaul requirements section (see 9.3). There is also a common chapter (chapter 0) dedicated to dimensioning the transport network.

## 8.1 Midhaul details

The Midhaul network is a logical portion of the transport network that supports C-RAN architectures where there is a “High level Split” (HLS) or split 2 in the 5G Radio architecture which implies the O-DU and O-CU are split into independent components. It facilitates:

1) O-DU and O-CUs communication and supports the transport of the 3GPP F1/W1/E1 interfaces. In scenarios where the O-DU and O-CU are a combined entity then these interfaces are not exposed, and the transport network does not have a Midhaul component.
2) Inter O-CU communication and supports the transport of the 3GPP Xn interface. In scenarios where the MNO has not implemented a split O-DU and O-CU RAN architecture then these interfaces need to be supported in the Backhaul network.

Figure 5 illustrates RAN architectures where a Midhaul or HLS is present.

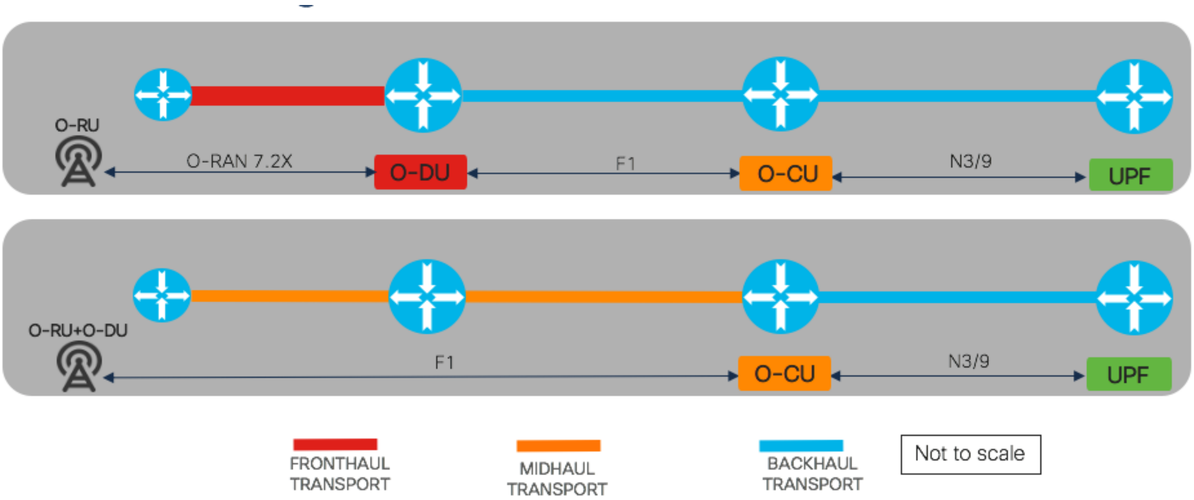



**Figure 5: RAN architectures where a Midhaul transport is required**
**Source: Cisco**

From an interface and protocol perspective 3GPP and O-RAN WG5 are defining these specifications.

Note: WG5 will shortly publish O-RAN Transport Specifications 1.0 on the transport requirements for Midhaul . The requirements should be used in conjunction with this document.

### 8.1.1 O-DU to O-CU communications

3GPP TS 38.401.[58] defines the de-aggregated RAN, it's characteristics and outlines the F1-U, F1-C and E1 interfaces. Figure 6, taken from 3GPP TS 38.401 illustrates the components and interfaces. The Midhaul transport infrastructure is responsible for supporting these interfaces.

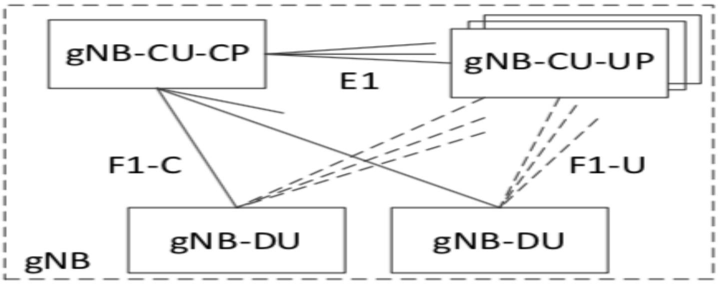



**Figure 6: De-aggregated gNB [58]**

The characteristics of a disaggregated gNB are:

- A gNB may consist of a gNB-CU-CP, multiple gNB-CU-UPs and multiple gNB-DUs
- DUs and CU-UPs are connected to one CU-CP via the E1 interface
- DUs can connect to multiple CU-UPs
- Multiple CU-UPs connect to one CU-CP
- For resiliency reasons DUs and CU-UPs may connect to multiple CU-CPs

The 3GPP interfaces associated with O-DU and O-CU communication are:

- **F1 interface** defines the inter-connection of a gNB-CU and a gNB-DU and has a control (F1-C) and user (F1-U) plane component.

- **E1 interface** defines the control plane inter-connection between the gNB-CU-CP and a gNB-CU-UP. It allows these two components to run as separate entities and potentially in different locations.

### 8.1.2 Inter O-CU communications

Xn is a 5G interface between the gNBs in 5G and X2 is the interface between eNBs in 4G. Figure 7 illustrates Xn interface in a D-RAN architecture.

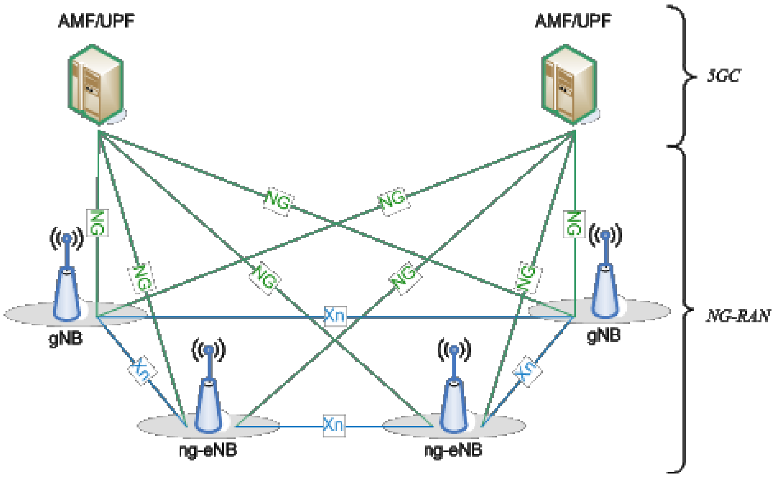



**Figure 7: Overall Architecture showing Xn interface [65]**

In scenarios where a "high level split" radio architecture has been adopted these interfaces run between the O-CUs and are considered to be part of the Midhaul transport architecture by O-RAN WG5. In D-RAN and RAN architectures that do not employ an HLS, then these interfaces will typically be considered part of the Backhaul network.

The Xn and X2 interfaces are used to exchange signalling information between RAN nodes, and the forwarding of PDUs between RAN nodes during UE handover. The X2 interface also has an important role in the migration from 4G to 5G as it is used in some Non-Standalone Architectures (NSAs) migration solutions to convey signalling information, and in some cases user data from the 5G New Radios to the 4G Evolved Packet Core.

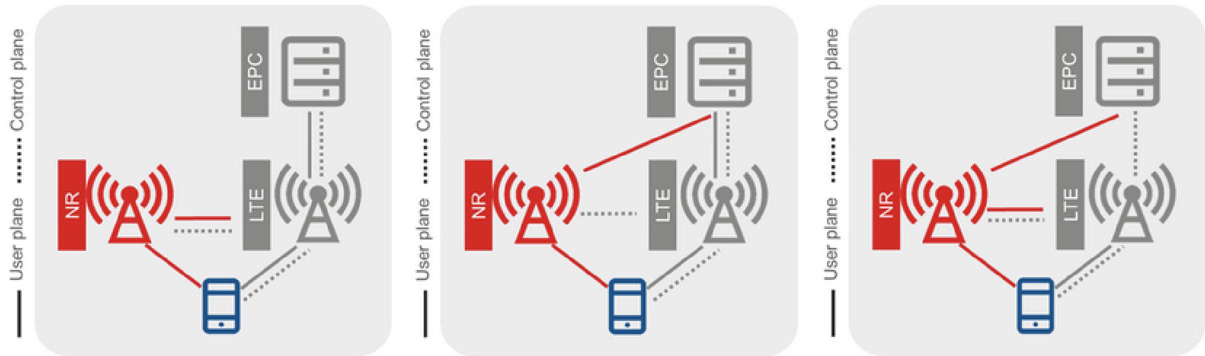



**Figure 8: NSA Option 3/3a/3x networking mode [66]**
**Source: GSMA 5G Implementation Guidelines v2: NSA Option 3**

Figure 8 shows the NSA option 3/3a/3x networking modes. In NSA option 3 (far left in figure) the signalling and user plane traffic associated with 5G UEs is sent from gNBs to eNBs and then onto the mobile core. In this mode, traffic levels between the gNB and the eNB and between the eNB and the EPC are a function of the amount of 5G spectrum and the number of 5G UEs. It is anticipated traffic levels will initially be low due to the scarcity of 5G UEs but could become very significant as the user population transitions towards 5G UEs and gets the benefits of increased capacity from using 5G NR.  This mode impacts the transport infrastructure between the gNB and the eNB and also the transport infrastructure between the eNB and the EPC.

In NSA option 3a (middle of Figure 8) only signalling traffic traverses the X2 interface.
NSA option 3x (far right in Figure 8) is roughly the opposite to NSA option 3. In this case signalling and user plane traffic from 4G UEs goes from eNBs via gNBs to the mobile core. In this NSA mode, the impact on the transport network is dependent on the level of 4G spectrum and the number of 4G UEs. The likely impact on the transport network is that traffic levels will be significant on the X2 interface initially, but as 4G users migrate to 5G so user plane traffic will decrease.

X2 and Xn are logically a point to point connection between gNBs or eNBs. However, there are Xn and X2 interfaces to all adjacent eNBs / gNBs so in reality there is a multi-point relationship between entities.

The O-CU-O-CU interfaces are:

- **X2 interface** is the LTE interface between RAN nodes. The interface is further split into a user plane and control plane components (X2-U user plane and the X2-C).
- **Xn interface** is the 5G interface between RAN nodes. The interface is further split into a user plane and control plane components (Xn-U user plane and the Xn-C).

## 8.2 Midhaul requirements

There are many similarities between Midhaul and Backhaul transport requirements. The following table highlights the items specific to Midhaul. For requirements that are consistent between Midhaul and Backhaul please refer to Table 6 in the Backhaul section.

| Capability | Requirements | Notes |
|---|---|---|
| 3GPP interfaces | Control Plane: F1-C, E1<br>User Plane: F1-U<br>Control Plane: Xn-C<br>User Plane: Xn-U | |
| Network and transport protocols | All 3GPP interfaces are IP<br>Control plane interfaces: IP/SCTP<br>User plane interfaces: IP/UDP/GTPv2 | |
| Logical connectivity requirements | Multi-point at IP layer | |
| Transport network scale for Midhaul | The size of the Midhaul infrastructure is highly dependent on how the C-RAN architecture is deployed.<br><br>In scenarios where an operator is running a Fronthaul infrastructure then the Midhaul will be between O-DU sites and the O-CU sites (1st topology shown in figure xx). In both cases there could be aggregation.<br>1) Multiple O-RUs consolidating onto a smaller number of O-DU sites.<br>2) Multiple O-DUs consolidating onto a smaller number of O-CU sites. | |

| | | |
|---|---|---|
| | In scenarios where the O-RU and the O-DU are co-located in the cell site (2nd topology shown in Figure 5) then the Midhaul will consist of every cell site plus sites where an O-CU component resides. | |
| Midhaul transport provisioning | F1 and E1 interfaces dimensioning is covered in chapter 10.<br>Xn and X2 interfaces are between gNBs and eNBs and traffic levels are highly dependent on the migration path being used by the MNO to move between 4G and 5G technology. | |
| End to end Midhaul transport delay (one way) | Delay constraint for midhaul are derived mainly from the target service's latency requirements, rather than specific requirements of the Midhaul' s user or control planes. As service delay targets become tighter it may become necessary to:<br>1) Place Midhaul and Backhaul mobile components in close proximity to each other to reduce the delay impact of the transport network.<br>2) Combine mobile functions together so 3GPP interfaces run internally within a "Network Function" or within a data center to remove the delay impact associated with the WAN transport network. For example, combining O-RU, O-DU and O-CU or combining the O-DU and O-CU functions together.<br><br><1.5ms-10ms [83] | See section 10.3 for more detail. |

**Table 5: Midhaul transport requirements.**

**For generic Midhaul and Backhaul requirements please see Table 6: Common Midhaul / Backhaul Xhaul transport requirements.**

# 9 Backhaul

There are many similarities between Midhaul and Backhaul components of a 5G RAN infrastructure and the transport infrastructure needed to support it. In order to avoid duplication this document has dedicated chapters covering Midhaul and Backhaul. These contain descriptions of the component and a requirements table. For requirements that are common for both Midhaul and Backhaul they are held in the Backhaul requirements section (see section 9.3). There is also a common chapter (chapter 0) dedicated to dimensioning the transport network.

## 9.1 Backhaul details

From a 5G architectural perspective Fronthaul, Midhaul and Backhaul components and associated interfaces are always present. However, the impact on the transport architecture depends on where the different 3GPP components are placed and their proximity to each other. In a traditional D-RAN architecture the O-RU, O-DU, O-CU (or equivalent 4G components) are either integrated together or contained within a single cell site and the transport network for Backhaul run from the cell site to the mobile core. In a C-RAN NR architecture or disaggregated RAN architecture the Backhaul network connects the "Centralised Unit" (O-CU) to the mobile core components.

Figure 9 shows some examples of how the placement of the various 5G NR components determines the size of the transport network associated with the Backhaul. The bottom architecture is a D-RAN architecture while all the others are C-RAN derivatives.

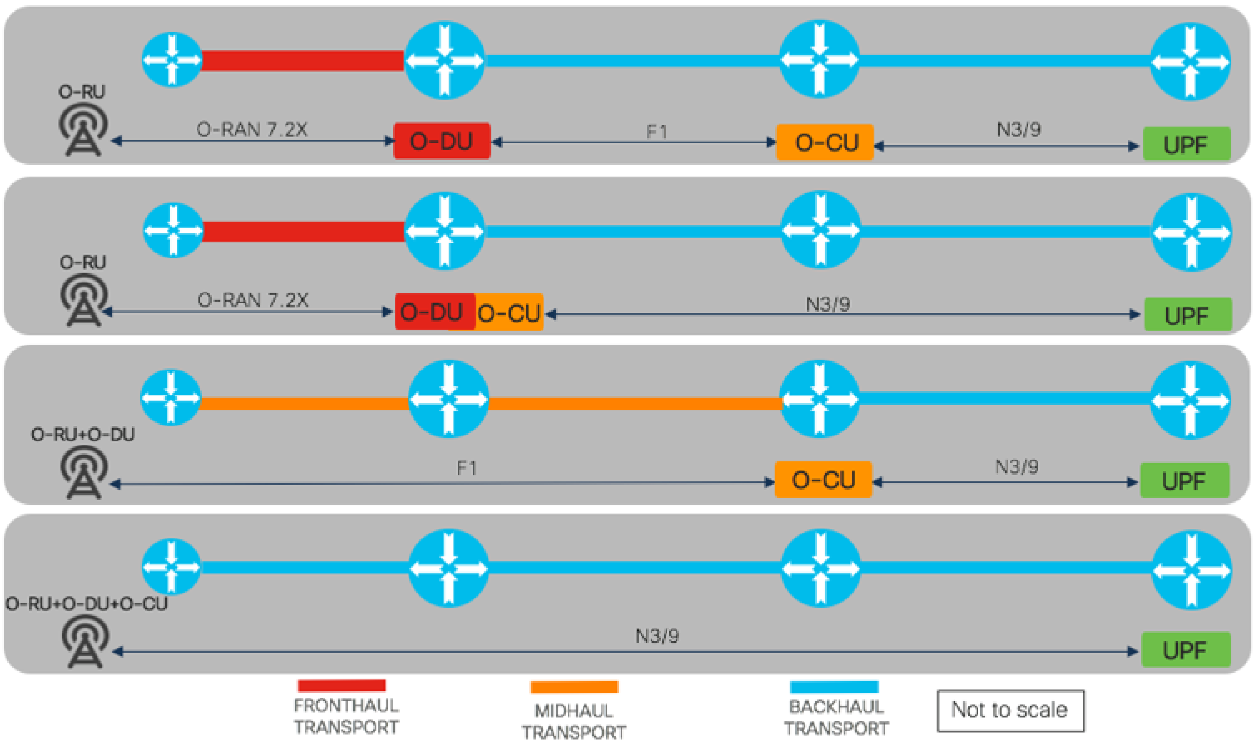



**Figure 9: Backhaul layout with various RAN splits**
**source: Cisco**

Figure 10 shows components and the 3GPP interfaces in the mobile Backhaul. It has a control plane component and user plane component. It is not uncommon to see the control plane and the user plane divided into separate closed user groups at the transport layer to ensure a clear demarcation between customer user data and the 3GPP control plane.

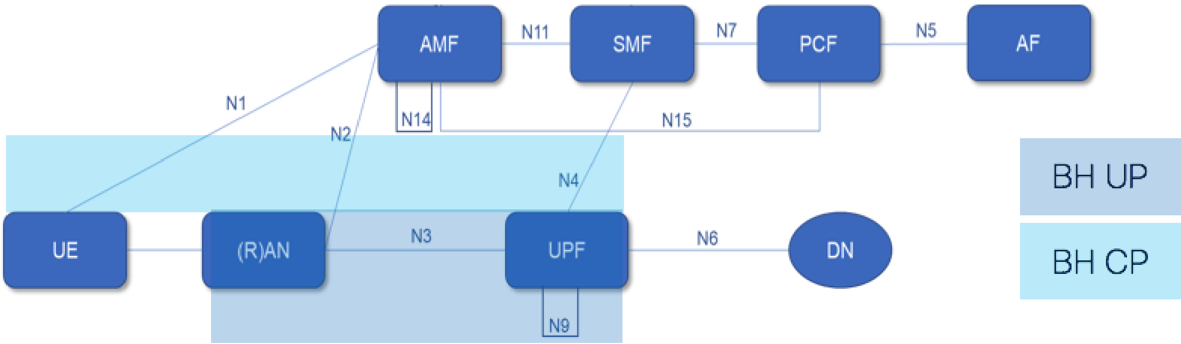



**Figure 10: 5G Backhaul components and interfaces**
**Source: Adapted from 3GPP TS 23.501 v6.4.0(2020-03): System Architecture for 5G [67] with control plane / user plane shading added by document authors.**

The 5G 3GPP interfaces associated with Backhaul are:

- **N1 interface** is a logical control plane interface between the mobile core network and the UE. From a physical perspective it flows via the RAN through the Backhaul infrastructure to the AMF. It is a signalling interface between the UE and the AMF.

- **N2 interface** supports control plane signalling between RAN and 5G core. It is primarily concerned with connection management, UE context and PDU session management, and UE mobility management. In addition, Non-Access Spectrum (NAS) signalling between the UE and the AMF is transported over the N2 connection for that UE. This signalling includes information regarding access control, authentication and authorization, and session management procedures.

- **N4 Interface** is the bridge between the control plane and the user plane of the 5GC. It runs between the SMF and the UPF and is responsible for conveying policy rules regarding policy handling, forwarding and usage reporting to the UPF.

- **N3 interface** is the user plane interface between the O-CU component of the (gNB) and the initial UPF.

- **N9 interface** is a user plane interface than runs between two UPFs. (i.e. an intermediate UPF and the UPF session anchor).

## 9.2 Backhaul transport evolution in 5G

The RAN Backhaul network has been a feature of every 3GPP generation, and many transport network engineers are familiar with the transport requirements RAN Backhaul of previous 3GPP generations. However, 5G introduces some significant changes that will alter the requirements and nature of the Backhaul infrastructure.

In the past 3GPP interfaces across the Backhaul networks tended to be hub and spoke in nature, with the radios at the edge and the mobile core control and user planes gateway components located in a fairly centralised location. See Figure 11 for details.

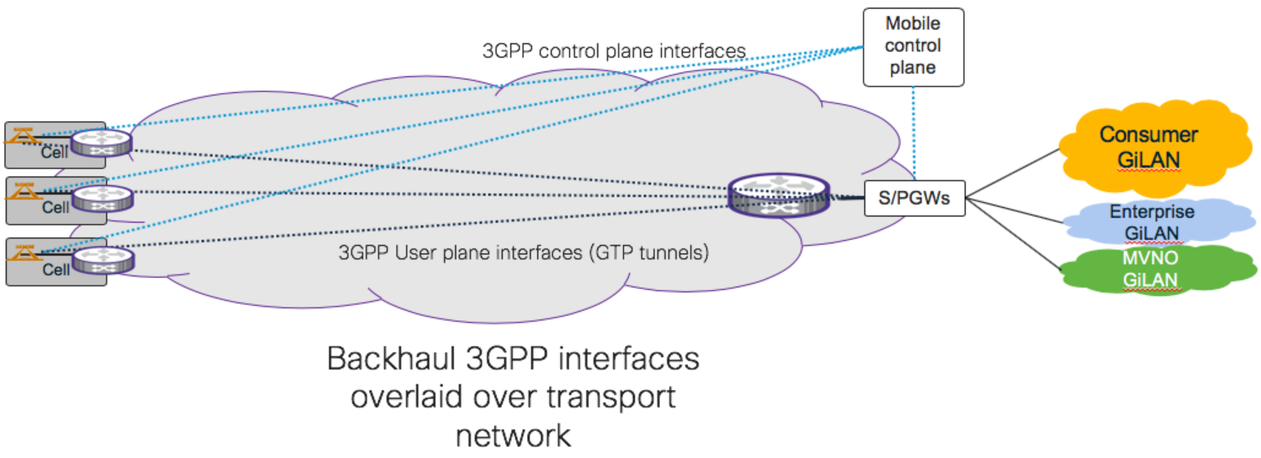



**Figure 11: Transport organization of tradition Backhaul networks (Source Cisco)**

With the advent of new 5G use cases, CUPS, MEC and slicing both the control and user plane Backhaul interfaces will become more multi-point in nature, with IP end points needing to communicate with other IP end points distributed around the whole transport network. This connectivity can be provided using either L3 routing or E-LAN / E-Tree services or a combination of both. In addition, with the advent of 5G slicing the transport network will need to support multiple L2 and L3 closed user groups on the transport infrastructure and in some cases permit controlled connectivity between and within closed user groups. See Figure 12 for details.

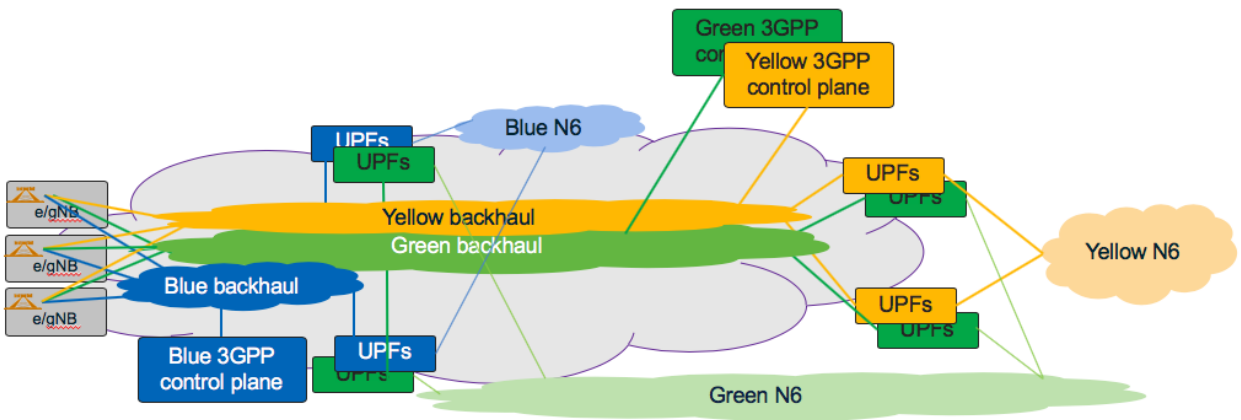


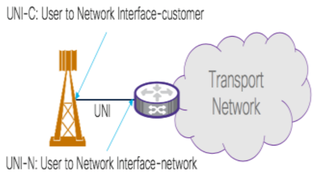

**Figure 12: 5G Backhaul infrastructure overlaying the transport infrastructure (Source Cisco)**

## 9.3 Backhaul and Midhaul transport requirements

The transport requirements for Midhaul and Backhaul are very similar. The table below captures Backhaul and common Midhaul / Backhaul transport requirements. For transport requirements specific only to Midhaul please refer to Table 6.

| Capability | Requirements | Notes |
|---|---|---|
| 3GPP interfaces | Control Plane: N1, N2, N4<br>User Plane: N3, N9 | |
| Network and transport protocols | All 3GPP interfaces are IPv4 or IPv6<br>Control plane: IP/SCTP<br>Data plane: IP/UDP/GTPv2 | |
| Logical connectivity requirements | Control Plane: Multi-point connectivity at the IP interface level (IPv4 or IPv6) between mobile components.<br>User Plane: Multi-point at the IP interface level (IPv4 or IPv6) between mobile components | This requirement could be met by the use of an L3 or an L2 solution or a combination of the two. Technology solution for the transport network to meet these requirements will be covered in technology specific O-RAN documents or by transport solutions specified by other organization. Later revisions of this document will reference these documents. |
| Scope of the transport network for Midhaul and Backhaul | The transport network consists of WAN components, the networking (switching) infrastructure within the DCs and Network Functions (physical or virtual) in DCs.<br><br>**R1:** The WAN transport network and the DC transport networks **MUST** inter-operate together and allow end to end connectivity between transport components and creation of transport slices that have components in the WAN and the DC.<br><br>Midhaul and Backhaul have strong similarities. These include:<br><br>1) IP endpoints with common protocols used in the Midhaul and Backhaul networks.<br>2) The O-CU is part of the 3GPP Midhaul and the Backhaul network, so from a | |

| | | |
|---|---|---|
| | transport network perspective, Midhaul and Backhaul connectivity is presented by different physical or logical interfaces in the same "Network Function" (NF) and most likely same physical locations.<br>3) For deployment reasons, some radios in a cell site may be running a D-RAN architecture and other radios may be running a C-RAN architecture. Consequently, the same part of the transport network could be running both Midhaul and Backhaul services.<br><br>**R2:** With these commonalities and overlaps strong consideration **MUST** be given by operators to designing, building and operating a single packet orientated transport infrastructure that supports both Midhaul and Backhaul services.<br><br>**R3:** In scenarios where a common transport technology is used in Backhaul, Midhaul and Fronthaul then an operator **MAY** choose to build a common end-to-end transport infrastructure supporting Backhaul, Midhaul and Fronthaul. | |
| Transport network scale for Backhaul | **R4:** For national mobile infrastructures the Transport network architecture:<br>**MUST** support mobile networks up to 100,000 O-RU locations.<br>**MAY** support mobile networks up to 500,000 O-RU locations. | The size of a Backhaul infrastructure depend on the radio architecture. In D-RAN scenarios the transport network could potentially need to support these very large numbers of transport endpoints.<br>The number of endpoints in the Backhaul will be smaller if radio architectures based on Fronthaul, Midhaul or both are implemented.<br><br>The architectural solution needs to scale to very large number of transport endpoints without exhausting key transport resources or significantly inflating the transport solution costs. |

| | | |
|---|---|---|
| Transport infrastructure | **Physical interfaces**<br>Mobile equipment associated with Midhaul and Backhaul present Ethernet interfaces at the data link layer.<br><br>In Midhaul and Backhaul the mobile equipment runs IPv4 and/or IPv6 at the network layer. | See ORAN-WG5 transport specification for Midhaul equipment. [60] |
| | **User Network Interface - Customer (UNI-C)**<br>**R5:** The Midhaul and Backhaul transport network **MUST** support physical Ethernet interfaces at the UNI-C. See Figure to the right.<br><br>**R6:** The Midhaul and Backhaul transport network **MUST** support Ethernet services based on a full Ethernet port towards the end-user. For example, an EPL service as defined by MEF 6.2.<br><br>**R7:** The Midhaul and Backhaul transport network **MUST** support Ethernet virtual services based on VLANs within an Ethernet port towards the end user. For example, an EVPL services as defined by MEF 6.2<br><br>**R8:** The Midhaul and Backhaul transport network **MUST** support subscriber IP services. For example, as defined by MEF61.1.<br><br>**R9:** The transport network **MUST** support subscriber IP services on a full Ethernet port basis or over VLANs within an Ethernet port.<br><br>**R10:** Subscriber IP services **MUST** be supported over a single UNI Access link. | <br><br>. |
| | **R11:** Subscriber IP services **MAY** be supported over:<br>1) UNI access links terminating on different devices at the SP.<br>2) UNI Access links terminating on different devices at the SP and the subscriber.<br>3) UNI Access links terminating on different devices at the subscriber | Refer to MEF 61.1 [68] section 7.3 for more details on IP service UNIs |
| | **R12:** The transport network **MUST** support ingress bandwidth control mechanisms for Ethernet, IPv4 and IPv6. This is applied to traffic flowing across the UNI interface from the subscriber towards the transport network. | See MEF 61.1 [68] "Bandwidth Profiles" for examples of typical |

| | | |
|---|---|---|
| | 1) Ingress classification and packet marking<br>2) Ingress traffic conditioning bases on classes with an Ethernet port.<br>3) Hierarchical ingress traffic conditioning based on VLANs and classes within the VLAN.<br><br>**R13:** The transport network **MUST** support egress bandwidth control mechanisms for Ethernet, IPv4 and IPv6. This is applied to traffic flowing across the UNI interface towards the end-user.<br>1) Egress traffic conditioning and scheduling based on classes with an Ethernet port.<br>2) Hierarchical ingress traffic conditioning and scheduling based on VLANs and classes within the VLAN.<br><br>**<u>Transport Services</u>**<br>**R14:** The transport infrastructure **MUST** support mechanisms to create:<br><br>1) Basic IPv4 and IPv6 routing infrastructure<br>2) IPv4 or IPv6 Virtual Private Networks – any to any<br>3) IPv4 or IPv6 Virtual Private Networks – controlled access<br>4) IPv4 or IPv6 Virtual Private Networks with extranet<br>5) EPL and EVPL<br>6) EP-LAN and EVP-LAN<br>7) EP-Tree and EVP-Tree<br><br>**<u>Transport network QoS and availability</u>**<br>**R15:** Transport network **MUST** have mechanisms or utilise an architecture that implements Quality of Service based on QoS markings within the actual Midhaul / Backhaul packet.<br><br>QoS markings could be Ethernet class of service markings, MPLS class of service marking, IPv4 DSCP or IPv6 traffic class marking. The appropriate QoS scheme will be determined by the transport architecture employed. | actions applied on ingress and egress for IP services<br><br>See MEF 10.3 [69]"Bandwidth Profiles" for examples of typical actions applied on ingress and egress of Ethernet services<br><br>Refer to MEF 61.1 [68] for details of IP services<br><br>Ref to MEF 6.2 [70] for details of Ethernet services |

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|---|---|---|
| | **R16:** Transport network **MUST** support QoS / availability mechanisms to enable SLAs to be offered to support 5G slices.<br><br>Transport network SLAs for slices cover IP network delay characteristics and IP network availability.<br><br>**R17:** Transport network **MUST** support mechanisms to ensure suitable behavioural isolation between transport slices on access and within the core of the transport network.<br><br>**R18:** Transport network **MUST** support mechanisms to control and map a transport slice to the transport network's physical topology.<br><br>**R19:** Transport network **MUST** implement transport slice protection / restorations schemes that allow 50ms protection of IP connectivity between slice endpoints.<br><br>**R20:** The transport network **MAY** support other mechanisms to improve Transport slice reliability between IP endpoints. These could be protection mechanisms or other schemes such as multi-path traffic delivery.<br><br>**Transport network OAM and management**<br>**R21:** Transport equipment (DC and WAN) **MUST** support standard model-based approaches to support basic device and network configuration.<br><br>**R22:** If appropriate, transport equipment (DC and WAN) **MUST** support standard model-based approaches to configure transport slices.<br><br>**R23:** Transport equipment **MUST** support OAM tools to test link level capabilities.<br><br>**R24:** Transport equipment **MUST** support OAM tools to test end to end connectivity.<br><br>**R25:** Mechanisms **MUST** exist to determine the liveliness of transport network equipment.<br><br>**R26:** Mechanisms **MUST** exist to determine liveliness of services running on the transport network | Note: A transport NSSI is not necessarily a network wide phenomenon. It may only be running in a small section of the network. |

| | | |
|---|---|---|
| | **R27:** Mechanisms **MUST** exist to determine delay and jitter of services running on the transport network | |
| Transport slicing for 3GPP Backhaul | **R28:** Transport network **MUST** support network slicing for the 3GPP Backhaul network.<br><br>**<u>Transport slice scale</u>**<br>**R29:** The transport network slicing architecture **MUST** support the key 5G services and within each service type support 1000s of different customers that require isolation from each other.<br><br>**R30:** The transport network slicing architecture **MUST** be capable of extending to every end site and also every DC locations.<br><br>**<u>Transport Slice capabilities</u>**<br>**R31:** The transport slicing solution **MUST** support the creation of slices that span from the WAN into the DC networking infrastructure.<br><br>**R32:** Midhaul / Backhaul transport slices **MUST** allow:<br><br>1) Multi-point connectivity model between IP endpoints.<br>2) Connectivity between 3GPP components residing solely in the WAN space.<br>3) Connectivity between 3GPP components residing in either the same data center or different data centers<br>4) Connectivity between 3GPP components residing in the WAN and 3GPP components residing in a data center.<br>5) For a NF (physical or virtual) to inject and learn slice connectivity information from either WAN or DC transport components.<br><br>**R33:** In situations where an operator builds a common transport infrastructure for Midhaul and Backhaul. Transport slices **MAY** be built so a common transport slice covers both the Midhaul and Backhaul interfaces or they **MAY** be built so there is a dedicated transport slice for | Please refer to Annex B: Slicing in Backhaul and Midhaul |

 

| | | |
|---|---|---|
| | Midhaul interfaces and another for Backhaul interfaces.<br><br>**Transport slice connectivity models**<br>**R34:** Transport network **MUST** enable the creation of discrete any-to-any VPNs for different transport slices. End points will be IP entities and may reside in the WAN or a DC.<br><br>**R35:** Transport network **MUST** support the ability to run the Midhaul/Backhaul control plane and user plane of a slice in different VPNs.<br><br>**R36:** The transport network **MUST** support complete connectivity isolation within a Transport slice so only those entities associated with that slice instance can communicate at the transport layer.<br><br>**R37:** The transport network **MUST** support controlled connectivity from within one transport slice to IP entities that are either common to multiple slices or reside in another Transport slice. This is often termed Extranet connectivity<br><br>**R38:** The transport network **MUST** support controlled connectivity between IP entities within the same Transport slice.<br><br>**Transport slice OAM**<br>**R39:** Transport network **MUST** support mechanisms to test and report transport slices edge-to-edge connectivity and response times to enable the performance of the transport slice to be monitored.<br><br>**R40:** Transport network **MUST** support mechanisms to export transport SLA measurement details to an external storage infrastructure. | |
| Peak 5G DL data rates | Peak 5G data rates are highly dependent on overall cell site configuration and radio characteristics. This document uses four example site configurations to illustrate bandwidth requirements. Theoretical 5G NR peak data bandwidths for each site type are:<br>Small Site (FR1): 1.8Gbps<br>Small Site (FR2): 3.3Gbps<br>Medium Site (FR1 + FR2): 25.8Gbps | See chapter 10 for more details on carrier and sector peak DL bandwidth. |

 

| | | |
|---|---|---|
| | Large site (FR1 + FR2): 62.7Gbps | |
| Peak site 5G DL rates with encapsulation (all carriers and sectors included). | An encapsulation overhead of 10% has been used to calculate the peak 5G DL traffic rates.<br><br>Small Site (FR1) (1 sector): 2.0Gbps<br>Small Site (FR2) (1 sector): 3.7Gbps<br>Medium Site (FR1 + FR2) (3 sector): 28.4Gbps<br>Large site (FR1 + FR2) (3 sector): 68.8Gbps | See chapter 10 for more details and considerations for selecting encapsulation overhead. |
| Transport provisioning | Midhaul and Backhaul traffic is primarily made up of user data and precise levels depend on usage. When provisioning a statistically multiplexed transport network it is normal to assume a statistic multiplexing gain as the network travels from the edge towards the core in such networks<br>**Access provisioning**<br>Backhaul traffic is only present on access circuits in D-RAN architectures.<br>Midhaul traffic is only present on access circuits when the RU/DU are co-located on the cell site.<br>Using the four example site configurations and the empirical dimensioning rule outlined in chapter 10 shows the following bandwidth would be required on the access circuit. These figures are similar for scenarios where the access circuit supports Backhaul or Midhaul.<br><br>Small Site (FR1 carrier only): ~2.0Gbps<br>Small Site (FR2 carrier only): ~3.7Gbps<br>Medium Site (FR1 + FR2 carriers): ~15.2Gbps<br>Large site (FR1 + FR2 carriers): ~36.8Gbps<br><br>**Pre-Aggregation and Aggregation**<br>Dependent on SPs specific transport dimensioning and capacity planning rules. The statistical gain will increase as the traffic moves from the access towards the mobile core if the traffic is traversing statistically multiplexing equipment. | See chapter 10 for more details on different provisioning rules.<br><br>It should be noted that even in single sector cell sites operators can choose to provision the access capacity below the peak radio rate of the site. |
| Transport Technology | Not part of the scope of this document. | Please refer to specific technology orientated documents coming from WG-9 for technology and architectural details. |
| End to end Backhaul Transport delay (one way) | Delay constraint for Backhaul are derived mainly from the target service's latency requirements, rather than specific requirements of the Backhaul's user or control planes. As | Dependent on 5G service type. See 10.3 |

| | | |
|---|---|---|
| | service delay targets become tighter it may become necessary to:<br>3) Place Midhaul and Backhaul mobile components in close proximity to each other to reduce the delay impact of the transport network. For example, O-DU, O-CU and UPF in the same data center.<br>4) Combine mobile functions together so 3GPP interfaces run internally within a "Network Function" or within a data center to remove the delay impact associated with the WAN transport network. For example, combining O-RU, O-DU and O-CU or combining the O-DU and O-CU functions together.<br><br>1ms – 50ms service dependent. | |
| Synchronization / timing requirements | See chapter 11 for synchronization and timing requirements. | |

**Table 6: Common Midhaul / Backhaul Xhaul transport requirements plus specific Backhaul requirements**

NOTES:

1) The above tables reference various documents from other standards organizations (for example the MEF). It is important to note that the requirement does not imply that the transport equipment, nor the transport network needs to be compliant with these particular documents. Rather these documents provide a good explanation or definition of the capability.
2) Technology solution for the transport network to meet these requirements will be covered in technology specific O-RAN documents or by other organizations specify transport solutions.

# 10 Transport network dimensioning for Midhaul and Backhaul

The Backhaul and Midhaul segments of a 5G network have many similarities in terms of dimensioning and provisioning rules which feed through to the transport network as requirements. This chapter covers transport dimensioning for Midhaul and Backhaul.

## 10.1 Transport capacity and radio density with 5G

5G represents a significant increase in capacity and size of the transport network over previous 3GPP generations. A common quote is 5G will bring a ten-fold increase in capacity, number of radios and end-user devices when compared with LTE.

## 10.2 Backhaul and Midhaul transport planning

Traffic rates in Midhaul and Backhaul traffic rates are highly dependent on end user usage and it is possible to dimension and provision the transport network for Midhaul and Backhaul assuming a statistic multiplexing gain. The precise gain will vary depending on the architecture of the transport infrastructure and the RAN architecture. There are three steps in dimensioning the transport network for Midhaul and Backhaul:

1) Calculate the peak rate for sectors within a site
2) Add Midhaul and Backhaul transport overheads
3) Calculate peak and average site usage
4) Apply a statistical multiplexing factor to determine the bandwidth to provision in various parts of the Midhaul and Backhaul transport network.

### 10.2.1 5G NR peak bandwidth

5G NR increases the data volumes seen in Backhaul, and if implemented in Midhaul, compared with previous generations of 3GPP technology. The formula below calculates the peak 5G data bandwidth for a single sector site.

$$\text{data rate (in Mbps)} = 10^{-6} \cdot \sum_{j=1}^{J} \left( v_{Layers}^{(j)} \cdot Q_m^{(j)} \cdot f^{(j)} \cdot R_{\max} \cdot \frac{N_{PRB}^{BW(j),\mu} \cdot 12}{T_s^{\mu}} \cdot \left(1 - OH^{(j)}\right) \right)$$

Where

- $j$ is the sum of the carriers
- $v_{layers}^{(j)}$ is the number of MIMO layers
- $Q_m^{(j)}$ is the modulation order
  - 2 - QPSK
  - 4 - 16QAM
  - 6 - 64QAM
  - 8 – 256QAM
- $f^{(j)}$ is the scaling factor
- $R_{max}$ is 948/1024

- $N_{PRB}^{BW(j),\mu}$ is RB allocation. Determined by subcarrier spacing, which can be elucidated from numerology (μ) and bandwidth.

- $T_s^{\mu} = \frac{10^{-3}}{14 \times 2^{\mu}}$ is the average OFDM symbol duration in a subframe for numerology
- $\mu$ is the numerology (0-15kHz SCS, 1-30kHz SCS, 2-60kHz SCS, 3 – 120kHz SCS)
- $OH^{(j)}$ is the overhead (0.14-FR1 DL, 0.18-FR2 DL, 0.08-FR1 UL, 0.10-FR2 UL)

For explanation of above formula see 3GPP TS 38.306 version 15.2.0 Release 15 [71] There are also multiple b/w calculators on the worldwide web. For example: https://5g-tools.com/5g-nr-throughput-calculator/ which calculates both "Frequency Division Duplex" FDD and "Time Division Duplex" (TDD) use cases.

**Notes**

1) The calculated data rate is the theoretical maximum achievable by the radio/radios. Real data rates depend on the radio placement, configuration of the cell site, the surrounding area, number of active UEs, their capabilities and usage.
2) This figure does not include Backhaul or Midhaul transport overhead; namely IP/UDP and GTP and potentially IPSEC encapsulation.

Table 7 shows the peak downlink (DL) data rates for some of the radio profiles outlined in Annex A of Fronthaul Interoperability Test Specification (IOT) document and the 5G NR radio components used in the small, medium and large sites examples used throughout this document.

| O-RAN IOT Profile or site profiles | Frequency range | Mode | Carriers (j) | MIMO layers v(j) | DL Modulation | B/W (MHz) | μ | TDD slot format | Peak DL b/w (Gbps) |
|---|---|---|---|---|---|---|---|---|---|
| Profile 1&2 | FR1 | TDD | 1 | 4 | 256QAM | 100 | 1 | Format 25 | 1.84 |
| Profile 3 (low) | FR2 | TDD | 1 | 2 | 256QAM | 100 | 3 | Format 25 | 0.85 |
| Profile 3 (high) | FR2 | TDD | 8 | 2 | 256QAM | 800 | 3 | Format 25 | 6.77 |
| Profile 1 | FR1 | FDD | 1 | 8 | 256QAM | 30 | 0 | NA | 1.37 |
| Profile 2 | FR1 | FDD | 1 | 8 | 256QAM | 20 | 1 | NA | 0.87 |
| Profile 3 | FR1 | FDD | 1 | 4 | 256QAM | 30 | 1 | NA | 0.67 |
| Profile 4 | FR1 | FDD | 1 | 4 | 256QAM | 20 | 0 | NA | 0.45 |
| Small site -FR1 | FR1 | TDD | 1 | 4 | 256QAM | 100 | 1 | Format 25 | 1.84 |
| Small site-FR2 | FR2 | TDD | 1 | 2 | 256QAM | 400 | 3 | Format 25 | 3.39 |
| Medium site | FR1 | TDD | 1 | 4 | 256QAM | 100 | 1 | Format 25 | 1.84 |
| Medium site | FR2 | TDD | 1 | 4 | 256QAM | 400 | 3 | Format 25 | 6.77 |
| Large site | FR1 | TDD | 1 | 16 | 256QAM | 100 | 1 | Format 25 | 7.34 |
| Large site | FR2 | TDD | 2 | 4 | 256QAM | 400 | 3 | Format 25 | 13.54 |
| Notes<br>Frequency Range (FR1) refers to frequencies below 7.225 GHz<br>Frequency Range (FR2) refers to frequency bands from 24.250 GHz to 52.6 GHz spectrum (also referred to as "millimeter wave range")<br>FDD mode: both uplink and downlink can transmit at the same time at different spectrum frequencies.<br>TDD mode, both uplink and downlink use the same spectrum frequencies but at different times.<br>Format 25 allocates 0.785714286 bandwidth to downlink<br>Calculation for a 1 sector cell site. | | | | | | | | | |

**Table 7: Peak Backhaul DL bandwidth for a selection of O-RAN IOT and 5G NR site examples**

### 10.2.2 Site peak data rates

To calculate the maximum downlink bandwidth, it is necessary to sum the bandwidths associated with all radios in the site and add encapsulation overhead. The peak 5G NR DL data rates associated with the three example site profiles; small, medium and large are shown below.

Note: Only the 5G radio components are considered. In the real-world, previous generations of 3GPP technology will most likely be deployed alongside 5G NR, so these components also need to be added.

| Frequency range | Mode | sectors | Carriers (j) | MIMO layers v(j) | DL Modulation | B/W (MHz) | μ | TDD slot format | Single sector DL b/w (Mbps) | Peak site DL b/w (Gbps) |
|---|---|---|---|---|---|---|---|---|---|---|
| FR1 | TDD | 1 | 1 | 4 | 256QAM | 100 | 1 | 25 | 1836 | 1.84 |
| | | | | | | | | | | |
| | | | | | | | | | | **Total (Gbps)** |
| | | | | | | | | | | 1.84 |

**Table 8: FR1 small site peak DL data bandwidth**

| Frequency range | Mode | sectors | Carriers (j) | MIMO layers v(j) | DL Modulation | B/W (MHz) | μ | TDD slot format | Single sector DL b/w (Mbps) | Peak site DL b/w (Gbps) |
|---|---|---|---|---|---|---|---|---|---|---|
| FR2 | TDD | 1 | 1 | 2 | 256QAM | 400 | 3 | 25 | 3386 | 3.39 |
| | | | | | | | | | | |
| | | | | | | | | | | **Total (Gbps)** |
| | | | | | | | | | | 3.39 |

**Table 9: FR2 small site peak DL data bandwidth**

| Frequency range | Mode | sectors | Carriers (j) | MIMO layers v(j) | DL Modulation | B/W (MHz) | μ | TDD slot format | Single sector DL b/w (Mbps) | Peak site DL b/w (Gbps) |
|---|---|---|---|---|---|---|---|---|---|---|
| FR1 | TDD | 3 | 1 | 4 | 256QAM | 100 | 1 | 25 | 1836 | 5.5 |
| FR2 | TDD | 3 | 1 | 4 | 256QAM | 400 | 3 | 25 | 6772 | 20.3 |
| | | | | | | | | | | |
| | | | | | | | | | | **Total (Gbps)** |
| | | | | | | | | | | 25.82Gbps |

**Table 10: Medium site peak DL data bandwidth**

| Frequency range | Mode | sectors | Carriers (j) | MIMO layers v(j) | DL Modulation | B/W (MHz) | μ | TDD slot format | Single sector DL b/w (Mbps) | Peak site DL b/w (Gbps) |
|---|---|---|---|---|---|---|---|---|---|---|
| FR1 | TDD | 3 | 1 | 16 | 256QAM | 100 | 1 | 25 | 7344 | 2.32 |
| FR2 | TDD | 3 | 2 | 4 | 256QAM | 400 | 3 | 25 | 13544 | 40.63 |
| | | | | | | | | | | |
| | | | | | | | | | | **Total (Gbps)** |
| | | | | | | | | | | 62.67 |

**Table 11: Large site peak DL data bandwidth**

To calculate the peak Backhaul and Midhaul transport bandwidth, add the network encapsulation overhead. This can be done by:

1) Calculating the packet per second
2) Adding the network encapsulation overhead
3) Calculating the transport bandwidth

Network encapsulation overhead depends on a number of factors including:

- L1/L2 technology
- IPv4 or IPv6
- Average packet size
- Mobile encapsulations
- Whether the Midhaul / Backhaul are running IPSEC or not.

The NGMN Backhaul group in "Guidelines for LTE Backhaul Traffic Estimation" [72] use an overhead of 10% to represent a general case for Backhaul (it is also applicable to Midhaul). For an Ethernet transport, IPv4, with no IPSEC encryption and an IMIX packet size (576 bytes) this is a good approximation. If IPSEC is providing Midhaul or Backhaul encryption, then the packet size increases due to the IPSEC overhead. In this scenario NGMN Backhaul group in "Guidelines for LTE Backhaul Traffic Estimation" [72] use an overhead of 14%.

 

| Site Type | Peak Backhaul b/w (Gbps) |
|---|---|
| Small (FR1) | 2.0 |
| Small (FR2) | 3.7 |
| Medium | 28.4 |
| Large | 68.8 |

**Table 12: Peak Backhaul site bandwidth**

Notes:

1) Midhaul and Backhaul traffic is IP and use GTP as an encapsulation for user traffic. One of the main differences is Midhaul traffic carries the "Packet Data Convergence Protocol" (PDCP), while Backhaul does not. This would suggest that Midhaul traffic volumes are greater than Backhaul traffic volumes, however although PDCP adds overhead it can, through Ethernet and IP header compression reduce the size of the user's packet size. For this reason, this document treats Backhaul and Midhaul traffic requirements as the same.

### 10.2.3 Estimating cell site loads

Backhaul and midhaul cell site throughput is the sum of all the traffic generated by all UEs using that site. UE throughput varies depending on the quality of the radio link to the gNB and the amount of spectrum assigned to it. 5G radios use adaptive modulation to adjust their data rates based on the radio conditions. In good conditions, where the UE has good signal strength from the radio and there is little interference, more information can be carried without errors for each unit of spectrum. This is in contrast with scenarios where the UE has low signal strength from the radio and interference levels are high. This is called spectrum efficiency and measured in bits per second, per Hz.

The highest radio throughput occurs when there is high spectral efficiency and largest spectrum allocation for UEs. Typically, this occurs at quiet times when there are a small number of active UEs that is in close proximity to the radio. This is known as the Quiet Time Peak rate. As the number of UEs and distribution of UE's around the cell site increases, so the busy time mean rate is seen. This is normally significantly lower than the quiet time peak rate and is impacted by interference between radios, carriers and UEs, along with environmental factors that impact signal strength and interference such as physical location of the cell site, its surroundings and other sources of interference.

In the provisioning examples shown in Table 13, busy time mean has been calculated as 30% of quiet time peak. This is applicable to 4G implementations, however at this time it is not clear whether this figure is appropriate to 5G NR. Transport engineers will need to liaise with the radio engineers to ascertain this figure for 5G environments.

### 10.2.4 Transport dimensioning and provisioning for Backhaul and Midhaul

Regardless of the RAN architecture employed, the transport network consists of various segments. Figure 13 shows two of the most common splits of the transport network between the radio and the 5G core. In the first, there are three layers of transport infrastructure; access, pre-aggregation and aggregation. In the second, there are two layers of transport infrastructure; access and aggregations. In both cases the transport network needs to be considered as a whole, however potentially different technologies and provisioning rules apply in each segment.

Notes: Neither diagrams show the core of the transport network which tends to be behind the 5G core components.

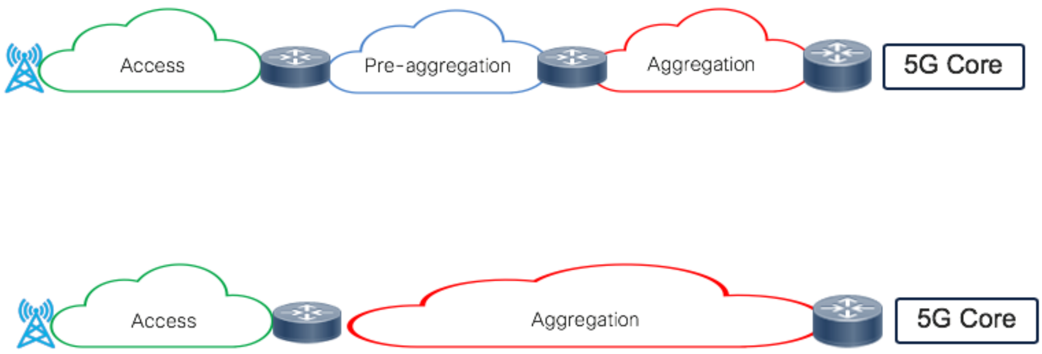


**Figure 13: 5G Backhaul infrastructure overlays the transport infrastructure consisting of physical networks. Source: Cisco**

## 10.2.4.1 D-RAN Backhaul dimension

In a D-RAN architecture the Backhaul component of the network goes from the cell site to mobile core which tend to be positioned centrally.

### 10.2.4.1.1 Access (last mile) provisioning

Access or last mile provisioning depends on the number of radios in each cell site location.

NGMA in “Guidelines for LTE Backhaul Traffic Estimation” [72] recommends for single cell last mile provisioning should be based on quiet time peak rate of the cell.

For multi-sector / multi-carrier cell sites then a statistical gain can be achieved on the last mile because it is unlikely that quiet peak time peaks will occur simultaneously on all radios. NGMA in “Guidelines for LTE Backhaul Traffic Estimation” [72] outlines a number of potential provisioning approaches for multi-sector, multi-carrier cell sites.

1) Peak rate provisioning: In this case it is assumed that peak throughput occurs at the same time on all cells. NGMN point out this is a worst-case scenario and is highly unlikely to occur in practise and would be an expensive provisioning strategy.

2) Lower bound provisioning: This assumes peaks are uncorrelated but that the busy time mean applies to all cells simultaneously. The provisioning for N off eNBs is therefore the larger of the single cell peak or N x the busy time mean, thus:

   *Lower Provisioning Bound for N cells = Max (peak, N x busy time mean)*

   Applying this to a 3-sector D-RAN site then

   *Access (last mile) dimensioning=Max (1 x peak, 3 x busy time mean)*

3) A more conservative approach assumes that whilst one cell is peaking, the others are generating traffic at the mean busy time rate, thus:

   *Conservative Lower Bound for N cells = Max [peak+(N-1) x busy time mean, N x busy time mean]*

   Applying this to a 3-sector D-RAN site then the general last mile provisioning rules is to use

   *Access (last mile) dimensioning = peak +(2 x busy time mean)*

In Table 13 the access bandwidth needed to cater for 5G example cell sites are shown using peak quiet time provisioning for single carrier, single sector sites. For multi-carrier, multi-sector sites a comparison is made between peak rate quiet time provisioning, lower bound provisioning and conservative bound provisioning.

| Site Type | Carrier types | Sectors | Quiet Time Peak sector rate (Mbps) | Busy time sector mean (Mbps) | | Lower provisioning bound (Gbps) | Conservative provisioning bound (Gbps) | Peak rate provisioning (Gbps) |
|---|---|---|---|---|---|---|---|---|
| Small (FR1) | FR1 carriers | 1 | 2020 | 606 | | N/A (single sector, carrier) | N/A (single sector, carrier) | 2.0Gbps |
| | | | | **Total site** | | **N/A** | **N/A** | **2.0Gbps** |
| | | | | | | | | |
| Small (FR2) | FR2 carriers | 1 | 3724 | 1117 | | N/A (single sector) | N/A (single sector) | 3.7Gbps |
| | | | | **Total site** | | **N/A** | **N/A** | **3.7Gbps** |
| | | | | | | | | |
| Medium | FR1 carriers | 3 | 2020 | 606 | | 2.0Gbps | 3.2Gbps | 6.1Gbps |
| | FR2 carriers | 3 | 7449 | 2234 | | 7.4Gbps | 11.9Gbps | 22.3Gbps |
| | | | | **Total site** | | **9.5Gbps** | **15.2Gbps** | **28.4Gbps** |
| | | | | | | | | |
| Large | FR1 carriers | 3 | 8078 | 2424 | | 8.1Gbps | 12.0Gbps | 24.2Gbps |
| | FR2 carriers | 3 | 14898 | 4470 | | 14.9Gbps | 23.8Gbps | 44.6Gbps |
| | | | | **Total site** | | **23.0Gbps** | **36.8Gbps** | **68.9Gbps** |

**Table 13: Last mile provisioning for 5G Backhaul (peak, lower and conservative bound)**

Notes:

1) In this example small sites are single sector, single 5G carrier sites. With additional carriers (4G or 5G) then a statistical gain can be achieved.

2) Medium and large sites are 3 sector, multi-carrier 5G sites.

3) Access circuit dimensioning only accounts for 5G services. 2G, 3G, 4G also needs to be considered as well. (discussed in more detail later).

4) Busy time mean is taken as 30% of peak quiet time rate for a sector. This number has been picked antidotally through discussions with an LTE MNO. There is on-going discussion whether this ratio will apply to a 5G NR implementations as the ratio between quiet time peak rate and busy time mean rate may change.

5) There is on-going discussion in the industry about whether these formula for LTE provisioning will apply in the 5G NR access circuits.

6) In the case of point-point last mile access technologies, the values in the table can be taken per cell. In the case of point-multipoint access technologies using a shared medium (e.g.; PON, DOCSIS), the last mile itself already performs a level of aggregation between multiple cells, and section 10.2.3.2 applies.

#### 10.2.4.2 Pre-aggregation and aggregation transport dimensioning

If the transport technology and the network design enable statistical multiplexing, then the initial provisioning for Backhaul in the “pre-aggregation” and the “aggregation” segments of the transport network is based on predicting the level of statistical multiplexing. This will be based on network usage, network topology, levels of aggregation at different layers and usage / traffic correlation between adjacent cell sites.

A similar initial provisioning approach could be taken as outlined by NGMA in “Guidelines for LTE Backhaul Traffic Estimation” [72] as discussed in previous section. However, when looking at aggregated Backhaul traffic then more emphasis needs to be placed on mean busy time rates than peak rates and mean busy time rates need to be calculated across multiple cell sites not across a single site (in most situations this will push the value down).

Longer term provisioning will be based on collecting accurate traffic matrixes at the transport layer, demand level modelling and developing capacity plans rule.

### 10.2.5 C-RAN Backhaul dimensioning

In C-RAN architectures the access or last mile segment of the transport is not part of the Backhaul network. In these environments Backhaul dimensioning and capacity planning will be a function of the number of DUs each CU aggregates and where the CUs and UPF/UPFs resides in relation to each other and their overall position in the transport infrastructure.

### 10.2.6 Midhaul dimension

The Midhaul RAN component is only present in C-RAN architectures Figure 5 shows two deployments of Midhaul. In the top case the O-RU, O-DU and O-CU reside as discrete entities and at different levels of the transport network. In this case the Midhaul does not span the access portion of the network. Similar considerations as outlined in C-RAN Backhaul dimensioning can be used.

In the lower case the O-RU and O-DU are co-located in the cell site and the Midhaul runs from the cell site, across the access infrastructure to the O-CU which is located higher up in the transport network. Similar techniques as outlined in D-RAN Backhaul dimensioning can be used.

## 10.3 Backhaul and Midhaul latency

Previous 3GPP generations aimed at voice and basic data services. In these scenarios' user plane one-way delay between the UE and the application could be multiple 10s of milliseconds, even reaching the low hundreds of milliseconds. These figures are the delay from the UE to the destination "Application Function".
In a 5G RAN infrastructure this is made up of:

*Overall one-way delay = UE delay + Radio air interface delay + FH/MH/BH transport networking delay + Radio component delays (DU, CU if used) + gateway delay + GiLAN transport network delay*

5G introduces support for different service types (eMBB, URLLC and mMTC) and aims to cover a wide range of vertical markets, such IoT, industrial and automobile. Different services and verticals have different latency requirements, some extremely tight such as industrial motion control applications while others, such as some of IoT applications very relaxed.

As an example, in the latest TR 22.804[85] the lowest maximum latency requirement for deterministic communication service is defined as 0.5ms for small industrial environments (50 m x 10 m x 10 m) with small packet sizes for motion control. A higher maximum latency of 500ms is given for periodic communication for standard mobile robot operation and communication services for CCTV surveillance cameras in mass rail transit with defined speeds of movement for each UE (UE speed < 50 km/h for mobile robots and ≤ 160 km/h in urban environments).

In scenarios where low one-way latency is required then the Midhaul and Backhaul networks will need to be designed to accommodate these requirements. As the latency requirements become tighter the following needs to be considered.

1) Proximity and physical path between the UE and AF
2) Siting of gateway and AFs in relation to each other
3) Delay characteristics of the physical media
4) Delay characteristics of the RAN components (radio, DU, CU)
5) Number of physical hops and delay characteristics of the switching equipment
6) Whether the network is a public 5G or private 5G infrastructure.

Figure 2 illustrates how adapting the RAN architecture and placement of RAN and "Application Function" (AFs) components can change the end-to-end latency characteristics of overall 5G infrastructure.

# 11 Transport operability

This section concerns transport requirements to ease operability of the transport. This section includes a first sub-section about transport system requirements, a second about transceiver and port monitoring and identification of the transport equipment, a third sub-section about power saving and energy efficiency. A last sub-section concerns an optional additional interface dedicated to remote monitoring of antenna site operation.

## 11.1 Operational transport requirements

### 11.1.1 Transport equipment at antenna site

It is highly desirable from the network operation perspective to manage a network transport system, i.e., the equipment at the hub site together with the equipment at the antenna site, as a single entity. In that sense, it is desirable that the equipment at the antenna site is managed via the equipment at hub site whenever possible. Therefore, transport equipment shall support real-time management and control functions of antenna site equipment by the hub site equipment.

### 11.1.2 Dual manage transport equipment at antenna site

The transport equipment at the antenna site shall optionally support collaborative management partition between the dedicated management by the transport equipment at hub site and also other configuration mechanisms.

### 11.1.3 Supervision

It is important to take care of operational expenditure dedicated to the medium of the transport and related equipment. The goal of supervision is to reduce the operational expenditure of the transport systems, without significantly increasing the capital expenditure by including as much test and diagnostic capability as possible. Naturally, this should be achieved without compromising the available bandwidth for services, i.e., test and diagnostics must be non-service affecting.
The ability to reliably differentiate between optical medium and electrical faults at the equipment and establish if the faults are in the optical medium or in the electronics is a key operator requirement. Error inference can usually be made from the presence (i.e., power or equipment failure), or absence (i.e., fibre failure), of the Dying Gasp alarm. Several key points for the supervision can be summarized as follows:

- optical medium monitoring/checking: Monitoring and on-demand checking the condition of optical medium independently from a transport system is important to differentiate optical medium failures from transport system failures. It is desirable that such monitoring and checking be available regardless of whether the transport equipment antenna site is in service or even connected. Several implementations could be proposed. Optical monitoring solution is proposed by ITU-T G.697 to detect anomalies, defects, degradation and fault affecting the quality of the optical transport. Another solution is to use an optical time domain reflectometer (OTDR) which is a powerful tool for diagnosing such faults in the optical medium. Power meter and light source can also be used to aid in this monitoring process. Several demarcation devices are under research for further improving the optical medium monitoring and checking.

 

- transport system would benefit from an ability to automatically and autonomously detect and locate optical medium fault (optical medium segments : patch panel at the hub or antenna site, optical fiber cable in ducts or on the poles,..).
- End-to-end performance monitoring up to the Ethernet layer: End-to-end performance monitoring enables operators to diagnose and register where traffic may have been dropped or throttled. Higher layer tools, such as Ethernet performance monitoring, need to support the capability monitoring and verification of ingress and egress traffic flows in transport network elements.
- Proactive versus reactive repair: transport systems with their monitoring and control systems will allow operators to decide on the utilization of proactive or reactive fault repairs in most fault cases. It is of course up to the operators to decide on how to use transport status reports.
- For instance, key-performance-indicators related to the optical transport supervision could be made available to an orchestrator, higher in the network, through an abstraction of the optical devices through software-defined networking.

### 11.1.4 Rogue behaviour and its mitigation in access transport segment

This clause is largely concerned with rogue behaviour between FTTH (Fiber To The Home) based on PON (Passive Optical Network) technologies and Xhaul access transport operations in last mile optical fiber infrastructure. The transport equipment at the antenna site must be initially disabled in order to avoid disturbing PON system in case of miss-connection in the optical fiber enclosure. The antenna site transport equipment shall enable the transmitter to enter a handshaking process with hub equipment only after confirming that the frame structure and/or the line coding of the received downstream signal are matched with those the antenna site equipment complies with. This confirmation shall be done with both hub and antenna site equipment.

The Xhaul transport equipment must support silent start operation to prevent bidirectional physical layer interfering with FTTH based on point to multi-point. The silent start means that the upstream physical layer doesn’t transmit unless a valid downstream signal is received.

### 11.1.5 Transport availability

Operators need to determine the most resilient transport architecture for their reliable mobile services. Transport system should include a range of cost-effective resilience options to obtain the targeted availability of mobile services. These resilience schemes should be options available on the transport scenarios for passive and active equipment. Different types of service and specific offerings will require different recovery speeds. These may range from a few microseconds, for critical services like motion control for factories of the future, up to the order of seconds or minutes for monitoring or remote control applications. Note that support for resilience options should not increase the cost of such systems if deployed without resilience options.

The protection architecture should be considered as one of the means to enhance the reliability of the Xhaul transport. However, protection shall be considered as an optional mechanism because its implementation depends on the realization of economical systems. It is also likely that other methods are used, such as cooperative technologies, e.g., fixed (optical fiber) and radio (micro-wave) for backup for cost reasons.

Combining protection mechanisms related to Xhaul transport interfaces and the optical fiber infrastructure should even be possible, provided that the switching time of the two mechanisms is compatible or configurable. The goal should be to recover the Xhauling service in less than the common 50 ms value used for protection.

## 11.2 Transceiver and port monitoring and identification

### 11.2.1 Transceiver digital diagnostic monitoring

A digital diagnostic monitoring interface for optical transceivers is used to allow access to device operating parameters. As specified in SFF-8472 and SFF-8636, data is typically retrieved from the transceiver module in a memory map of an EEPROM. Such data must be available by the data plane. With QSFP and other advanced form factor transceivers, the optical links could be multi-wavelength (4xTx & 4xRx) and/or multi-fibers (MPO - Multifiber Parallel Optic). The antenna site and hub interface management must describe a management applicable to any kind and group of media lanes. The QSFP digital diagnostic (SFF-8636) describes such media lanes.

### 11.2.2 Transceiver class of operation for bidirectional transmission

A plurality of transceiver modules is used today and can define operational states for pluggable form factors (like SFP, SFP+, SFP28, XFP and QSFP, QSFP+, QSFP14, QSFP28, CFP, CFP2…). Each transceiver is associated with a unique interface name and port number value.
Concerning fiber connectivity, in the last mile network (fixed access network to reach antenna)BiDi (BiDirectional - single singlemode fiber) transceiver is the preferred implementation to simplify operation (risk of mismatch…), reduce the cost and the dimensioning of fiber cable and reduce potential path delay asymmetry.

The interoperability between transceiver at antenna site and hub is a must. Operations at antenna site and hub must support different timeline operation, refresh and other network operations requiring different purchasers of transceivers. In order to achieve this interoperability, working classes have to be clearly identified for the required transceivers.

### 11.2.3 Transceiver class of operation for WDM transmission

In order to save optical fiber, wavelength division multiplexing (WDM) could be proposed. It is already the case for high bit rate transceivers (ex. 100GBase interface) with multiple wavelength per stream and per fiber. In case that Xhaul transport uses WDM transmission, a single fiber operation (bidirectional multiple wavelength) will ease network operations. This single fiber operation concerns the colorized transceiver plugged in transport equipment ports and thus sharing optical fiber infrastructure. This single fiber operation is important for the last mile fiber infrastructure to reach the antenna site. One optical fiber per stream could be also proposed.

The wavelength assignment per port could be static or tuneable. Auto-tuneable wavelength allocation simplifies inventory management. Each wavelength channel is tuned thanks to an embedded control channel. This control channel must be interoperable to ease network operations. Similar to previous subsection, interoperability is a must for WDM operation and working classes (including optical spectrum parameters) have to be clearly identified.

### 11.2.4 Port-ID to ease field operation

In order to facilitate retrieval of the transport port identifier and other physical layer parameter indicators (ex. Launched optical power) during field operation (installation, maintenance,…), a port-ID could be tagged on the transport hub equipment. As an example, comparison of the locally measured optical power and the launched optical power information inside the port-ID should give operators a mean for measuring optical power budget. Optical monitoring and supervision parameters could refer to ITU-T G.697 for WDM systems and ITU-T G.988 for access systems based on received signal strength indicator of transceivers.

### 11.2.5 Eye safety

Given the higher launched optical power that can be injected into the fibre by transport equipment, both at the antenna and hub sites, all necessary mechanisms must be provided to insure that no eye damage can be caused to the end users unaware of the risks, especially if fibre is terminated inside public facilities (small cell). All transport equipment need to conform to eye safety classes. For access transport segment, the equipment must conform to the class 1M at the hub and class 1 at the antenna site defined in IEC 60825-2.

## 11.3 Power saving and energy efficiency

Saving energy in telecommunications network systems has become an increasingly important concern in the interest of reducing operators' operational expenses (OPEX) and the network's contribution to greenhouse gases. The power saving mechanism could be applied to reduce power consumption either continuously or during a time period.

Transport equipment need to achieve a power saving mechanism in coordination with CORE and RAN equipment like O-CU, O-DU and O-RU. Coordination interface could be proposed to achieve such mechanism. Antenna and hub equipment may provide the best network energy efficiency experience combining both sleep periods approaches when the link is idle and line rate switching according to the actual payload to be conveyed. For the latter case, it is essential to enable the necessary logic to adapt the clock rate or number of active ports and wavelengths to the necessary payload at border equipment.

In order to provide the most energy efficient transmission for variable traffic loads, antenna site and hub equipment must have the ability to adapt to it. As an example, transport equipment must provide a dynamic auto-negotiation of the Ethernet PHY line rate between antenna site and hub equipment and this should be enabled among the plurality of Ethernet PHY line rates supported according to the actual payload. For multi-wavelength transport (or transceiver), the number of active wavelength pair could be adapted to support the required traffic.

Because of the high clock quality requirements, and long recovery time of clock recovery circuitry, no phase drift will be permitted in the downstream direction when switching line rate. Also, such switching will have to be hitless, i.e., without any Ethernet packet loss whatsoever.

## 11.4 Remote monitoring antenna site operation

The antenna tower site requires also a remote monitoring of sensors and actuator (collection of alarm, active action on site…) for environmental, power, tower light, building and facility. This remote operation requires a logical link with a master unit at the hub site or other remote site. This link could be based on Ethernet (Fast or GigaEthernet). This link should be considered by the transport system between antenna site and hub site.

## 11.5 Operability requirements

Table 14 captures operability transport requirements.

| Capability | Requirements | Notes |
|---|---|---|
| Management | The transport equipment at the antenna site MAY be managed via the transport equipment at the hub site. | |
| Supervision | The transport equipment supervision MUST differentiate equipment and infrastructure faults. | |
| Rogue behaviour | For access network segment, the transport equipment at antenna site MUST support mechanism to avoid disturbing other network operations like silent start network function | This requirement allows to prevent jamming transmission on the FTTH networks in cases of unintentional connection. |
| Availability | Operator MAY choose to use resilience mechanism for transport equipment and infrastructure. | Technology solution to meet this requirement will be covered based on coordination with CORE and RAN equipment. |
| Transceiver | The transport equipment MUST provide the digital diagnostic data of transceivers.<br>The interoperability between transceivers at antenna site and hub is a MUST.<br>Operator MAY choose to select bidirectional (single fiber) to ease operation. In case of WDM transport equipment, operator MAY choose auto-tunable wavelength transceivers. | |
| Port ID | For antenna site operation, optical monitoring and supervision parameters MUST be supported for remote operations. | |
| Eye safety | The transport equipment for access segment MUST be conform to the class 1M at the hub and class 1 at the antenna site defined in IEC 60825-2 | |

| | | |
|---|---|---|
| Power saving energy efficiency | The transport equipment MUST be capable to support power saving mechanism. | Technology solution to meet this requirement will be covered based on coordination with CORE and RAN equipment. |

**Table 14: Operability transport requirements**

# 12 Synchronization

This chapter spells out synchronization requirements for fronthaul networks in alignment with WG CUS specification [74].

## 12.1 Frequency, Phase and Time Accuracy Requirements

The following set of synchronization requirements have been identified as relevant for O-RAN:

- Radio frame alignment (O-RU radio interface)
  - Absolute sync to support TDD : relative 3µs between antennas is transformed into +/- 1.5µs with regarding to a common reference(e.g. GNSS)
  - Relative sync to support radio coordination functions. Most stringent requirement between "non-collocated" O-RUs is 260 ns TAE. Other applicable requirements are 3µs (to support TDD networks). In case of co-located O-RUs 130 ns may also apply.
- Control of the latency between O-DU and O-RU (section 2.3 from O-RAN CUS specification):
  - The relative time error between the O-DU and O-RU shall be within a limit of 3µs (±1.5µs). This requirement applies whether the O-DU is on the synchronization path towards O-RU or not.
- O-DU to O-DU synchronization for Radio Frames handling (e.g., SFN generation):
  - Expected in the ms range
- Frequency sync of the radio signal
  - Frequency accuracy/stability of the O-RU radio interface (50 / 100 ppb)
- O-CU to O-DU synchronization
  - No stringent requirement identified (alarm timestamping is one possible use case)

Further details are provided below for some of these requirements.
The frequency synchronization requirements are summarized in Table 15.

| Application/ Technology | Frequency Accuracy Requirements | Specification |
|---|---|---|
| LTE Wide Area BS | ±0.05 ppm | 3GPP TS 36.104 (01/2020) [75] section 6.5.1 |
| LTE Medium Range BS | ±0.1 ppm | 3GPP TS 36.104 (01/2020)[75] section 6.5.1 |
| LTE Local Area BS | ±0.1 ppm | 3GPP TS 36.104 (01/2020) [75] section 6.5.1 |
| LTE Home BS | ±0.25 ppm | 3GPP TS 36.104 (01/2020 [75] section 6.5.1 |
| NR Wide Area BS | ±0.05 ppm | 3GPP TS 38.104 (01/2020) [76] section 6.5.1 |
| NR Medium Range BS | ±0.1 ppm | 3GPP TS 38.104 (01/2020) [76] |

| | | |
|---|---|---|
| | | section 6.5.1 |
| NR Local Area BS | ±0.1 ppm | 3GPP TS 38.104 (01/2020) [76] section 6.5.1 |

**Table 15: Frequency Accuracy Requirements**

**Time/Phase synchronization requirements:**

The requirements for Time/Phase synchronization for LTE features and 5G features covered in WG4 CUS specification [74] can be referenced as described below:

- Table 9-1: LTE features with time alignment error requirement at the air interface
- Table 9-2: 5G features with time alignment error requirement

## 12.2 Error Budget Allocation Requirements

In case of LLS-C1 and LLS-C2 the frequency error budget allocation can be based on Table 9-3 of ORAN-WG4.CUS.0-v03.00 (04/2020) [74].

In case of LLS-C3 the frequency error budget allocation is provided in Table 16 and is based on Table 9-4 of ORAN-WG4.CUS.0-v03.00 (04/2020) [74].

| Timing Reference | O-RAN transport network contribution limit (LLS-C3) |
|---|---|
| PRTC | MTIE per ITU-T G.8272/Y.1367 (11/2018) [82] clause 6.2 |
| ePRTC | MTIE per ITU-T G.8272.1/ Y.1367.1 (08/2019) [79] clause 6.2 |
| PRTC in holdover | FFS (Note 1) |
| ePRTC in holdover | <100ns for 14 days per G.8272.1 clause 8.2 |
| Note 1: PRTC holdover is for further study. As an example, G.8271.1 (08/2019) Annex V.3 Failure scenarios, refers to a holdover failure scenario of 400 ns for a short interruption (e.g. 5 min) of GNSS. This could be extended to longer periods (e.g. several hours or longer) depending on choice of oscillator and system design. | |

**Table 16: Wander generation requirement for PRTC/ePRTC**

ITU-T G.8272/Y.1367 (11/2018): **Timing characteristics of primary reference time clocks**
https://www.itu.int/rec/T-REC-G.8272-201811-I/en

ITU-T G.8272.1/Y.1367.1 (11/2016) Amendment 2 (08/2019): Timing characteristics of enhanced primary reference time clocks
https://www.itu.int/rec/T-REC-G.8272.1-201908-I!Amd2/en

 

**ITU-T G.8271.1/Y.1366 (2017) Amendment 2 (08/2019) : Network limits for time synchronization in packet networks**
https://www.itu.int/rec/T-REC-G.8271.1-201908-S!Amd2/en

For the case of LLS-C1 and LLS-C2 the time error budget allocation is summarized Table 17 and is based on Table 9-3 of ORAN-WG4.CUS.0-v03.00 (04/2020) [74]. Two types of O-RU are considered in the CUS specification: *Enhanced* O-RU with |TE| < 35 ns and *Regular* O-RU with |TE| < 80 ns.

The below table considers a time error budget allocation model from Xhaul transport point of view from end to end Grandmaster to O-RU. Here it is simplified to show the transport network budget based on different PRTC/GM and type of O-RU selected for the entire Xhaul network.

| Time error budget allocation (LLS-C1/C2) | | | |
|---|---|---|---|
| Timing Reference | O-RAN transport network contribution limit (NOTE2) | O-RU | Air interface target |
| No relative \|TE\| contribution by PRTC/T-GM since PRTC/T-GM is common PTP and SyncE master to all co-operated O-RU | Relative \|TE$_L$\| ⩽60ns<br>Between 2 =-RUs UNI<br>Note 1<br>Note 2 | *Enhanced* O-RU<br><br>*NOTE- regular O-RU can't meet this requirement* | 130ns \|TAE\| between antennas<br><br>For NR Intra-band contiguous carrier aggregation (FR2) |
| | Relative \|TE$_L$\| ⩽190ns<br>Between 2 O-RUs UNI<br>Note 1<br>Note 2 | *Enhanced* O-RU | 260ns TAE between antennas<br><br>For NR Intra-band contiguous carrier aggregation (FR1) |
| | Relative \|TE$_L$\| ⩽100ns<br>Between 2 O-RUs UNI<br>Note 1<br>Note 2 | *Regular* O-RU<br>(Note 4) | |
| Absolute \|TE\| ⩽ 100ns<br>PRTC-A/T-GM spec per ITU-T | Network \|TE$_L$\| ⩽ 1365ns<br>• Between T-GM port and O-RU UNI | *Enhanced* O-RU | 3µs TAE between antennas (TDD, NR Inter-band carrier |

| | | | |
|---|---|---|---|
| G.8272 (03/2020) [78] | Network $\lvert TE_L \rvert \leqslant 1320$ns<br>• Between T-GM port and O-RU UNI | *Regular* O-RU | aggregation or NR Intra-band non-contiguous carrier aggregation) |
| Absolute $\lvert TE \rvert \leqslant$ 30ns ePRTC/T-GM spec per ITU-T G.8272.1 (08/2019) [79] | Network $\lvert TE_L \rvert \leqslant 1435$ns<br>• Between T-GM port and O-RU UNI | *Enhanced* O-RU | |
| | Network $\lvert TE_L \rvert \leqslant 1390$ns<br>• Between T-GM port and O-RU UNI | *Regular* O-RU | |
| Absolute $\lvert TE \rvert \leqslant$ 40ns PRTC-B/T-GM spec per ITU-T G.8272.1 (08/2019) [79] | Network $\lvert TE_L \rvert \leqslant 1425$ns<br>• Between T-GM port and O-RU UNI | *Enhanced* O-RU | |
| | Network $\lvert TE_L \rvert \leqslant 1380$ns<br>• Between T-GM port and O-RU UNI | *Regular* O-RU | |

**Table 17: Time Error Budget Allocation**

Note 1 – Further details are being defined by ITU-T.
Note 2 – Examples for allocation of time error are provided in Section 12.4.
Note 3 – In general the table-16 describes the time error allocation break out for network versus end device requirement. The simple breakout model can be described as

GM/GNSS + Network + End device (O-RU) = Total budget.

Note 4 – Regular O-RU refers to Class-B O-RU as per ORAN-WG4.CUS.0-v03.00 (04/2020) [74].

The time error budget allocation for the case of LLS-C3 is specified by ITU-T G.8271.1 (03/2020) [77].

## 12.3 Synchronization solution requirements

Successful synchronization deployment depends on many factors. A solution architecture document for timing and synchronization will cover more in detail the following aspects:

- Building blocks of network based synchronization
- Timing profiles

- Synchronization time error budgeting models
- Synchronization network models - factors to be considered
- Other applications and sync model
- Synchronization network monitoring and management models
- Best practices and network models

## 12.4 Summary

In summary, the use of Precision Timing Protocol (PTP) has been in use for many network iterations. With the migration to NR and eCPRI, it will become more prevalent and have an extended reach in mobility networks, all the way to the O-RU. This will require a PTP profile based on ITU-T G.8275.1 (03/2020) [80] with Synchronous Ethernet, in the Fronthaul, from O-DU to O-RU (note: for the O-RU it is optional the use of SyncE). The Technical Solutions Document will further describe options for the enhancing the network synchronization performance and reliability.

Finally, Figure 14 to Figure 16 provide some examples of absolute and relative time error requirements as diagrams for LLS-C1 and LLS-C2.

Config LLS-C3 is being studied in ITU-T (planned to be covered in ITU-T G.8271.1 (03/2020) [77]

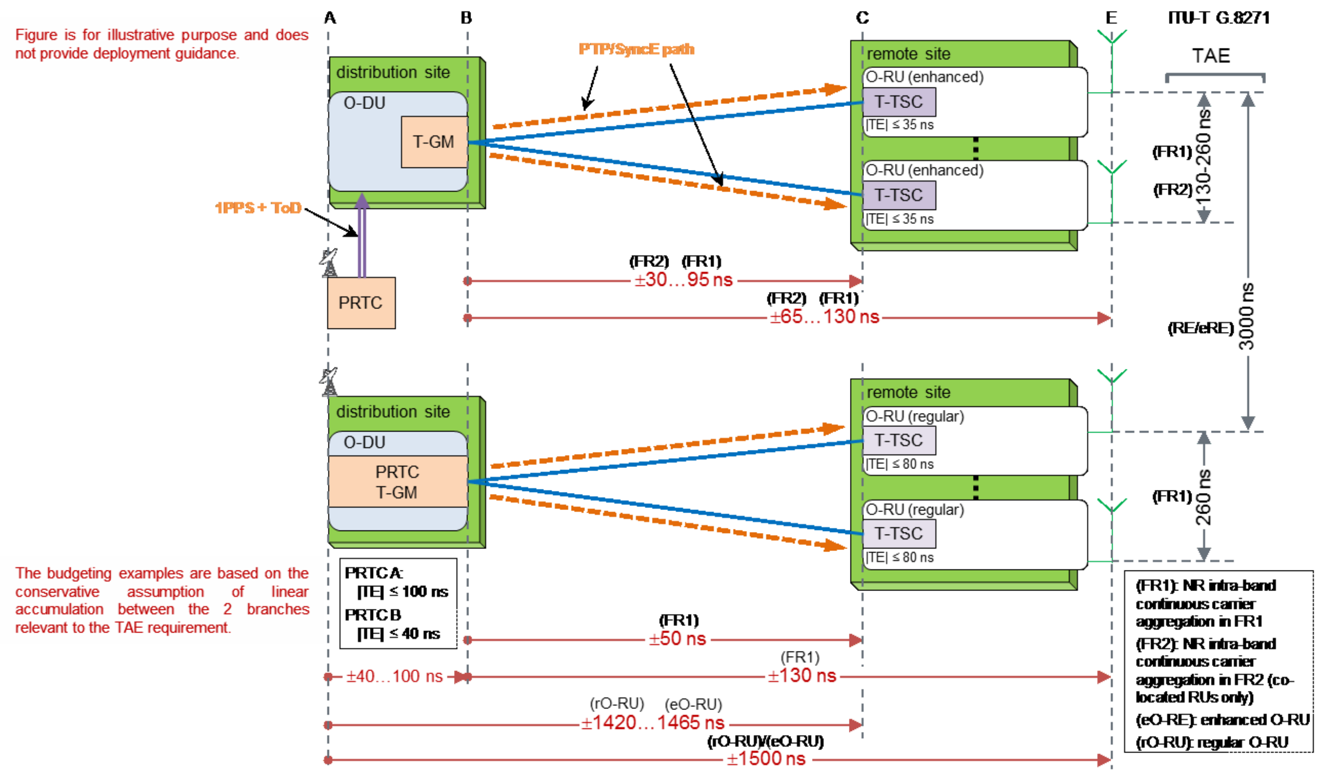


**Figure 14: Example of Absolute vs Relative Requirements (Config LLS-C1 Option A, where T-GM is embedded in O-DU)**

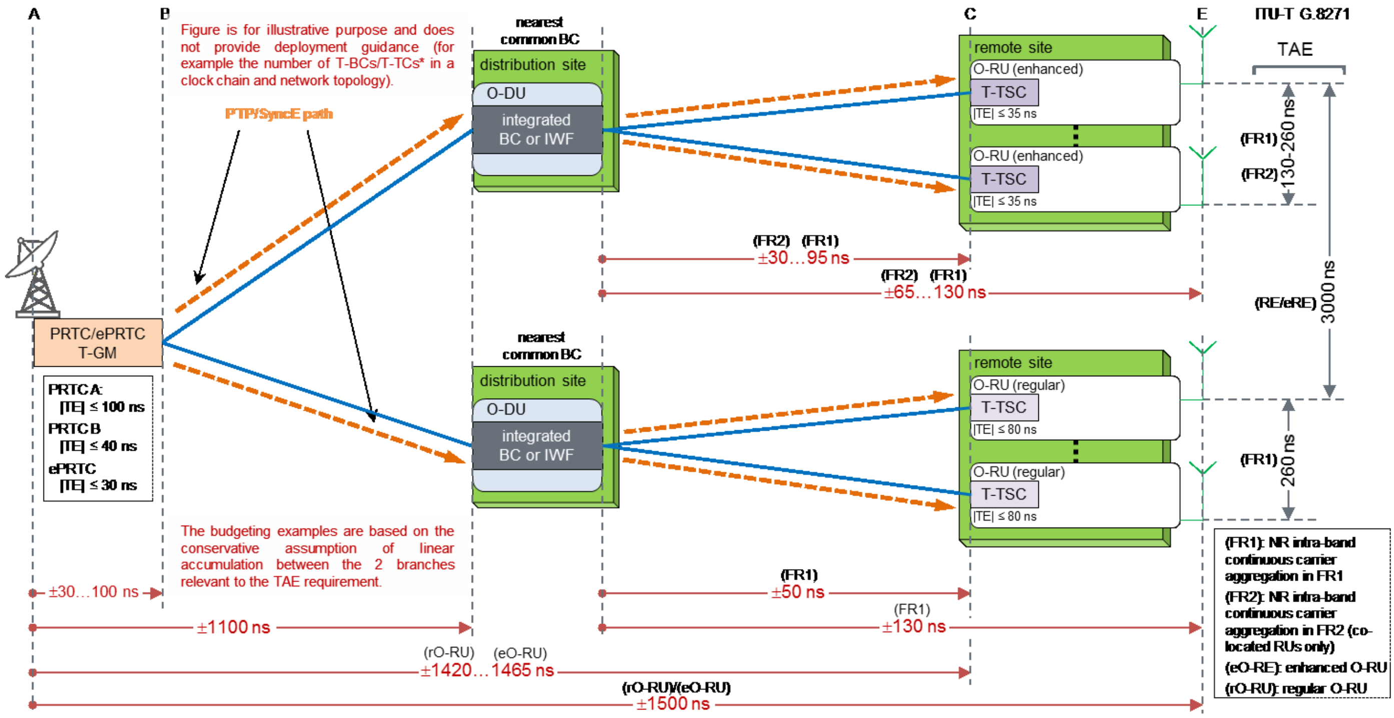


**Figure 15: Example of Absolute vs Relative Requirements (Config LLS-C1 Option B, where T-GM is directly connected to O-DU)**

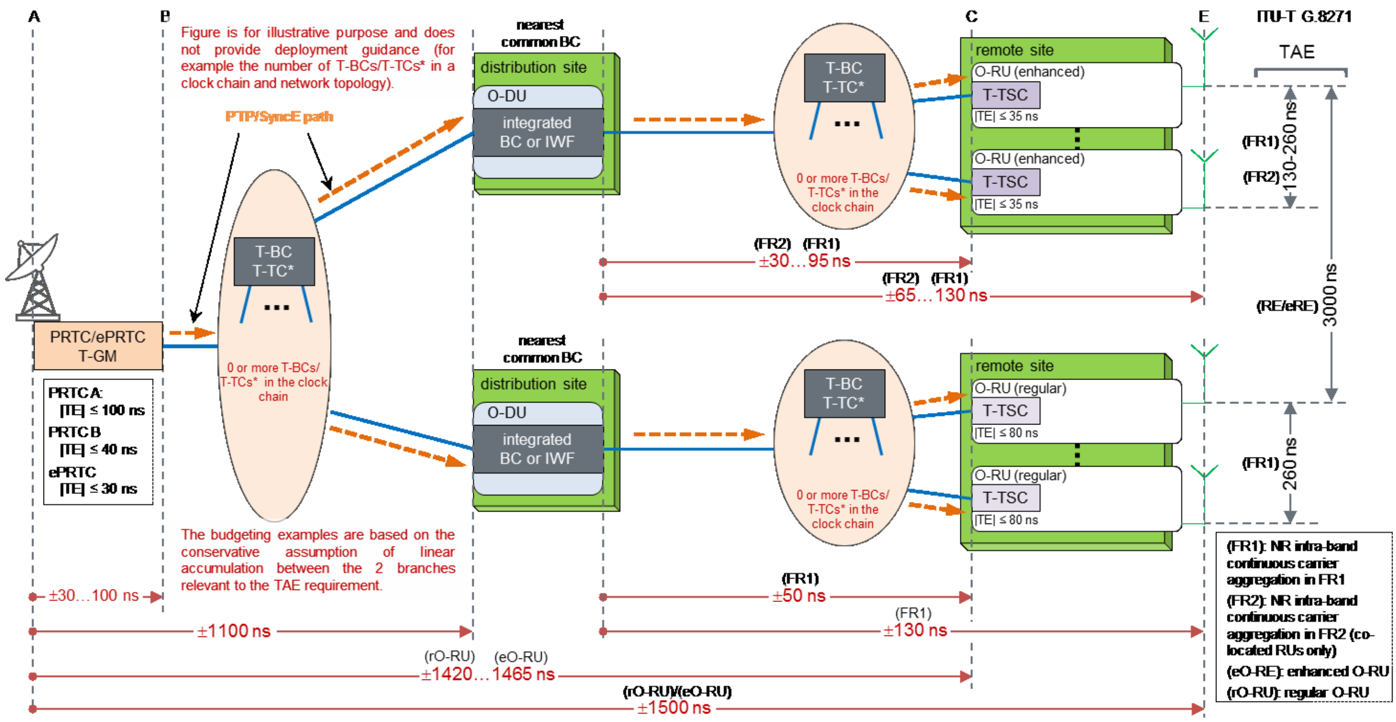


**Figure 16: Example of Absolute vs Relative Requirements (Config LLS-C2 Option A, where O-DU is nearest common T-BC)**

 

Note: All three figures (14, 15 and 16), the T-TSC embedded in remote site and T-BC embedded in O-DU need not to be compliance to ITU-T G.8273.2, 03/2020 [81] specification. Refer the WG4 CUS spec [74] for additional details on this.

# 13 Legacy Requirements

Legacy radio equipment plays a role in the 5G network evolution and must be supported in the new network implementations. This means support of the Common Public Radio Interface (CPRI) must be taken into consideration as it is the interface between radios and BBU. As stated in the Scope section, legacy transport will follow 3GPP split Option 8, the PHY-RF split. This option allows to separate the RF and the PHY layer. In addition, it allows for centralization of processes at all protocol layer levels, resulting in very tight coordination of the RAN and provides efficient support of functions such as CoMP, MIMO, and load balancing.

CPRI is a digitized and serial interface that establishes a connection between BBU and an RRH. The BBU contains the radio functions of the digital baseband domain and the radio contains the analog radio frequency functions. CPRI supports three information flows:

1. IQ Data – user plane information in the form of In-Phase and Quadrature modulation data
2. C&M Data – Control and Management data which is exchanged between the “REC” and “RE”
3. Synchronization Data – used for CPRI frame and time alignment

The three CPRI information flows are supported separately with a flow of frames supporting the IQ data information flow and a flow supporting the C&M data. Synchronization is provided separately.

The Table 18 below breaks out the different requirements for each flow:

| Plane/CPRI Flow | Latency (RTT) | Frame Loss Ratio | Traffic Type Repartion | Traffic Pattern | Traffic QoS |
|---|---|---|---|---|---|
| IQ Data | 125 µs | $10^{-7}$ | >90% | Constant Bit Rate | High |
| C&M Data | n/a | $10^{-6}$ | <10% | Burst | Best Effort |
| Synchronization | n/a | n/a | n/a | n/a | Very High |

**Table 18: CPRI Flow Requirements**

For legacy LTE radios, the Fronthaul bandwidth reference for CPRI traffic is classified in Table 19

| | number of sectors | Total CBW (MHz) | MIMO layers | ABW (MHz) | FH BW (Gbps) |
|---|---|---|---|---|---|
| Small | 1 | 40 | 4 | 160 | 10 |
| Medium | 3 | 40 | 4 | 480 | 29 |
| Large | 3 | 80 | 4 | 960 | 59 |

**Table 19: Fronthaul Bandwidth Reference for LTE traffic in CPRI**

For CPRI rate calculation associated with option 8 split,

$$\text{FH BW} = = 2 \cdot 10^{-9} \cdot 1.25 \cdot f_s \cdot N_{bit} \cdot N_{ant} \ \text{(Gbps)}$$

Where

- $f_s$ is the sample frequency, and $f_s = 30.72$ MHz for 20MHz LTE carriers
- 1.25 is the increasing factor due to the overhead from 8b/10b line code. When 66b/64b line code is used, this factor should be changed to 66/64=1.03125
- $\frac{16}{15}$ is the CPRI control word overhead
- $N_{bit}$ is the bitwidth of the radio I/Q sample
- $N_{ant}$ is the number of antennas

Unlike eCPRI, the CPRI traffic will be constant regardless the user data payload. If CPRI interface is not efficiently used (such as empty AxCs in the CPRI Basic Frame) the required Fronthaul bandwidth will be expected higher.

For co-existence of the 5G NR and LTE radios in the same cell site, both eCPRI and CPRI traffic should be considered. Combining the results given in section 7.2 for eCPRI traffic, Table 20 gives the total Fronthaul bandwidth reference with both eCPRI and CPRI traffic included.

| | CPRI | | eCPRI | | Total FH |
|---|---|---|---|---|---|
| | ABW | FH BW | ABW | FH BW | BW (Gbps) |
| Small | 160 | 10 | 800 | 15 | 24 |
| Medium | 480 | 29 | 6000 | 110 | 140 |
| Large | 960 | 59 | 14400 | 265 | 324 |

**Table 20: Fronthaul Bandwidth Reference for eCPRI + CPRI**

For specific RAN equipment implementation, the RAN split point may not be O-RAN option7-2x. So, different RAN vendors have different results due to different implementation details and parameter settings. Taking the following split choice as an example:

- Downlink User Plane: option 7-3,
- Uplink User Plane: Between "Resource Element De-Mapping" and "Channel estimation";

Table 21 provides the bandwidth calculation based on the split point shown above and with both eCPRI and CPRI traffic included.

| | Number of sectors | CBW (MHz) | MIMO Layers | $\mu$ | ABW (MHz) | Frequency Band | Fronthaul Interface | Air Interface | FH BW (GHz) | Example FH Interface |
|---|---|---|---|---|---|---|---|---|---|---|
| Carrier 1 | 3 | 100 | 16 | 1 | 4800 | 2.6GHz | eCPRI | NR | 68.4(22.8*3) | 3*25G eCPRI |
| Carrier 2 | 3 | 60 | 16 | 1 | 2880 | 2.6GHz | eCPRI | NR | 42.2(14.06*3) | 3*25G eCPRI |

**Table 21: Large site configuration, Sub 6 NR(massive MIMO)**

# Annex A Fronthaul Bandwidth Calculation

This section provides more details for the bandwidth calculation in 7.2 with site carrier configuration examples. Different types of deployments can occur in practice; single-RAT (e.g. 5G fronthaul) versus multi-RAT (e.g. LTE CPRI + 5G fronthaul), pure front- or mid- or backhaul versus a mix of different of X-haul cases. The examples in Table 22 to Table 26 illustrate different cases and different combinations thereof.

Given below are the parameter settings in evaluating the Fronthaul bandwidth via the equation provided in section 7.2 for 7-2x split based eCPRI:

- $N_{PRB} = 264, \mu = 3$ for 400MHz mmWave carriers [3GPP 38.101]
- $N_{PRB} = 273, \mu = 1$ for 100MHz Sub 6 carriers [3GPP 38.101]
- $N_{mantissa} = 9$
- $N_{exponent} = 4$

With about settings, a 400MHz mmWave carrier with 2 layer MIMO is found to have 14.96Gbps FH BW and 100MHz Sub 6 carrier with 4 layer MIMO being 7.74Gbps.

According to the BW calculation equation provided in section 13 the parameters are set as

- $N_{bit}$=15
- $f_s = 30.72$ MHz

Thus for a 20MHz LTE carrier with 2 antenna branches, the CPRI rate is found to be 2.46 Gbps, which is the typical CPRI-3 line rate.

The carrier setting examples are illustrated in Table 22 to Table 26, for small, medium, and large scenarios respectively. The Fronthaul BW for each carrier is aggregated over all sectors and is reported in FH BW column. For the purpose of reference, the optical interfaces to the radios for all sectors are provided at last Colum. Note that these FH interfaces are only exemplary. Actual interface configuration may vary depending on the radio designs from different vendors. For example, if carrier 2 and 3 is cascaded, the resulting transport can be carried by a CPRI 7 link.

Small Examples:

| | number of sectors | CBW (MHz) | MIMO Layers | μ | ABW (MHz) | Frequency Band | Fronthaul Interface | Air Interface | FH BW (Gbps) | Example FH Interface |
|---|---|---|---|---|---|---|---|---|---|---|
| carrier 1 | 1 | 400 | 2 | 3 | 800 | 39GHz | eCPRI | NR | 14.57 | 1x25G eCPRI |
| carrier 2 | 1 | 20 | 4 | | 80 | B-2 | CPRI | LTE | 4.92 | 1xCPRI5 |
| carrier 3 | 1 | 20 | 4 | | 80 | B-4 | CPRI | LTE | 4.92 | 1xCPRI5 |
| | | | | | | | | Total | 24.40 | |

**Table 22: Small site configuration, LTE + mmWave NR**

| | number of sectors | CBW (MHz) | MIMO Layers | µ | ABW (MHz) | Frequency Band | Fronthaul Interface | Air Interface | FH BW (Gbps) | Example FH Interface |
|---|---|---|---|---|---|---|---|---|---|---|
| carrier 1 | 1 | 100 | 4 | 1 | 400 | C-band | eCPRI | NR | 7.5 | 1x10G eCPRI |
| carrier 2 | 1 | 20 | 4 | | 80 | B-2 | CPRI | LTE | 4.9 | 1xCPRI5 |
| carrier 3 | 1 | 20 | 4 | | 80 | B-4 | CPRI | LTE | 4.9 | 1xCPRI5 |
| | | | | | | | | Total | 17.4 | |

**Table 23: Small site configuration, LTE+Sub 6 NR:**

Medium Examples:

| | number of sectors | CBW (MHz) | MIMO Layers | µ | ABW (MHz) | Frequency Band | Fronthaul Interface | Air Interface | FH BW (Gbps) | Example FH Interface |
|---|---|---|---|---|---|---|---|---|---|---|
| carrier 1 | 3 | 400 | 4 | 3 | 4800 | 39GHz | eCPRI | NR | 87.4 | 6x25G eCPRI |
| carrier 2 | 3 | 100 | 4 | 1 | 1200 | C-band | eCPRI | NR | 22.6 | 3x10G eCPRI |
| carrier 3 | 3 | 20 | 4 | | 240 | B-2 | CPRI | LTE | 14.7 | 3xCPRI5 |
| carrier 4 | 3 | 20 | 4 | | 240 | B-4 | CPRI | LTE | 14.7 | 3xCPRI5 |
| | | | | | | | | Total | 139.5 | |

**Table 24: Medium site configuration, LTE + Sub 6 NR + mmWave NR**

| | number of sectors | CBW (MHz) | MIMO Layers | µ | ABW (MHz) | Frequency Band | Fronthaul Interface | Air Interface | FH BW (Gbps) | Example FH Interface |
|---|---|---|---|---|---|---|---|---|---|---|
| carrier 1 | 3 | 100 | 16 | 1 | 4800 | C-Band | eCPRI | NR | 90.4 | 6x25G eCPRI |
| carrier 2 | 3 | 20 | 4 | | 240 | B-2 | CPRI | LTE | 14.7 | 3xCPRI5 |
| carrier 3 | 3 | 20 | 4 | | 240 | B-4 | CPRI | LTE | 14.7 | 3xCPRI5 |
| | | | | | | | | Total | 119.9 | |

**Table 25: Medium site configuration, LTE + Sub 6 NR (massive MIMO)**

Large Example:

| | number of sectors | CBW (MHz) | MIMO Layers | µ | ABW (MHz) | Frequency Band | Fronthaul Interface | Air Interface | FH BW (Gbps) | Example FH Interface |
|---|---|---|---|---|---|---|---|---|---|---|
| carrier 1 | 3 | 400 | 4 | 3 | 4800 | 39GHz | eCPRI | NR | 87.4 | 6x25G eCPRI |
| carrier 2 | 3 | 400 | 4 | 3 | 4800 | 24GHz | eCPRI | NR | 87.4 | 6x25G eCPRI |
| carrier 3 | 3 | 100 | 16 | 1 | 4800 | C-band | eCPRI | NR | 90.4 | 6x25G eCPRI |
| carrier 4 | 3 | 20 | 4 | | 240 | B-2 | CPRI | LTE | 14.7 | 3xCPRI5 |
| carrier 5 | 3 | 20 | 4 | | 240 | B-4 | CPRI | LTE | 14.7 | 3xCPRI5 |
| carrier 6 | 3 | 20 | 4 | | 240 | B-30 | CPRI | LTE | 14.7 | 3xCPRI5 |
| carrier 7 | 3 | 20 | 4 | | 240 | B-66 | CPRI | LTE | 14.7 | 3xCPRI5 |
| | | | | | | | | Total | 324.2 | |

**Table 26: Large site configuration, LTE + Sub 6 NR (massive MIMO) + mmWave NR**

Note that the FH interfaces provided in last column are only exemplary. Actual interface configuration may vary depending on the radio designs from different vendors. For example, if carrier 2 and 3 is cascaded, the resulting transport can be carried by a CPRI 7 link.

# Annex B: Slicing in Backhaul and Midhaul

Network slicing is a key component of the 5G architecture. It is an end to end capability and a "Network Slice Instances" (NSIs) covers multiple "Network Subnet Slices Instances" (NSSIs) including the "Access Network" or radio network, the mobile "Core Network" (CN) and the "Transport Network". (TN)

Figure 17 shows the relationship between NSIs and NSSIs. These can be:

1) 1:1: Each NSI utilises has its own NSSIs which is not shared with other NSIs.
2) n:m: NSIs share NSSIs. For example, an NSI has a dedicated access NSSI but uses a shared mobile core NSSI, or multiple NSIs have dedicated access and core NSSIs but use a common transport NSSI.

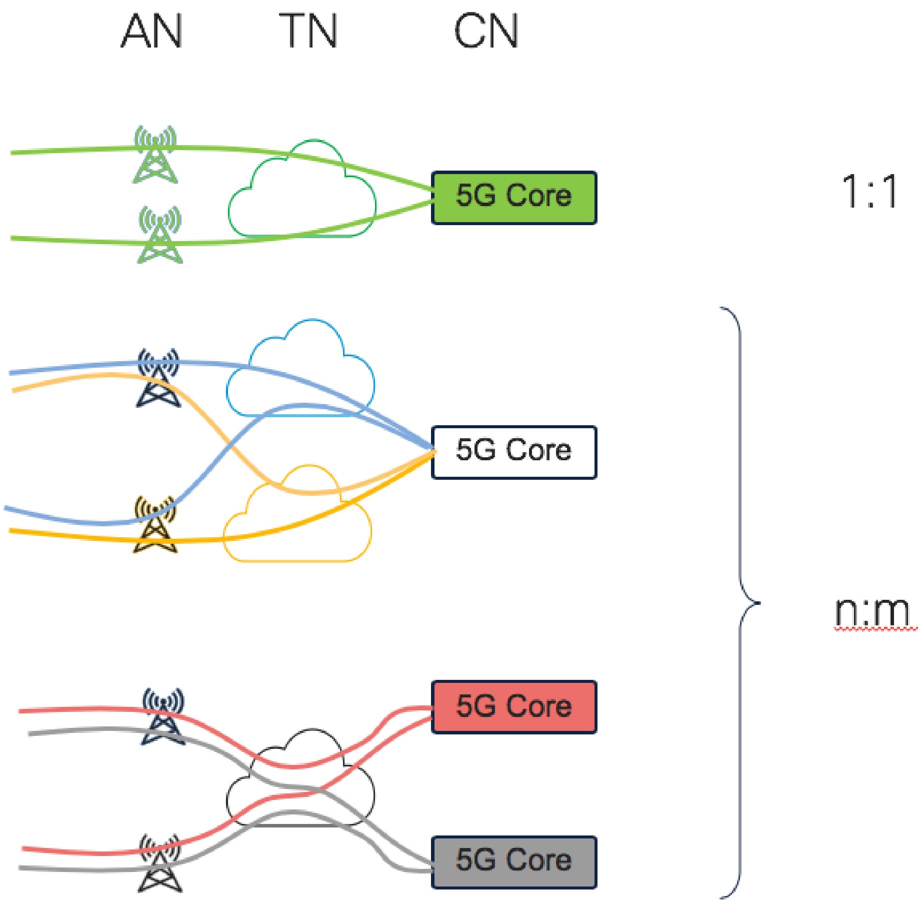


**Figure 17: NSI to NSSI relationships (Source: Cisco)**

The transport infrastructure needs to be able to account for these different eventualities and allow:

1) The transport NSSI to be completely closed. In this case only components connected to the transport NSSI can communicate with each other at the IP level.

2) The transport NSSI is partially closed. In this case components connected to the transport NSSI can communicate with each other at the IP layer but also communicate with entities that are shared between NSIs. For example, a common AMF or other mobile core components used by multiple slices.
3) Controlled connectivity within a transport NSSI. In this case components connected to same transport NSSI have their IP communication controlled to other entities within the same transport NSSI. For example, radio access components within the slice can communicate with each other and with all UPFs, but UPFs owned by different customers cannot communicate with each other across the transport NSSI.

Transport slicing is a required capability within the Backhaul network. Figure 18 shows a high-level example of a transport NSSI in a D-RAN architecture and Figure 19 shows a similar example of a transport network NSSI in a C-RAN architecture. Figure 20 shows further detail of an NSSI supporting purely Backhaul and how that an NSSI can have different VPNs for different functions.

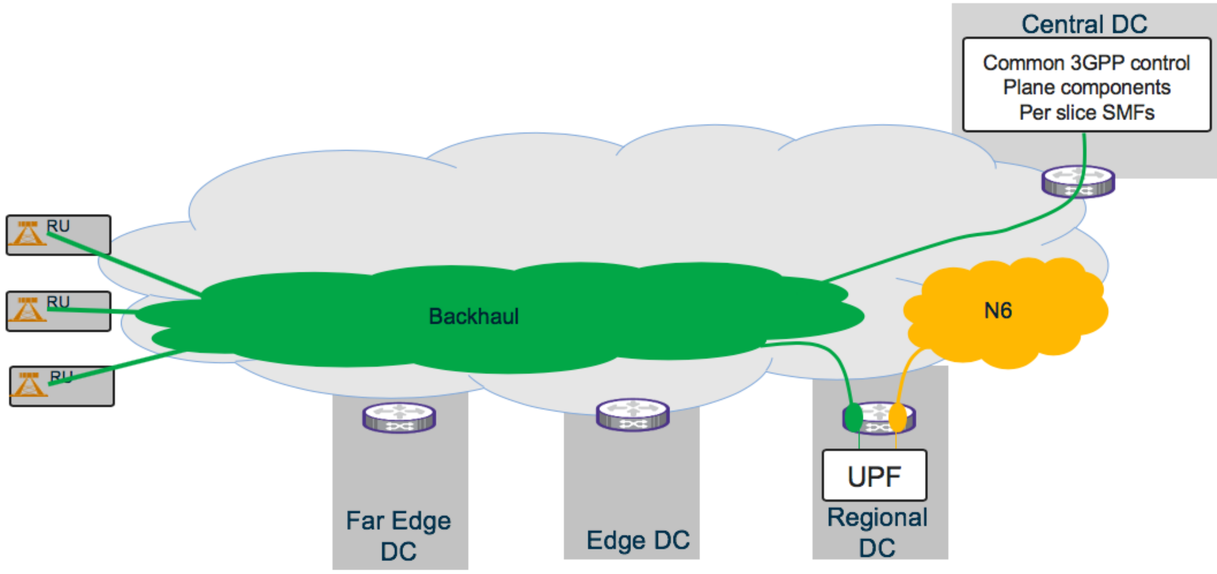


**Figure 18: Transport Network NSSI in a D-RAN architecture. Transport NSSI is two discrete networks (Source: Cisco)**

 

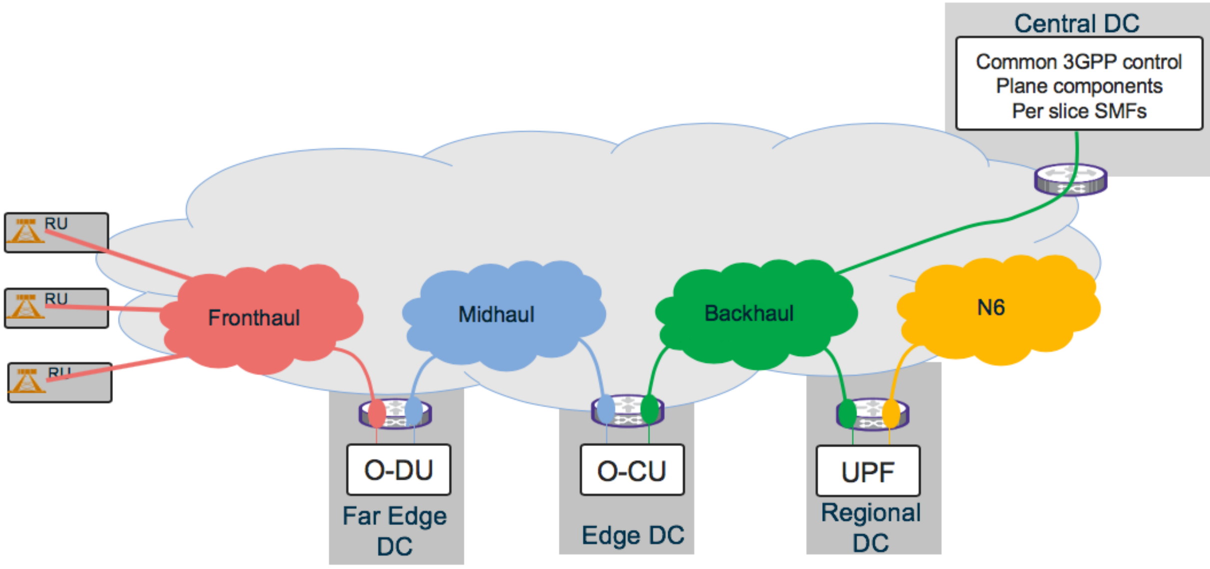


**Figure 19: Transport Network NSSI in a C-RAN architecture. Transport NSSI is 4 discrete networks**

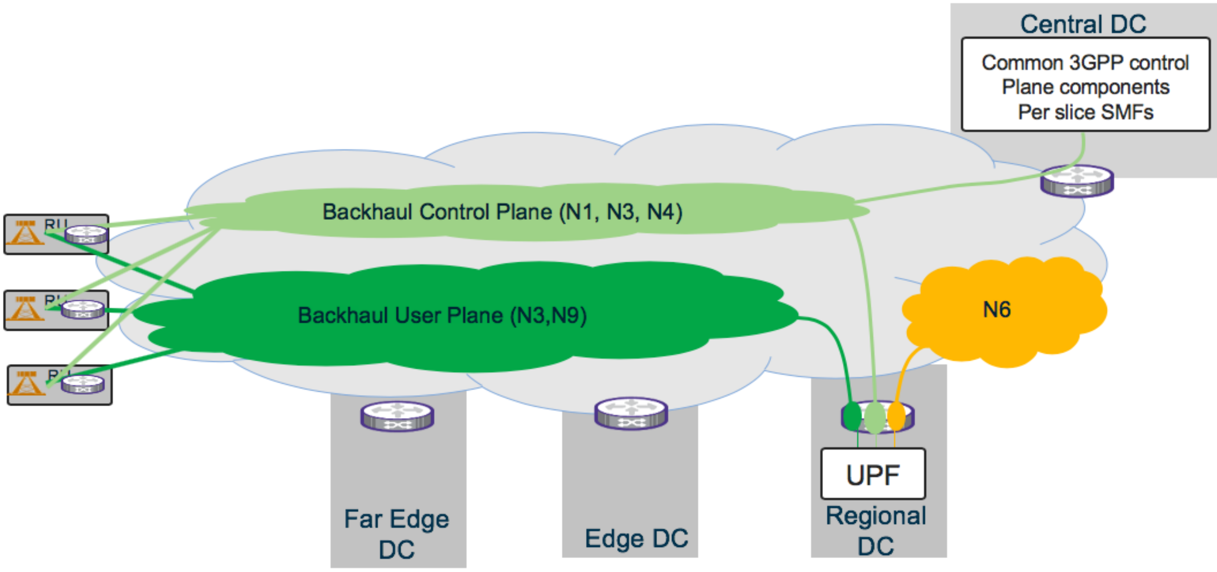


**Figure 20: More details on the Transport Network NSSI in a D-RAN architecture. D-RAN component of transport NSSI consists two discrete networks, one for control plane interfaces and the other for user plane interfaces (source: Cisco)**

General requirements of the TN have been identified as:

1) Management and life cycle management of transport slice through automation
    a. Creation
    b. Change
    c. Deletion

 

2) Isolation between TN slices
    a. Performance
    b. Operation
    c. Reliability
    d. Security

3) TN slice OAM
    a. Dynamic discovery
    b. Performance and SLA measurement

4) Virtualization and abstraction
    a. Use virtualization technology
    b. Isolation between slices

5) Multi-domain
    a. With other components of the slice
    b. Between network domains

## Transport engineer's considerations

With the introduction of network slicing transport network engineers need to consider:

1) Concurrent connectivity between:
    a. WAN to WAN components
    b. WAN to DC based NFs
    c. DC based NFs to DC based NFs (local and remote)
2) L2 or L3 connectivity models
3) Closed user groups / VPNs
4) Multi-point connectivity (any to any)
5) Point to point connectivity
6) Point to multipoint.
7) Flexible connectivity models with the NSSI
8) Support consistent Quality of Service (QoS) on an end-to-end basis
9) Management infrastructure on transport devices and DC components to enable device level management
10) Management infrastructure on transport devices and DC components to enable transport slice definition and orchestration.

# Annex C: Delay Asymmetry

This section is not intended to describe a requirement, but rather specify a problem that is important for the design of transport networks, and yet can only be defined and solved in cooperation with other organizations such as WG4.

Fronthaul transport networks could create a delay asymmetry between the downlink and uplink. This delay asymmetry could be caused by

i) difference of optical fiber lengths when uplink and downlink use separate fiber (7 m of standard single mode fiber approximatively corresponds to a 34 ns delay),
ii) the difference of wavelength propagation times when wavelengths are not similar for uplink and downlink (typically 1.3 µm and 1.55 µm wavelength diplex causes a ~33 ns time difference over 20 km of standard single mode fiber ITU-T G.652),
iii) the difference of processing time (including functions such as time multiplexing, encapsulation, compression) at transport equipment. Other transport functions could contribute to this latency asymmetry.

We propose to have specifications (Table 27) in function of two type of RU: legacy RU (e.g. option 8 without PTP/SyncE) or O-RU (specified by WG4 based on split 7.2 and with PTP/SyncE).

We also propose to have separate specification for cases with or without end user geolocation RAN services based on time measurement (OTDOA [observed time difference of arrival] or UTDOA [uplink time difference of arrival]).

Another factor to be considered is the type of service and/or frequency range as listed in Table 27.

 

<table>
<tr><th rowspan="2">Latency asymmetry up & downlink fronthaul</th><th rowspan="2">Without geolocation based on time measurement</th><th colspan="3">With geolocation based on time measurement</th></tr>
<tr><th>4G</th><th>5G FR1</th><th>5G FR2</th></tr>
<tr><td></td><td></td><td>OTDOA accuracy : +/- 130.2 ns<br>OTDOA resolution : 32.5 ns<br>(higher-resolution mode based on 16.2 ns)</td><td>Not yet specified by 3GPP. This proposed value is based on replica of 4G mechanisms:<br>OTDOA accuracy: +/-32.5 ns<br>OTDOA resolution : 8.1 ns<br>Need to be updated by 3GPP Rel. 16 & 17</td><td>Not yet specified by 3GPP. This proposed value is based on replica of 4G mechanisms:<br>OTDOA accuracy : +/-8.1 ns<br>OTDOA resolution : 2 ns<br>Need to be updated by 3GPP Rel. 16 & 17</td></tr>
<tr><td>Legacy RU</td><td>DU could compensate this asymmetry for known value in the margin of +/- 10 000 ns</td><td>DU could compensate this asymmetry for known value in the margin of +/- 10 000 ns.<br><br>Latency fiber asymmetry < OTDOA resolution 32.5 ns (or 16.2 ns)<br>Proposition of values by WG9<br>- For negligible impact on geolocation time measurement < 3 ns<br>- For residual impact on geolocation time measurement < 13 ns</td><td>N/A</td><td>Not concerned</td></tr>
<tr><td>O-RU</td><td>O-RAN WG4 proposes absolute and relative time error margin to fiber asymmetry in annex H of WG4.CUS.0-v03.00</td><td>Latency fiber asymmetry < O-RU |TE| < OTDOA resolution 32.5 ns (or 16.2 ns)<br><br>Need to be updated by O-RAN WG4 based on 3GPP TS 36.133v14.3.0</td><td>Latency fiber asymmetry < O-RU |TE| < OTDOA resolution 8.1 ns<br><br>Need to be updated by O-RAN WG4 when 3GPP Rel. 16 & 17 will be available</td><td>Latency fiber asymmetry < O-RU |TE| < OTDOA resolution 2 ns<br><br>Need to be updated by O-RAN WG4 when 3GPP Rel. 16 & 17 will be available</td></tr>
</table>

**Table 27: Delay Asymmetry**

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