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5G Wireless Backhaul/X-Haul

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Keywords

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Foreword

This Group Report (GR) has been produced by ETSI Industry Specification Group (ISG) millimetre Wave Transmission (mWT).

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Executive summary

Mobile communication technology is evolving at rapid pace towards its fifth generation, namely 5G, deployment phase, which aims to develop new business opportunities related to enhanced Mobile Broadband, Ultra-Reliable and Low Latency Communications and massive Machine-Type Communications. New radio access network architecture trends, aiming at higher network efficiency and improved service delivery, are also discussed within the scope of 5G. In parallel, it is expected that 5G deployments will be characterized by increased network density, mainly driven by small-cells implementations.

In order to support the aforementioned 5G targets, there is a need to push the envelope of performance in various network segments, including backhaul, as it is part of the end-to-end 5G network architecture. Figure 1 depicts how 5G will impact wireless backhaul/X-Haul networks (X-Haul is a newly-coined term to describe the evolved transport interface resulting from different RAN split options, hence it will be used throughout the present document). For instance, higher capacity (even more Mbps at existing hop lengths), lower latency, improved spectral efficiency, highly-accurate synchronization, advanced networking functionalities and network automation, are discussed for 5G wireless backhaul/X-Haul networks.

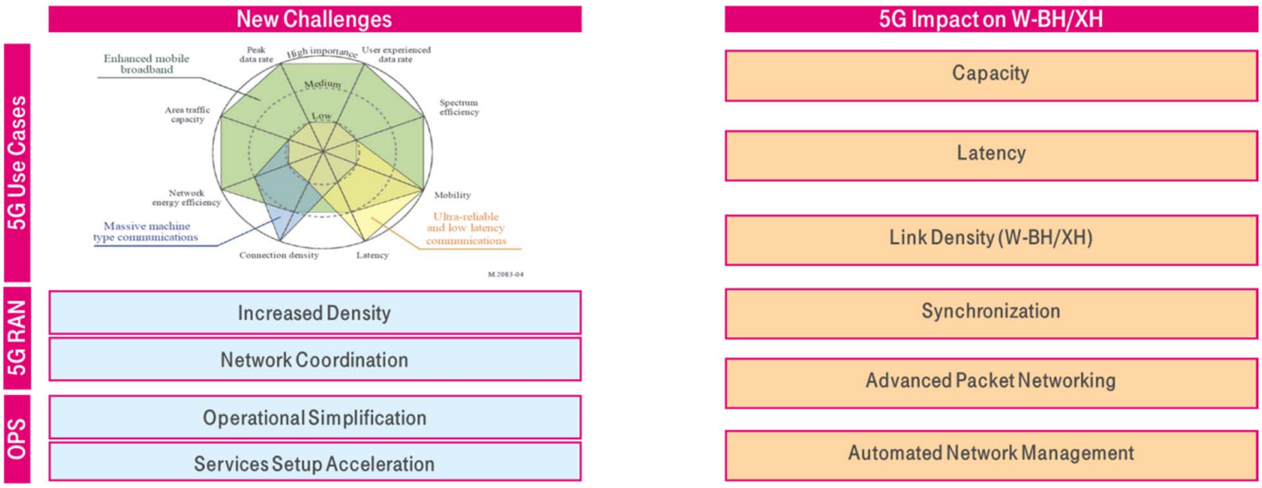

Figure 1: 5G Impact on W-BH/XH Network

The present document presents the important 5G wireless backhaul/X-Haul scenarios focusing on their critical requirements. Specifically, areas of deployment and network topologies, data rates, latency, hop lengths and networking functionalities are discussed. The report draws attention to the fact that next-generation backhaul/X-Haul applications will be more relevant within a mid/long-term time horizon, namely from around 2020 and beyond, additionally innovations in microwave and millimetre wave technologies that are anticipated over the next few years have also been taken into consideration. Topics related to regulation and licensing are discussed.

The present document shows that microwave and millimetre wave transmission technologies are going to continue to play a pivotal role in the 5G era as they will be fundamental pillars of service providers' network development strategy to address the future 5G demands. This view is also strengthened due to the inherent benefits of wireless backhaul/X-Haul with regard to:

- Performance
- Ease of deployment
- Fast time-to-market
- Cost efficiency

Consequently, key recommendations discussed include:

- **Technology Innovations:** More backhaul spectrum and bandwidth, band and carrier aggregation, LOS MIMO/OAM (Orbital Angular Momentum) plus XPIC, advanced interference cancellation techniques, higher directivity and smart antennas solutions, SDN automation, etc. (see clauses 6.2, 6.3, 6.4 and 6.5).
- **Regulation and Licensing:** Apply regulatory policies and costs in-line with the use cases' requirements (see clause 7).

Introduction

Today wireless backhaul technologies serve more than 50 % of the total mobile backhaul connections worldwide and they are apparently key solutions to address demands of mobile access networks at fast pace and in an economical way. In fact, the key benefits of wireless transmission (backhaul) technologies as enablers for LTE-A as well as for other fixed broadband applications and use cases have been analysed and provided in ETSI GS mWT 002 [i.1]. However, significant changes and progress has been observed since then in different areas, including applications and network requirements, technology capabilities, regulatory and standardization matters.

The 5G use cases categories (eMBB, URLLC, mMTC) that are under discussion present extremely diverse requirements and from network design perspective all of them will be served by the same network infrastructure. Consequently, future backhaul/X-Haul architecture will need to ensure that all "conflicting" targets are satisfied and blend well with each other.

Further on, 5G RAN architecture will need to be highly flexible, which could be enabled by splitting RAN functions. As a result, new X-Haul interfaces are being discussed in SDOs and in related industry activities (e.g. in 3GPP, xRAN, IEEE 1914, TIP, etc.) to allow less stringent transport demands, in terms of capacity and latency, when compared to typical fronthaul (e.g. CPRI), whilst still accomplishing high performance and optimum use of radio access resources.

Moreover, it is foreseen that ultra-dense radio access networks will be built to increase end customers QoE and this is depicted in the 5G area traffic capacity target of reaching 10 Mbps per m2. By this regard, a new backhaul layer, namely small-cell backhaul, is expected to grow massively over the next few years. Naturally, such a network development will impose additional challenges, so efficient technologies, supporting easy roll-out approach, are targeted.

Considering the above points, it is of paramount importance for industry's stakeholders to prepare the ground for the new backhaul/X-Haul architecture. To this end, wireless backhaul/X-Haul technologies, namely covering V-band (60 GHz), E-band (70/80 GHz), in future W-band (100 GHz) and D-band (150 GHz) as well as critical traditional microwave bands, will be solution enablers to achieve radical enhancement of existing use cases and to develop emerging use cases that today are not possible on existing networks.

The present document represents an evolution of the ETSI mWT ISG "Microwave and Millimetre-wave for 5G Transport" white paper [i.2].

1 Scope

The present document provides information about the prominent 5G wireless backhaul/X-Haul scenarios. In addition, it shows how current microwave and millimetre wave transmission technologies as well as their foreseen evolution, in the pertinent areas of innovation, are going to satisfy upcoming 5G access requirements. Moreover, it points out the importance of the appropriate regulation and licensing to ease 5G wireless backhaul/X-Haul deployments.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] ETSI GS mWT 002 (V1.1.1) (08-2015): "millimetre Wave Transmission (mWT); Applications and use cases of millimetre wave transmission".

[i.2] ETSI ISG mWT White Paper No. 25 (First edition, 02-2018): "Microwave and Millimetre-wave for 5G Transport".

NOTE: Available at http://www.etsi.org/images/files/ETSIWhitePapers/etsi_wp25_mwt_and_5g_FINAL.pdf.

[i.3] Recommendation ITU-R M.2083-0 (09-2015): "IMT Vision - Framework and overall objectives of the future development of IMT for 2020 and beyond".

[i.4] ETSI TR 138 913 (V14.3.0) (10-2017): "5G; Study on scenarios and requirements for next generation access technologies (3GPP TR 38.913 version 14.3.0 Release 14)".

[i.5] NGMN (V1.0) (24th February 2018): "NGMN Overview on 5G RAN Functional Decomposition".

[i.6] 3GPP TR 38.801 (V14.0.0) (03-2017): "3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Study on new radio access technology: Radio access architecture and interfaces (Release 14)".

[i.7] ETSI GR mWT 015 (V1.1.1) (11-2017): "Frequency Bands and Carrier Aggregation Systems; Band and Carrier Aggregation".

[i.8] ETSI GR mWT 008 (V1.1.1) (08-2018): "millimetre Wave Transmission (mWT); Analysis of Spectrum, License Schemes and Network Scenarios in the D-band".

[i.9] ETSI GR mWT 016 (V1.1.1) (07-2017): "Applications and use cases of Software Defined Networking (SDN) as related to microwave and millimetre wave transmission".

[i.10] IEEE Std 802.11ad-2012 (Amendment to IEEE Std 802.11-2012, as amended by IEEE Std 802.11ae-2012 and IEEE Std 802.11aa-2012): "IEEE Standard for Information technology--Telecommunications and information exchange between systems--Local and metropolitan area networks--Specific requirements-Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amendment 3: Enhancements for Very High Throughput in the 60 GHz Band".

3 Definition of terms and abbreviations

3.1 Terms

For the purposes of the present document, the following terms apply:

DU-bb: Baseband of Distribution Unit

gNB: radio access node which supports the NR

3.2 Abbreviations

For the purposes of the present document, the following abbreviations apply:

3GPP	3rd Generation Partnership Project
4G	4th Generation of Mobile Networks
5G	5th Generation of Mobile Networks
BBU	Baseband Unit
BCA	Band and Carrier Aggregation
BH	Backhaul
BW	Bandwidth
CPRI	Common Public Radio Interface
C-RAN	Centralized RAN
CS	Circuit-Switched
CU	Centralized Unit
DL	Downlink
D-RAN	Distributed RAN
DU	Distributed Unit
eCPRI	enhanced CPRI
eMBB	enhanced Mobile Broadband
EPC	Evolved Packet Core
FDD	Frequency Division Duplex
GSM	Global System for Mobile communications
HLS	High Layer Split
IEEE	Institute of Electrical and Electronics Engineers
ISG	Industry Specification Group
ITU	International Telecommunication Union
LLS	Low Layer Split
LOS	Line Of Sight
LTE	Long Term Evolution
LTE-A	LTE-Advanced
MEC	Multi-access Edge Computing
MIMO	Multiple Input Multiple Output
mmW	millimetre Wave
mMTC	massive Machine-Type Communications
MPLS	Multi-Protocol Label Switching
MW	Microwave
NG	Next Generation
NGC	Next Generation Core
nLOS	near LOS
NLOS	Non-LOS
nRT	non Real-Time
NR	New Radio
OAM	Orbital Angular Momentum
OPS	Operations
PoP	Point of Presence
PtP	Point-to-Point
PtMP	Point-to-MultiPoint
QoE	Quality of Experience

RAN	Radio Access Network
RF	Radio Frequency
RRU	Remote Radio Unit
RT	Real-Time
RTT	Round-Trip Time
RU	Radio Unit
SDN	Software-Defined Networking
SDO	Standard Defining Organization
SLA	Service-Level Agreement
TDD	Time Division Duplex
TIP	Telecom Infrastructure Project
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunications System
UPF	User Plane Functions
URLLC	Ultra-Reliable and Low Latency Communications
W-BH/XH	Wireless Backhaul/X-Haul
XH	X-Haul
XPIC	Cross Polarization Interference Cancellation

4 5G Access Network Overview

4.1 Moving From 4G To 5G Technology

Nowadays, the deployed LTE macro cell access sites are typically rooftop (or tower) sites consisting of three (3) sectors, each one having at least two frequency layers with 20 MHz BW channels and 2x2 MIMO configuration. GSM and UMTS radio access technologies complete the site configuration, in order to support CS voice services and the typical backhaul capacity provisioning can reach up to 1 Gbps per site.

The advent of 5G technologies will improve user experience and it will increase network performance significantly. Figure 2 illustrates the enhancement of key capabilities from IMT-Advanced towards IMT-2020 based on Recommendation ITU-R M.2083-0 [i.3].

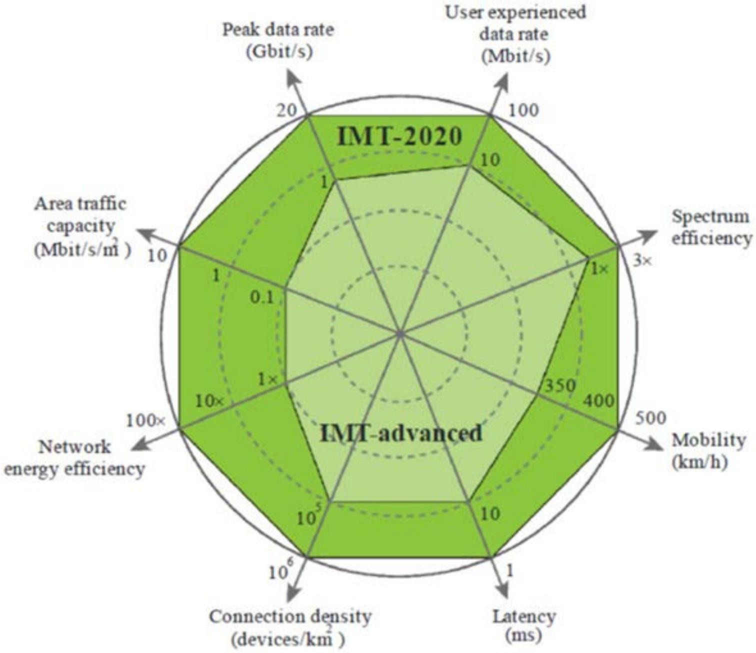

Figure 2: From IMT-Advanced to IMT-2020

In 5G a new radio interface (NR) will be introduced, where the use of more bandwidth at higher frequency bands (e.g. around 4 GHz, around 30 GHz, etc.) can be available, whilst a higher number of antenna ports and MIMO layers can be supported by the future radio access technology. Specifically, according to ETSI TR 138 913 [i.4], the 5G NR can support up to 1 GHz system bandwidth and up to 256 Tx and Rx antenna elements.

Typically, different configurations of mobile sites are implemented per area of deployment. This aspect relates to the most suitable access spectrum, the number of MIMO layers, even to the type of installed radio access nodes; for instance, outdoor small cells are more likely to be implemented as hot-spots in highly populated areas. More, transmission distances to be addressed and the number of hops to the nearest fiber-enabled PoP differ per area. In the following clauses, scenarios with regard to dense *urban, urban, sub-urban, semi-rural and rural areas* are examined.

As with the previous 3GPP generations, it is predicted that service providers will start with an early stage of deployment and they will progressively move towards long-term maturity, hence *mobile access sites are going to be gradually upgraded to 5G configurations that will appear in different flavours and iterations of standards*. This view refers not only to the number of installed 5G sites, but also how advanced each 5G configuration will be over time. For example, more capacity demanding configurations could be part of later deployments due to higher bands (> 6 GHz) spectrum availability. For this reason, the terms of 5G "Early Stage" and "Mature Stage" are used later in the document.

4.2 5G Radio Access Configurations

Apart from the foreseen benefits, the future 5G radio access configurations will obviously have major impact on the 5G backhaul/X-Haul networks. Radio access configuration for 5G is dependent on a number of critical parameters, including:

- market requirements and use cases
- technology capabilities and availability
- standardization development
- regulatory and spectrum issues
- areas of deployment and network infrastructure readiness

Table 1 presents indicative sites configurations based on ETSI TR 138 913 [i.4] and as per ETSI mWT ISG view.

Table 1: 5G Access Sites Configurations

Area Type	Sites Configurations (indicative)	Cell Type
Dense Urban ('DU')	• LTE 50-100 MHz (Macro-cell) • NR 100 MHz 16L MIMO ~4 GHz (Macro-cell) • NR 100 MHz 4L MIMO ~4 GHz (Small-cell) • NR ≤ 800 MHz 4L MIMO ~30 GHz	• Macro-cell • Small-cell
Urban ('U')	• LTE 50-100 MHz • NR 100 MHz 16L MIMO ~4 GHz • NR ≤ 800 MHz 4L MIMO ~30 GHz	• Macro-cell
Sub-Urban ('SU') Semi-Rural ('SR')	• LTE 50-100 MHz • NR 100 MHz 8L MIMO ~4 GHz	• Macro-cell
Rural ('R')	• LTE 50-100 MHz • NR 50 MHz 4L MIMO ~2 GHz • NR 20 MHz 4L MIMO ~700 MHz	• Macro-cell

It is assumed that each macro-cell site consists of three (3) sectors, serving 5G and 4G services, whilst small-cells, namely, outdoor pico-cell sites, are assumed as 5G NR only single-sector radio access nodes. It is also worthwhile to indicate the 5G bandwidth as being mostly unpaired for TDD operation as opposed to the LTE case, where spectrum is usually paired (FDD operation).

4.3 5G RAN Architecture Options

Development of 5G RAN network architecture can follow different paths in future as a "cloud concept" gains increasing traction in the standardization organizations and in the industry [i.5]. Today, the vast majority of macro mobile access deployments is based on distributed architecture, nonetheless, as per 3GPP TR 38.801 [i.6], the functional split between CU and DU (figure 3) is discussed.

Specifically:

- Option 2: HLS, assumed to be in the F1 interface between CU and DU
- Option 7: LLS, assumed to be in the F2 interface between DU-bb and (Remote)RU and eCPRI (inside of which three possible inner splits are considered, two for downlink and one for uplink)

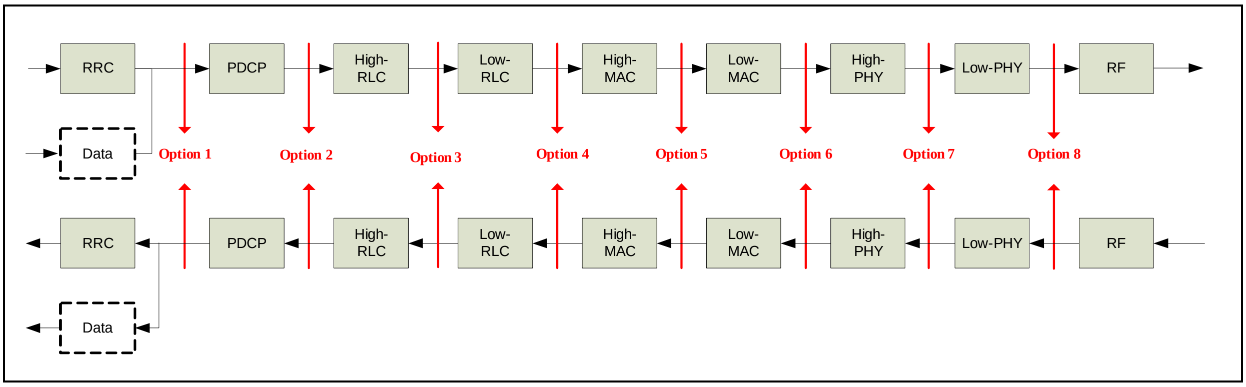

Figure 3: 3GPP Function Split Options

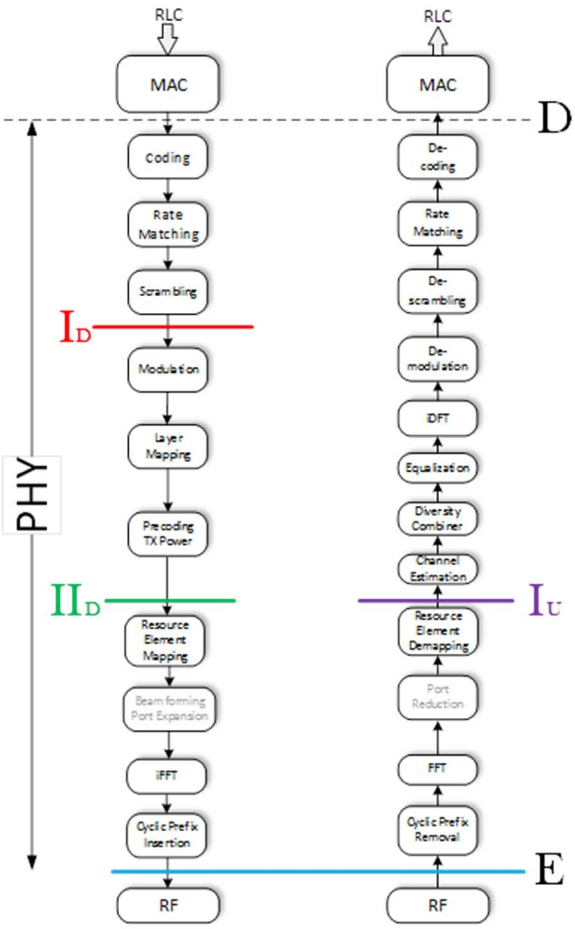

Figure 4: eCPRI Inner Splits

Furthermore, figure 5 shows a high-level overview of backhaul and Centralized RAN (High-Layer and Low-Layer Split) architectural options that can co-exist network-wide. In the typical D-RAN architecture, each gNB is located at the RF site and it is connected to the radio core (EPC, NGC) via S1/NG interfaces. Alternatively, C-RAN architecture discusses the decomposition of conventional RAN functions. For instance, by disaggregating gNB functions, two new RAN entities appear, CU and DU. In order to enable optimal radio network coordination and to realize the benefits of virtualisation, CU is targeted to be placed in a (more) central location, whilst DU could remain at the RF site (HLS option) or could be also moved to a more central location (LLS option), e.g. co-located with CU (DU-bb). As stated above, new X-Haul interfaces between CU and DU (i.e. F1 HLS) and between DU-bb and (R)RU (i.e. F2 LLS) are under discussion, whilst S1/NG interfaces are still employed for the connection between CU and core network.

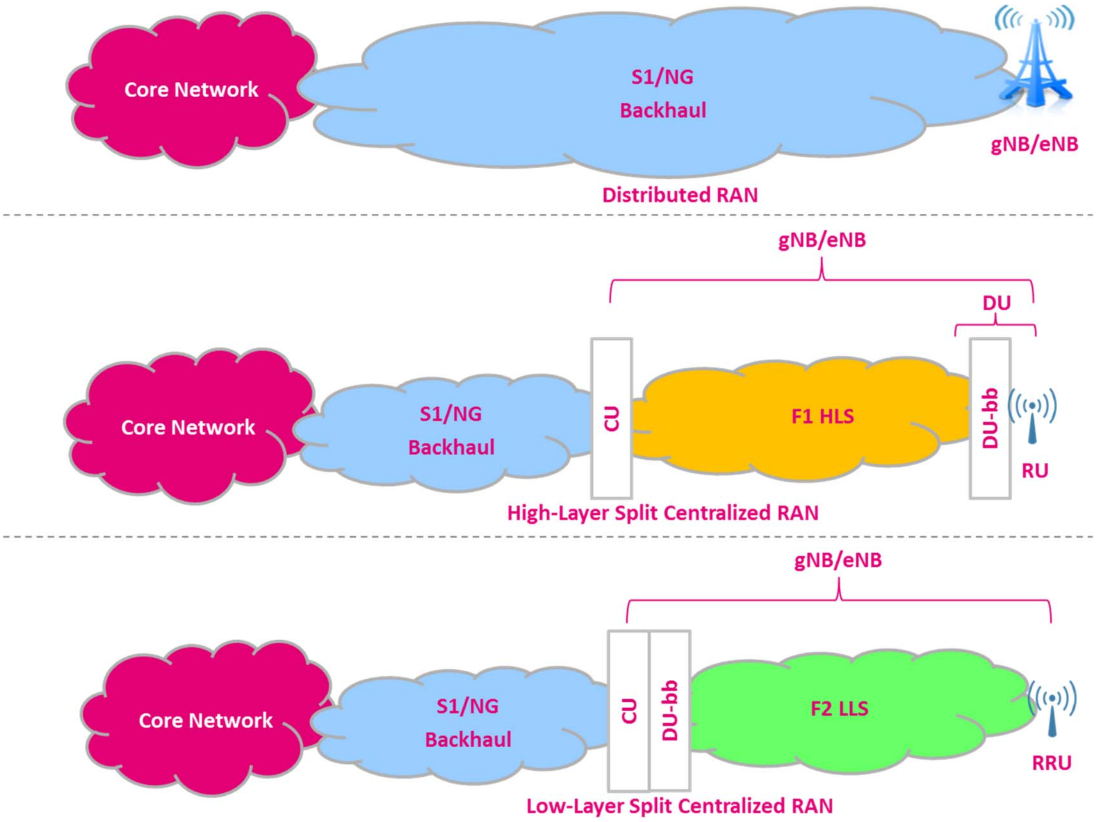

Figure 5: Distributed and Centralized RAN Architectures

Depending on the layer of the functional split, the new X-Haul interfaces have different requirements in terms of capacity and latency. As the splits move away from the RF split as per the legacy CPRI (i.e. option 8 per 3GPP, E in eCPRI), the requirements become less stringent. As an example, a split approach could be HLS, where the Layer 3 functions and the nRT Layer 2 functions of the BBU are placed in the CU entity and separated from the lower layer functions (RT Layer L2, Layer 1) that are kept within the DU entity.

The present document concentrates on HLS interface Option 2 in-line with 3GPP primary focus (Release 15). LLS requirements are left for later releases of this report due to the absence of consensus on the specific functional split by the industry. *Note that traditional backhaul and F1-based X-Haul (namely, Option 2 HLS) present equivalent capacity and latency requirements.*

5 Wireless Backhaul/X-Haul Network Overview

5.1 Backhaul/X-Haul Network Topologies

Mobile backhaul network topologies generally evolve over time with the aim of optimizing overall network capacity and latency performance. The densification of radio access network and increased fiber penetration, which reaches closer to the access network are the on-going trends. Such factors result in a growth in the number of radio links and a transformation from daisy-chain (relay) connections to star network topologies with shortened backhaul chains, as illustrated in figure 6.

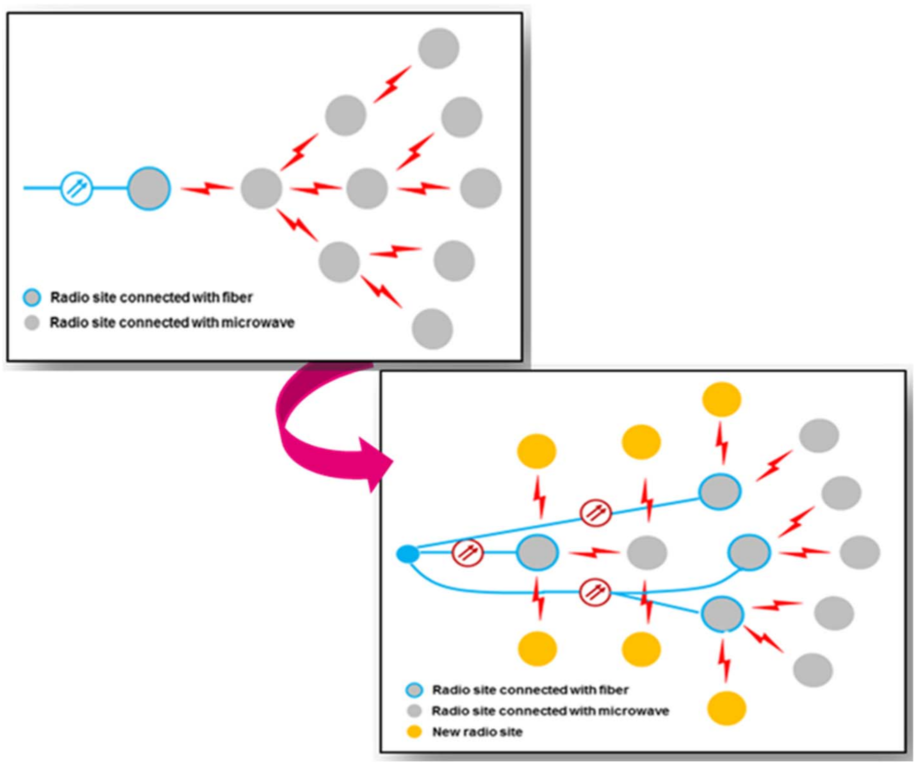

Figure 6: Macro-Cell Backhaul Network Topologies Shift

The distance of the wireless backhaul link from its nearest fiber PoP site differs per area of deployment and this situation usually varies across different networks. For the sake of simplicity, the following practical assumptions are taken into account when classifying deployment scenarios:

- **Dense Urban/Urban Areas:** A single-hop distance from the closest fiber PoP site.
- **Sub-Urban/Semi-Rural Areas:** Up to two-hop distance from the closest fiber PoP site.
- **Rural Areas:** Up to three-hop distance from the closest fiber PoP site.

Since each hop carries traffic closer to the fiber site, it is conventionally assumed that each hop enters into an area, which is denser (in terms of mobile sites) than the previous one.

Moreover, the radio propagation conditions are different between macro-cell and small-cell deployment layers. Whilst the LOS connectivity is generally preferred which can be largely achieved for macro-cell backhaul, this cannot be guaranteed for small cell backhaul use cases. Small cells, namely outdoor operator-managed pico-cells, could be installed at a relatively low height above ground (for example, up to 6 m height) and placed at lampposts, outside building walls, etc. In such a use case, clear LOS conditions are not easily found from respective fiber-enabled PoP sites due to existing obstacles (e.g. signposts) or even new ones after the installation (e.g. tree foliage), whereas moving vehicles could dynamically disrupt a working link. The particularity of the street-level transmission leads to the need of employing technologies with automation at radio level, namely dynamic beam-steering/beam-forming/null-forming and potentially nLOS/NLOS capabilities that could further assist to establish a wireless link during installation and even optimizing it during operation.

In addition, macro-cell wireless backhaul is generally implemented by PtP links, however the restricted space at street furniture to install small-cell backhaul/X-Haul equipment make PtMP/mesh connectivity an attractive solution, since it reduces equipment count as well as related costs. Further on, the target for increased network availability in the RAN can also be satisfied when mesh topologies are supported by the wireless technology at RF level and higher layers, as well. Figure 7 depicts street-level transmission use cases for small-cell wireless backhaul/X-Haul application.

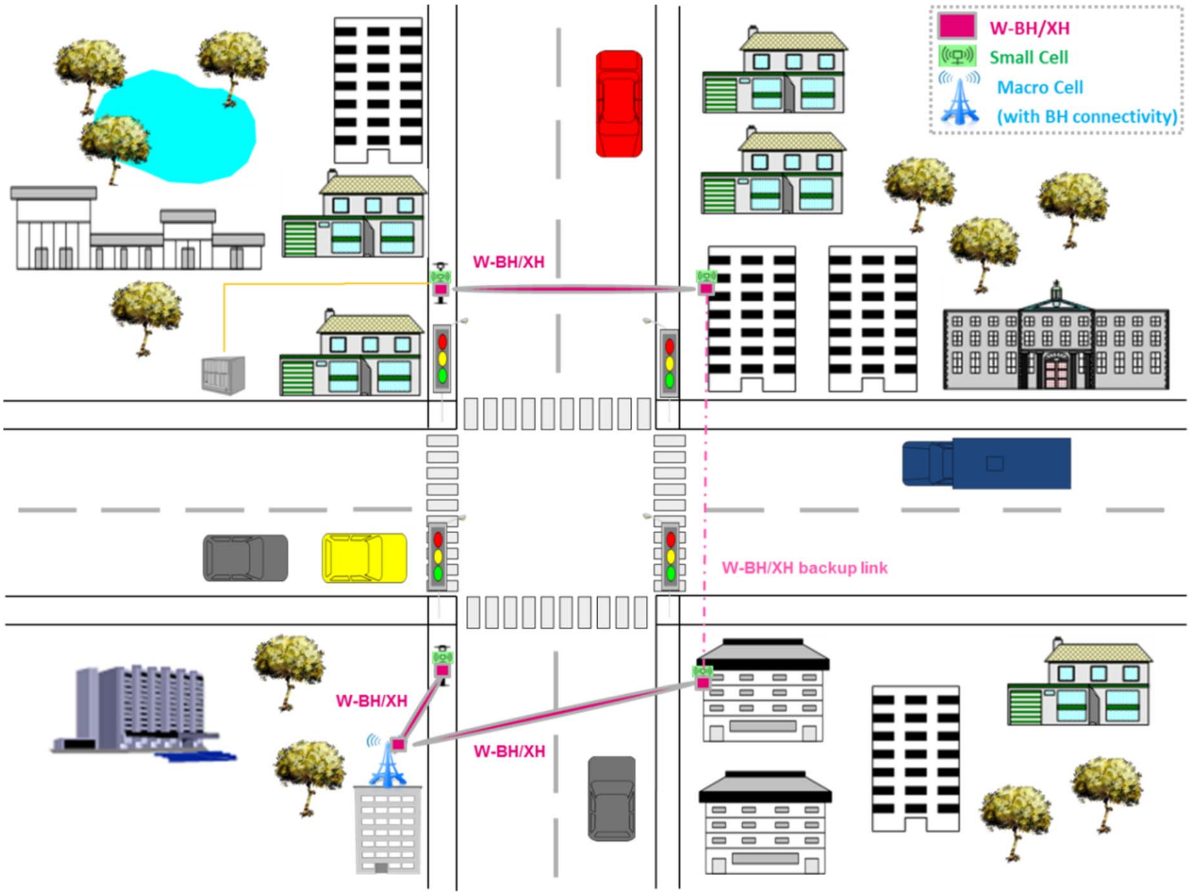

Figure 7: Small-Cell Backhaul/X-Haul Network Topologies

Table 2 summarizes the wireless backhaul/X-Haul topologies according to the network access layer, namely macro-cell layer and small-cell layer.

Table 2: Network Topologies Summary

Network Access Layer	Wireless Backhaul/X-Haul Network Topologies
Macro-cell	Star (mainly)/ chain
Small-cell	PtMP/mesh

5.2 Backhaul/X-Haul Capacity Requirements

The calculation of the backhaul capacity is provided in table 3 and by taking into account the information provided in table 1. Specifically, it is shown the foreseen backhaul capacity requirements per area and stage of deployment for tail links and for (pre-)aggregation sites, once 5G access configurations are introduced ("Early Stage") and onwards ("Mature Stage").

Table 3: Backhaul/X-Haul Capacity Requirements

Area Type	Sites Configurations	Cell Type	Tail Link Capacity Requirements: 5G "Early Stage"	Tail Link Capacity Requirements: 5G "Mature Stage"	Access (Pre-)Aggregation Capacity Requirements
Dense Urban ('DU')	• LTE 50-100 MHz (Macro-cell) • NR 100 MHz 16L MIMO ~4 GHz (Macro-cell) • NR 100 MHz 4L MIMO ~4 GHz (Small-cell) • NR ≤800 MHz 4L MIMO ~30 GHz	• Macro-cell • Small-cell	< 5 Gbps	Mix of 5-10 Gbps & ≥ 10 Gbps sites	- (single-hop)
Urban ('U')	• LTE 50-100 MHz • NR 100 MHz 16L MIMO ~4 GHz • NR ≤ 800 MHz 4L MIMO ~30 GHz	• Macro-cell			
Sub-Urban ('SU') Semi-Rural ('SR')	• LTE 50-100 MHz • NR 100 MHz 8L MIMO ~4 GHz	• Macro-cell	< 3 Gbps	< 5 Gbps	< 10 Gbps (2nd hop 'U')
Rural ('R')	• LTE 50-100 MHz • NR 50 MHz 4L MIMO ~2 GHz • NR 20 MHz 4L MIMO ~700 MHz	• Macro-cell	< 2 Gbps	< 3 Gbps	< 5 Gbps (2nd hop 'SU') | < 10 Gbps (3rd hop 'U')

It is further assumed that macro-sites consist of 4G access technology adding at least 1 Gbps of backhaul capacity requirement per site, whilst small-cells (outdoor capacity hot-spots) support 5G NR only. The capacity impact of any co-located 2G/3G traffic is considered as negligible.

Last, but not least, it is estimated that the above capacity figures also address the X-Haul requirements based on F1 (HLS) interface.

5.3 Backhaul Spectrum

Spectrum is a vital asset to support the mobile backhaul requirements and certainly this topic becomes increasingly relevant as future mobile access data rates and respective backhaul capacity requirements continue to rise. Various frequency bands are used today for mobile backhaul depending on the requested capacity, hop length, link availability, spectrum availability and frequency re-use capability. The spectrum that is available for mobile backhaul ranges from the traditional microwave bands up to the millimetre wave spectrum (figure 8).

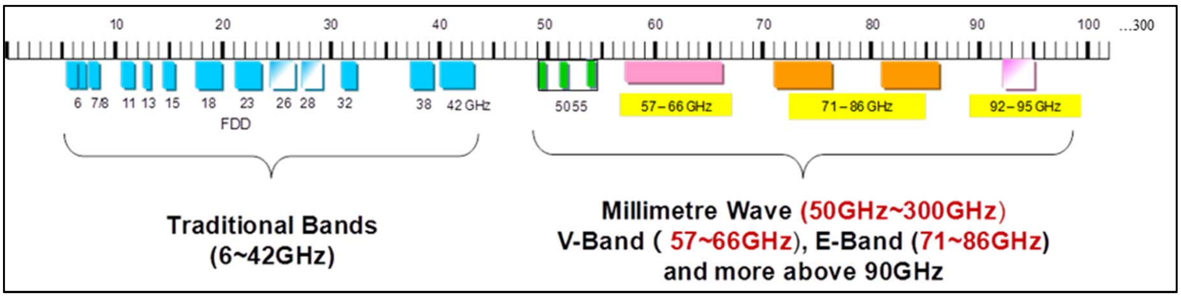

Figure 8: Microwave and Millimetre Wave Spectrum

Specifically, most of the wireless backhaul connections exist in the frequency bands 6-23 GHz and 32/38 GHz with a continuously growing number of E-band links, especially due to LTE/LTE-A macro-cell deployments. Table 4 presents an overview of the wireless backhaul spectrum providing information on:

- the total available bandwidth and the maximum channel size *(can vary per region);*
- the typical area of deployment in single-carrier and band and carrier aggregation arrangements;
- which bands are candidate for 5G access technologies, emphasizing also on those who receive the primary attention.

Table 4: Wireless Backhaul Spectrum Overview

Spectrum	Candidate 5G Access Bands	Frequency Band	Total BW	Max Channel Size	Areas of Deployment (Typical)	
					Single Carrier	BCA (Higher frequency indicated below)
MW		L6 GHz	533.7 MHz	29.65 MHz	Rural	
		U6 GHz	640 MHz	40 MHz	Rural	
		L7 GHz	238 MHz	28 MHz	Rural	
		U7 GHz	224 MHz	56 MHz	Rural	
		L8 GHz	533.7 MHz	29.65 MHz	Rural	
		U8 GHz	168 MHz	28 MHz	Rural	
		11 GHz	960 MHz	40 MHz	Rural	
		13 GHz	448 MHz	56 MHz	Rural	
		15 GHz	336 MHz	56 MHz	Sub-Urban/Semi-Rural/Rural	
		18 GHz	1,870 MHz	110 MHz	Sub-Urban	Semi-Rural/Rural
		23 GHz	1,008 MHz	112 MHz	Urban/Sub-Urban	Semi-Rural/Rural
	WRC-19 (EU pioneer band) (initial attention)	26 GHz	1,736 MHz	112 MHz	Urban	
	US (initial attention)	28 GHz	1,750 MHz	112 MHz	Urban	Sub-Urban/Rural
	WRC-19	32 GHz	1,484 MHz	112 MHz	Urban	Sub-Urban/Rural
	WRC-19 (initial attention)	38 GHz	2,240 MHz	112 MHz	Urban	
	WRC-19 (initial attention)	42 GHz	3 GHz	224 MHz	Urban	
mmW	WRC-19 (w.r.t. 66-71 GHz)	V-band (57-66 GHz CEPT) (57-71 GHz FCC)	9 GHz (CEPT) 14 GHz (FCC)	nx50 MHz (*2.16GHz WiGig)	Dense Urban / Urban	
	WRC-19	E-band (70/80 GHz)	10 GHz	nx250 MHz	Dense Urban / Urban	Sub-Urban
		**W-band (92-114.25 GHz)	12 GHz	nx250 MHz	Dense Urban / Urban	
		**D-band (130-174.8 GHz)	32 GHz	nx250 MHz	Dense Urban / Urban	

As a further remark, channel sizes of V-band spectrum could change to 2,16 GHz(*) in case multi-gigabit wireless systems based on IEEE 802.11ad/ay standards [i.10] are allowed for outdoor fixed installation usage, whilst D-band and W-band are new bands to be regulated at national level(**).

Based on table 3 and table 4, it is well understood that wireless backhaul network will need to rely in future on:

- Millimetre wave bands that offer abundant amount of bandwidth, namely *E-band (70/80 GHz), D-band (150 GHz), W-band (100 GHz) and V-band (60 GHz).*
- Medium microwave bands that can provide wider channels (at least 112 MHz), namely, *18 GHz, 23 GHz, 32 GHz and 38 GHz frequency bands.*
- Long-range microwave bands for distant links and carrier-grade link availability, namely, *6 GHz, 7 GHz, 8 GHz, 11 GHz, 13 GHz and 15 GHz frequency bands.*
- *BCA implementations*, namely, the right combination of a higher and a lower frequency band in a single logical link to enjoy the best of the both worlds, in terms of capacity, latency, reach (hop length) and availability.

6 Wireless Backhaul/X-Haul Technologies

6.1 Backhaul/X-Haul Technologies Landscape

Wireless backhaul technologies have already manifested major advancements related to critical performance areas of radio capacity and latency. Data rates of up to 10 Gbps have been exhibited in the millimetre wave bands, whilst the increase of data rates has also brought significant reductions at the respective latency figures. In addition, the first band and carrier aggregation implementations have been realized by combining MW and mmW bands. Table 5 depicts current typical radio capacity and latency performance of MW and mmW technologies and how they are compared to the backhaul capacity figures of 5G "Early Stage".

Table 5: Wireless Backhaul Technologies Overview

Backhaul Technology	Configuration (indicative)	Backhaul Capacity (typical)	Backhaul Latency One-Way (typical)	5G "Early Stage" (as per table 3)	Cell Type	Area
6-15 GHz	4+0 56 MHz or 2+0 XPIC 56 MHz	2 Gbps	< 250 us	< 2 Gbps	Macro-cell	Rural
18-42 GHz	BCA MW 56 MHz + E-band 500 MHz	3,7 Gbps	< 250 us	< 3 Gbps	Macro-cell	Sub-Urban/ Semi-Rural
V-band (PtP 60 GHz)	200 MHz	1 Gbps	< 500 us	< 5 Gbps	Small-cell	Dense Urban/ Urban
E-band (70/80 GHz)	500 MHz-2 GHz	3-10 Gbps	< 50-100 us		Macro-cell	

It is observed that wireless backhaul technologies can satisfy the macro-cell and small-cell backhaul requirements of 5G "Early Stage".

6.2 Backhaul/X-Haul Technologies Evolution

The impact of the 5G on wireless backhaul is due to use cases' demands, particular requirements of radio access network and the need for agile network management, including simplified network operations and fast service turn-up. It was shown in figure 1 that 5G multifaceted influence is not limited only to capacity and latency, but additional parameters need closer attention and in-line with the end-to-end access backhaul network architecture.

In this regard, wireless backhaul/X-Haul technologies are expected to further evolve to fit better into the "Maturity Stage" of the 5G deployments. The future 5G-grade performances of wireless backhaul/X-Haul technologies are expected to rely on the following factors:

- **Spectrum:**
  - New bands above 90 GHz, namely W-band and D-band (offer > 1,7x and > 3x times more spectrum compared to E-band)
  - Wider channels of 112/224 MHz at traditional MW bands
  - Band and Carrier Aggregation [i.7]
- **Efficiency:**
  - LOS MIMO/OAM (Orbital Angular Momentum) [i.8] combined with XPIC
  - Smart antennas and/or antennas of higher directivity
  - Advanced interference cancellation techniques
  - Multi-band/-carrier/-RF

- **Networking Functionality:**
  - Ultra-low and deterministic transmission latency (a few tens of us) and jitter
  - Ultra-high precision time/phase packet-based synchronization
  - 10GE and higher-speed ports
  - SDN automation & advanced packet networking (L3VPN MPLS, Segment Routing, etc.)

In figure 9, the key pillars of wireless backhaul/X-Haul technologies evolution and innovation are presented.

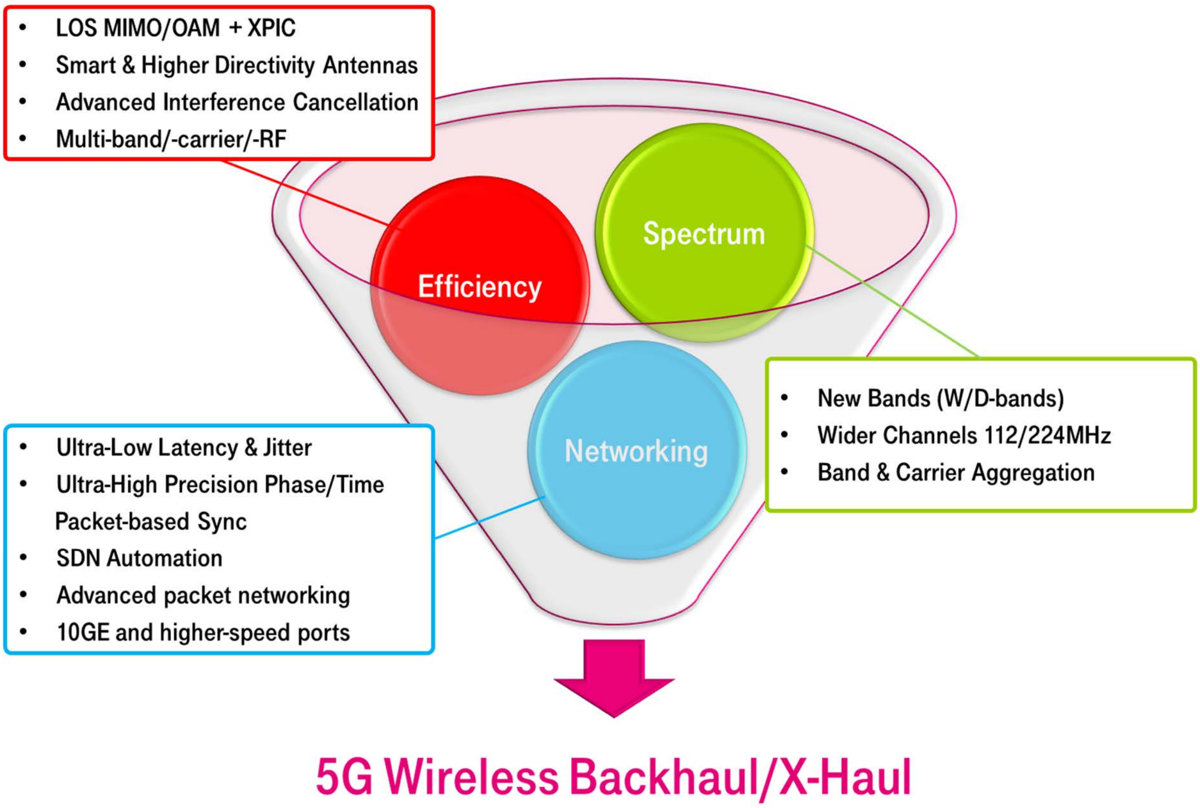

Figure 9: Pillars of 5G Wireless Backhaul/X-Haul Evolution & Innovation

6.3 5G Wireless Backhaul/X-Haul Capacity Potential

By using the aforementioned tools, capacity projections about future wireless backhaul/X-Haul technologies can be made. If one considers that capacity at 56 MHz channel size is 0,5 Gbps and either by doubling the BW or by adding XPIC or by adding LOS 2x2MIMO/OAM, the capacity is roughly doubled per case, then the wireless backhaul/X-Haul capacity performance, as illustrated in table 6 and table 7, can be achieved in future.

Table 6: MW Backhaul/X-Haul Technologies Future Capacity Performance

MW Backhaul Technology	56 MHz BW	112 MHz BW (or 2x 56 MHz BW)	224 MHz BW *(where available)*	+XPIC	+LOS 2x2 MIMO	+BCA *(with higher MW Band)*	+BCA *(with mmW Band)*
6-15 GHz	0,5 Gbps	1 Gbps		2 Gbps		3-4 Gbps	
18-42 GHz	0,5 Gbps	1 Gbps	2 Gbps	2-4 Gbps	4-8 Gbps		4-10 Gbps

Table 7: mmW Backhaul/X-Haul Technologies Future Capacity Performance

mmW Backhaul Technology	500 MHz BW	2 GHz BW	4 GHz BW *(where available)*	+XPIC	+LOS 2x2 MIMO/OAM (see note 2)
V-band (60 GHz)		> 4 Gbps			
E-band (70/80 GHz)	3,2 Gbps (see note 1)	12,8 Gbps		25,6 Gbps	51,2 Gbps
W-band (100 GHz)	3,2 Gbps	12,8 Gbps	25,6 Gbps	51,2 Gbps	102,4 Gbps
D-band (see note 2) (150 GHz)	3,2 Gbps	12,8 Gbps	25,6 Gbps	51,2 Gbps	102,4 Gbps

NOTE 1: Due to higher physical modulation and physical interfaces of higher speed (compared to currently typical E-band technologies).

NOTE 2: As per [i.8], when targeting backhaul/X-Haul applications in dense urban environments (in particular, link distances around 100 m. to serve 5G small cells transmission applications), OAM (Orbital Angular Momentum) signal transmission at D-band spectrum can be an efficient technology.

6.4 5G Wireless Backhaul/X-Haul Latency Potential

Another critical aspect of the 5G network architecture is end-to-end latency, since stricter requirements could be needed either due to specific 5G use cases or due to the applied (transport) interface between CU and DU. Indicatively, as per ETSI TR 138 913 [i.4], target for user plane latency will need to be in the order of 4 ms for UL and 4 ms for DL for eMBB, whilst for URLLC, target for user plane latency will need to be in the order of 0,5 ms for UL and 0,5 ms for DL. In general, by having such stringent latency goals, the topic of where to place the CU and DU entities, as well as, any UPF or MEC functions, becomes critical from performance and cost perspective. Taking into account [i.5], the following points are into consideration:

- **eMBB use cases (max ~10 ms RTT):**
  - The latency objectives of this kind of use cases can be satisfied by placing DU, CU entities and possibly UPF, MEC functions at aggregation sites.
- **URLLC use cases (max ~1 ms RTT):**
  - These are likely to be applied at selected spots, served by respective cell site(s), not everywhere, since by placing DU, CU entities and possibly UPF, MEC functions at higher aggregation sites, targeted latency of < 1 ms RTT cannot be satisfied; a << 1 ms transport technology is recommended for this category of use cases.

The wireless backhaul/X-Haul technologies can offer highly improved latency performance compared to existing deployments based on the following factors:

- **Enhanced technology design:** Data interfaces, packet processing engines, radio modem and air interface.
- **Higher data rates:** As wider channels and higher physical modulations are employed for radio links, higher data rates are achieved and less time is required for symbol transmission.

Wireless backhaul/X-Haul technologies need to contribute positively to the 5G end-to-end latency budget in order to satisfy user plane targets. By taking into account:

- Discussed network topologies (clause 5.1), where up to 3 hops could be part of a chain topology
- 5G use cases latency requirements (eMBB, URLLC)
- Relevant foreseen advancements in wireless backhaul/X-haul technologies
- Delays due to other network elements of the end-to-end network architecture, such as UEs, mobile base stations, cables, switches/routers, servers, etc.

It should be aimed that the one-way maximum latency (including transmission and service processing delay) of wireless backhaul/X-Haul link to be lower than 100 us, displaying > 50 % latency reduction compared to typical deployments. About the mmW bands and by leveraging the very high data rates capabilities, a further latency reduction down to 50 us (one-way) can be ideally achieved.

Moreover, the introduction of SDN concepts in the wireless backhaul/X-Haul domain for the automated management and operation of these technologies can enable the dynamic mapping of ultra-low latency service flows to appropriate sub-channel by taking into account individual service properties in order to further guarantee the respective SLAs over radio link in an agile manner [i.9].

Figure 10 depicts the latency performance potential of discussed technologies to address the 5G latency targets.

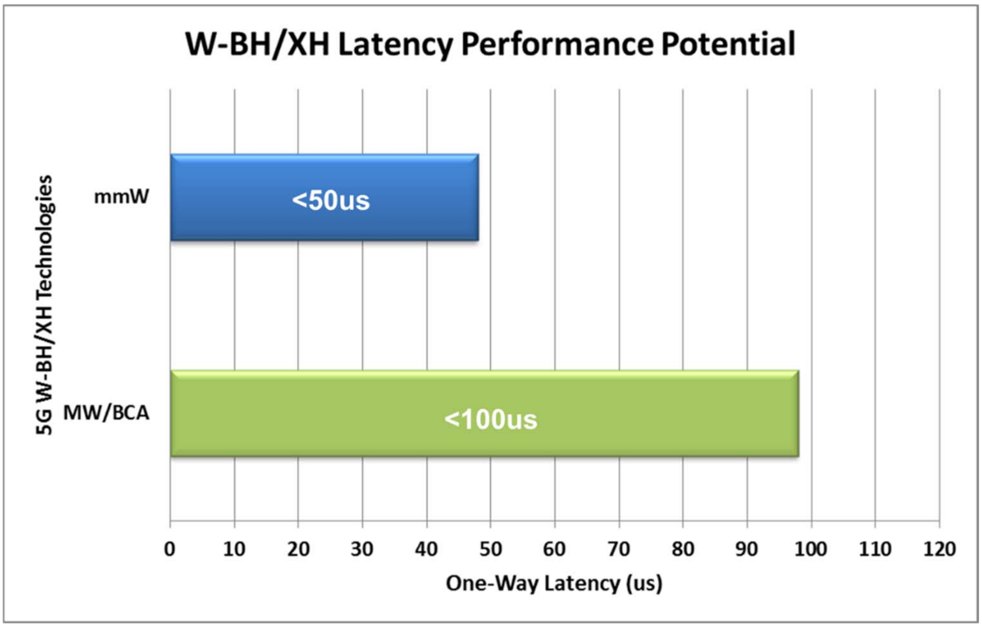

Figure 10: MW Backhaul/X-Haul Technologies Future Latency Performance

6.5 Wireless Backhaul/X-Haul Technologies Fit into 5G Scenarios

The end-to-end 5G network architecture will evolve over time and as with the previous 3GPP technologies evolutions, it is logically anticipated that 5G deployments will start with an initial phase and then they will gradually continue to their full deployment phase over a period of time. Backhaul network upgrades will as a result need to be aligned to the roadmap of 5G access network, but in reality backhaul architecture has to be anticipated and prepared in advance.

It was shown in table 5 how current microwave and millimetre wave technologies fulfil the 5G "Early Stage" demands. By considering the foreseen technological advancements, as analysed in clauses 6.3 and 6.4, wireless backhaul/X-Haul technologies are going also to address the requirements of 5G "Mature Stage" as presented in figure 11.

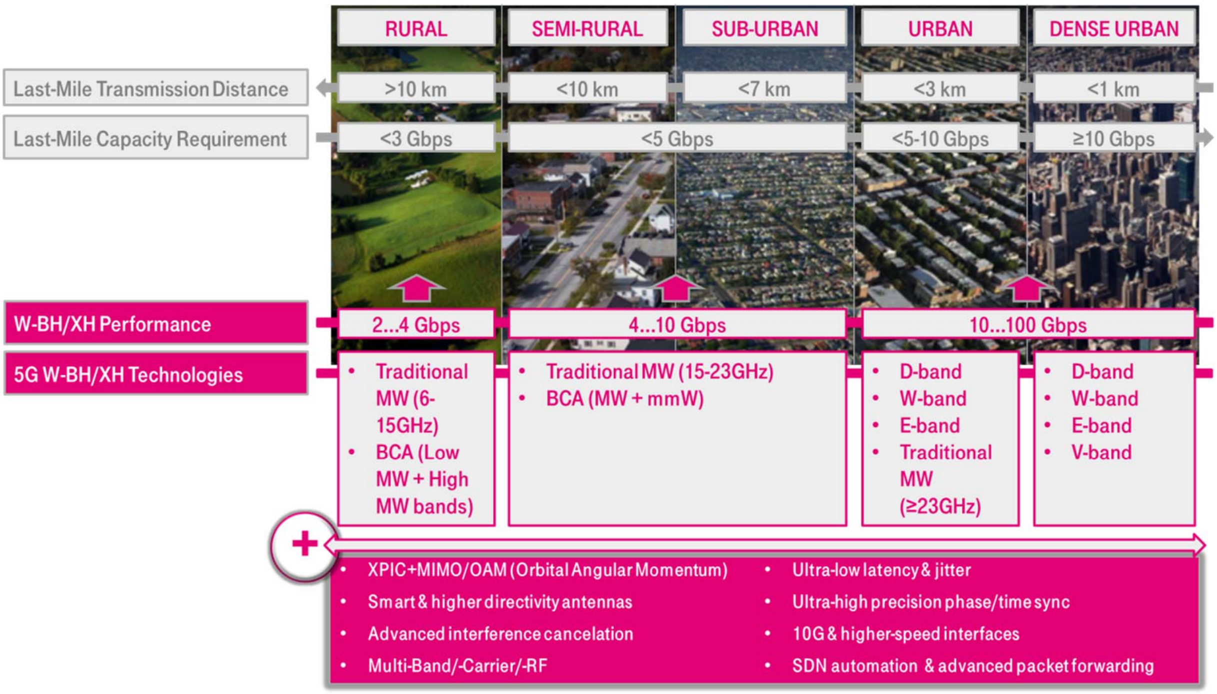

Figure 11: Wireless Backhaul/X-Haul Technologies Fit 5G

The transmission distances shown above are in-line with [i.2]. In case of extended ranges compared to capacity, BCA configuration is proposed, where the lower capacity link is typically designed with carrier-grade availability (e.g. 5 '9's) and the higher capacity link is designed with lower, but acceptable link availability according to each service provider's design targets. Moreover, continuous evolution of wireless backhaul/X-Haul technologies, focusing on enhanced system gain, will increase the applicability of these technologies - as per today's view - under further challenging scenarios.

With regard to table 7, note that the future performance of mmW technologies and the availability of new spectrum will allow supporting fronthaul (or LLS-based X-haul) applications with data rates ranging from 10 Gbps to 100 Gbps.

7 Considerations on Regulation and Licensing

It is understood and emphasized within the present document that the availability of both suitable backhaul spectrum and spectrally efficient technologies are necessary to address the foreseen 5G access demands. This opinion indicates the following aspects:

- The necessity for more backhaul spectrum, including:
  - New frequency bands, like W-band, D-band, other mmW/MW bands as per local situation
  - Wider channels for MW bands (e.g. 112/224 MHz)
  - BCA for high-capacity links over longer distances

needs proper and timely regulation to allow high-speed transmission over the air and relevant pricing has to be in-line with the current and foreseen capacity and roll-out requirements of mobile access.

- The evolution of technologies, including:
  - XPIC
  - LOS MIMO/OAM (Orbital Angular Momentum)
  - higher directivity and smart antennas solutions
  - advanced interference cancellation, etc.

lead to higher spectral efficiency and/or higher frequency re-use, so respective licencing need to facilitate and motivate their usage.

Timely regulation and cost-efficient pricing of spectrum and spectral efficient technologies are critical factors for successful 5G backhaul/X-Haul network implementations.

8 Conclusions

The evolution of mobile communications is fundamental, so that, in the future, entire society, including households, businesses and public sectors are able to enjoy advanced services, whilst "everything" will be connected in a "smarter" living and working environment. This certainly entails the enhancement of existing applications, in the sense that high-speed broadband connectivity is the basic medium to fulfil various tasks in shorter time or to gain better experience (for instance, during ultra-high quality video content streaming). In addition, new unique end-user applications will become possible. At the end, communications will transform significantly and in a positive way the daily life and the productivity of individuals and organizations.

To this end, various developments in the domains of technology, regulation and standardization are in progress, including respective activities on the wireless backhaul/X-haul domain. In reality, the microwave and millimetre wave transmission technologies satisfy the aforementioned 5G "Early Stage" requirements.

Under a forward-looking view and by keeping in mind the discussed 5G "Mature Stage" requirements, it becomes important that innovations on wireless backhaul/X-haul technologies will continue towards 5G, focusing on capacity, latency, spectral efficiency, higher transmission distances, synchronization and networking functionalities.

It is clear that the combination of having advanced wireless backhaul/X-Haul technologies in an appropriate regulatory environment will be catalyst to enable successful 5G network roll-outs worldwide. Therefore, regulation and licensing, where necessary, should aim to further facilitate the 5G wireless backhaul/X-Haul innovations and implementations in future by applying the right policies and costs.

Finally, wireless backhaul/X-Haul technologies will continue to be an essential solution pillar, since they will be able to address the most stringent future requirements of 5G access efficiently and timely.

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