International Telecommunication Union

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

Series G
Supplement 67
(07/2019)

SERIES G: TRANSMISSION SYSTEMS AND MEDIA,
DIGITAL SYSTEMS AND NETWORKS

Application of optical transport network Recommendations to 5G transport

ITU-T G-series Recommendations – Supplement 67

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Supplement 67 to ITU-T G-series Recommendations

Application of optical transport network Recommendations to 5G transport

Summary

Supplement 67 to ITU-T G-series Recommendations describes the use of existing optical transport network (OTN) Recommendations [ITU-T G.709] and the [ITU-T G.709.x] series in order to address the requirements for supporting 5G transport in 5G transport networks as described in [ITU-T GSTR-TN5G].

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T G Suppl. 67	2019-07-12	15	11.1002/1000/13992

Keywords

5G, mobile, optical transport network, OTN, transport

* To access the Recommendation, type the URL http://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID. For example, http://handle.itu.int/11.1002/1000/11830-en.

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1 Scope

Supplement 67 to the ITU-T G-series Recommendations (ex. G.Sup.5gotn) provides a profile of current approved optical transport network (OTN) Recommendations [ITU-T G.709] and the [ITU-T G.709.x] series in order to support 5G transport networks as described in [ITU-T GSTR-TN5G].

2 References

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[eCPRI] eCPRI Specification V1.2 (2018-06), *Common Public Radio Interface: eCPRI Interface Specification*.

3 Definitions

None.

4 Abbreviations and acronyms

This Supplement uses the following abbreviations and acronyms:

3GPP 3rd Generation Partnership Project

5GC 5G Core

AAU Active Antenna Unit

AMF Access and Mobility Management Function

BBU Baseband Unit

BNG Broadband Network Gateway

CN Core Network

CO Central Office

CP Control Plane

CPRI Common Public Radio Interface

CPE Customer Premises network Elements

CR Core Router

C-RAN Centralized RAN

CU Central Unit

D-RAN Distributed RAN

DL	Downstream Link
DSLAM	Digital Subscriber Line Access Multiplexer
DU	Distribution Unit
eCPRI	enhanced Common Public Radio Interface
eMBB	enhanced Mobile Broadband
eNB	enhanced Node B (eNB)
eOEC	enhanced OTN Equipment Clock
EPC	Evolved Packet Core
F*n*	5G logical interface between the gNB DU and CU
gNB	Next generation NodeB, 5G base station name
MEC	Mobile Edge Compute
NG	Next Generation
NGC	Next Generation Core
NR	New Radio
NRT	Non-Real Time
NSA	Non-Stand Alone
OEC	OTN Equipment Clock
OLT	Optical Line Terminal
OTN	Optical Transport Network
PDCP	Packet Data Convergence Protocol
RAN	Radio Access Network
RRC	Radio Resource Control
RU	Remote Unit
SLA	Service-Level Agreement
T-BC	Telecom Boundary Clock
UE	User Equipment
UL	Upstream Link
UP	User Plane
UPF	User Plane Function
URLLC	Ultra-Reliable Low Latency Communication
VN	Virtual Network
X*n*	(Logical) Interfaces internal to the RAN ("Xn" specifically refers to one connected between two gNB nodes)

5 Conventions

The terms fronthaul, midhaul and backhaul are frequently used when describing 5G architecture. In the transport network the different domains are often classified as metro edge, metro aggregation, metro core and backbone. The use of the terms fronthaul, midhaul and backhaul in the context of a transport network is described below:

A transport network that supports the low layer functional split point of 3GPP NG-RAN, (e.g., Option 6 for MAC/PHY split or Option 7 for intra PHY split) [3GPP TR 38.801], is commonly known as fronthaul.

A transport network that supports 3GPP NG-RAN F1 interface (between a gNB-CU and a gNB-DU), or the Xn interface that provides interconnection between different NG-RAN nodes (gNB or ng-eNB), is sometimes referred to as midhaul.

A transport network that supports the 3GPP NG interface (between the 5GC and the NG RAN) or the Xn interface that provides interconnection between different NG-RAN nodes (gNB or ng-eNB) [3GPP TS 38.401], is commonly known as backhaul.

6 Introduction and background

Technical report [ITU-T GSTR-TN5G] documents a reference model of IMT-2020/5G network and a set of deployment scenarios. It documents the requirements on transport networks in order to support IMT-2020/5G networks, particularly at interfaces between IMT 2020/5G entities and transport networks.

This Supplement describes the use of existing OTN Recommendations [ITU-T G.709] and the [ITU-T G.709.x] series in order to address the requirements for supporting 5G transport in the fronthaul, midhaul and backhaul networks as described in [ITU-T GSTR-TN5G].

7 Reference 5G wireless architecture

The reference 5G wireless architecture is documented in [ITU-T GSTR-TN5G].

8 5G transport network architecture

8.1 Impact of 3GPP functional split and core network deployment on the transport network architecture

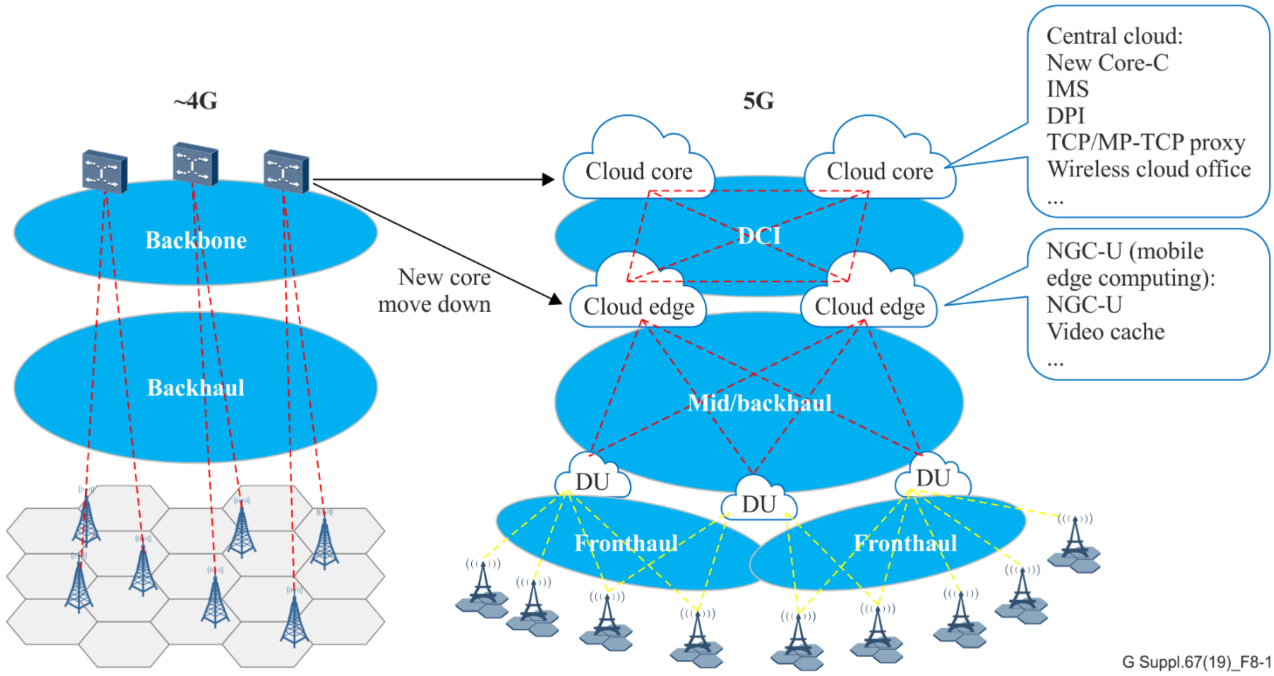

Figure 8-1 – Deployment location of core network in 5G network

Due to the reason that 3GPP specifies several functional split options, and it drives the deployment of NGC network to the cloud edge, there are four possible deployment locations of transport network, fronthaul, midhaul, backhaul and NGC interconnection.

1) Fronthaul

The function split point is located between a high PHY and low PHY; the bandwidth of a UNI interface is about 25 Gbit/s. For a new 5G network, the typical bandwidth of an NNI interface is about 75 Gbit/s or 150 Gbit/s (considering a high frequency case). For a 4G and 5G hybrid network, the typical bandwidth of NNI interface is about 100 Gbit/s or 200 Gbit/s. The latency requirement is strict (< 100 us). The transport network is always deployed in P2P mode.

2) Midhaul

The function split point is located between the PDCP and RLC. The bandwidth of a UNI interface is about 10 or 25 Gbit/s, and the bandwidth of an NNI interface is about N times 10 Gbit/s or 25 Gbit/s (related to the aggregation capability of a DU). The transport network is always deployed in tree or ring mode. Multiple DUs are aggregated to one CU.

3) Backhaul

The function split point is above the RRC, and the bandwidth requirements are similar to midhaul. There are two types of traffic: horizontal traffic and vertical traffic. Xn is the interface which carried a coordination service between the base stations, therefore, horizontal traffic scheduling is needed. NG is the interface which carried different services (such as V2X, eMBB and IoT) from the base station to the 5G core. Usually, different services are deployed in different clouds, therefore vertical traffic grooming is needed.

4) NGC interconnection

This is the interconnection between nodes after the core network has been deployed in the cloud edge; the bandwidth of the UNI and NNI interface is equal or larger than 100 Gbit/s. One hop connection is required to reduce the bandwidth waste caused by multiple hops.

8.2 OTN transport network architectures to support 5G

8.2.1 Overview of 5G transport network architecture

Generally, a 5G transport network would contain fronthaul, midhaul and backhaul. However, different operators may deploy their network according to their own scenario. Thus, four types of RAN deployment may exist [ITU-T GSTR-TN5G].

As for each AAU, the bandwidth requirements for midhaul and backhaul are very similar; also, packet based flexible networking capabilities (e.g., IP/MPLS forwarding) are required for both midhaul and backhaul. So, using one universal transport solution for both midhaul and backhaul is desired.

On the other hand, the bandwidth requirement for fronthaul is much higher than midhaul and backhaul, and simply point-to-point transport of eCPRI traffic is enough for fronthaul. Therefore, from perspective of bandwidth requirement and flexible networking capabilities, 5G transport network architecture can be classified into two major types: C-RAN and D-RAN.

8.2.1.1 C-RAN

In this scenario, the AAU and DU are separated; the DU and CU could be co-located or separated. Therefore, there are fronthaul and backhaul networks, and possibly also midhaul ones. The distance between an AAU and DU is up to several kilometres (0-10 km) while the distance between the DU and CU is up to tens of kilometres.

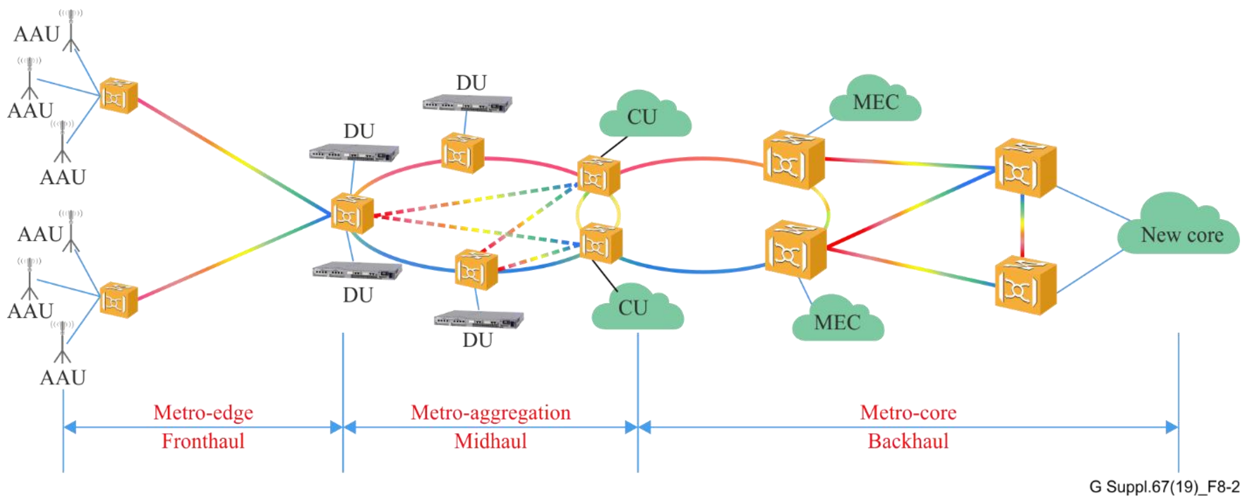

Figure 8-2 – 5G transport network architecture: C-RAN

For fronthaul/edge the topology could be ring or point to point (p2p) at the optical layer; but at the OTN layer point-to-point topology will be used to lower the cost and latency.

Based on the location of centrally deployed DUs, C-RAN can be further divided into the following two types, as illustrated in Figure 8-2:

– Large C-RAN: DUs are centrally deployed at the central office (CO), which typically is the intersection point of metro-edge fibre rings. The number of DUs within in each CO is between 20 and 60 (assume each DU is connected to 3 AAUs).

– Small C-RAN: DUs are centrally deployed at the metro-edge site, which typically is located at the metro-edge fibre ring handover point. The number of DUs within each metro-edge site is around 5~10.

8.2.1.2 D-RAN

In this scenario the AAU and DU are co-located; the DU and CU could be co-located or separated. Therefore, there is only a backhaul network, and possibly also a midhaul one, but no fronthaul. Figure 8-3 illustrates a D-RAN scenario with only backhaul.

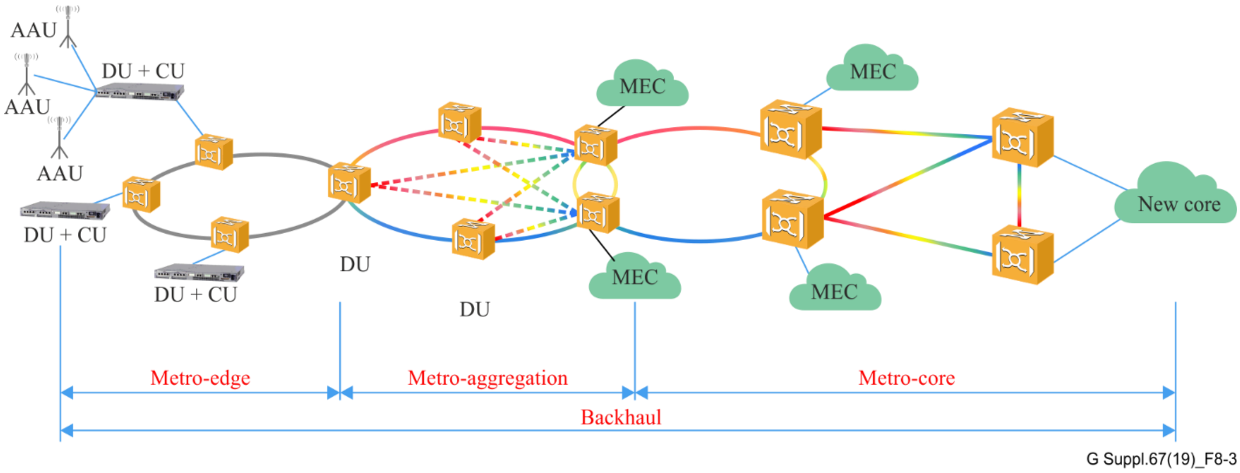

Figure 8-3 – 5G transport network architecture: D-RAN

For D-RAN the transport network metro-edge node will be co-located with 5G gNB. In order to improve the link utilization and network reliability, usually packet ring topology will be deployed at the metro-edge domain.

8.2.2 NGC interconnection

Table 8-1 lists the requirements for NGC interconnection.

Table 8-1 – Transport network requirement summary for NGC

Parameter	Requirement	Comments
Capacity	0.8-2 Tbit/s	Each NGC node has 500 base stations. The average bandwidth of each base station is about 3Gbit/s, the convergence ratio is 1/4, and the typical bandwidth of NGC nodes is about 400Gbit/s. 2~5 directions are considered, so the NGC node capacity is 0.8~2Tbit/s.
Latency	1 ms	Round trip time (RTT) latency between NGCs required for DC hot backup intra-city.
Reach	100-200 km	Typical distance between NGCs.
NOTE – The ranges will vary greatly between different network operators.		

8.3 OTN transport network architectures to support 5G in detail

An OTN network architecture that supports 5G transport is illustrated in Figure 8-4. It consists of metro-core, metro-aggregation and large cloud radio access network (C-RAN), small C-RAN and distributed radio metro-edge network (D-RAN) metro-edge network domains. The blue boxes in this figure represent the 5G network elements, the orange boxes represent the OTN network elements, specifically their electrical layer functionality, and the clouds represent the optical layer OTN functionality. This OTN network is providing connectivity between the following 5G network elements:

– Active antenna unit (AAU) ⇔ next generation node B (gNB),
– AAU ⇔ gNB distributed unit (DU),
– DU ⇔ DU,
– DU ⇔ gNB centralized unit (CU),
– CU ⇔ CU ⇔ gNB ⇔ gNB,
– CU ⇔ mobile edge computing (MEC),
– gNB ⇔ MEC,
– MEC ⇔ MEC,
– MEC ⇔ core network (CN) and
– CN ⇔ CN.

The connectivity (Xn) between CUs and gNBs can be supported by a multipoint-to-multipoint connection or by a set of point-to-point connections.

NOTE – This OTN network architecture will also support connectivity between

– 4G network elements: active antenna unit (AAU), baseband unit (BBU), enhanced node B (eNB) and evolved packet core (EPC) (see Figure 8-5),
– broadband network elements: optical line terminal (OLT) or digital subscriber line access multiplexer (DSLAM), broadband network gateway (BNG) and core router (CR) (see Figure 8-6),
– data centres (see Figure 8-7), and
– private line customer premises network elements (CPE) (see Figure 8-8).

OTN network elements in the network domains are interconnected via OTUk and OTUCn/FlexO interface signals compliant with [ITU-T G.709], [ITU-T G.709.1], [ITU-T G.709.2] and [ITU-T G.709.3].

Only in case there is no direct optical layer connection possible, such OTN to OTN network element interconnectivity is established via one or more intermediate OTN network elements; e.g., two OTN network elements located at the boundary of a metro-aggregation and a metro-edge domain (EA) may be interconnected via the OTN network element located at the boundary of the metro-aggregation and metro-core domains (AC).

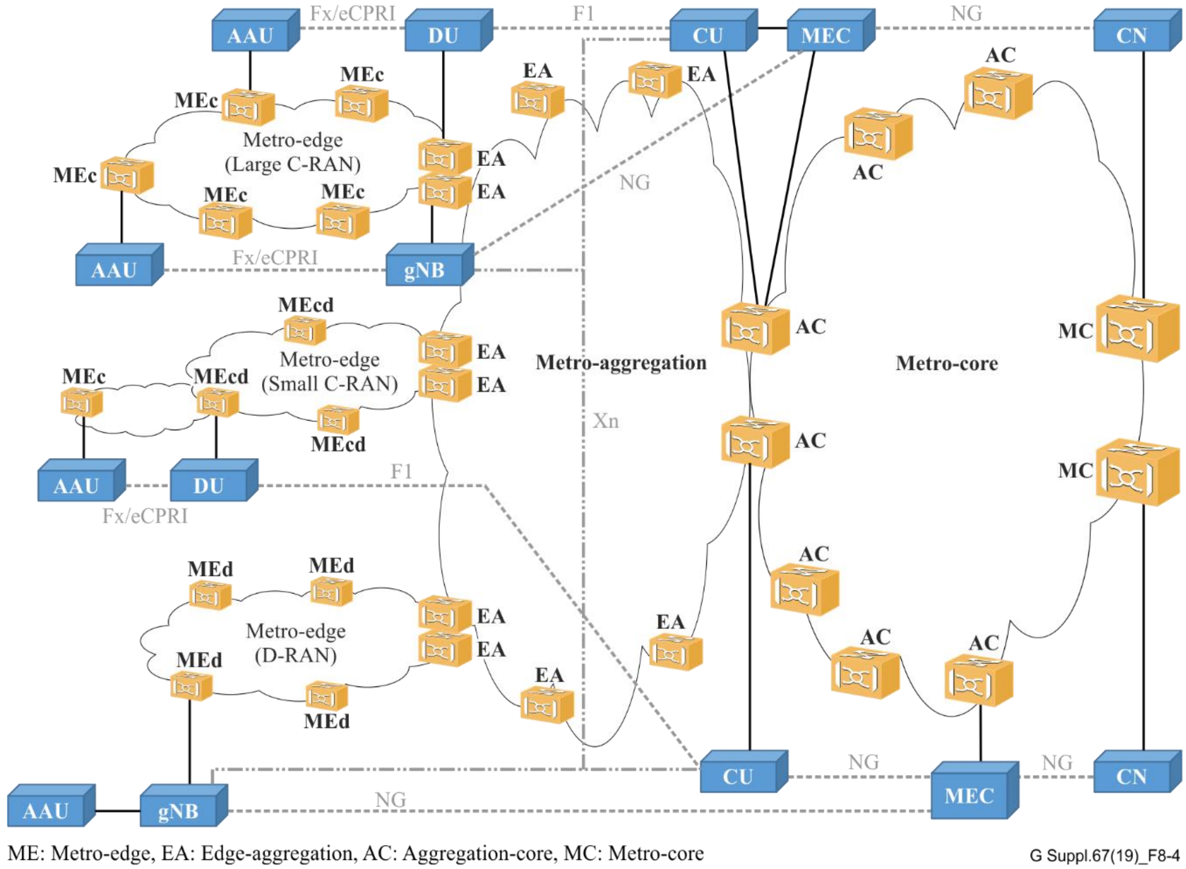

Figure 8-4 – OTN network architecture with 5G client network elements

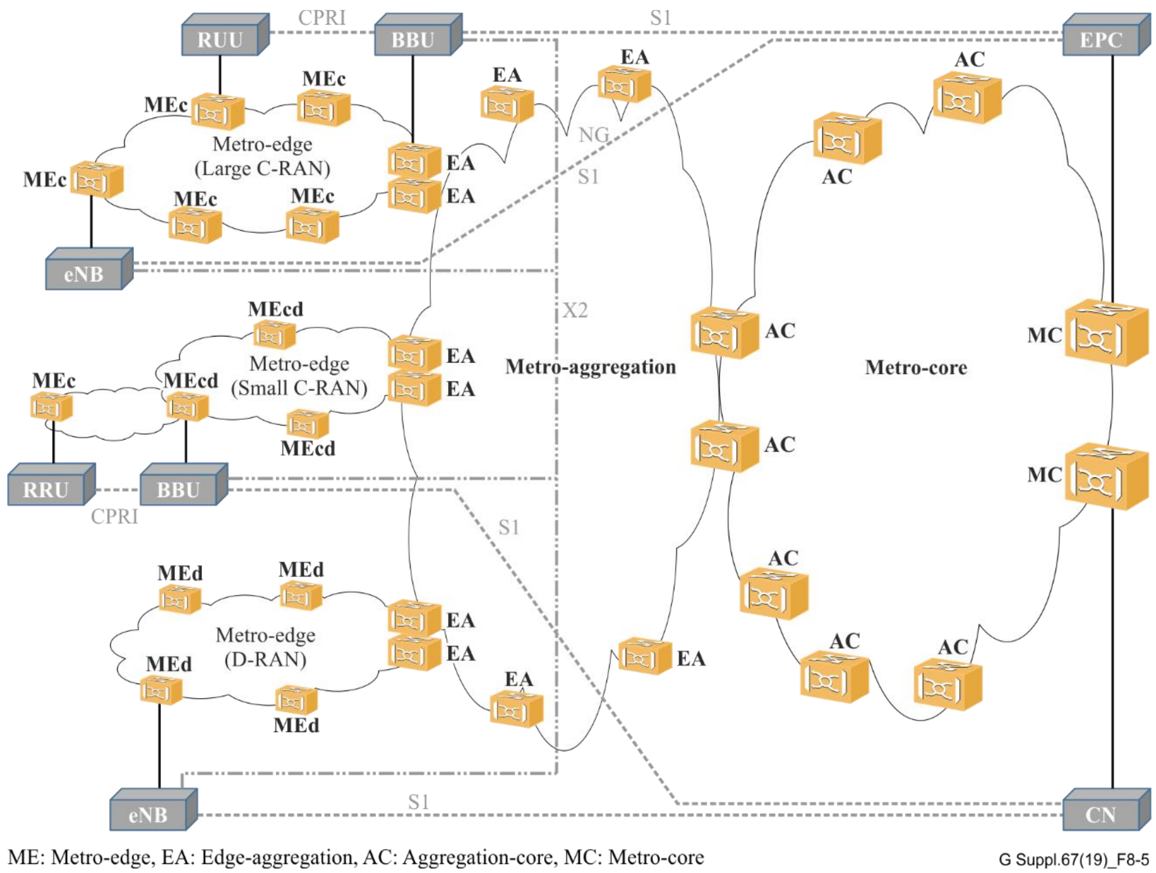

Figure 8-5 – OTN network architecture with 4G client network elements

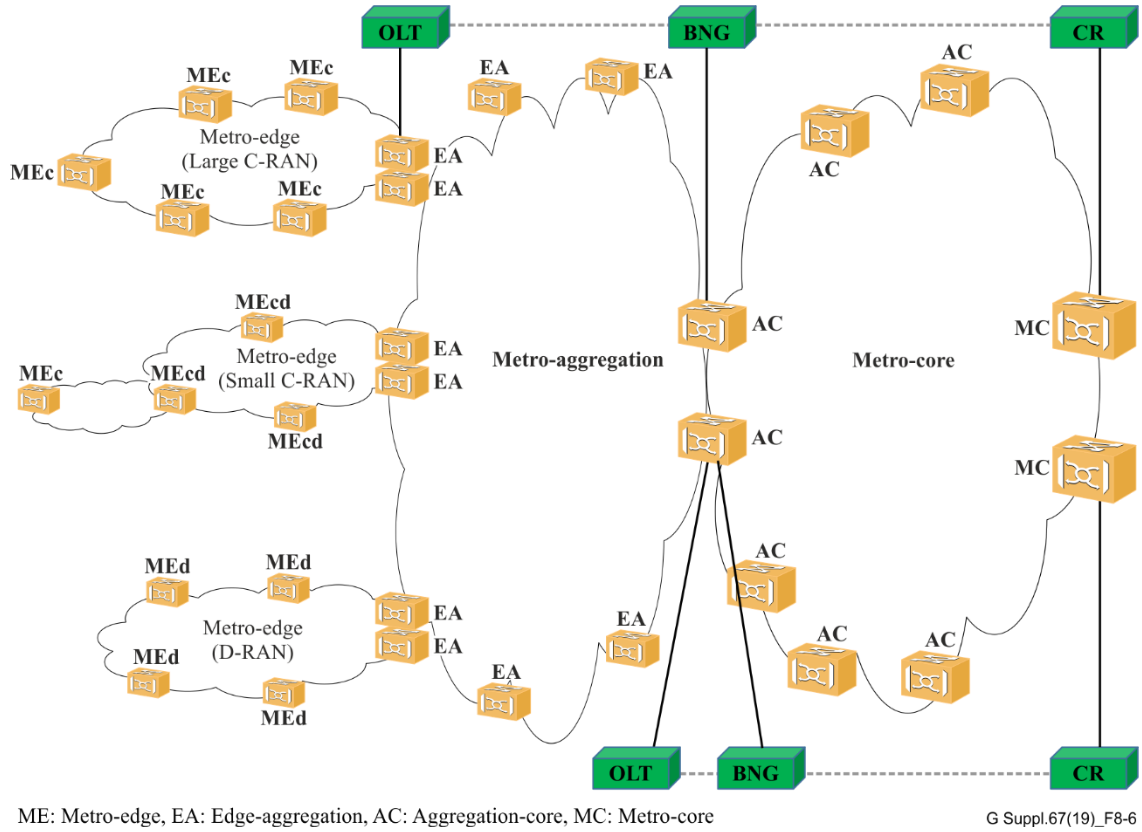

Figure 8-6 – OTN network architecture with broadband client network elements

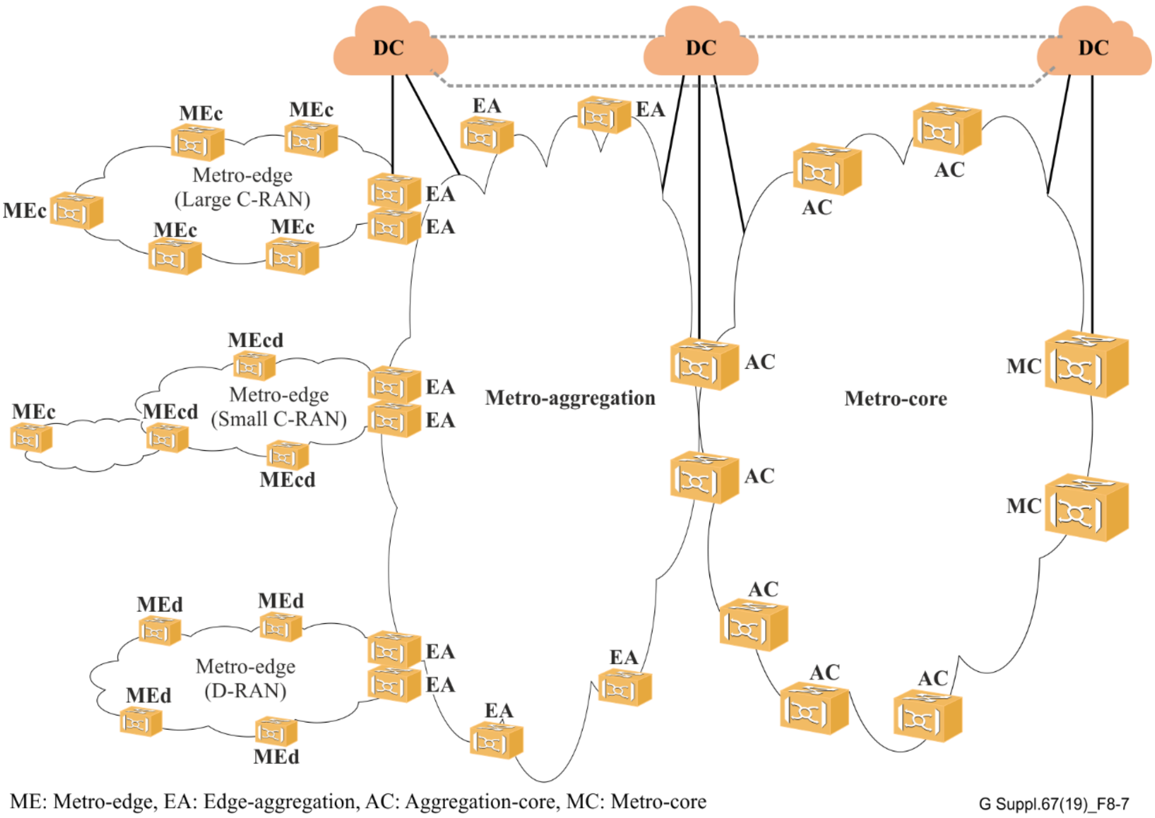

Figure 8-7 – OTN network architecture with data centre client network elements

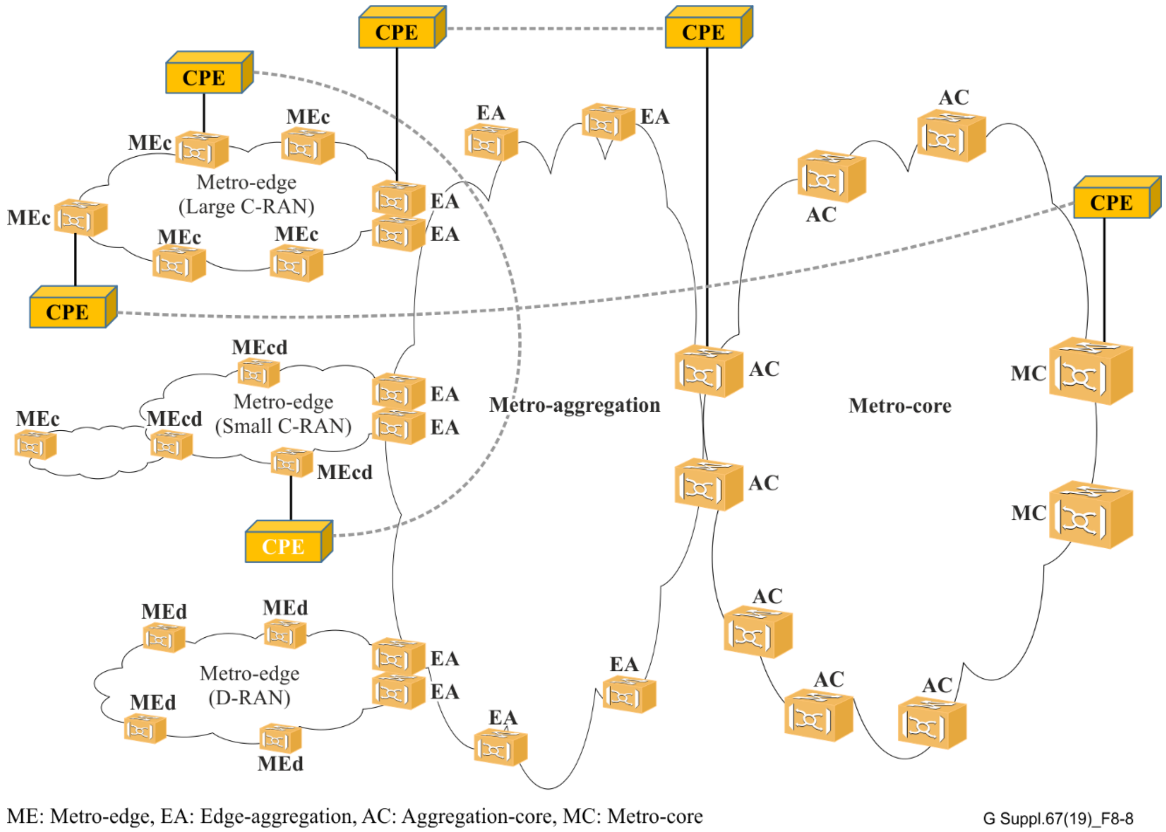

Figure 8-8 – OTN network architecture with private line client network elements

Figures 8-9 and 8-10 show the relationship between the fronthaul, midhaul and backhaul domains in 5G and the metro-edge, metro-aggregation and metro-core domains in an OTN network.

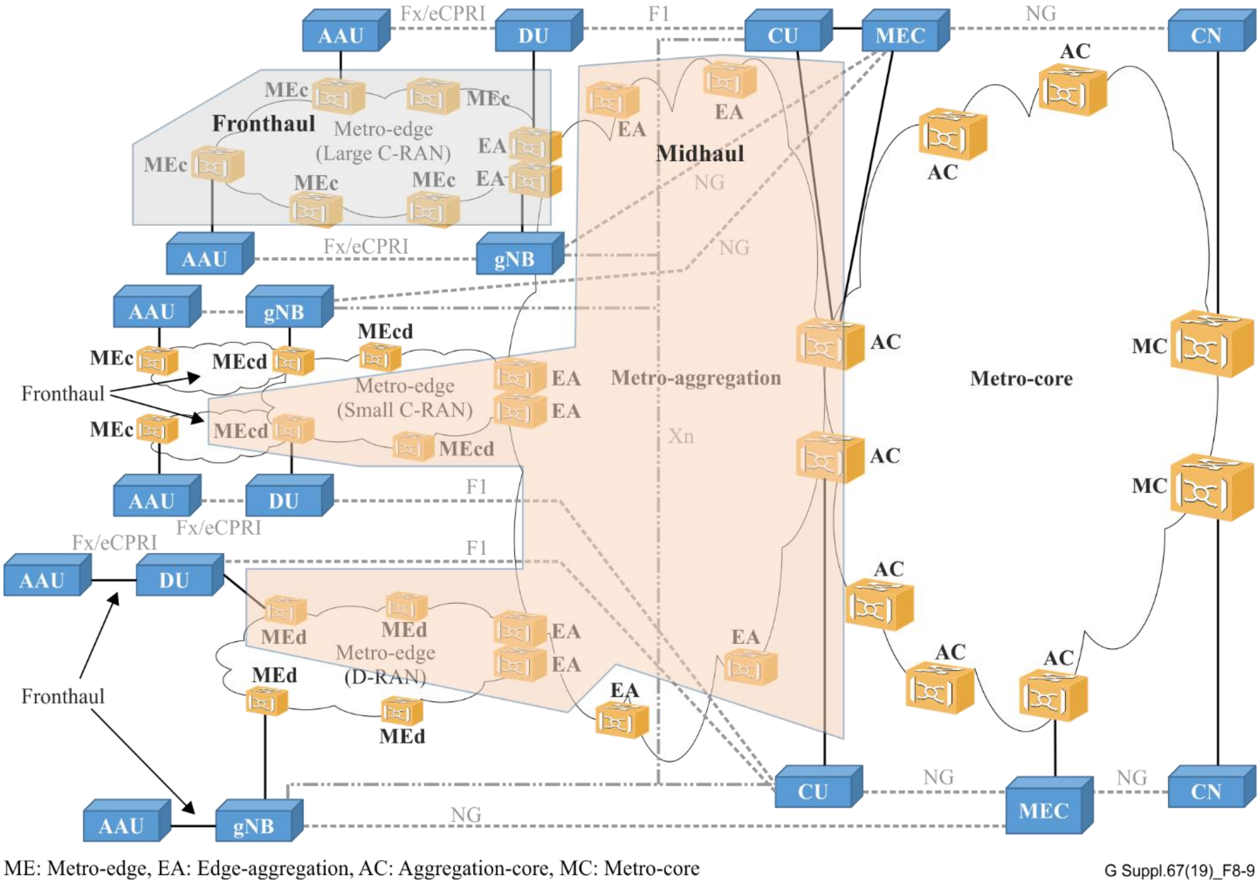

Figure 8-9 – 5G fronthaul and midhaul domain relationship with OTN network domains

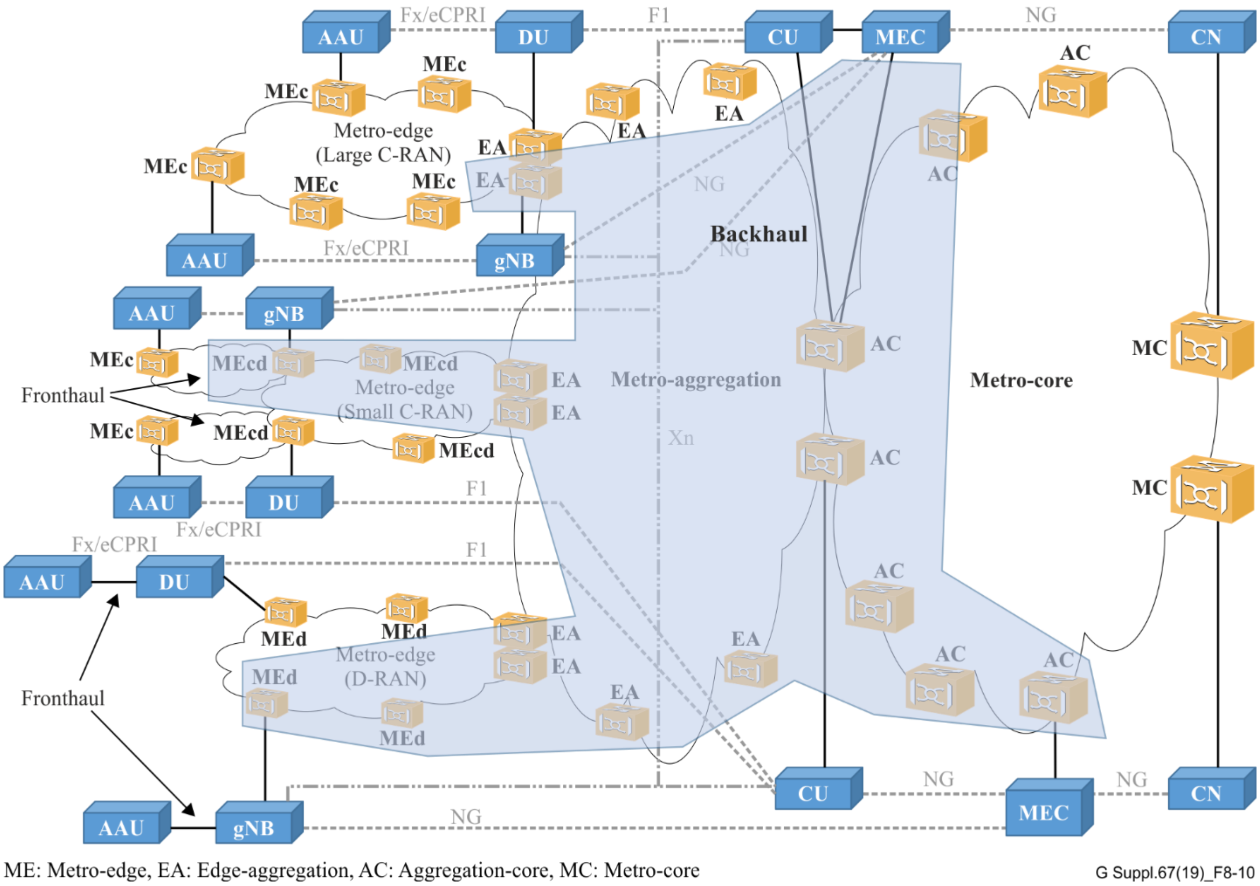

Figure 8-10 – 5G backhaul domain relationship with OTN network domains

8.3.1 OTN metro-core network domain

The OTN metro-core network domain may deploy an optical mesh network topology, optical ring network topology or hybrid mesh and ring network topology. Optical path distances are assumed to be between 20 km and 450 km. The bandwidth requirements between the OTN network elements at the domain boundaries will be around N×100G.

100G, 200G and 400G OTN interfaces are available in the formats OTU4-SC as specified in [ITU-T G.709]/[ITU-T G.709.2], OTUC1/FlexO-1-SC, OTUCn/FlexO-1-SC-n, OTUC2/FlexO-2-DSH, OTUCn/FlexO-2-DSH-m (m= $\lceil n/2 \rceil$), OTUC4/FlexO-4-DSH and OTUCn/FlexO-4-DSH-m (m= $\lceil n/4 \rceil$) as specified in [ITUT-G.709]/[ITU-T G.709.3]. The 100G and future 200G and 400G application codes in [ITU-T G.698.2] are applicable.

8.3.2 OTN metro-aggregation network domain

The OTN metro-aggregation domain may deploy a point-to-point (p2p) optical layer network topology or an optical ring based optical layer network topology. Optical path distances are assumed to be between 5 and 20 km in a metropolitan area and 5 and 40 km in a rural area. Via the longest optical path in an optical ring these values would double to 40 km and 80 km. The bandwidth requirements between the OTN network elements at the domain boundaries will be around 100G~200G.

For a point-to-point scenario, 100G or 200G OTN interfaces are available in the formats OTU4 as specified in [ITU-T G.709], OTUC1/FlexO-1-RS-1, OTUC2/FlexO-2-RS-1 and OTUC2/FlexO-1-RS-2 as specified in [ITU-T G.709]/[ITU-T G.709.1]. The optical tributary signal class NRZ 25G and PAM4 50G application codes 4I1-9D1F, 4L1-9C1F, 4L1-9D1F, 8R1-4D1F, 4I1-4D1F and 8I1-4D1F in [ITU-T G.959.1] are applicable.

For an optical ring scenario, Figure 8-11 shows a pair of OTN network elements at the boundary of the metro-core and metro-aggregation domains that are connected to up to e.g., four optical metro-aggregation rings, each connected to 4 to 6 OTN network elements at the boundary of the metro-aggregation and metro-edge domains. The ring bandwidth will be in the range of 400~1200G.

100G and 200G OTN interfaces are available in the formats OTU4-SC [ITU-T G.709], [ITU-T G.709.2], OTUC1/FlexO-1-SC, OTUC2/FlexO-1-SC-2 and OTUC2/FlexO-2-DSH [ITU-T G.709]/[ITU-T G.709.3]. The 100G and future 200G application codes in [ITU-T G.698.2] are applicable.

Data centre to data centre connections with bit rates in the same order as the bit rates of the OTN interfaces would typically be provided via the OTN optical layer directly.

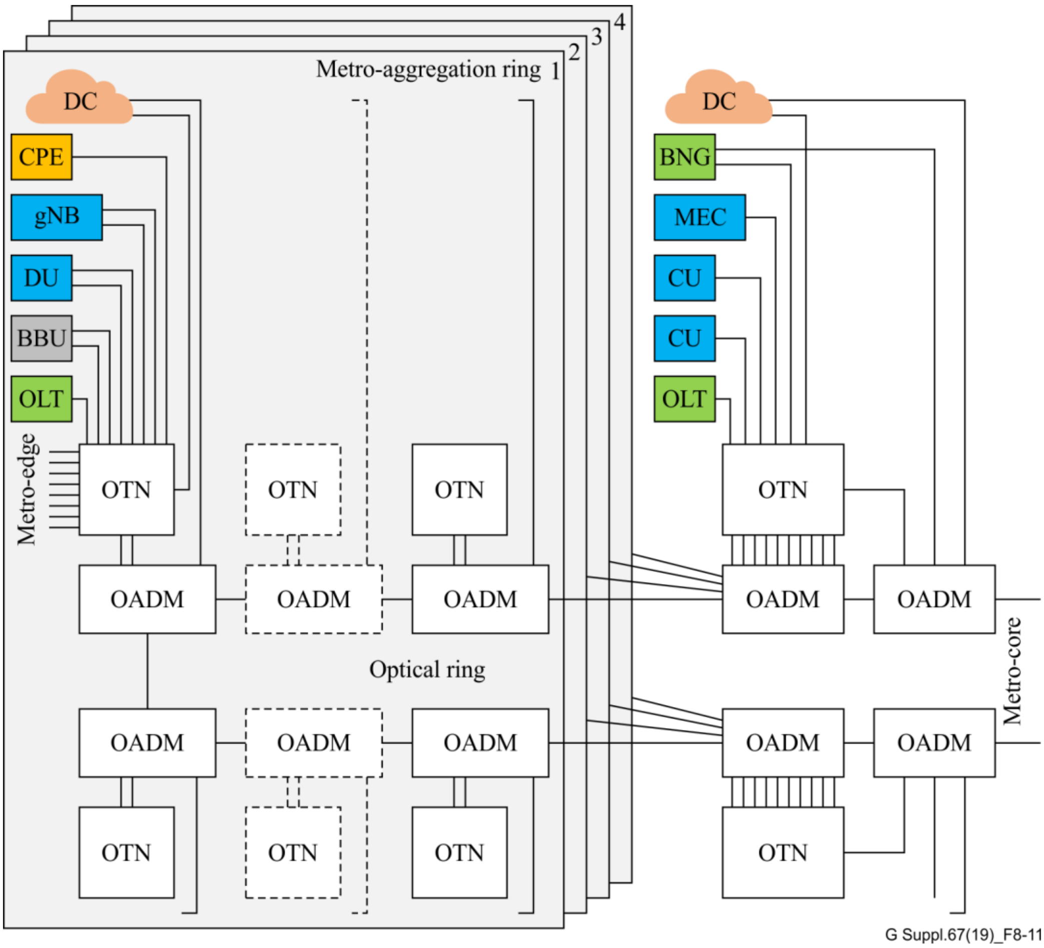

Figure 8-11 – Optical metro-aggregation network ring interconnecting a pair of OTN network elements at the boundary with the metro-core domain with 4 to 6 OTN network elements at the boundary with the metro-edge domains

8.3.3 OTN metro-edge network domain

8.3.3.1 OTN large C-RAN metro-edge network domain

The OTN large C-RAN metro-edge domain may deploy a point-to-point (p2p) optical layer network topology or an optical chain based optical layer network topology. Optical path distances between an OTN node at the boundary of metro-edge and metro-aggregation domains and an OTN node at the edge of the metro-edge domain are assumed to be between 1 and 5 km in a metropolitan area and 1 and 10 km in a rural area. The bandwidth requirements between the OTN network elements at the domain boundaries will be around 100G~200G.

For a point-to-point scenario, 100G or 200G OTN interfaces are available in the formats OTU4 as specified in [ITU-T G.709], OTUC1/FlexO-1-RS-1, OTUC2/FlexO-2-RS-1 and OTUC2/FlexO-1-RS-2 as specified in [ITU-T G.709]/[ITU-T G.709.1]. The optical tributary signal class NRZ 25G and PAM4 50G application codes 4I1-9D1F, 4L1-9C1F, 4L1-9D1F, 8R1-4D1F, 4I1-4D1F and 8I1-4D1F in [ITU-T G.959.1] are applicable.

For an optical chain scenario, Figure 8-12 shows an OTN network element at the boundary of the metro-aggregation and metro-edge domains that are connected to up to five optical large C-RAN metro-edge chains, each connected to 6 OTN network elements at the boundary of the metro-edge domains. The chain bandwidth will be in the range of 700~1000G.

100G and 200G OTN interfaces are available in the formats OTU4-SC [ITU-T G.709], [ITU-T G.709.2], OTUC1/FlexO-1-SC, OTUC2/FlexO-1-SC-2 and OTUC2/FlexO-2-DSH

[ITU-T G.709]/[ITU-T G.709.3]. The 100G and future 200G application codes in [ITU-T G.698.2] are applicable.

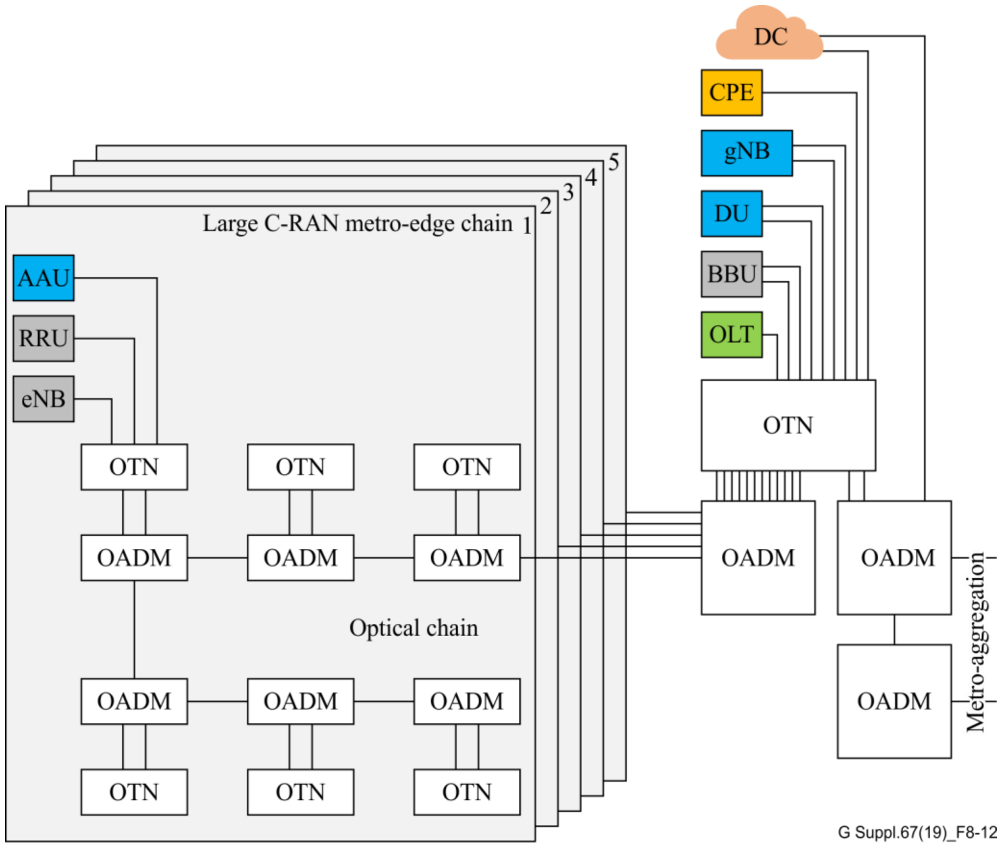

Figure 8-12 – Optical large C-RAN metro-edge chain interconnecting a pair of OTN network elements at the boundary with the metro-aggregation domain with 6 OTN network elements at the boundary of the metro-edge domain

8.3.3.2 Small C-RAN metro-edge network domain

In the small C-RAN metro-edge network domain there is no true optical layer network.

The OTN small C-RAN metro-edge domain deploys a point-to-point (p2p) optical layer network topology in which the OTN node at the metro-edge and metro-aggregation boundary is interconnected via a p2p fibre with an OTN node at the edge of the metro-edge domain (see Figure 8-13). Optical path distances are assumed to be between 1 and 5 km in a metropolitan area and 1 and 10 km in a rural area. The bandwidth requirements between the OTN network elements at the domain boundaries will be around 25G~50G.

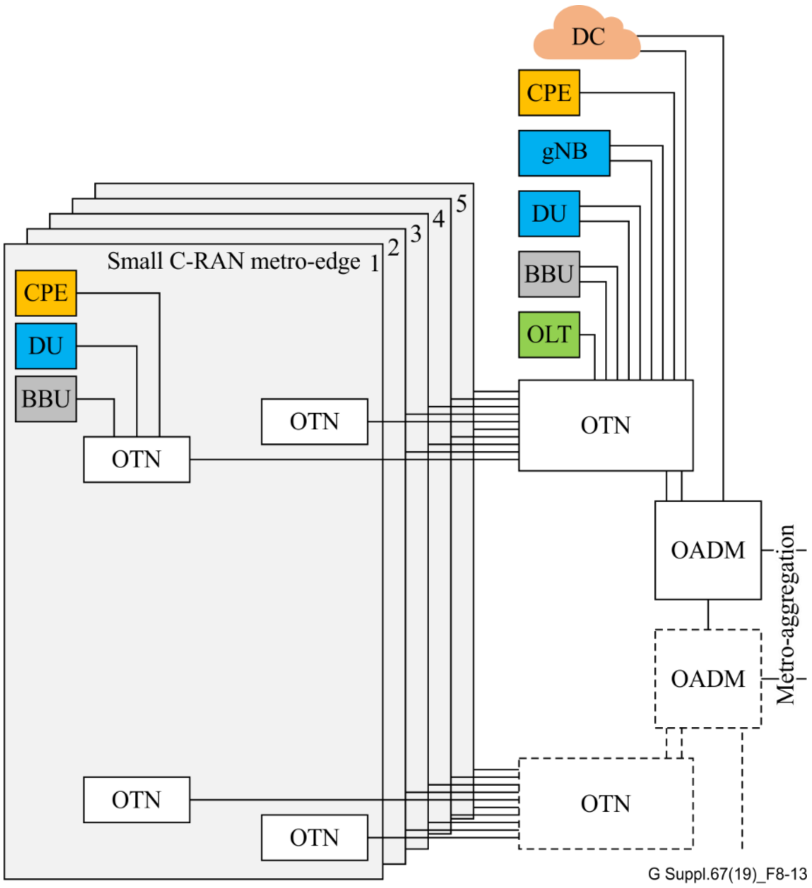

Figure 8-13 – Optical small C-RAN metro-edge fibres interconnecting a pair of OTN network elements at the boundary with the metro-aggregation domain with 3 or 4 OTN network elements at the boundary of the metro-edge domain

For this point-to-point scenario, 10G or 100G OTN interfaces are available in the formats OTU2 and OTU4 as specified in [ITU-T G.709] and OTUC1/FlexO-1-RS-1 as specified in [ITU-T G.709]/[ITU-T G.709.1]. The optical tributary signal class NRZ 10G and multichannel NRZ 25G application codes in [ITU-T G.959.1] are applicable.

Note that forthcoming projects to specify 25G and 50G OTN interfaces would provide a better fit.

8.3.3.3 D-RAN metro-edge network domain

In the D-RAN metro-edge network domain there is no true optical layer network.

The OTN D-RAN metro-edge domain deploys a point-to-point (p2p) optical layer network topology in which a pair of OTN nodes at the metro-edge and metro-aggregation boundary are interconnected via an MPLS-TP or Ethernet packet over OTN ring with OTN nodes at the edge of the D-RAN metro-edge domain (see Figure 8-14). Optical path distances between adjacent OTN nodes in this ring are assumed to be between 1 and 5 km in a metropolitan area and 1 and 10 km in a rural area. The bandwidth requirements between all OTN network elements at the domain boundary will be around 25G~50G.

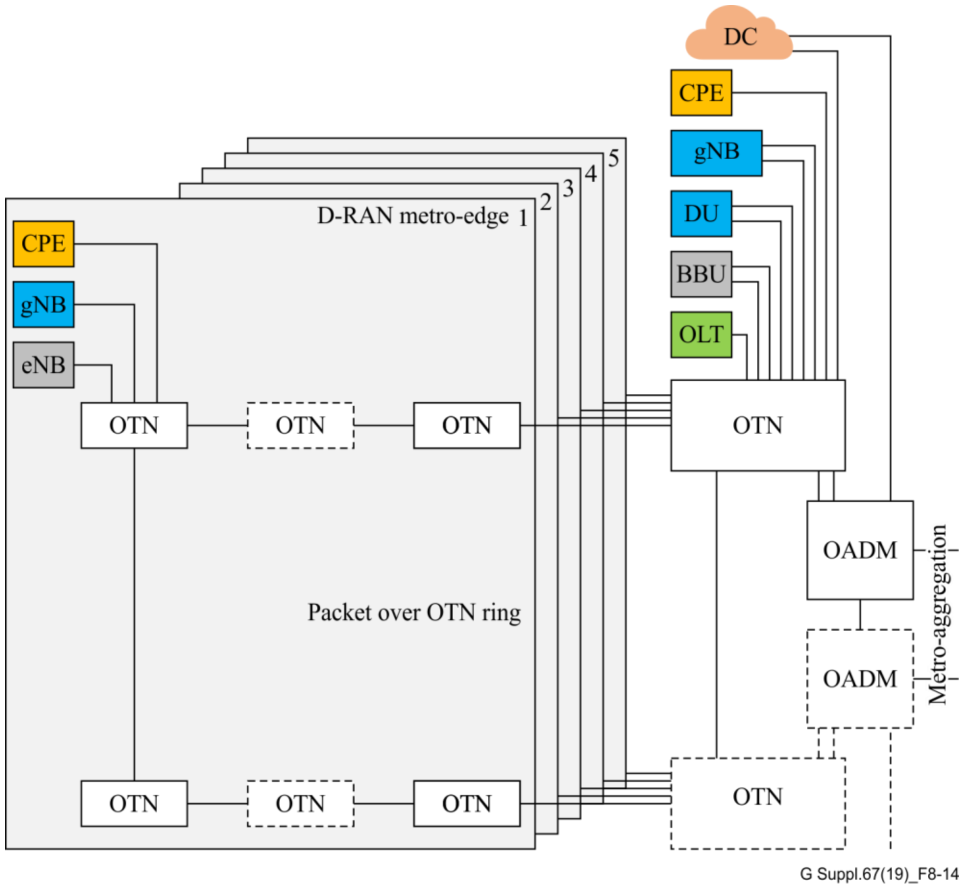

Figure 8-14 – D-RAN metro-edge packet over OTN ring interconnecting OTN network elements at the boundary with the metro-aggregation domain with 6 OTN network elements in the D-RAN metro-edge domain

For this "grey" ring scenario, 10G or 100G OTN interfaces are available in the formats OTU2 and OTU4 as specified in [ITU-T G.709] and OTUC1/FlexO-1-RS-1 as specified in [ITU-T G.709]/[ITU-T G.709.1]. The optical tributary signal class NRZ 10G and multichannel NRZ 25G application codes in [ITU-T G.959.1] are applicable.

Note that forthcoming projects to specify 25G and 50G OTN interfaces would provide a better fit.

9 Network slicing support in OTN

OTN provides network slicing support in which client layer characteristic information forwarding is performed via ODUk or ODUflex based slice tunnels and client layer switching functions that support ODUP/<client>_A functions defined in [ITU-T G.798] and <client>_C functions.

Clients include SDH VCn, Ethernet MAC/VLAN (ETH), MPLS-TP PW/LSP, etc.

10 Frequency and time synchronization in the OTN network

In the 5G OTN transport network, frequency and phase/time synchronization are needed to support requirements at the air interface of a mobile system. This section describes 5G synchronization requirements and defines the synchronization solution for the OTN transport network.

10.1 Synchronization requirement

Based on 5G mobile technology, the frequency offset at the air interface of every AAU should be less than the value in the following table, which is a copy of Table 6.5.1.2-1 of [3GPP TS 38.104].

Table 10-1 – Frequency offset requirement

BS class	Accuracy
Wide area BS	±0.05 ppm
Medium range BS	±0.1 ppm
Local area BS	±0.1 ppm

The relevant phase/time synchronization requirements are listed in Tables II.1 and II.2 of [ITU-T G.8271].

10.2 Synchronization solution for OTN transport network

For meeting frequency and phase/time synchronization requirements, the full timing support solution, which is defined in [ITU-T G.8275], should be used in the OTN transport network. This solution requires that every node between the clock server and the end application node should support the OEC, eOEC and T-BC clock.

Generally, the frequency reference server PRC/ePRC is deployed in the core network, and the phase/time server PRTC/ePRTC is deployed in the backhaul, fronthaul or midhaul network. The deployment position is limited by the number of hops from the clock server to the AAU, which is described in the HRMs of [ITU-T G.8271.1].

For the frequency synchronization solution, the OTN nodes between the PRC/ePRC and AAU shall support the OEC or eOEC physical layer clock. The OEC clock specification is defined in [ITU-T G.8262] and the eOEC specification in [ITU-T G.8262.1], and the network limit is defined in [ITU-T G.8261]. Other relevant Recommendations specify synchronization layer functions ([ITU-T G.781]), the SSM/eSSM message format ([ITU-T G.7041]), and SSM/eSSM message channel defined in [ITU-T G.709] and the [ITU-T G.709.x] series.

For the phase/time synchronization solution, the OTN nodes between the PRTC/ePRTC and AAU shall support the T-BC PTP layer clock. The clock specification is [ITU-T G.8273.2], and the network limit is defined in [ITU-T G.8271.1]. Other relevant Recommendations specify the PTP full timing support profile (G.8275.1), the PTP message format ([ITU-T G.7041]), and PTP message channel defined in [ITU-T G.709] and the [ITU-T G.709.x] series. The 1PPS phase and time synchronization interface is defined in [ITU-T G.8271].

NOTE – OTN optical layer nodes and without optical protection/restoration are not required to support the OEC, eOEC or T-BC. This is because these nodes do not affect the accuracy of the OTN synchronization network.

11 Survivability techniques in OTN networks to support 5G

The [ITU-T G.873.x] series of Recommendations provide a number of protection options for OTN:

– [ITU-T G.873.1] defines linear subnetwork connection protection for the ODU layer, and also includes appendices describing linear protection for OTS and OMS maintenance entities, individual OTSi, and SNC/I protection for client signals of OTN.

– [ITU-T G.873.2] defines shared ring protection at the ODU layer.

– [ITU-T G.873.3] defines shared mesh protection at the ODU layer.

While any of these mechanisms could be used in any part of the 5G network, it is anticipated that the transport network for fronthaul will either be unprotected (any required redundancy would be provided in the wireless network) or use bidirectional linear SNC/N protection, while the transport network for midhaul and backhaul will be protected using linear protection in either the optical or ODU layer, shared ring protection, or shared mesh protection, depending on the network topology and the amount of resources the operator is willing to deploy for protection.

12 Conclusion

In conclusion to this analysis, OTN provides capabilities such as interfaces, OAM, survivability and synchronization applicable to transport 5G, and in addition is fully ready today to do so.

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Printed in Switzerland
Geneva, 2019