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Foreword

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

Modal verbs terminology

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Executive summary

Modern consumers, individuals and corporate entities, request for advanced personalized services to perform their daily activities. Social interactions, entertainment, news, HD video streaming, distant learning, e-health, commercial transactions, e-business, cloud services, M2M applications represent a sample of a countless list of digital services that are requested from either stationary or moving end-users. Whilst different growth rates of broadband data are envisioned per region due to the existence of local idiosyncrasies, such as broadband market maturity, operators' pricing policy, consumers' psychographic characteristics and buying patterns, degree of access to the latest technological advancements, overall macro-economic climate and so forth, the demand for packet-based broadband data will continue to soar both in mobile and fixed access domains.

In order to address the increasingly diversified needs of digital natives and enterprises of the 2010s and onwards, telecommunication networks will have to be modernized at different segments. Fixed transmission networks represent a critical part of this effort and they play a pivotal role to achieve the target end-to-end KPIs per service and enhance end-users' QoE.

A variety of wireline as well as wireless technologies are available to build transmission infrastructures and usually a mixed environment of physical media is adopted. While optical fibre is perceived as the physical medium with the top performance, there are techno-economic factors that make installation or even extension of optical fibre network not always the most appropriate solution. Hence, wireless technologies represent today a significant or even a dominant percentage of various operators' transmission networks to serve efficiently the increasing upward trend for providing data-hungry applications.

While microwave solutions at traditional bands are more or less employed by all kinds of service providers (mobile, fixed), it becomes clear that moving to millimetre wave frequency bands, where underutilized massive bandwidth is available, will assist to deliver transmission services of equal to optical fibre performance avoiding the constraints that the latter might impose at particular scenarios. In this sense, millimetre wave frequency bands can be used in an immense number of current and future high-speed wireless transmission applications.

Introduction

Information society's foreseeable demand for additional broadband data consumption is further augmented by the high uptake of faster connections and the popularity of powerful data devices. In the mobile access domain, technology advances as a result of the ceaseless evolution of 3GPP standardizations that has taken mobile broadband to the next level. Similarly, at fixed access domain, increased broadband speeds become available as technologies, like fibre to the home (FTTH) or business, VDSL variants and so on are adopted. Furthermore, use of devices like smart-phones, 802.11ac routers will contribute to increase of broadband applications' usage, like video streaming, web surfing, etc.

The above dynamic situation puts more pressure on transmission networks, in order for services to be delivered tailored to consumers' expectations. While from client perspective services' data rate, response and uninterrupted availability constitute key metrics, from operators' experience additional parameters have to be carefully thought and designed to achieve the desired overall performance. In this sense, the challenges for the next generation transmission networks are multiple and are related to factors, such as:

- Network architecture, topology and density.
- Throughput.
- Range and service availability (with reference to wireless transmission networks).
- Latency and jitter.
- Interference management (with reference to wireless transmission networks).
- Network automation.
- Networking and synchronization features for advanced packet-based/mobile networks.
- Improved match between spectrum resource consumption and consumers' traffic patterns requirements.
- Equipment physical form factor.
- Power consumption.
- Security for data transport.

In the light of the expected emerging broadband communication demands and the increased challenges for the next generation transmission networks, ETSI Industry Specification Group (ISG) on millimetre Wave Transmission (mWT) aims to be a worldwide initiative with global reach that will facilitate the use of [i.1]:

- the V-band (57 - 66 GHz);
- the E-band (71 - 76 & 81 - 86 GHz); and
- - in the future - higher frequency bands from 50 GHz up to 300 GHz.

ETSI ISG mWT envisions that established and emerging broadband transmission services would benefit from high-speed wireless transmission that millimetre wave spectrum technology can accomplish.

It should be noted that although the addressed by ETSI ISG mWT spectrum ranges between 50 GHz and 300 GHz bands, as Figure 1 [i.1] shows, presently the 57 - 66 GHz, 71 - 76 GHz and 81 - 86 GHz bands or parts of them are open at various, but not all, countries across the world for broadband wireless fixed services. Moreover, as per Recommendation ITU-R F.2107-2 Report [i.2], frequencies up to 134 GHz band were also approved.

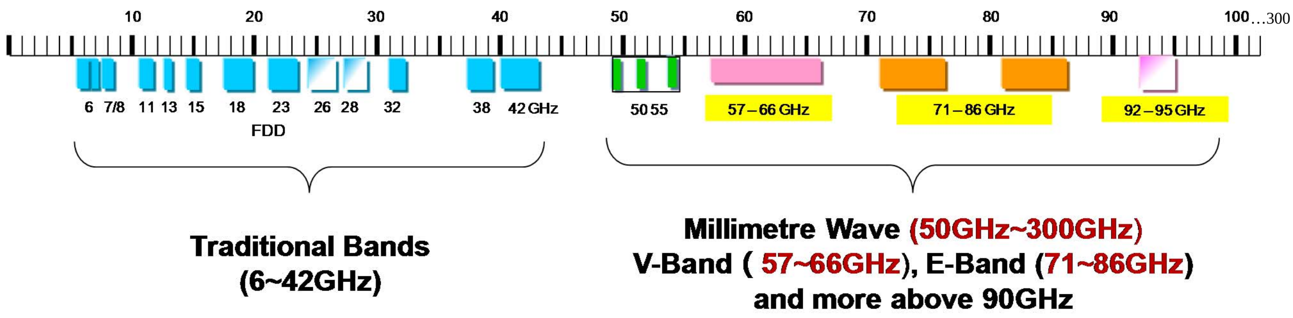

Figure 1: Millimetre wave spectrum (50 GHz to 300 GHz)

The present document, as part of ISG mWT framework, intends to propose the wireless transmission applications and use cases that can be addressed by millimetre wave spectrum, focusing on frequency bands from 50 GHz up to 300 GHz (or wavelengths from 6 mm down to 1 mm).

1 Scope

The purpose of the present document is to provide information on the following topics:

- Millimetre wave spectrum technology overview.
- Millimetre wave spectrum technology key performance benefits.
- Potential transmission applications and use cases for millimetre wave spectrum technology.
- Key requirements per transmission application/use case of millimetre wave spectrum technology.
- Enablers of millimetre wave spectrum technology per transmission application/use case.

2 References

2.1 Normative 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 reference document (including any amendments) applies.

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2.2 Informative references

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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] An Introduction to mWTISG.

NOTE: Available at https://portal.etsi.org/Portals/0/TBpages/mWT/Docs/Introduction%20to%20mWT%20ISG%20v1-0.pdf.

[i.2] Report Recommendation ITU-R F.2107-2 (11/2011): "Characteristics and applications of fixed wireless systems operating in frequency ranges between 57 GHz and 134 GHz".

[i.3] ECC Recommendation (09)01: "Use of the 57 - 64 GHz frequency band for point-to-point fixed wireless systems".

[i.4] ECC Recommendation (05)07: "Radio frequency channel arrangements for fixed service systems operating in the bands 71-76 GHz and 81-86 GHz".

[i.5] ECC Recommendation (14)01: "Radio frequency channel arrangements for fixed service systems operating in the band 92-95 GHz".

[i.6] ECC Recommendation (05)02 (2009): "Use of the 64-66 GHz frequency band for fixed service".

[i.7] Report Recommendation ITU-R F.2323: "Fixed service use and future trends".

[i.8] ERC Recommendation 12-11 (2015): "Radio frequency channel arrangements for Fixed Service systems operating in the bands 48.5 to 50.2 GHz/50.9 to 52.6 GHz".

[i.9] ERC Recommendation 12-12 (2015): "Radio frequency channel, arrangement for Fixed Service Systems operating in the band 55.78 to 57.0 GHz".

[i.10] Report Recommendation ITU-R M.2134: "Requirements related to technical performance for IMT-Advanced radio interface(s)".

[i.11] MEF 22.1.1, Mobile Backhaul Phase 2, Amendment 1 - Small Cells, July 2014.

[i.12] CPRI Specification V6.0 (2013-08-30), Common Public Radio Interface (CPRI); Interface Specification.

[i.13] OBSAI, Reference Point 3 Specification, Version 4.2.

[i.14] ETSI GS ORI 002-1 (V4.1.1) (2014-10): "Open Radio equipment Interface (ORI); ORI interface Specification; Part 1: Low Layers (Release 4)".

[i.15] ETSI GS ORI 002-2 (V4.1.1) (2014-10): "Open Radio equipment Interface (ORI); ORI Interface Specification; Part 2: Control and Management (Release 4)".

[i.16] "NGMN 5G WHITE PAPER", a Deliverable by NGMN Alliance, 17th of February 2015.

[i.17] "Understanding 5G: Perspectives on future technological advancements in mobile", GSMA Intelligence, December 2014.

[i.18] Milestones: First Millimeter-wave Communication Experiments by J.C. Bose.

NOTE: Available at http://www.ieeeghn.org/wiki/index.php/Milestones:First_Millimeter-wave_Communication_Experiments_by_J.C._Bose.

3 Abbreviations

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

2G	Second Generation of Mobile Networks
3GPP	Third Generation Partnership Project
5G	Fifth Generation of Mobile Networks
B2B	Business-to-Business
B2G	Business-to-Government
BBU	Baseband Unit
BER	Bit Error Rate
CNR	Carrier-to-Noise Ratio
CoMP	Coordinated Multipoint
CPRI	Common Public Radio Interface
CSP	Communication Service Provider
DL	Downlink
FTTH	Fibre To The Home
HD	High Definition
HD-SDI	High Definition Serial Digital Interface
HetNet	Heterogeneous Network
IMT-Advanced	International Mobile Telecommunications-Advanced
IPTV	Internet Protocol Television
IQ	In-phase and Quadrature components
ITU-R	International Telecommunication Union - Radiocommunication Sector
KPI	Key Performance Indicator
LOS	Line Of Sight
LTE	Long Term Evolution
LTE-A	LTE-Advanced
M2M	Machine-to-Machine

MIMO	Multiple Input Multiple Output
MNO	Mobile Network Operator
nLOS	near Line Of Sight
NLOS	Non Line Of Sight
OBSAI	Open Base Station Architecture Initiative
OpEx	Operational Expenditures
ORI	Open Radio equipment Interface
PoP	Point of Presence
PtMP	Point to Multipoint
PtP	Point to Point
QoE	Quality of Experience
QoS	Quality of Service
RAN	Radio Access Network
RF	Radio Frequency
RRU	Remote Radio Unit
SISO	Single Input Single Output
SLA	Service-Level Agreement
TCO	Total Cost of Ownership
TV	Television
UL	Uplink
VDSL	Very-high-bit-rate Digital Subscriber Line
WCDMA	Wideband Code Division Multiple Access

4 Millimetre wave spectrum technology: Overview and benefits

The high interest in millimetre wave bands has risen due to the enormous amount of bandwidth that lies in this part of the electromagnetic spectrum. With respect to the present regulatory status, typically V-band offers 7 GHz bandwidth of contiguous spectrum (57 - 64 GHz), extendable to 9 GHz whenever also the 64 - 66 GHz is open for fixed services and E-band provides two times 5 GHz bandwidth, namely 10 GHz aggregate spectrum (71 - 76 GHz and 81 - 86 GHz). Similarly, at frequency bands above 100 GHz, there are blocks of plentiful spectrum, which could be allowed for extra bandwidth for future broadband wireless transmission services. Figure 2 [i.1] illustrates the channel spacing of the fixed radio systems as function of the corresponding frequency band. The obvious advantage is that over 1 Gbps capacity figures could be provided in SISO configurations and with average physical modulations (e.g. 500 MHz and 16QAM combination), while over 2 Gbps capacity figures could be achieved by having more capable physical modulations (e.g. 64QAM).

Another significant advantage of millimetre wave spectrum apart from being massive is that it is congested-free. The requirement for non-crowded spectrum becomes more critical in urban and sub-urban environments, especially as the number of installed links begins to grow as more high-capacity sites at smaller distances are to be served. Since multiple network operators already use the long-established microwave bands in the same area, at some point in time excessive bandwidth might become more difficult to be sourced at legacy bands to cover their needs adequately. In order to avoid any potential "spectrum asphyxia", networks operators could turn to higher frequency bands. Millimetre wave bands have not been extensively used, so this part of the electromagnetic spectrum offers an alternative path to evolve wireless transmission networks effectively.

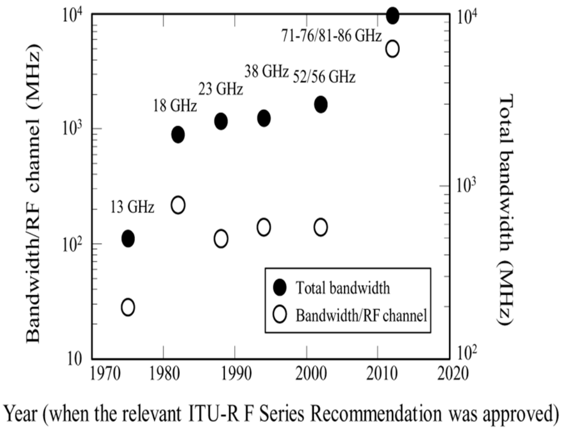

Figure 2: Channel spacing of the fixed radio systems

Additionally, it is worthwhile stating that the extraordinary amount of millimetre bandwidth facilitates the fulfilment not only of existing wireless transmission applications, but aids the development of wireless systems of future-proof performance, as well. The engineering of wide-spectrum radio systems leads to very high throughput and low packet delay figures that will be increasingly required in the next-generation transmission applications, for instance LTE-A and 5G mobile backhaul. Considering channel sizes, physical modulations and coding rates that are supported by recent implementations, it could be extrapolated that only by employing wider channels, a capacity in the range of 10 Gbps could be achieved. Also, increase of capacity, by keeping other things equal, results to further reduction of packet delay, which is observed in millimetre wave spectrum technology. At present, the one-way latency of millimetre wave radios can be lower than half a millisecond even down to 100 microseconds or less, depending on actual implementation. As specifications of certain transmission applications become increasingly stricter and require fibre-like performance even at the last-mile, millimetre wave spectrum technology could be the enabler to meet upcoming stricter demands and be conceived as a future-proof over-the-air technology.

With reference to their radio propagation properties, millimetre wave bands are defined by short-to-medium ranges (from a few hundred metres up to several kilometres), making technology at this spectrum suitable for applications in urban and sub-urban areas. It has to be stressed though that transmission distances are subject to exact frequency channel, bandwidth, target link availability at reference physical modulation and rain zone, besides system capabilities, such as transmitting power, receiver's sensitivity and antenna performance.

Furthermore, millimetre wave spectrum technology provides very high-frequency re-use capabilities. Due to the high operating frequency and resulting short wavelength even physically small antennas would provide relatively high directivity and low side lobe level. That antenna directivity ensures good spatial isolation between links operating in close proximity and reduces significantly the probability of generating interference or being subject to interference. The high operating frequency and short wavelength are further effective to reduce specular reflections from many physical surfaces (as they would appear rough at these wavelengths), in case such a surface is illuminated by the main lobe or a side lobe of a millimetre wave antenna. The reduced reflection levels would further contribute to the reduction of the chances of unintended interference. The frequent re-use gain of a single frequency channel becomes even more obvious at cases where atmospheric absorption is a significant degradation factor at some frequency bands, as shown in Figure 3 of [i.2].

Network design and implementation benefit from millimetre wave spectrum technology. Sizeable number of available frequency channels and very high frequency re-use ease frequency planning. Also, seeing that millimetre wave spectrum technology is capable of employing wider channels, for example in the order of 200 MHz or more, by transmitting fewer bits per symbol, target data rates could be attained for certain cases. Thus, respective CNR thresholds (at a BER of 10^{-6} or better) could be low and robustness of millimetre wave rises. Moreover, lower probability of undesired interference and availability of antennas of high directivity allow the installation of more millimetre wave links per area unit by supporting any type of interconnectivity options, e.g. chain, star, tree, ring, mesh. Consequently, millimetre wave spectrum technology facilitates increased deployment density, before exhausting the expandability cap in a given area. Another benefit of millimetre wave related to network implementation appears in cases where demand for high-capacity data-centric connectivity is in locations that are fully or partially isolated by surrounding obstacles (trees, buildings, hills, rivers, etc.). In such cases, when the path length permits, use of millimetre wave offers the advantage, as compared to use of lower frequencies, that its short wavelength results in narrow Fresnel zone radius, so enabling reliable transmission over the obstacle without requiring tall masts or towers.

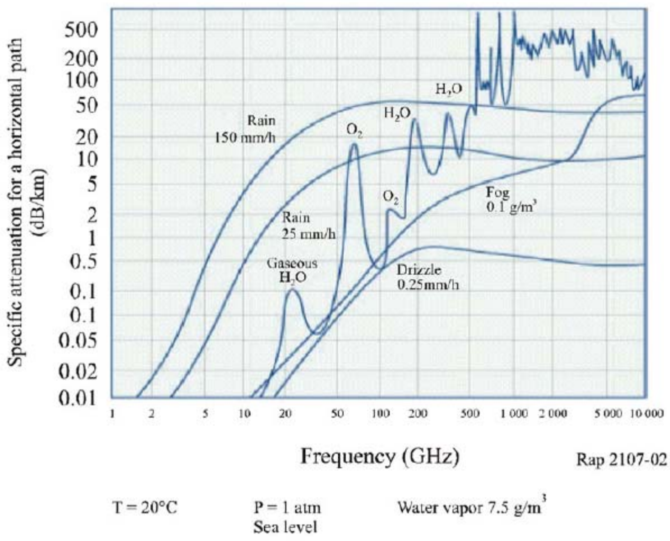

Figure 3: Specific attenuation due to rain attenuation and atmospheric gases

In addition, millimetre wave spectrum technology facilitates the manufacturing of compact products. Antenna size depends on wavelength of electromagnetic signal, so in principle millimetre wave antennas of very small dimensions can be designed. In fact, millimetre technology allows entire digital and analogue circuitry, such as network interfaces and processor, modem, radio transceiver and antenna to be accommodated at full-outdoor and small-form factor architecture, thus contributing to discreet and fast installations.

Last, but not least, another important trait of millimetre wave spectrum is that it can significantly contribute to an optimized TCO and an accelerated roll-out of a wireless transmission network. Based on the individual radio propagation characteristics of each millimetre wave frequency band, license-exempt or light licensing regimes are feasible (see [i.3], [i.4], [i.5], [i.6], [i.7], [i.8] and [i.9]). Whilst licensed regime could be of course wanted for ensuring more certainty in the expected QoS performance, the capability of adopting unlicensed and light licensing schemes can really benefit transmission network applications as a consequence of:

- Reduced OpEx due to zero or low annual spectrum fees.
- Rapid deployment, because of none or simplified (no time-consuming) registration processes.

5 Applications and use cases: Overview

The attributes of the millimetre wave spectrum technology facilitate its usage in a sizeable number of wireless transmission applications. The applications and use cases (latter are shown within brackets) that are discussed in this paper are:

- Macro-cell mobile backhaul application (mobile network upgrade, expansion)
- Small-cell mobile backhaul application (rooftop-to-street/street-to-street connectivity, multi-hop)
- Fronthaul for small cells application (rooftop-to-street/street-to-street connectivity, multi-hop)
- Fronthaul for macro cells application (mobile network upgrade, expansion)
- Next-generation mobile transmission application
- Fixed broadband application (wireless to the home, wireless to the cabinet)
- Temporary infrastructure application (special events, public safety)
- Business-to-business application
- Business-to-government application (broadband connectivity, public Wi-Fi hotspot backhaul)

- Redundant network application
- Video surveillance backhaul application
- TV signal relay application

The aforementioned applications and their respective use cases are analysed in the following clauses including current and new features that could favour them. It should be noted that certain features are not conventional with current millimetre wave spectrum technology. The key technologies listed hereafter can be considered the critical ones to fully address the applications and use cases mentioned in the present document and will be considered in future works of the ISG mWT:

- above 10 Gbps data rates
- PtMP/mesh topologies
- nLOS/NLOS radio propagation
- automation (self-configuration, self-optimization, self-healing)
- smart antennas (antenna beam-steering/beam-forming capabilities)

In this regard, the present ISG mWT paper sets also the future targets for the millimetre wave transmission technology.

6 Applications and use cases: Description

6.1 Macro-cell mobile backhaul application

6.1.1 Use Case 1: Mobile network upgrade (existing cells)

The growing demand of mobile broadband data and the high popularity of mobile devices, like smartphones and tablets drive mobile network operators to lay access technologies that are more spectrally efficient. The roll-out of LTE and LTE-A access networks has already launched, featuring Carrier Aggregation (3GPP Rel. 10) and CoMP (3GPP Rel. 11) that put higher throughput and lower packet delay requirements per cell site compared to the ones needed for 2G and WCDMA networks.

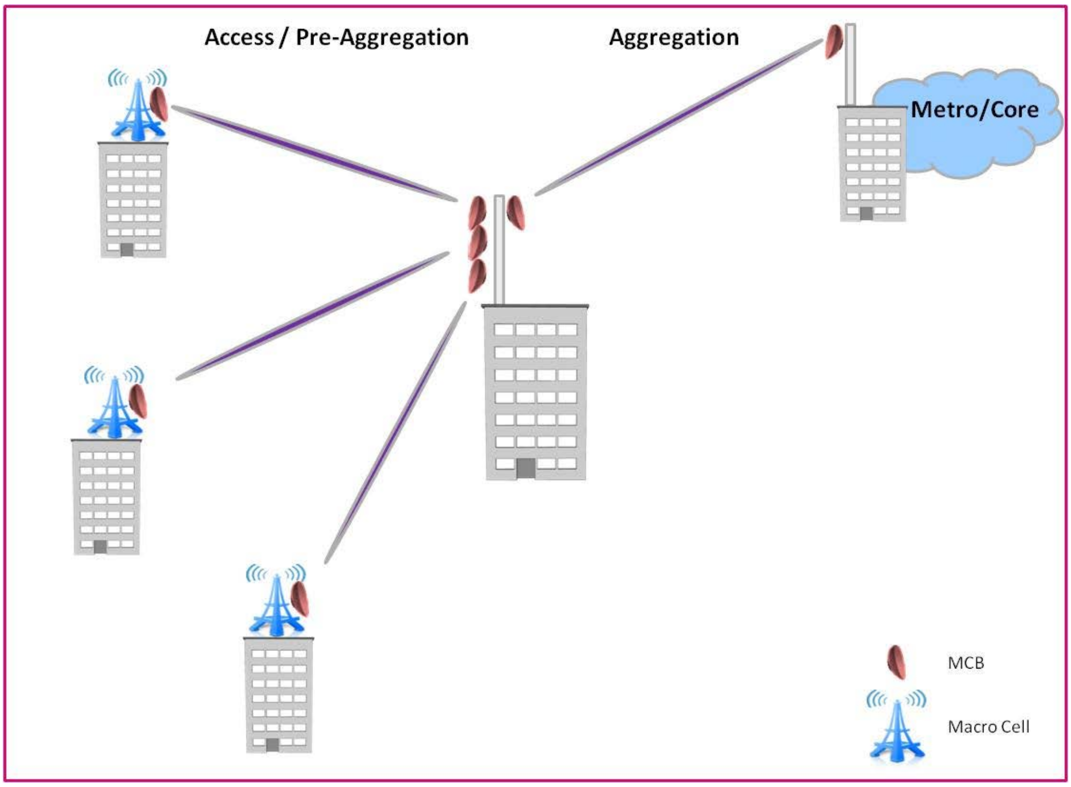

Figure 4: Macro-cell backhaul application

Mobile network operators could upgrade current macro-cell sites to host LTE/LTE-A technologies by preserving their 2G/WCDMA access layers to satisfy also their existing subscribers' base. In this use case, PtP LOS links are installed at the telecom infrastructure and connect each mobile site back to a pre-aggregation point. The pre-aggregation site could be connected to an aggregation site either via fibre or by a consecutive PtP LOS radio link. Regulation schemes that ensure interference-managed operation are preferred.

Inside urban and sub-urban environments, MNOs typically utilize microwave links at frequency bands equal to and greater than 18 GHz, reaching last-mile distances of up to 5 km and target availability (at reference physical modulation) ranging from 99,99 % - 99,999 %. The target DL peak rates per site could range from 400 Mbps at present and reach up to 2 Gbps over the next 5 years with respect to gradual increase of mobile access bandwidth and spectral efficiency (15 bps/Hz at minimum as per [i.10] and up to 30 bps/Hz under current specifications). At achieved transmission distances, target DL peak rates should be provided and target availability figures should be guaranteed. Subject to the evolution of RAN technology and expected performance, backhaul packet delay should be reduced to sub-1 ms (even down to 200 us or less), to meet the stringent requirements of certain CoMP features via the LTE-A X2 interface. Auto-alignment of radio units might be handy, in case it expedites drastically the installation time over relatively long transmission distances.

6.1.2 Use Case 2: Mobile network expansion (new cells)

Apart from improving the spectral efficiency of their current macro-cell network, MNOs could add macro-cell sites into their network in order to enlarge their cellular coverage and/or augment their cellular capacity.

At both cases, new backhaul links will have to be established to serve the new LTE/LTE-A sites. Besides the requirements described in clause 6.1.1 above, another design and deployment difficulty for backhaul network arises from the densification of macro-cell layer that reduces the inter-site distances among cell sites in a given area. As pre-aggregation site will have to accommodate more backhaul links, unless more fibre is deployed, which is often prohibitively expensive, the need for suitable spectrum and of a solution with very high frequency re-use capabilities becomes more probable.

Table 1 summarizes the key requirements of macro-cell backhaul application.

Table 1: Macro-cell backhaul application key requirements

Requirement	Indicative Value	Comment
RF Path Clearance	LOS	
Connectivity	PtP	
Capacity	0,4 - 2 Gbps (DL)	(a) w.r.t to annual cell site spectrum efficiency increase (b) subject to number/type/channel size/antennas' number of served macro cells
Range	< 5 km	
Availability (at reference physical modulation)	99,99 % - 99,999 %	
Latency (one-way)	Sub -1 ms (even ≤ 0,2 ms)	w.r.t target RAN implementation/efficiency
Form Factor	typical radio unit	
Automation	Yes (optional)	w.r.t. alignment (if it improves alignment time over relatively long distances), configuration, optimization, healing, etc.
Spectrum Regulation	interference-managed operation (link/block-allocated)	

6.2 Small-cell mobile backhaul application

6.2.1 Use Case 1: Rooftop-to-street/Street-to-street connectivity

Network densification in urban environment represents a strategic option to manage the mobile data crunch and HetNets plays a vital role to enhance subscribers' QoE by providing additional capacity under congested macro cells, additional coverage (and in turn more capacity) where macro coverage is weak and better service delivery by leveraging higher QoE.

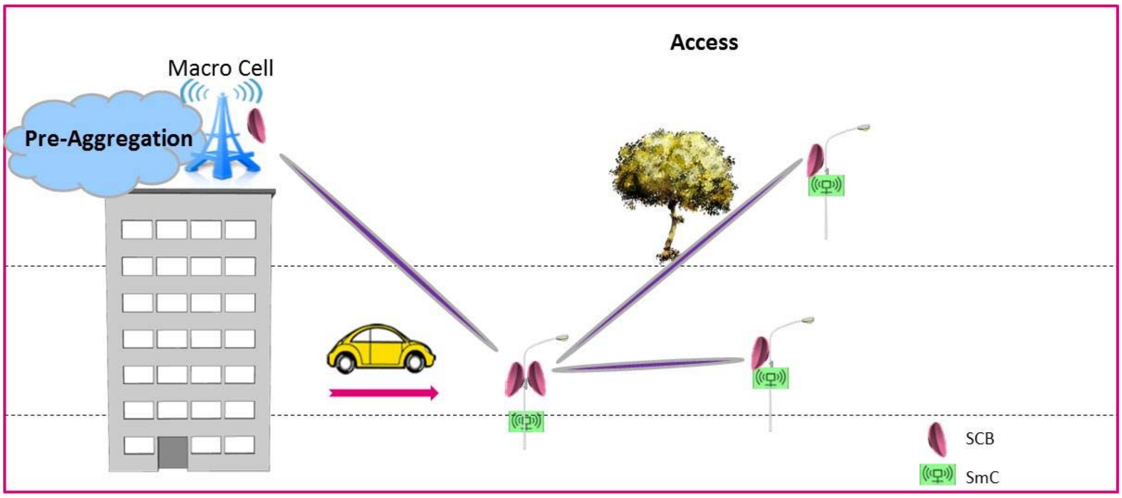

Figure 5: Small-cell backhaul application

MNOs could start building their small-cell layer by leveraging their current telecom assets, where backbone connection and power supply infrastructure are available. Single-hop connections could begin from a macro-cell site (rooftop-to-street connectivity) and/or from a fibre-enabled PoP site, such as a micro-cell site and/or multi-function street cabinet (street-to-street connectivity) and serve reachable small cells. Outdoor operator-managed small cells are placed at lampposts, outside buildings' walls, payphones, notice boards and similar public spots. This introduces a few new requirements for the backhaul solution.

At street-level radio propagation conditions express a more dynamic behaviour compared to macro-cell layer due to the increased phenomenon of multipath resulting from the environment's geometry. Moving vehicles (e.g. cars, buses) might cause fast fading at the receiver by impacting severely its reception levels. In addition, clear LOS conditions are not always found because of obstacles (e.g. signposts) or could be variable (e.g. seasonal trees' foliage). Moreover, roll-out has to be easy and fast, due to the "non-telecom" working environment and because in certain cases only the cities' personnel is allowed to have access to cities' street furniture. Therefore, automation mechanisms, such as self-alignment (beam-forming/beam-steering), self-configuration, self-optimization, self-healing and so on, look to be quite significant for efficient small-cell backhaul. Additionally, small-cell backhaul equipment's aesthetics need to blend into urban environment, thus small form factor and built-in antenna are preferred, while its power consumption should be low.

Furthermore, this type of application could greatly benefit not only from LOS connectivity, but also from nLOS/NLOS capabilities of a small-cell backhaul solutions. Given also the nature of site locations and their limited space, a small-cell backhaul solution that apart from PtP topology could additionally support PtMP/mesh topologies would allow a more flexible network deployment.

Typically, target transmission distances for mature small cell deployments are below 500 m. (few small cell backhaul links during early deployments could reach 1 km distance) with target availability (at reference physical modulation) between 99,9 % - 99,99 % (as macro-cell coverage is assumed). Except for LTE/LTE-A small cells, it is subject to each operator's policy to include WCDMA and Wi-Fi at small-cell spots to serve greater number of subscribers, but this also increases the throughput requirements per small cell backhaul link. As a result, the target DL peak rates per site could range from 300 Mbps in the short-term and reach up to 1 Gbps over the next 5 years. As always, backhaul packet delay has to be as low as possible and depends on evolution of RAN technology and desired efficiency. In this sense, small-cell backhaul packet delay should be less than 1 ms.

Increased backhaul network density, resulting from relatively low inter-site distances among small cells, as well as a need of very low recurring costs, makes this application benefit from technologies that facilitate high frequency re-use and could be regulated at free, coordinated (light licensed) or block-allocated spectrum.

6.2.2 Use Case 2: Multi-hop (in-clutter extensions)

Further hops can be founded inside urban street canyon as small-cell layer expands. The requirements are the same as use case described in clause 6.2.1, but extra emphasis has to be put on:

First hop is transformed into a "fat pipe" that carries the entire capacity of in-clutter small-cell backhaul connections.

Delay budget of in-clutter network increases as small-cell backhaul network scales; however it should remain within acceptable limits, keeping also in mind that the gain of LTE-A CoMP feature-set (tight coordination between macro-cell and small-cells) becomes optimum as packet delay decreases, see [i.11]. Thus, each additional small-cell backhaul link of the in-clutter chain should respect the total planned delay budget.

The key requirements discussed above for small-cell backhaul application are shown in Table 2.

Table 2: Small-cell backhaul application key requirements

Requirement	Indicative Value	Comment
RF Path Clearance	LOS/nLOS/NLOS	
Connectivity	PtP/PtMP/mesh	
Capacity	0,3 - 1 Gbps (DL)	(a) w.r.t to annual cell site spectrum efficiency increase (b) subject to number/type/channel size/antennas' number of served small cells
Range	≤ 500 m	
Availability (at reference physical modulation)	99,9 % - 99,99 %	macro-cell coverage is assumed
Latency (one-way)	Sub - 1 ms	(a) w.r.t target RAN implementation/efficiency (b) about use case 2, each additional link's delay should respect total planned delay budget (i.e. ≤ 1 ms)
Form Factor	"Non-telecom"-shaped unit with built-in antenna	
Automation	Yes	w.r.t. alignment, configuration, optimization, healing, etc.
Spectrum Regulation	unlicensed/light licensed (link)/block-allocated	

6.3 Fronthaul for small cells application

6.3.1 Use Case 1: Rooftop-to-street/Street-to-street connectivity

Mobile network operators could adopt fronthaul architecture to deploy RRUs at different spots of urban small-cell layer and aggregate the entire traffic (here, digital samples) at designated BBU hotels. Such an approach allows centralized management of shared baseband resources amongst several RRUs and facilitates the implementation of certain latency-sensitive LTE-A features, like CoMP DL Coordinated beamforming and UL Joint processing, see [i.11].

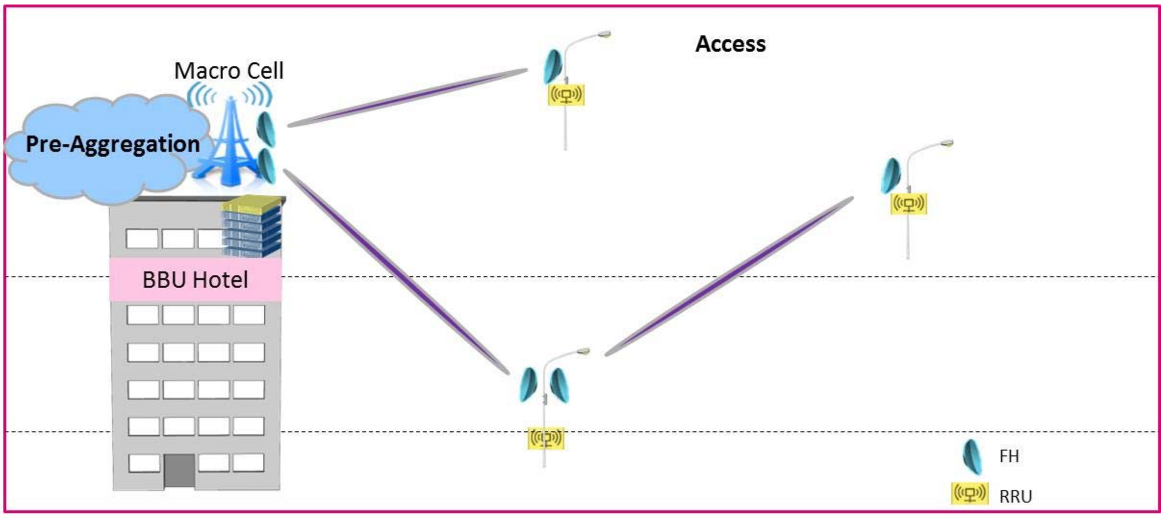

Figure 6: Fronthaul for small cells application

Mobile network operators could deploy single-hop connections either from rooftop down to street level and/or from in-clutter PoP sites to the reachable RRUs. The core differences from the small-cell backhaul application lie on the throughput and latency requirements, which are now much more stringent. Data rates become higher per link if additional to LTE access technologies are deployed per site (e.g. WCDMA).

Table 3: CPRI [i.12] fronthaul data rate requirements for LTE/LTE-A small cell configurations

Total Bandwidth	MIMO	Fronthaul Line Rate(s) per Channel	Total Fronthaul Data Rate
20 MHz	2x2	2 457,6 Mbps	2 457,6 Mbps
[20 + 20] MHz	2x2	[2 457,6 + 2 457,6] Mbps	4 915,2 Mbps
[20 + 20 + 20] MHz	2x2	[2 457,6 + 2 457,6 + 2 457,6] Mbps	7 372,8 Mbps
[20 + 20 + 20 + 20] MHz	2x2	[2 457,6 + 2 457,6 + 2 457,6 + 2 457,6] Mbps	9 830,4 Mbps

Table 4: OBSAI [i.13] fronthaul data rate requirements for LTE/LTE-A small cell configurations

Total Bandwidth	MIMO	Fronthaul Line Rate(s) per Channel	Total Fronthaul Data Rate
20 MHz	2x2	3 072,0 Mbps	3 072,0 Mbps
[20 + 20] MHz	2x2	3 072,0 + 3 072,0 Mbps	6 144,0 Mbps
[20 + 20 + 20] MHz	2x2	[3 072,0 + 3 072,0 + 3 072,0] Mbps	9 216,0 Mbps
[20 + 20 + 20 + 20] MHz	2x2	[3 072,0 + 3 072,0 + 3 072,0 + 3 072,0] Mbps	12 288,0 Mbps

CPRI and OBSAI transmit the I and Q samples of the signals and this increases significantly the required bit rates for fronthaul. To overcome these high rates compression techniques on the IQ signals could be implemented. In this sense, ORI 002-1 defined a standard IQ compression on LTE 10 MHz, 15 MHz and 20 MHz channels, which reduces the overall capacity of IQ stream by a factor of 2.

For RAN equipment that supports standard ORI (see [i.14] and [i.15]) compression the respective fronthaul rates are:

Table 5: Fronthaul data rate requirements for LTE/LTE-A small cell configurations with standard ORI compression

Total Bandwidth	MIMO	Fronthaul Line Rate(s) per Channel	Total Fronthaul Data Rate
20 MHz	2x2	1 044,48 Mbps	1 044,48 Mbps
[20 + 20] MHz	2x2	[1 044,48 + 1 044,48] Mbps	2 088,96 Mbps
[20 + 20 + 20] MHz	2x2	[1 044,48 + 1 044,48 + 1 044,48] Mbps	3 133,44 Mbps
[20 + 20 + 20 + 20] MHz	2x2	[1 044,48 + 1 044,48 + 1 044,48 + 1 044,48] Mbps	4 177,92 Mbps

Also, very low transport latency figures are required. The hard requirements in terms of throughput and latency make this application benefit from PtP LOS link configurations.

6.3.2 Use Case 2: Multi-hop (in-clutter extensions)

Fronthaul in-clutter network could scale by expanding fronthaul links in the urban street canyon. The requirements of this use case are similar to the ones described in clause 6.3.1. It should be noted though that each additional hop puts very tough requirements from data rate and latency point of view. For instance, assuming two consecutive fronthaul radio links in daisy-chain configuration serving two LTE 64QAM 2x 20 MHz 2x2 MIMO RRUs, the entire latency budget should fall within the target range, while the total throughput of the first hop should be 9 830,4 Mbps (over a CPRI line bit rate option 7). Tables 3, 4 and 5 above show fronthaul data rate requirements for various LTE/LTE-A small cell configurations.

The aforementioned key requirements of fronthaul for small cells application are gathered in Table 6 below.

Table 6: Fronthaul for small cells application key requirements

Requirement	Indicative Value	Comment
RF Path Clearance	LOS	to achieve max performance
Connectivity	PtP	to achieve max performance
Capacity	w.r.t. Tables 3, 4 and 5	subject to number/type/channel size/antennas' number of served RRUs
Range	"urban"-oriented	w.r.t to target performance
Availability (at reference physical modulation)	99,9 % - 99,99 %	macro-cell coverage is assumed
Latency (one-way)	very low	(a) w.r.t target RAN implementation/efficiency (b) about use case 2, each additional link's delay should respect total planned delay budget
Form Factor	"Non-telecom"-shaped unit with built-in antenna	
Automation	Yes	w.r.t. alignment, configuration, optimization, healing, etc.
Spectrum Regulation	unlicensed/light licensed (link)/block-allocated	

6.4 Fronthaul for macro cells application

6.4.1 Use Case 1: Mobile network upgrade (existing cells)

Mobile networks operators could also adopt fronthaul architecture at macro-cell layer.

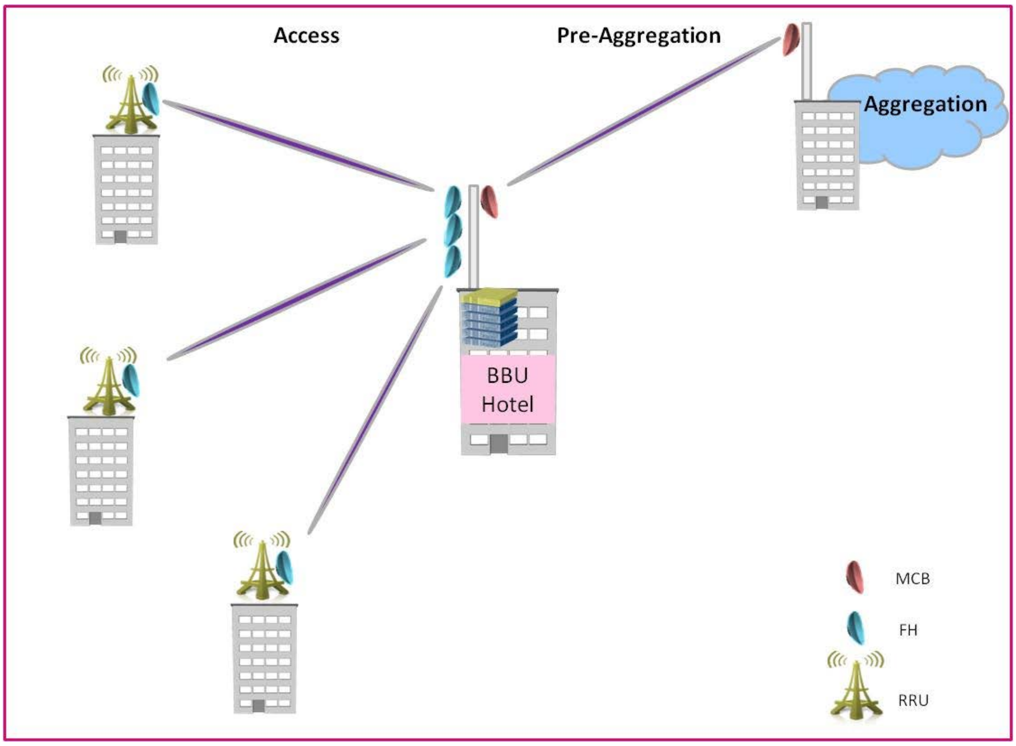

Figure 7: Fronthaul for macro cells application

While a 2G/WCDMA backhaul network is in place, mobile network operators could use fronthaul solutions to serve LTE/LTE-A cells to improve spectral efficiency of a current macro-cell site. Apart from the throughput and latency specifications, this use case has similar requirements to the ones presented in clause 6.1.1 for the macro-cell backhaul use case. Full site configuration addressing LTE/LTE-A fronthaul only could consist of up to 9 RRUs (assuming 3 frequency layers). Again, fronthaul link's latency should be very low.

Table 7: CPRI fronthaul data rate requirements for LTE/LTE-A macro cell configurations

Total Bandwidth (tri-sector site)	MIMO	Fronthaul Line Rate(s) per Channel	Total Fronthaul Data Rate
3x [10 + 20 + 20] MHz	2x2	3x [1 228,8 + 2 457,6 + 2 457,6] Mbps	18 432,0 Mbps
3x [20 + 20 + 20] MHz	2x2	3x [2 457,6 + 2 457,6 + 2 457,6] Mbps	22 118,4 Mbps
3x [20 + 20 + 20] MHz	4x4	3x [4 915,2 + 4 915,2 + 4 915,2] Mbps	44 236,8 Mbps
3x [20 + 20 + 20 + 20] MHz	4x4	3x [4 915,2 + 4 915,2 + 4 915,2 + 4 915,2] Mbps	58 982,4 Mbps

Table 8: OBSAI fronthaul data rate requirements for LTE/LTE-A macro cell configurations

Total Bandwidth (tri-sector site)	MIMO	Fronthaul Line Rate(s) per Channel	Total Fronthaul Data Rate
3x [10 + 20 + 20] MHz	2x2	3x [1 536,0 + 3 072,0 + 3 072,0] Mbps	23 040,0 Mbps
3x [20 + 20 + 20] MHz	2x2	3x [3 072,0 + 3 072,0 + 3 072,0] Mbps	27 648,0 Mbps
3x [20 + 20 + 20] MHz	4x4	3x [6 144,0 + 6 144,0 + 6 144,0] Mbps	55 296,0 Mbps
3x [20 + 20 + 20 + 20] MHz	4x4	3x [6 144,0 + 6 144,0 + 6 144,0 + 6 144,0] Mbps	73 728,0 Mbps

As previously discussed, for RAN equipment that supports standard ORI compression, the respective fronthaul rates are:

Table 9: Fronthaul data rate requirements for LTE/LTE-A macro cell configurations with standard ORI compression

Total Bandwidth (tri-sector site)	MIMO	Fronthaul Line Rate(s) per Channel	Total Fronthaul Data Rate
3x [10 + 20 + 20] MHz	2x2	3x [583,68 + 1 044,48 + 1 044,48] Mbps	8 017,92 Mbps
3x [20 + 20 + 20] MHz	2x2	3x [1 044,48 + 1 044,48 + 1 044,48] Mbps	9 400,32 Mbps
3x [20 + 20 + 20] MHz	4x4	3x [1 966,08 + 1 966,08 + 1 966,08] Mbps	17 694,72 Mbps
3x [20 + 20 + 20 + 20] MHz	4x4	3x [1 966,08 + 1 966,08 + 1 966,08 + 1 966,08] Mbps	24 330,24 Mbps

6.4.2 Use Case 2: Mobile network expansion (new cells)

New LTE/LTE-A cells, possibly together with 2G and/or WCDMA cells, could be served by fronthaul solution, as part of mobile network operators' plans to expand their cellular footprint and augment provisioned over-the-air cellular capacity. The specifications of this use case are identical to the ones presented in clause 6.4.1, but extra care for more capacity per link and CPRI/OBSAI interfaces should be taken, in case 2G/WCDMA cells and/or more LTE frequency layers per site are also to be served by fronthaul solution. Full site configuration having LTE/LTE-A (assuming 3 frequency layers), 2G and WCDMA could have up to 15 RRUs. The additional capacity requirements per site when having 2G and WCDMA technologies along with LTE/LTE-A deployment (assuming all mobile technologies use different frequency layers) are summarized in Table 10 below.

Table 10: 2G/WCDMA fronthaul data rate requirements

Technology	ORI/CPRI Line Rate with 3 RRUs per site	OBSAI Line Rate with 3 RRUs per site
2G 1T1R	614,4 Mbps	768,0 Mbps
WCDMA 1T2R	1 228,8 Mbps	3 072,0 Mbps

Table 11 below presents the fundamental requirements of fronthaul for macro cells application.

Table 11: Fronthaul for macro cells application key requirements

Requirement	Indicative Value	Comment
RF Path Clearance	LOS	to achieve max performance
Connectivity	PtP	to achieve max performance
Capacity	w.r.t. Tables 7, 8, 9 and 10	subject to number/type/channel size/antennas' number of served RRUs
Range	"urban/sub-urban"-oriented	w.r.t to target performance
Availability (at reference physical modulation)	99,99 % - 99,999 %	
Latency (one-way)	very low	w.r.t target RAN implementation/efficiency
Form Factor	typical radio unit	
Automation	self-alignment (optional)	if it improves alignment time over relatively long distances
Spectrum Regulation	interference-managed operation (link/block-allocated)	

6.5 Next-generation mobile transmission applications

Entire ecosystem of the mobile industry is now paving the way towards the standardization of the fifth generation of mobile telecommunications technology, in order to meet the demands of the next decade. The unprecedented growth of mobile traffic is going to be driven by established and new use cases, which will be delivered across a wide range of devices and across a fully heterogeneous environment, see [i.16]. As per [i.17], the potential attributes that would be unique to 5G are sub-1 ms latency and over 1 Gbps DL speed, while the data rate of 10 Gbps is the minimum theoretical upper limit speed discussed for 5G.

Moreover, as discussed in [i.16] in-band backhauling solutions where the radio access shares the same spectrum with the backhaul links are considered as a cost effective solution for deploying a large number of small cells for the 5G capacity solutions. In this context, millimetre wave bands are specifically mentioned as frequency bands of interest, see [i.16].

The above indicate that 5G wireless transmission technologies, either as backhaul or fronthaul, will have to also to adapt significantly to these tremendous changes at both macro-cell and small-cell layers. It is logical that in order to achieve fibre-like performance, 5G wireless transmission technologies will require massive amount of spectrum. Furthermore, as 5G mobile networks will display higher density to accomplish the 1 000x capacity per unit area, see [i.17], a 5G wireless transmission application will benefit from high frequency re-use schemes, dense deployments, new licensed spectrum complemented by unlicensed spectrum according to the layer (small-/macro-cell) that network is developed.

6.6 Fixed broadband application

6.6.1 Use Case 1: Wireless to the home

A fundamental market that is addressed by CSPs is the provision of fixed broadband services to residential in urban and sub-urban environments. On top of this, fixed broadband application covers also broadband connectivity among telephone exchanges and neighbour street cabinets.

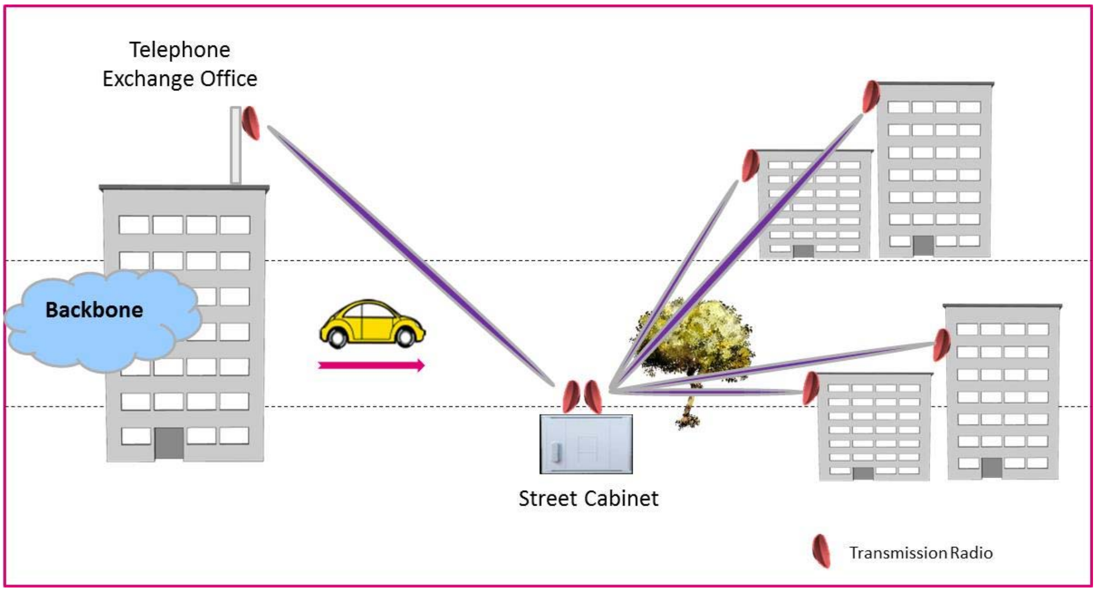

Figure 8: Fixed broadband application

CSPs aim to provide connectivity to residential buildings arriving from adjacent street cabinets, in order for their clients to enjoy services, such as voice, Internet and IPTV. In case, a wireline solution, e.g. VDSL, is not a viable option, wireless technology could fill the gap. Given the street-level environment of this use case, a wireless transmission technology that could support PtP/PtMP topologies, nLOS/NLOS radio propagation conditions and building penetration is desired.

A wireless technology will need to support data rates of up to 1 Gbps that could be shared among different apartments of a multi-dwelling unit. Typically, below 3 ms packet delay and short distances, in the range of 100 metres, will have to be achieved, with availability ranging between 99,9 % - 99,99 %.

Wireless technology form factor and aesthetics are important. Also, a technology that could facilitate easy and fast installation with auto-alignment (beam-forming/beam-steering) mechanisms would be preferred. Equipment power consumption should be low. Zero-cost spectrum would favour this use case.

Table 12: Wireless to the home use case key requirements

Requirement	Indicative Value	Comment
RF Path Clearance	LOS/nLOS/NLOS	plus building penetration
Connectivity	PtP/PtMP	
Capacity	≤ 1 Gbps	
Range	≤ 100 m	
Availability (at reference physical modulation)	99,9 % - 99,99 %	
Latency (one-way)	≤ 3 ms	≤ 1 ms could be needed
Form Factor	"Non-telecom"-shaped unit with built-in antenna	
Automation	Yes	w.r.t. alignment, configuration, optimization, healing, etc.
Spectrum Regulation	Unlicensed	

6.6.2 Use Case 2: Wireless to the cabinet

Relevant to the use case 1 described above (clause 6.6.1), a connection between street cabinet and local telephone exchange office needs to be established. If optical fibre is not available or it is too difficult to deploy, a wireless transmission technology could be employed instead to reach distances in the range of 1 km in urban areas and up to 3 km in sub-urban environment, with typical availability in the range of 99,99 % - 99,999 %. As this would be an aggregation link, a "fat-pipe" at the range of 10 Gbps should be established with packet delay of up to 3 ms. In addition to LOS, nLOS/NLOS radio propagation conditions in PtP configurations are considered applicable for this use case.

The specifications relevant to form factor and auto-alignment (beam-forming/beam-steering) are the same as the ones described in clause 6.6.1, while equipment power consumption should also be low. Interference-managed spectrum would favour this use case.

Table 13: Wireless to the cabinet use case key requirements

Requirement	Indicative Value	Comment
RF Path Clearance	LOS/nLOS/NLOS	
Connectivity	PtP	
Capacity	≤ 10 Gbps	
Range	≤ 1 km (urban) ≤ 3 km (sub-urban)	
Availability (at reference physical modulation)	99,99 % - 99,999 %	
Latency (one-way)	≤ 3 ms	≤ 1 ms could be needed
Form Factor	"Non-telecom"-shaped unit with built-in antenna	
Automation	Yes	w.r.t. alignment, configuration, optimization, healing, etc.
Spectrum Regulation	interference-managed operation (link/block-allocated)	

6.7 Temporary infrastructure application

6.7.1 Use Case 1: Special events

Except for transmission networks that serve their strategic roll-out plans, CSPs might be assigned with the responsibility to support one-off events and emergency situations. In such circumstances, temporary transmission networks should be established timely, thus unlicensed or light-licensed/block-allocated (no-time consuming registration process) massive spectrum is preferred. It is worthwhile mentioning that especially for this application and its relevant use cases the installation of a wireless technology becomes even more important compared to wireline alternatives, since transmission network equipment could be re-used as soon as temporary network is no longer required.

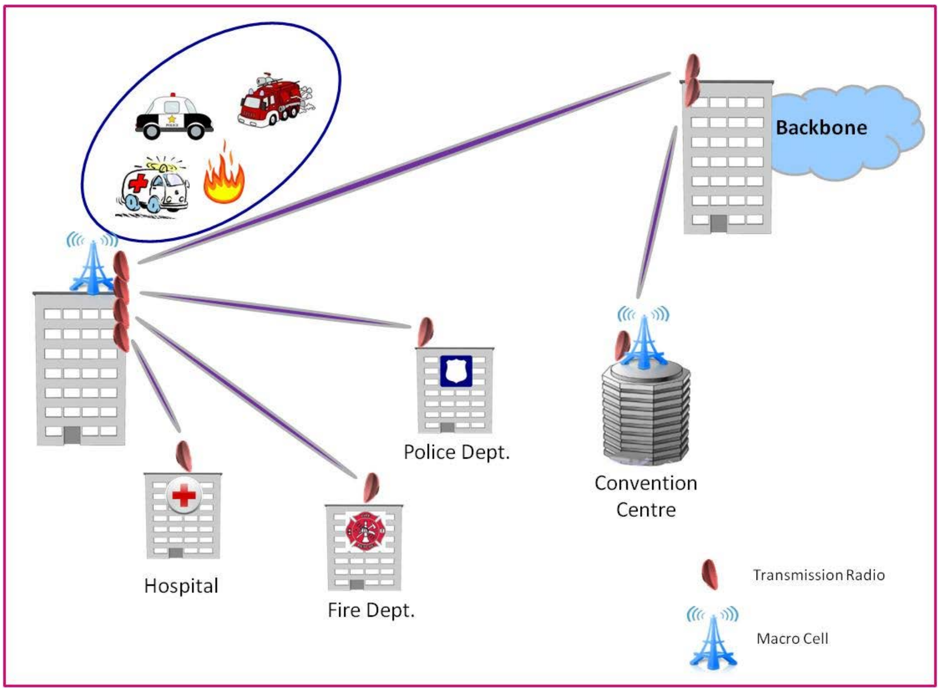

Figure 9: Temporary infrastructure application

During special events, such as congresses, trade fairs, live concerts and sports, broadband services are usually provisioned to the participants. Since these events last from a couple of hours up to several days, high-speed transmission networks have to be built fast to support the short-term broadband data delivery. The target data rates depend on the offered end-user services. For example, if LTE/LTE-A mobile broadband is provided, the requirements are relevant to the ones described previously for mobile transmission applications. On top, if live event is to be broadcasted, HD and increased Ultra HD video content could be transmitted in an uncompressed video format, e.g. over HD-SDI; hence a 1,485 Gbps (or greater) PtP LOS link would be required. The target availability for this service should be high (in the range of 99,999 %).

Table 14: Special events use case key requirements

Requirement	Indicative Value	Comment
RF Path Clearance	LOS	
Connectivity	PtP	
Capacity	very high (e.g. 1,485 Gbps for video content)	more capacity subject to offered services, e.g. LTE/LTE-A requirements
Availability (at reference physical modulation)	~99,999 %	
Latency (one-way)	subject to offered services, e.g. LTE/LTE-A requirements	
Spectrum Regulation	unlicensed/light licensing (link)/block-allocated spectrum	

6.7.2 Use Case 2: Public safety

Public safety organizations, including police, fire departments, rescue squads, Emergency Medical Services, have to cope with dire situations once severe natural disasters occur. To accomplish their critical mission, public safety communications are needed, thus reliable transmission networks of high data rate and low latency performance should be built on-time. The target availability for this type of service should be in the range of 99,999 %.

Table 15: Public safety use case key requirements

Requirement	Indicative Value	Comment
Capacity/Latency	very important	e.g. LTE/LTE-A requirements
Availability (at reference physical modulation)	~99,999 %	
Spectrum Regulation	unlicensed/light licensing (link)/block-allocated spectrum	

6.8 Business-to-business application

Private sector (enterprises, private organizations) represents an important market segment for the provision of broadband connections. Typically, the connectivity is realized between a central PoP and a private company's remote site (rooftop level). Direct connections among private company's branches could also be implemented.

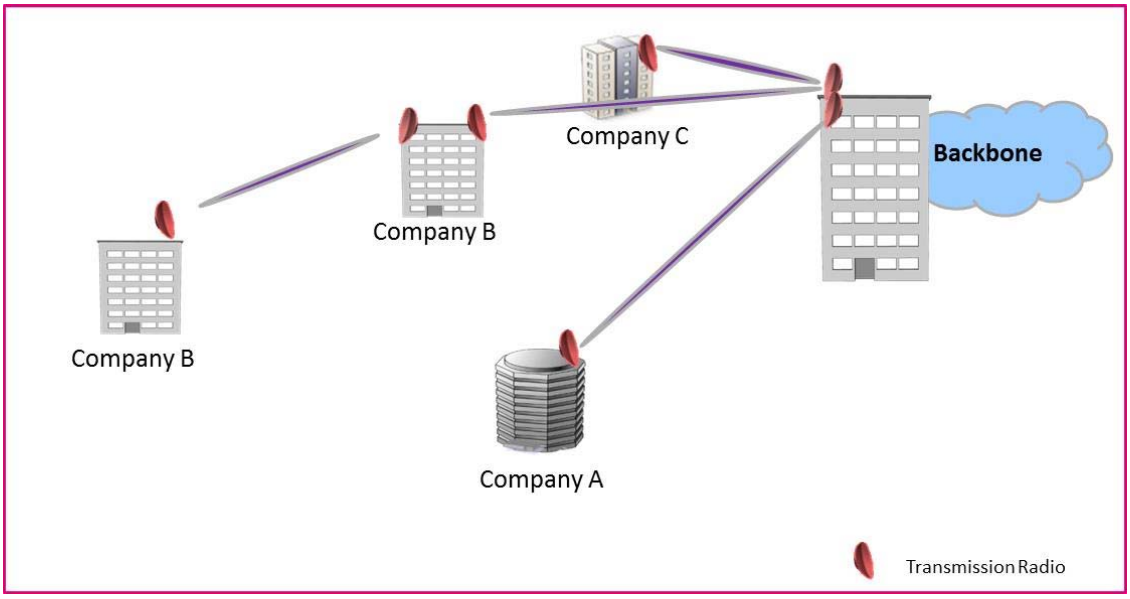

Figure 10: Business-to-business application

Transmission distances range from a few hundred metres up to several kilometres in urban and sub-urban environments and target availability figures are subject to agreed SLAs (99 % at the minimum). Service models with regards to offered throughput figures vary and could be several Mbps and as high as 10 Gbps per business customer. Similarly to use case 1 in clause 6.6.1, reduced recurring costs and rapid time to market are crucial factors for the selection of the appropriate technology, thus zero-cost or low-cost spectrum is preferred.

Table 16: Business-to-business application key requirements

Requirement	Indicative Value	Comment
RF Path Clearance	LOS	
Connectivity	PtP/PtMP	
Capacity	several Mbps up to 10 Gbps	
Range	"urban/sub-urban"-oriented	
Availability (at reference physical modulation)	≥ 99 %	
Spectrum Regulation	unlicensed/light licensing (link)/block-allocated spectrum	

6.9 Business-to-government application

6.9.1 Use Case 1: Broadband connectivity to governmental buildings

Government organizations require broadband services, like voice, Internet, videoconferences, as well as interconnectivity among public buildings. Throughput rates and availability figures are provided in the similar concept as of B2B application described in clause 6.8.

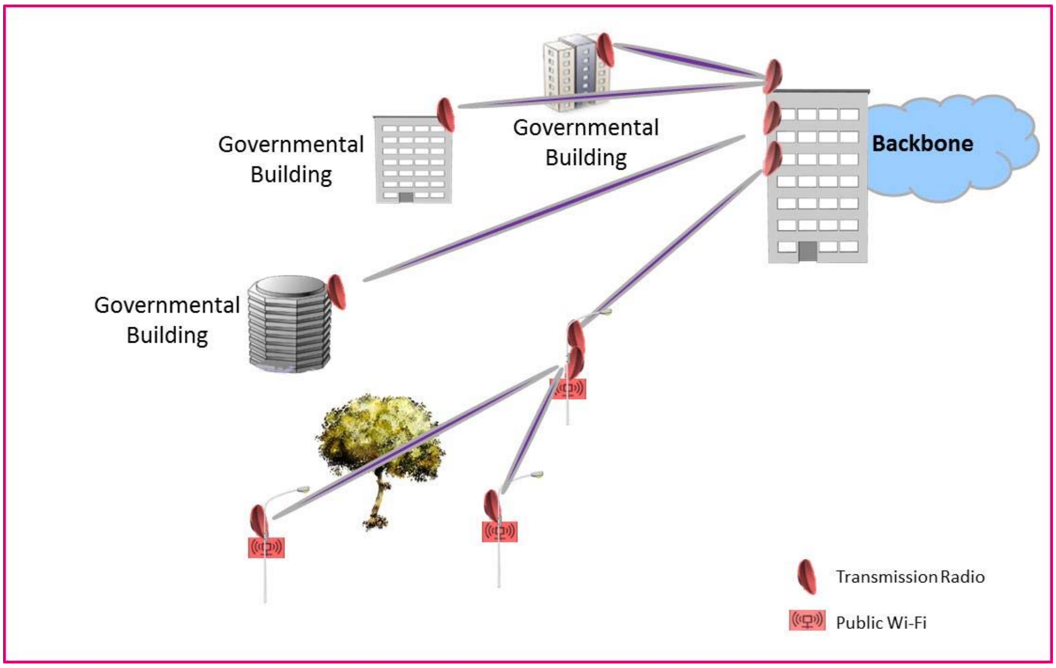

Figure 11: Business-to-government application

Table 17: Broadband connectivity to governmental buildings use case key requirements

Requirement	Indicative Value	Comment
RF Path Clearance	LOS	
Connectivity	PtP/PtMP	
Capacity	several Mbps up to Gbps-level	
Range	"urban/sub-urban"-oriented	
Availability (at reference physical modulation)	≥ 99 %	
Spectrum Regulation	unlicensed/light licensing (link)/block-allocated spectrum	

6.9.2 Use Case 2: Public Wi-Fi hotspot backhaul

Municipalities throughout the world are keen on providing Internet access over Wi-Fi technology. Outdoor Wi-Fi hotspots are placed in facilities like parks, squares and along major shopping streets. In case, fibre cannot be deployed, a high-capacity wireless transmission technology could be used to backhaul the Wi-Fi access points. Backhaul equipment's form factor, low power consumption and ease of installation (auto-alignment) are important attributes, especially when deployment is realized in places classified as historic heritage sites. Free/low-cost spectrum could be an advantage, since this service is often offered as free of charge, whilst PtP/PtMP/mesh and LOS/nLOS/NLOS configurations would benefit this use case.

Table 18: Public Wi-Fi hotspot backhaul use case key requirements

Requirement	Indicative Value	Comment
RF Path Clearance	LOS/nLOS/NLOS	
Connectivity	PtP/PtMP/mesh	
Capacity	nx 50 Mbps (DL)	subject to number/type/channel size/antennas' number of served APs
Range	"urban"-oriented	
Availability (at reference physical modulation)	≥ 99 %	
Form Factor	"Non-telecom"-shaped unit with built-in antenna	
Automation	Yes	w.r.t. alignment, configuration, optimization, healing, etc.
Spectrum Regulation	unlicensed/light licensing (link)/block-allocated spectrum	

6.10 Redundant network application

CSPs might need to maximize availability for certain applications by creating two parallel networks, a primary and a secondary one. The primary path relies on optical fibre medium and the backup network is based on wireless technology that will handle traffic only if primary path fails.

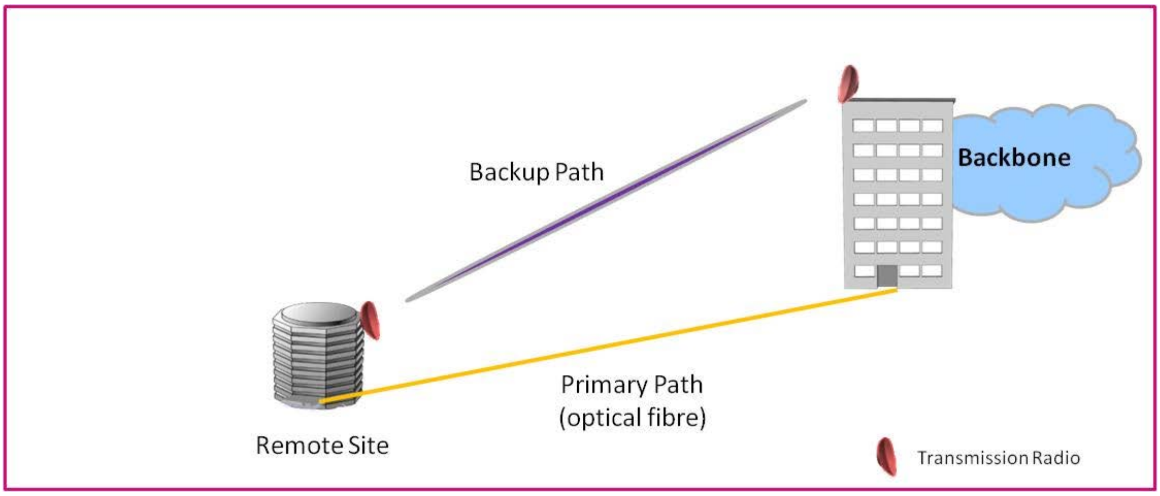

Figure 12: Redundant network application

Fibre-like performance is therefore required by the wireless technology that would be used as redundant transmission network. Typically, combined availability of the two parallel paths should be high (for instance, 99,999 %) and this should be taken into account when calculating the target availability of millimetre wave link as backup path.

Table 19: Redundant network application key requirements

Requirement	Indicative Value	Comment
RF Path Clearance	LOS	
Connectivity	PtP	
Capacity/Latency	Very important	"fibre-like" performance
Availability (at reference physical modulation)	subject to target availability of the two parallel paths	
Spectrum Regulation	subject to end-user application	

6.11 Video surveillance backhaul application

Video surveillance cameras are adopted by public and private organizations in a number of cases. For instance, traffic monitoring and surveillance of specific areas (e.g. cities' central districts, parking spaces) are two of the most important ones. A crucial factor to accomplish target performance in an outdoor environment (metropolitan area, university campus, industrial plant, etc.) is the efficiency of backhaul network that routes entire traffic back to a remote surveillance centre.

Capacity per site (uplink here is more bandwidth-intensive) largely depends on the number of cameras per location and each camera's capabilities (e.g. frame rate, resolution, video compression algorithm and so forth). Indicatively, an uplink data rate could be approximately 50 Mbps for a single camera (assuming H.264 compression format, 30 fps frame rate, 10 megapixels resolution) at high link availability figure (e.g. 99,999 %). Furthermore, PtP/PtMP/mesh topologies and LOS/nLOS/NLOS radio propagation conditions are desired transmission properties for this application. Wireless technology form factor and aesthetics have to blend into the environment of deployment. Also, a technology that could ensure easy, discreet and fast installations with auto-alignment (beam-forming/beam-steering) mechanisms could be advantageous. Equipment power consumption should be low. Zero-cost or light-licensed/block-allocated spectrum would favour this use case.

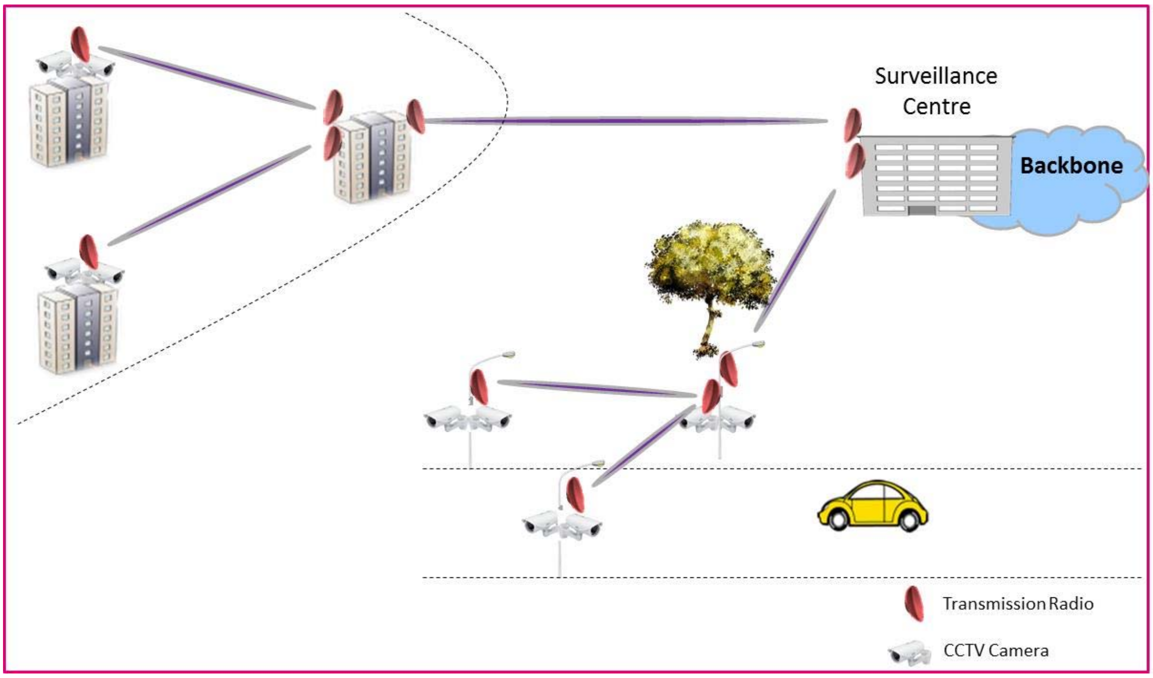

Figure 13: Video surveillance backhaul application

Table 20: Video surveillance backhaul application key requirements

Requirement	Indicative Value	Comment
RF Path Clearance	LOS/nLOS/NLOS	
Connectivity	PtP/PtMP/mesh	
Capacity	several Mbps (UL)	subject to number/type of served video cameras
Availability (at reference physical modulation)	~99,999 %	
Form Factor	"Non-telecom"-shaped unit with built-in antenna	
Automation	Yes	w.r.t. alignment, configuration, optimization, healing, etc.
Spectrum Regulation	unlicensed/light licensing (link)/block-allocated spectrum	

6.12 TV signal relay application

Television broadcast systems typically transmit TV signals from broadcast venue (e.g. inside urban and sub-urban environments) to a central broadcast station.

With respect to total transmission distance, intermediate relay links could be installed as well. Moreover, if high-definition content has to be relayed, TV signals could be transported over their native format to guarantee optimum video quality. As a result, wireless transmission technology needs to provide high data rates and availability figures, like the use case described in clause 5.7.1.

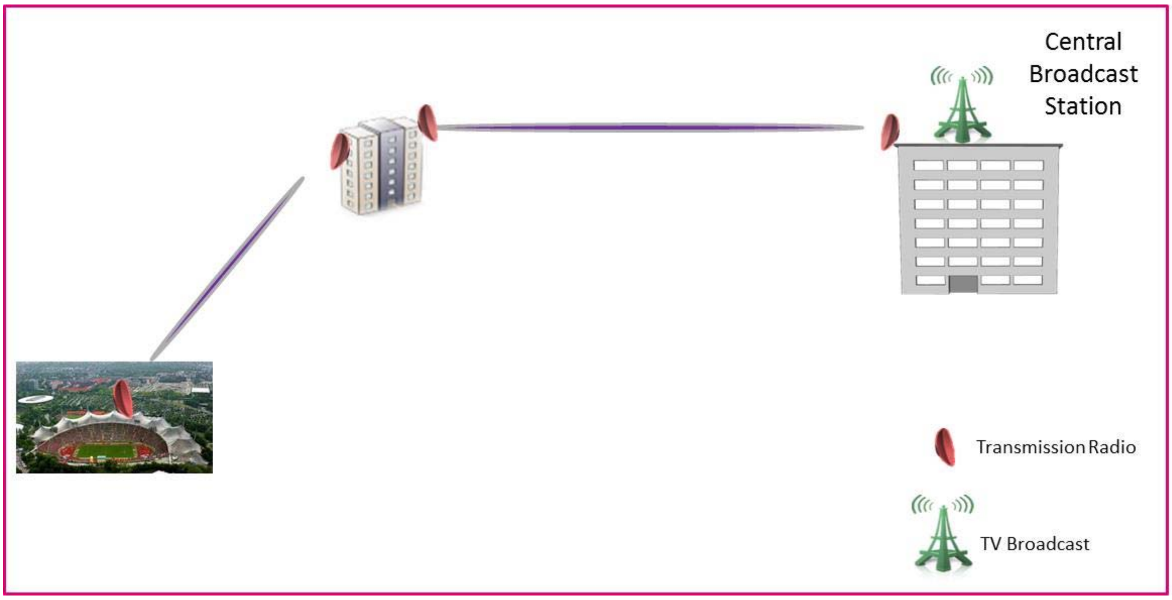

Figure 14: TV signal relay application

Table 21: TV signal relay application key requirements

Requirement	Indicative Value	Comment
RF Path Clearance	LOS	
Connectivity	PtP	
Capacity	(can be) very high (e.g. uncompressed HD video)	subject to video format
Availability (at reference physical modulation)	~99,999 %	
Spectrum Regulation	unlicensed/light licensing (link)/block-allocated spectrum	

7 Millimetre wave spectrum technology enablers for transmission applications and use cases

Network design and implementation practices indicate that there is no single transmission technology that can fulfil the requirements of each application and use case. With regards to characteristics and advantages of millimetre wave spectrum technology, as described in clause 4, Table 22 displays its potential enablers for various transmission applications and use cases.

Table 22: Enablers for millimetre wave spectrum technology

Index	Enabler	Reason
[E1]	Multi-Gbps capacity and sub-ms latency performance of millimetre wave spectrum technology	Packet-based transmission applications that require very high data rates and benefit from low packet delay
[E2]	"10 Gbps"-level capacity possible for millimetre wave spectrum technology	Exceptionally high capacity requirements (e.g. RAN evolution) could be satisfied over wireless medium
[E3]	"Well-below 100 us"-level one-way latency possible for millimetre wave spectrum technology	Exceptionally strict latency requirements (e.g. fronthaul) could be satisfied over wireless medium
[E4]	Lack of fibre	Fibre could be impossible or too costly and time-consuming to be deployed (mainly at last-mile, but in particular scenarios a second hop could be assumed, as well) or temporary infrastructure is needed
[E5]	Need of high frequency re-use and network densification	Millimetre wave spectrum technology could be chosen in certain transmission deployment scenarios (e.g. HetNets) that benefit from highly dense and increased frequency re-use deployments, especially where there is lack of required spectral efficiency (bps/Hz) or non-economical cost per Hz at traditional microwave bands
[E6]	"Non-telecom"-shaped equipment form factor/aesthetics	Millimetre wave spectrum technology facilitates design of compact full-outdoor form factor equipment that blends into urban environment, which becomes important mainly for street-level transmission applications
[E7]	Optimized TCO and rapid time-to-market of broadband services	Millimetre wave transmission contributes to TCO optimization and services' time to market acceleration due to regulation schemes that embrace free (unlicensed) or low-cost (light licensed) spectrum and simplified registration (no time-consuming) processes, which are crucial for transmission applications

A broad number and type of wireless transmission applications and use cases could be served by millimetre wave spectrum technology. With reference to Table 22, the potential enablers of millimetre wave spectrum technology for each transmission application/use case described in clause 5 are collected in Table 23.

Table 23: Millimetre wave spectrum technology enablers mapping to applications/use cases

Application	Use Case	Enabler Index
Macro-cell mobile backhaul application	Mobile network upgrade (existing cells)	*[E1], [E4], [E5], [E7]*
	Mobile network expansion (new cells)	*[E1], [E4], [E5], [E7]*
Small-cell mobile backhaul application	Rooftop-to-street/Street-to-street connectivity	*[E1], [E4], [E5], [E6], [E7]*
	Multi-hop (in-clutter extensions)	*[E1], [E4], [E5], [E6], [E7]*
Fronthaul for small cells application	Rooftop-to-street/Street-to-street connectivity	*[E1], [E2], [E3], [E4], [E5], [E6], [E7]*
	Multi-hop (in-clutter extensions)	*[E1], [E2], [E3], [E4], [E5], [E6], [E7]*
Next-generation mobile transmission applications	5G back-/front-haul at macro-/small-cell layer	*[E1], [E2], [E3], [E4], [E5], [E6], [E7]*
Fixed broadband application	Wireless to the home	*[E1], [E4], [E5], [E6], [E7]*
	Wireless to the cabinet	*[E1], [E2], [E4], [E5], [E6], [E7]*
Temporary infrastructure	Special events	*[E1], [E4], [E5], [E7]*
	Public safety	*[E1], [E4], [E5], [E7]*
B2B		*[E1], [E2], [E4], [E5], [E7]*
B2G	Broadband connectivity to governmental buildings	*[E1], [E4], [E5], [E7]*
	Public Wi-Fi hotspot backhaul	*[E1], [E4], [E5], [E6], [E7]*
Redundant network		*[E1], [E2], [E3], [E5], [E7]*
Video surveillance backhaul		*[E1], [E4], [E5], [E6], [E6], [E7]*
TV signal relay		*[E1], [E4], [E5], [E7]*

8 Conclusions

Globally the demand for broadband data will continue to increase as end-user applications become more capacity-intensive, new uses cases will emerge and the penetration of data-capable devices is expected to boost. Technology advancements in mobile and fixed domains aim to fulfil the upcoming needs and contribute to the increased capacity demand.

Fixed transmission networks represent a fundamental link of the entire network chain. Therefore, they have to be transformed to meet the foreseeable demands and be prepared before the latter appear. It is envisioned that as world becomes more digital, a wider range of capacity-significant transmission applications will have to be established in an area, making the requirement of top-class performance transmission technologies that favour dense architectures even more vital.

The millimetre wave frequency range provides massive and underutilized spectrum that can be engineered to deliver multi-Gbps throughput over the air, while its radio propagation properties facilitate network densification. Nevertheless, it seems that millimetre wave transmission industry is still in its early phase, see [i.1], despite the fact that more than a century has passed since the realization of the first experiment at millimetre wave frequency range, see [i.18].

With respect to the aforementioned, the mission of ETSI ISG mWT is to promote the use of millimetre wave spectrum from 50 GHz up to 300 GHz for present and future critical transmission applications and use cases. Moreover, ETSI ISG mWT will focus on enhancing the confidence of all stakeholders and the general public in the use of millimetre wave technologies, see [i.1].

The present document has analysed each potential wireless transmission application and use case that could be served by millimetre wave spectrum technology in an efficient manner. It should be pointed out though that in the future, as transmission networks become denser having to deliver very high data rates, additional ones could turn up and be included, as well.

Furthermore, key requirements of each transmission application and use case were provided, setting in parallel the objectives for the millimetre wave transmission technology. More, millimetre wave spectrum and technology properties and benefits were described. Finally, enablers of millimetre wave spectrum technology were mapped to each transmission application and use case, highlighting the main drivers for employing millimetre wave spectrum technologies into transmission network and explaining why applications and use cases could benefit from them.

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