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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Access, Terminals, Transmission and Multiplexing (ATTM).

Modal verbs terminology

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Introduction

The present document studies the main characteristics of the Small Cell Backhauling.

1 Scope

The present document investigates the possible impacts to standard documentations in charge to ETSI TM4 working group.

The starting point is represented by the definition of Small Cell coming from Standards, Mobile Operators and Technical Literature and the characterization of one or more (maximum three) deployment scenario(s).

Preliminary studies, based on recognized Small Cell backhauling requirements, would be carried on within TM4 and, whenever encouraging results happen, other SDO's, e.g. ECC SE19, will be involved for possible review of the issues from regulatory point of view.

Frequency bandwidths from sub 6 GHz, trough traditionally coordinated MW bands (6 GHz to 56 GHz) and up to mmWV (above 57 GHz) are inside the scope of the present document.

Satellite, White Space, WiFi applications and frequency bands together with Wired solutions are considered out of the scope of the present document.

Backhaul carried on by Point to Multipoint systems, and backhaul realized by means of complex system mechanisms (e.g. multiple distributed MIMO) are outside the scope of the present document.

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] NGMN White Paper: "Small Cell Backhaul Requirements", June 2012.

[i.2] NGMN White Paper: "Guidelines for LTE Backhaul Traffic Estimation", July 2010.

[i.3] Report ITU-R M.2290-0: "Future spectrum requirements estimate for terrestrial IMT".

[i.4] ETSI EN 302 217-4-2 (V1.5.1): "Fixed Radio Systems; Characteristics and requirements for point-to-point equipment and antennas; Part 4-2: Antennas; Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive".

[i.5] ETSI EN 302 217-4-1: "Fixed Radio Systems; Characteristics and requirements for point-to-point equipment and antennas; Part 4-1: System-dependent requirements for antennas".

[i.6] Recommendation ITU-R P.530: "Propagation data and prediction methods required for the design of terrestrial line-of-sight systems".

[i.7] Recommendation ITU-R P.526: "Propagation by diffraction".

[i.8] Recommendation ITU-R P.1410: "Propagation data and prediction methods required for the design of terrestrial broadband radio access systems operating in a frequency range from 3 to 60 GHz".

[i.9] Recommendation ITU-R P.1411: "Propagation data and prediction methods for the planning of short-range outdoor radiocommunication systems and radio local area networks in the frequency range 300 MHz to 100 GHz".

[i.10] ETSI TS 133 401: "3GPP System Architecture Evolution (SAE); Security architecture". Digital cellular telecommunications system (Phase 2+); Universal Mobile Telecommunications System (UMTS); LTE; 3GPP System Architecture Evolution (SAE); Security architecture (3GPP TS 33.401).

[i.11] Recommendation ITU-R M.1768-1: "Methodology for calculation of IMT spectrum".

[i.12] ECC/REC/14-03: "Harmonised radio frequency channel arrangements and block allocations for low and medium capacity systems in the band 3400 MHz to 3600 MHz".

[i.13] CEPT/ERC/REC 12-08: "Harmonised radio frequency channel arrangements and block allocations for low, medium and high capacity systems in the band 3600 MHz TO 4200 MHz".

[i.14] ECC/REC/(14)01: "Radio frequency channel arrangements for FS systems operating in the band 92-95 GHz".

[i.15] ECC/REC 14-02: "Radio frequency channel arrangements for high, medium and low capacity digital fixed service systems operating in the band 6425 to 7125 MHz".

[i.16] ECC/REC/(02)06: "Channel arrangements for digital fixed service systems operating in the frequency range 7125 -8500 MHz".

[i.17] CEPT/ERC/REC 12-05: "Harmonised radio frequency channel arrangements for digital terrestrial fixed systems operating in the band 10.0 - 10.68 GHz".

[i.18] ERC/REC 12-06: "Preferred channel arrangements for fixed service systems operating in the frequency band 10.7-11.7 GHz".

[i.19] ERC/REC 12-02: "Harmonised radio frequency channel arrangements for analogue and ditigal terrestrial fixed systems operating in the band 12.75-13.25 GHz".

[i.20] ERC/REC 12-07: "Harmonised radio frequency channel arrangements for digital terrestrial fixed systems operating in the bands 14.5 - 14.62 GHz paired with 15.23 - 15.35 GHz".

[i.21] CEPT/ERC/REC 12-03: "Harmonised radio frequency channel arrangements for digital terrestrial fixed systems operating in the band 17.7 GHz to 19.7 GHz".

[i.22] Recommendation T/R 13-02: "Preferred channel arrangements for fixed service systems in the frequency rang 22.0 - 29.5 GHz".

[i.23] ECC/REC/(11)01: "Guidelines to FWS in 24.5-26.5/ 27.5-29.5/ 31.8-33.4 GHz".

[i.24] ERC/REC(01)02: "Preferred channel arrangements for fixed service systems operating in the frequency band 31.8 - 33.4 GHz".

[i.25] Recommendation T/R 12-01: "Preferred channel arrangements for fixed service systems operating in the frequency band 37.0 - 39.5 GHz".

[i.26] ECC Recommendation (01)04: "Recommended guidelines for the accommodation and assignment of multimedia wireless systems (MWS) and point-to-point (P-P) fixed wireless systems in the frequency band 40.5 - 43.5 GHz".

[i.27] ERC Recommendation 12-11: "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.28] ERC Recommendation 12-12: "Radio frequency channel, arrangement for Fixed Service Systems operating in the band 55.78 to 57.0 GHz".

[i.29] ECC/REC/(09)01: "Use of the 57 - 64 GHz frequency band for point-to-to point fixed wireless systems".

[i.30] ECC/REC/(05)02: "Use of the 64-66 GHz frequency band for fixed service".

[i.31] ECC/REC/(05)07: "Radio frequency channel arrangements for fixed service systems operating in the bands 71-76 GHz and 81-86 GHz".

[i.32] Recommendation ITU-R F.635-6: "Radio-frequency channel arrangements based on a homogeneous pattern for fixed wireless systems operating in the 4 GHz (3 400-4 200 MHz) band".

[i.33] Recommendation ITU-R F.382-8: "Radio-frequency channel arrangements for fixed wireless systems operating in the 2 and 4 GHz bands".

[i.34] Recommendation ITU-R F.1099-4: "Radio-frequency channel arrangements for high- and medium-capacity digital fixed wireless systems in the upper 4 GHz (4 400-5 000 MHz) band".

[i.35] Recommendation ITU-R F.383-8: "Radio-frequency channel arrangements for high-capacity fixed wireless systems operating in the lower 6 GHz (5 925 to 6 425 MHz) band".

[i.36] Recommendation ITU-R F.384-11: "Radio-frequency channel arrangements for medium- and high- capacity digital fixed wireless systems operating in the the 6 425-7 125 MHz band".

[i.37] Recommendation ITU-R F.385-10: "Radio-frequency channel arrangements for fixed wireless systems operating in the 7 110-7 900 MHz band".

[i.38] Recommendation ITU-R F.386-8: "Radio-frequency channel arrangements for fixed wireless systems operating in the 8 GHz (7 725 to 8 500 MHz) band".

[i.39] Recommendation ITU-R F.747-1: "Radio-frequency channel arrangements for fixed wireless system operating in the 10.0-10.68 GHz band".

[i.40] Recommendation ITU-R F.387-12: "Radio-frequency channel arrangements for fixed wireless systems operating in the 10.7-11.7 GHz band".

[i.41] Recommendation ITU-R F.497-7: "Radio-frequency channel arrangements for fixed wireless systems operating in the 13 GHz (12.75-13.25 GHz) frequency band".

[i.42] Recommendation ITU-R F.636-4: "Radio-frequency channel arrangements for fixed wireless systems operating in the 14.4-15.35 GHz band".

[i.43] Recommendation ITU-R F.595-10: "Radio-frequency channel arrangements for fixed wireless systems operating in the 17.7-19.7 GHz frequency band".

[i.44] Recommendation ITU-R F.637-4: "Radio-frequency channel arrangements for fixed wireless systems operating in the 21.2-23.6 GHz band".

[i.45] Recommendation ITU-R F.748-4: "Radio-frequency arrangements for systems of the fixed service operating in the 25, 26 and 28 GHz bands".

[i.46] Recommendation ITU-R F.746-10: "Radio-frequency arrangements for fixed service systems".

[i.47] Recommendation ITU-R F.1520-3: "Radio-frequency arrangements for systems in the fixed service operating in the band 31.8-33.4 GHz".

[i.48] Recommendation ITU-R F.749-3: "Radio-frequency arrangements for systems of the fixed service operating in sub-bands in the 36-40.5 GHz band".

[i.49] Recommendation ITU-R F.2005: "Radio-frequency channel and block arrangements for fixed wireless systems operating in the 42 GHz (40.5 to 43.5 GHz) band".

[i.50] Recommendation ITU-R F.1496-1: "Radio-frequency channel arrangements for fixed wireless systems operating in the band 51.4-52.6 GHz".

[i.51] Recommendation ITU-R F.1497-1: "Radio-frequency channel arrangements for fixed wireless systems operating in the band 55.78-66 GHz".

[i.52] Recommendation ITU-R F.2006: "Radio-frequency channel and block arrangements for fixed wireless systems operating in the 71-76 and 81-86 GHz bands".

[i.53] Recommendation ITU-R F.2004: "Radio-frequency channel arrangements for fixed service systems operating in the 92-95 GHz range".

3 Abbreviations

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

BS	Base Station
BW	BandWidth
ECC	Electronic Communications Committee
EM	Electro Magnetic (Field)
FDD	Frequency Division Duplex
FS	Fixed Service
FSL	Free Space Loss
HH	Horizontal Horizontal (Polarization)
HSPA	High Speed Packet Access
IMT	International Mobile Technology
ITS	Intelligent Transportation System
LOS	Line Of Sight
MIMO	Multiple Input Multiple Output
mmWV	millimetre WaVe
MW	MicroWave
NGMN	New Generation Mobile Networks
NLOS	Non Line Of Sight
QAM	Quadrature Amplitude Modulation
QoE	Quality of Experience
RF	Radio Frequency
SDO	Standard Developing Organization
TDD	Time Division Duplex
TR	Technical Report
TS	Technical Standard
UTD	Uniform Theory of Diffraction
VV	Vertical Vertical (Polarization)
XPIC	Cross-Polar Interference Cancellor

4 Small Cell Application Scenario

4.1 Small Cell Definition

Small Cell definition is an input definition from SDO's, Mobile Operators and Technical Literature: "Small cells" is an umbrella term for operator-controlled, low-powered radio access nodes, including those that operate in licensed spectrum and unlicensed carrier-grade Wi-Fi.

Small cells are felt as a solution to cope with expected evolution of mobile networks, which will need higher traffic densities than today.

Such traffic management could greatly benefit from provision of cells much smaller than actual macrocells, avoiding the necessity of increasingly complex equipment to control a very high number of access devices in a big cell.

Small cells are generally understood as low-powered radio access nodes operating in licensed and unlicensed spectrum, with a range of 10 to several hundred meters in urban applications, up to few kms outside, while actual mobile macro cell might have a range of a few tens of kilometres.

NOTE: The range should be met the coverage requirement stated later.

To support the growth in mobile data traffic, mobile operators are using data off-load techniques as more efficient way to use spectrum resources.

Data off-loading will be predominant in very dense urban areas but small cell may have also a role in coverage lacks in rural areas.

In literature it is possible to find some different types of small cell:

- femtocells;
- picocells;
- microcells.

In the present document the interest is focused on hot spot (under macro Base station coverage) and not spot (without macro Base station coverage) and not on residential/enterprise or distributed-antenna systems (DAS)/fronthaul scenarios.

Such small cells can be controlled by small size devices, capable of allowing easy installations in urban contexts, such as area coverage can be increased and higher capacity can be made available, provided that backhaul network has sufficient traffic transport capability.

Backhaul is needed to connect the small cells to the macro base station or to other network nodes /points of presence (e.g. other small cell acting as hub or other equipment).

Mobile operators, network planners and vendors often consider backhaul provision for small cells more challenging than usual macrocell backhaul, due to the expected high number of installations, because:

- There could be a need for many small cells to be installed in hard-to-reach and less protected positions, near street level, rather than in the clear and isolated locations above rooftops (NLOS situation may happen frequently, pointing stability is not guaranteed…).
- Carrier grade connectivity, comparable to macro base station targets, needs to be provided at much lower cost per bit.

An example of network including small cells is shown in figure 1.

Together with a traditional macro cell and network point of presence (PoP), some small cells are included, connected to realize different topologies: star, linear, redundant linear and mesh.

Concerning connection links, four kinds are shown: type A connections require backhaul for a single small cell, type B require backhaul for more than one small cell, type C and D represent traffic aggregation with higher capacity.

In this example, only type A and B are provided by radio, although in principle, there is no preclusion for implementing also C and D type of connection by radio, provided that sufficient capacity and performance level can be guaranteed.

Conversely, also connection types A and B can be realized by cables/fibres, depending on specific installation /location constrains.

Many different wireless and wired technologies have been proposed as solutions for future networks, and it is common understanding that a "toolbox" of all possible available technologies will be needed to cover efficiently the overall range of deployment scenarios.

Hereafter only wireless backhaul solution issues will be investigated.

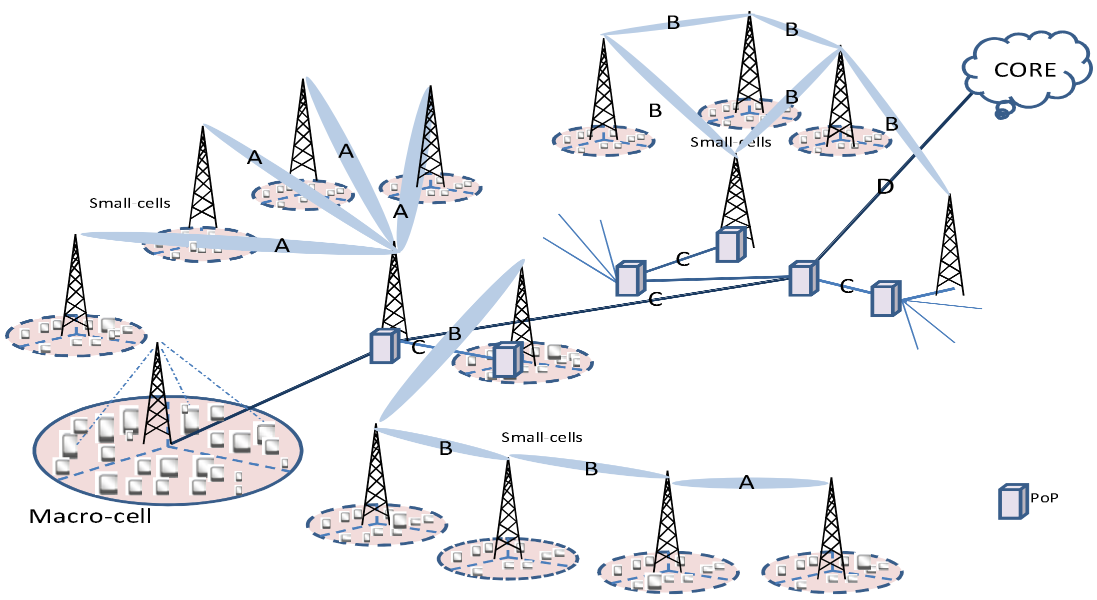


Figure 1: Example of network including small cells

4.2 Small Cell Use Cases Choice

Few small cell use cases are proposed in figure 2 and the connection types are described in the following table 1.

Both LOS and NLOS conditions are considered and in NLOS case use cases also diffraction, penetration and reflection propagation models are included (figure 3).

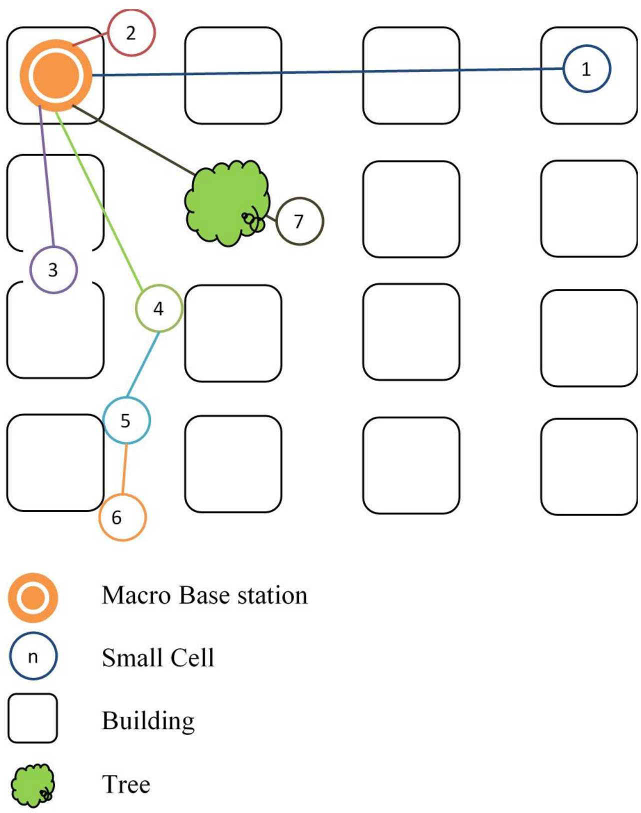


Figure 2: Examples of Small cells use cases

Table 1: Macro Base station and Small Cells connection types

Small Cell Number	Macro Base station Visibility	Other Small Cell Visibility	Note
1	LOS	None	Roof to roof
2	NLOS	LOS to 4	Reflection
3	NLOS	NLOS to 4	Diffraction
4	NLOS	LOS to 2, 5 & 6 / NLOS to 3	Diffraction
5	NLOS	LOS to 4 & 6	
6	NLOS	LOS to 4 &5	
7	NLOS	None	Penetration

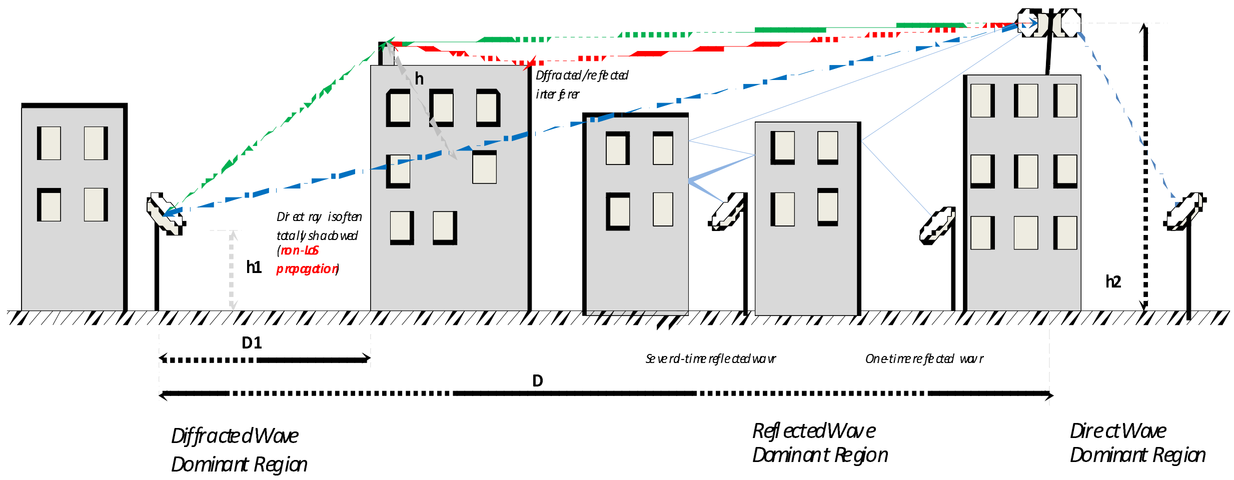


Figure 3:Typical Propagation Situation

4.3 Small Cell Backhauling Requirements

4.3.0 General

Characteristics of traffic to be transported are essential to fix requirements.

If a single small cell is considered, the traffic behaviour is variable, depending on density and use of access customers.

In particular, measurements have shown that meaningful variations in user plane traffic exists between a 'busy time loaded' state (high density of people accessing the cell working hours, Sundays) and a 'quiet time' (few subscribers active, e.g. late evening, night) state.

The highest backhaul throughputs are generated during the quiet time, when the cell is serving a single user in good signal conditions and there is low interference from other cells. In these conditions, cells can use most efficient transmission condition (like higher spectral density) for very few users, generating peak rates in order of hundreds of Mbps for some configurations.

During busy times, some users experience poor signal conditions and the cell's average spectral efficiency decreases. Measurements have confirmed this expectation from theory.

In addition, busy time traffic is concentrated in same time for all cells in a macrocell, while quiet time peaks tend to be uncorrelated.

Measured backhaul traffic generated during busy time from a single small cell (HSPA and LTE) is about 34 Mbit/s, while during peak quiet time is in the order of 190 Mbit/s. In general, it is assumed that the "small cell" (named eNodeB) is composed by 3 single cells covering 120 degrees, generating a 360 degrees coverage.

4.3.1 Capacity

LTE Access Network technologies is considered as the service to be backhauled. Also LTE evolution (LTE Advanced) may be considered.

Since small cell backhauling is intended to allow increasing network throughput and coverage, ideally, the capacity of the small cell would not be constrained by the backhaul.

In particular, backhaul should be dimensioned to carry both busy time traffic for all cells and quiet time peaks.

In order to fix a reasonable target for required capacity, some considerations are necessary on foreseen number of cells per macrocell. Recent studies on behalf indicate that less than seven cells should cover, in principle, most cases at least up to year 2019.

As a guideline, the following rule has been suggested for satisfactory backhaul of N small cells:

Capacity = Max (peak, N x busy time mean)

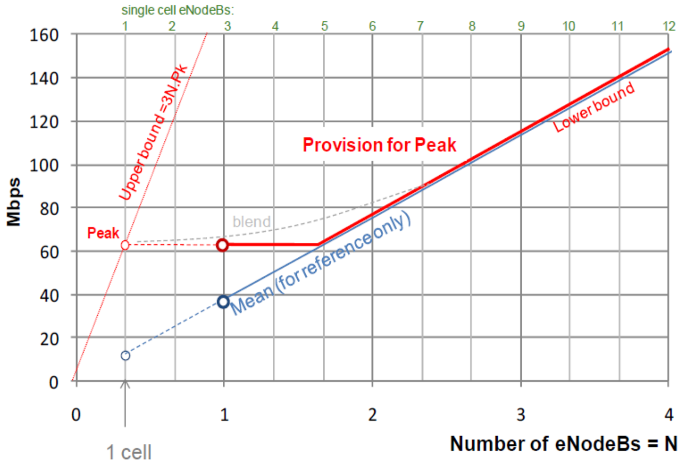


Figure 4: Required capacity [i.1]

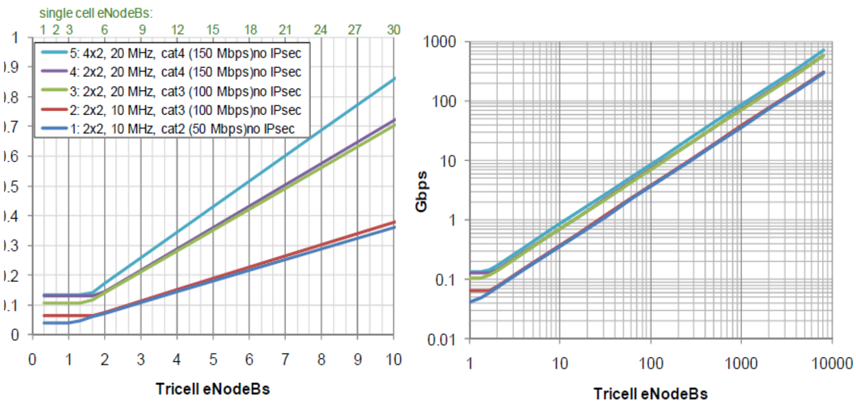


Figure 5: Required capacity [i.1]

Figures 4 and 5 (from report NGMN [i.1]) show required capacity according above principles as a function of served small cells.

Considerations above are based on measurements on LTE applications.

Even higher capacities are expected from future applications, like in IMT- advanced oriented networks, due the high demanding spectrum requirement by some service types ("uncompressed transmission") and the high density of devices expected in certain urban areas (see Report ITU-R M. IMT.2290 [i.3] and Recommendation ITU-R M.1768-1 [i.11]).

4.3.2 Latency and delay

Recommended packet delay budgets for various service types represented by the different Quality Class Indicators (QCIs) used by LTE/EPC to label traffic priorities can be found in literature. The most stringent of these is the gaming service with a 50 ms delay. Analyses of delay produced by other segments of networks suggests that Backhaul delay up to 20 ms should be compatible with the need of not limiting the QoE of the more delay-sensitive services like gaming. NGMN requirement exists: The overall backhaul delay budget in one direction from small cell connection point to the core network equipment should not exceed 20 ms, for 98 % packets for high priority Classes of Service or in uncongested conditions.

It is considered only an equipment design and/or network development argument. In any case qualitative consideration may be discussed in backhauling solutions comparison.

Latency: no backhauling specific requirement is foreseen at the moment. Considering that backhaul latency is a component of the operator's overall End-to-End latency budget for the service(s) being offered, backhaul latency should be kept as low as possible and latency aware QoS mechanisms can be implemented.

4.3.3 Security

It is considered only an equipment design and/or network development argument.

Since backhaul systems can be located in positions easier to reach than macrocells site, two aspects of security need to be considered: physical security and network security.

Some deliverables are available, addressing security issues: impact on overhead of Security mechanisms is in general not negligible, and needs to be evaluated in throughput estimation. Guidance can be found in ETSI TS 133 401 [i.10].

4.3.4 Frequency and Time Synchronization

It is considered only an equipment design and/or network development argument.

The backhaul should be designed to carry synchronization packets to the Base station so that the minimum requirements for small cells (Local Area BS) in terms of frequency accuracy (at least ±0,1 ppm) and phase accuracy for TDD system (±1,5 us) are met.

4.3.5 Availability/Objectives

Availability has been considered since long time in networks and radio systems as a kind of indicator of a serious event of inability to provide required service, sometimes potential indicator of equipment/network malfunctions.

For this reason, a minimum criterion of 10 consecutive seconds base time of service interruption has been adopted to declare this condition.

Related objectives have been referred to one year period.

Since the advent of packet based networks, it was questioned whether these criteria should still be representative of periods of unacceptable performance, due to change of perception from customers (driven by final clients QoE).

In addition to the historical definition of unavailability based on 10 seconds base, the other alternative criteria, based on shorter time bases, were proposed in contests other than ITU. As an example the following denominations can be found in technical literature:

- **The availability is the proportion of time that a backhaul connection is fully functional.**

Definition for additional parameters can also be found:

- Any **time when a** connection is not available is referred to as an **outage.**
- **Resiliency** is the ability of a connection to recover quickly from outages or avoid them altogether.

Object availability: no specific numerical value is recommended for availability, nevertheless the objectives applicable to microsites (and small cells) should be lower than those used by transport links. As consequence a typical figure in range of 99,9 ÷ 99,99 % is expected to cover most of realizations.

NOTE : In case time base of one year is no more actual and a new time base is deemed necessary, current models for calculations, wherever used for planning, should be investigated for their applicability.

4.3.6 Ethernet Features

The present document considers only equipment design and/or network development argument. Payload features are not in the scope.

5 Radio Specific Aspects Overview

5.1 Channel transport capacity

In order to check the conditions where the requirements can be met, figure 6 shows typical expected transmission capacity for some channel bandwidths foreseen in ITU-R/ETSI Standards, and for some modulation levels, once link budget allows sufficient margin.

Figure 7 shows the theoretical capacity increase for channel, in case XPIC (indicated as "+X") or XPIC in combination with MIMO (2 × 2 MIMO, indicated as "+ X × M") are adopted.

It should be noticed that not all combination shown could be available at the moment, but they are expected to be achieved in a midterm bases, due to development of technology.

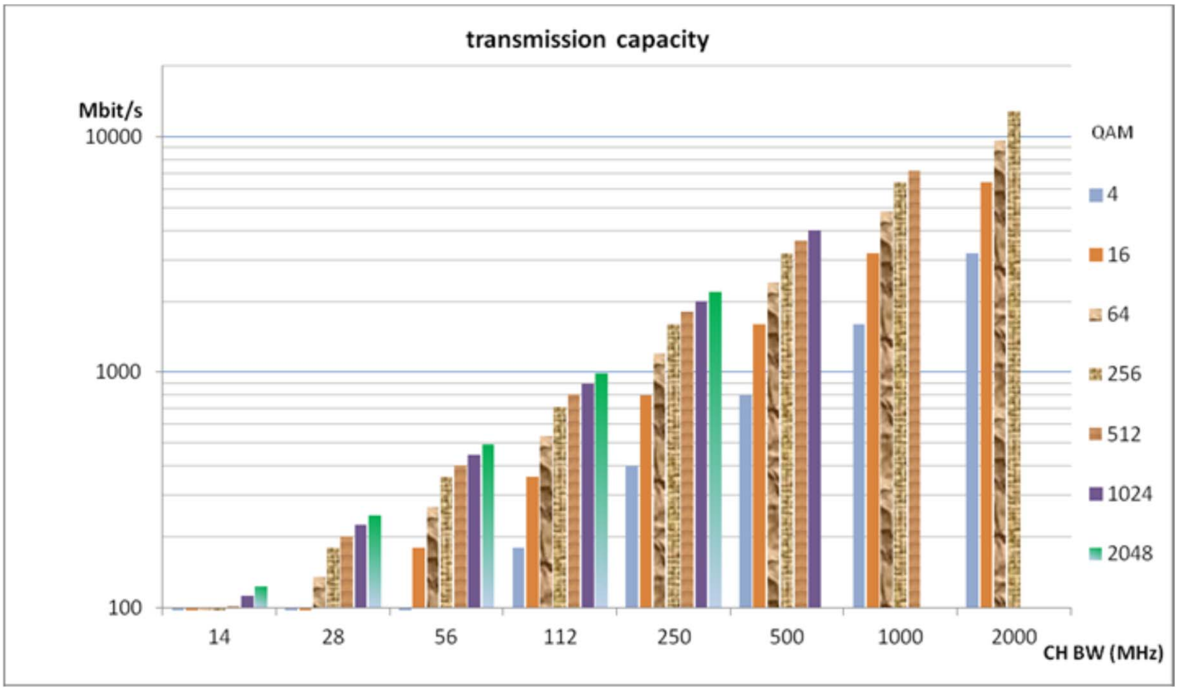


Figure 6: Capacity/Ch BW

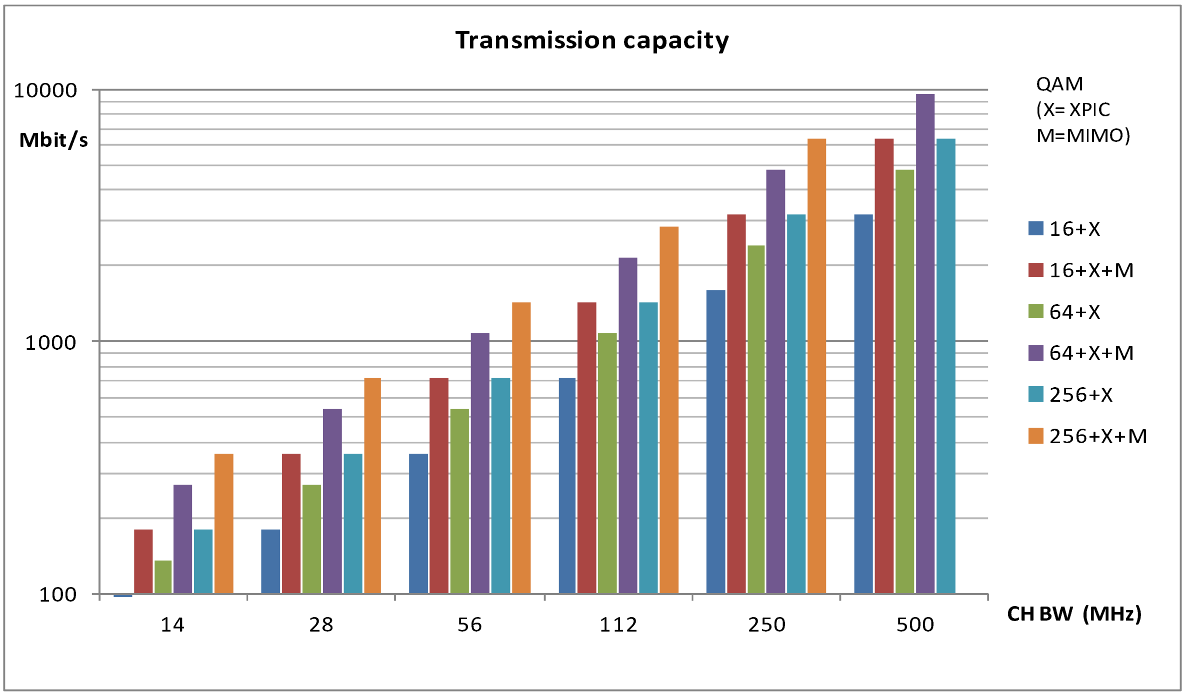


Figure 7: Capacity/Ch BW assuming cross-polarization and cross-polarization + MIMO is adopted

5.2 Link Planning

5.2.0 General

These topics are related to propagation aspects, to be addressed during the preliminary simulation as reasonable working hypothesis.

5.2.1 Propagation Model Suitable for Application Scenario

In general, links traditionally adopted for Fixed Service (FS) applications are designed according to Recommendation ITU-R P.530 [i.6]. Such recommendation allows predicting the probability that a required attenuation is exceeded in a given link, for frequencies at least up to 45 GHz (for multipath propagation effects) or to 100 GHz (for rain and atmospheric gas related propagation effects).

In case of NLOS, an approximation for additional attenuation due to average terrain is given vs. clearance.

The Recommendation refers to another one, Recommendation ITU-R P.526 [i.7], for practical cases, where diffraction is due to different mechanisms (e.g. knife edge, see figure 8).

Recommendation ITU-R P. 526 [i.7] ("Propagation by diffraction") allows calculation of additional loss respect to free space loss due to presence of some obstacles with known geometries.

Applicability of Recommendation ITU-R P.526 [i.7] is limited by the geometry of the connection.

Validity is restricted to cases where a specific angle (the angle between directions of two rays , first going from TX to the obstacle, second from obstacle to Rx) is less than roughly 12°, if a single diffracting "knife edge shaped" obstacle is placed between TX and RX (see figure 8).

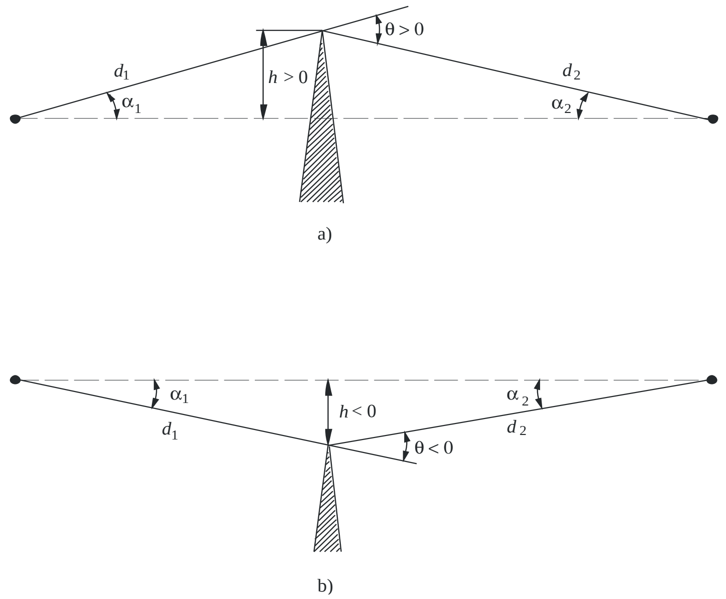


Figure 8: Single knife-edge obstacle geometries

At the time this deliverable was developed, length of great majority of connection was typically of the order of several km (frequently tens). Such links are associated with quite "flat" geometries, where angles tend to be small and the condition "< 12°" is easily complied with.

In urban / suburban areas, especially in case of installations near road level , for example in case of lamp poles installations, due to the higher heights of surrounding buildings, links tend to be much more "vertical", and the angle to be checked results often higher than 12°, so out of the applicability range from Recommendation ITU-R P.526 [i.7].

To summarize, the above Recommendations appear to be of uncertain use for many FS links intended to be used for backhauling. Especially for those intended to be applied in urban context, which are short (< 1 km) and often in NLOS or in nLOS.

Other two recommendations of ITU-R appear to be developed addressing such kind of environments.

Recommendation ITU-R P. 1410-5 [i.8]:

Area coverage design is the main objective of this Recommendation, where ray tracing methods are suggested in areas where a database of land coverage is available.

Instead for the other cases, a statistical model is suggested, including considerations on building penetration, vegetation, propagation mechanisms, use of two or more receiver stations and use cases are considered.

In addition, a path loss prediction method for a real link as a function of geometrical characteristics is provided.

Recommendation ITU-R P. 1411-7 [i.9]:

Recommendation includes a classification of frequently encountered environments and calculation methods for single hops. Where geometries are known, path loss calculations methods are given in cases of: street canyons, propagation over rooftop or above rooftop (Urban and Suburban, LoS and nLoS), propagation from below roof-top height to near street level. Paths topologies for MIMO channels are also described, based on building heights and location densities, together with statistical model for path loss, delay and angular spread. A cross-correlation model of multi-link channel in a residential environment is described in a specific section too.

These two Recommendations appear to adopt a quite similar model (figure 2 in Recommendation ITU-R P.1411 [i.9] and figure 10 in Recommendation ITU-R P.1410 [i.8], similar to figure 2 in the present document), although calculation procedures are different; moreover, they have been developed for mobile applications, so their applicability to fixed systems for mobile backhauling need further analyses.

Following points were clarified by means of liaison activity between TM4 and ITU-R WP3:

- Neither Recommendation ITU-R P.1410 [i.8] nor Recommendation ITU-R P.1411 [i.9] are intended to be used for planning NLOS PtP links.

  In meanwhile it is believed that Recommendation ITU-R P.1411, § 4.2.2 [i.9] is more suitable for Small-Cell planning applications but not for interference predictions. However P.1411 was developed using omnidirectional antenna and this may not consider the advantage coming from pointing a directional antenna in the direction of the main reflection point, if any, rather than to a diffraction wedge.

- Currently the two recommendations present discrepancies in the diffraction-dominated part models and that these differences will be solved in next Study Group.

- Extensions of the two recommendations in order to cover higher frequency bands is ongoing (established a dedicated Correspondence Group 3K-6).

- Recommendation ITU-R P.526-13, § 4.1 [i.7] notes that the diffraction angle, θ, is assumed to take values less than about 200 mrad. This 12° limit for the diffraction angle is a fairly strict criterion which can be relaxed to some extent. ITU-R WP3 is unable at present to give detailed information on how the error would increase for diffraction angles above 12°, but it has been observed that at diffraction angles up to about 45° knife-edge diffraction predicts losses which tend to be intermediate between the losses predicted for parallel and perpendicular polarization, using a UTD formulation on a 90° perfectly absorbing wedge. However, a diffraction calculation alone may over-estimate loss due to not taking reflections into account.

5.2.2 FDD & TDD

Most frequency bands used by Point-to-Point Fixed links rely on a licensed, mostly link by link coordinated regime.

Most channel plans are typically FDD. Such scheme allows proper control of local interference by means of filters, due to frequency separation of transmitters from receivers. Use of spectrum is symmetrical for each channel, since channel separation is the same for the 2 directions of link. Asymmetrical FDD has recently been discussed, but not practically used up to now.

V-band as a whole spans 57 GHz to 66 GHz, and a significant part of it, which is centred on the Oxygen absorption peak at 61 GHz, spanning 59 GHz to 64 GHz, is often widely available and license exempt worldwide.

These 5 GHz of spectrum can be continuous, but in some Countries part of it can be allocated to Military use (59 GHz to 61 GHz) or used by/shared with other services (e.g. ITS).

As a consequence, attempting to divide the band into two paired sub-bands may result difficult, due to different local regulations. In this case TDD system can be effectively deployed.

Due to these different characteristics and requirements it is impossible to state which is the best choice between the two duplex modes in general, since different conditions require different solutions. It can be stated that no preclusion of both technologies exists, in case were such use is not forbidden by regulatory constraints.

5.3 Frequency Bands

Table 2 summarizes the current status of available frequency bands allocated to FS in the range 3,5 GHz to 300 GHz.

Table 2: Frequency bands, channel separations and normative references

Band (GHz)	Frequency range (GHz)	Channel separation (MHz)	ECC (CEPT/ERC) Recommendations	ITU-R Recommendations
3,5	3,410 to 3,600	1,75 to 14	14-03 [i.12]	-
4	3,600 to 4,200	1,75 to 60	(12)08 [i.13]	F.635-6 [i.32] F.382-8 [i.33]
U4	4,400 to 5,000	28, 56, 60	-	F.1099-4 [i.34]
L6	5,925 to 6,425	3.5 to 59,3	(14)01 [i.14]	F.383-8 [i.35]
U6	6,425 to 7,100	3.5 to 60	14-02 [i.15]	F.384-11 [i.36]
7	7,125 to 7,725	1,75 to 56	(02)06 [i.16]	F.385-10 [i.37]
8	7,725 to 8,500	1,75 to 59,3	(02)06 [i.16]	F.386-8 [i.38]
10,5	10,000 to 10,680	3,5 to 56	12-05 [i.17]	F.747-1 [i.39]
11	10,700 to 11,700	7 to 56	12-06 [i.18]	F.387-12 [i.40]
13	12,75 to 13,25	1,75 to 56	12-02 [i.19]	F.497-7 [i.41]
15	14,5 to 15,35	1,75 to 56	12-07 [i.20]	F.636-4 [i.42]
18	17,7 to 19,700	13,75 to 110	12-03 [i.21]	F.595-10 [i.43]
23	22,0 to 23,6	3,5 to 112	T/R 13-02 [i.22]	F.637-4 [i.44]
26	24,5 to 26,5	3,5 to 112	T/R 13-02 [i.22]	F.748-4 [i.45]
28	27,5 to 29,5	3,5 to 112	T/R 13-02 [i.22]	F.748-4 [i.45]
31	31,0 to 31,3	3,5 to 28/56	(11)01 [i.23]	F.746-10 [i.46]
32	31,8 to 33,4	3,5 to 112	(01)02 [i.24]	F.1520-3 [i.47]
38	37,0 to 39,5	3,5 to 112	T/R 12-01 [i.25]	F.749-3 [i.48]
42	40,5 to 43,5	7 to 112	(01)04 [i.26]	F.2005 [i.49]
50	48,5 to 50,2	3,5 to 28	12-11 [i.27]	-
52	51,4 to 52,6	3,5 to 56	12-11 [i.27]	F.1496-1 [i.50]
55	55,78 to 57,0	3,5 to 56	12-12 [i.28]	F.1497-1 [i.51]
60	57 to 64	n*50	(09)01 [i.29]	-
64	64 to 66	n*30, n*50	(05)02 [i.30]	-
70	71,0 to 76,0	250 to 2 250	(05)07 [i.31]	F.2006 [i.52]
80	81,0 to 86,0	250 to 2 250	(05)07 [i.31]	F.2006 [i.52]
70 /80 paired	71,0 to 76,0 paired with 81,0 to 86,0	250 to 4 500	(05)07 [i.31]	F.2006 [i.52]
92	92 to 95 (see note)	50 to 400	(14)01 [i.14]	F.2004 [i.53]
95	95 to 100	-	-	-
102	102 to 105	-	-	-
105	105 to 109.5	-	-	-
110	111,8 to 114,25	-	-	-
	122,25 to 123	-		
130	130 to 134	-	-	-
	141 to 148,5	-	-	-
	151,5 to 164	-	-	-
	167 to 174,8	-	-	-
	191,8 to 200	-	-	-
	209 to 226	-	-	-
	231,5 to 235	-	-	-
	238 to 241	-	-	-
	252 to 275	-	-	-
NOTE: 94 GHz to 94,1 GHz band is not available for FS.				

Although the above allocations are allowed by Radio Regulations (RRs), the actual availability of frequency band or part of them to FS is ruled by on national basis.

In the following, a short description for main frequency bands is provided.

- **Frequency bands up to 11 GHz:**

These bands are extensively used for Point-to-Point applications since propagation characteristics allow long haul hops, normally up to 50 km.

Lower bands (< 6 GHz) can operate also in some NLOS conditions, such as they could be used for backhaul in urban scenarios where LOS is not guaranteed.

Another possibility for backhaul is to support long-haul hops outside urban areas.

Due to the trend of trying to allocate more BW to mobile service to increase capacity available for mobile users, with particular interest to lower frequencies, some of such bands could be not available in the future on a large scale.

Due to the high number of existing links and licensing regimes (general coordination, on a link by link bases), execution of processes necessary for implementing an high number of links (frequency determination, link planning, interference analyses) could conflict with the needs of fast provisioning of service and network expansion.

- **Frequency bands from 13 GHz to 38 GHz:**

These bands are also extensively used for Point-to-Point applications, associated to medium hop length, normally from about 10 km to 20 km.

Recent measurements have shown that possibility to use some frequency exist even in condition where LOS cannot be guaranteed, when additional attenuation due to diffraction and reflection can be compensated by sufficient antenna gain.

Wide channels are available for provisioning of high capacities, allowing backhaul for low aggregation level.

Frequency increase facilitates manufacturing of high gain antennas with reduced size.

Backhaul for applications outside urban areas are still possible.

As far lower frequencies, especially for some frequencies (e.g. 38 GHz), the high number of existing links and licensing regimes could be a burden for an agile provisioning of new or expansion of existing networks.

- **Frequency bands from 40 to 57 GHz:**

These bands are not widely used for Point-to-Point applications although propagation characteristics, allow links with hop lengths of about few km, and channel separation allow in principle medium/ high transport capacities.

In particular, while 42 GHz is available since few years, about 50 GHz there is a limited choice of components available. Total available BW available consists in 3 GHz (42 GHz band) and 3 slots wider than 1 GHz (50 to 57).

- **Frequency bands from 57 GHz to 86 GHz:**

Very wide channels are available above 57 GHz for provisioning of quite high capacities, allowing radio backhaul in principle available also for some aggregation level.

These high frequencies are well suited to produce high gain antennas with reduced size, allowing production of quite compact integrated equipment, with limited visual impact as required by installation in towns and densely populated areas.

MM-wave frequencies from above 55 GHz to 90 GHz are available in two main bands:

- V-band: 57 GHz to 66 GHz, most of this band (59 GHz to 64 GHz) is license exempt in most of the world.
- E-band: 71 GHz to 76 GHz /81 GHz to 86 GHz, lightly licensed band in many countries (but also coordinated in some countries).

V-band benefits from the following advantages:

- Very wide, largely non-populated 9 GHz of spectrum.

License exempt in most of the world.

High Free Space Loss (FSL) due to Oxygen absorption (frequency and temperature dependent. Its range is 7 dB/km to 14 dB/km). This phenomenon limits link distance, but also limits interference, giving possibility to achieve high frequency reuse in same area.

Smaller antenna gain requirements (at most of the countries which studied this band in recent years).

This makes V-band as a promising solution for street level installation.

E-band is lightly licensed, and in some countries even fully coordinated, it has more strict regulation requirements that generally mandate higher antenna gains and thus make its form factor less suitable for street level deployments. Due to very large channel bandwidth foreseen, quite high transport capacities are possible, allowing backhaul for aggregated signals be handled in urban areas. Connections between mid-capacity network nodes, like ring closure can also be implemented.

Backhaul for applications outside urban areas are not excluded, provide that sufficient system gain can be achieved.

- **Frequency bands 90 GHz and higher:**

Large amount of spectra is available from 92 GHz and above for Fixed service (92 GHz to 109,5 GHz, 11,8 GHz to 114,25 GHz, 130 GHz to 134 GHz, 141 GHz to 148,5 GHz, 151,5 GHz to 164 GHz), allowing significant addition to transport capacities offered by lower bands (mainly V and E-band).

At the moment, just the 92 GHz to 95 GHz band is covered by Recommendations.

Apart experimental applications, these bands are actually unused.

Proper consideration should be given to the aspect that, due to band segmentation, most of them could be not optimal for FDD applications, due to relatively small wide bandwidth relative to centre frequency, with related limitation for diplexer realization.

Mixed use inside bandwidth (part FDD, part TDD), or joint use with other higher frequency bands, could be considered if necessary.

In order to encourage the development of FS applications in these frequency bands, due attention should be reserved to licensing regime, with particular attention to low cost licensing schemes such as unlicensed or light licence. Block assignments allocation could be useful to facilitate network planning.

5.4 Line-Of-Sight (LOS)

Frequency Bandwidths: Traditionally Coordinated MW (6 GHz to 56 GHz) & mmWV (57 GHz to 66 GHz, 71 GHz to 86 GHz and 94 GHz); higher frequency bands, assigned to Fixed Service as primary use, could be considered, not referred to some specific Recommendations yet, as a complement or alternative, due to similar BW available, allowing large size channels to be adopted. Since propagation characteristics are not substantially worse than for the 90 GHz-band (moderate increase in specific attenuation) links with comparable performances, in terms of length, capacity and availability are expected.

5.5 Non-Line-Of-Sight (NLOS)/Mixed LOS and NLOS Solutions Coexistence

The Line of Sight condition, which constitutes the bases of planning for most PtP links, is available with less confidence in dense urban environment and/or street level. As such, deterministic planning is not possible in all cases, due to the unpredictable penetration losses and seasonal different behaviour, generating variations in direction and attenuation of RF signals.

So, Point-to-Point (Fixed Services) with fixed beam antennas are not expected to represent the most suitable solution for dense urban backhaul networks

Meshed networks, where each network node is provided with beam-steerable antennas, and could be connected by other nodes from more than one direction, are felt as a better solution to fit the dense urban scenario.

5.6 Antennas

Due to their categorization (fixed point to point), small cells backhauling links should be equipped with antennas compliant with requirements in ETSI EN 302 217-4-1 [i.5] and ETSI EN 302 217-4-2 [i.4].

Frequency range covered by these Standards spans from 1 to 86 GHz;

It should be noticed that active antennas are not specifically referred, so, at the moment, existing classes are in principle not excluded to be applicable to this kind of antennas.

Unlike installations used in traditional point-to-point links, great majority of which are realized in protected locations, with no or very limited access to public, many installations links used for small cells backhauling will be needed in more accessible locations (i.e. near street level) and on poles with limited stability (i.e. lamp poles). In addition, equipment will be required to have a small visual impact, and to allow fast installation, in order to minimize impact on traffic (operations occupying part of road lanes).

As a consequence, application of active antennas, able to electronically move or shape the beam, while keeping small dimensions, is felt as a possible solution, both for installation phase, not needing a very accurate alignment, and in operation, to continuously compensate the effects of pole movement.

Annex A: Depolarization field test in NLoS scenarios

A.1 Introduction

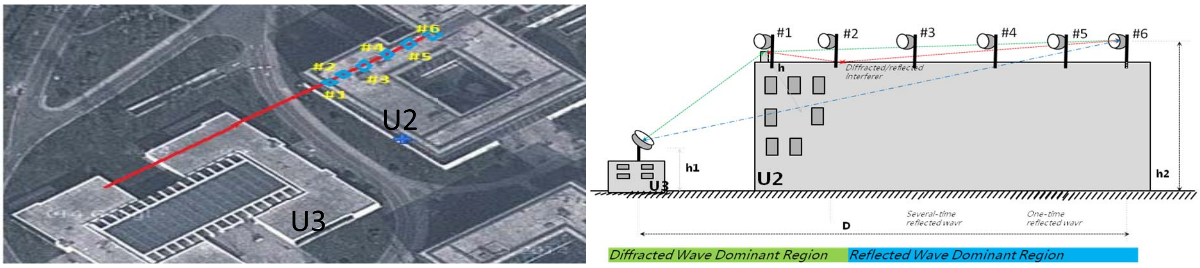
A.1.0 General

A series of test scenarios have been constructed mainly for reflection and diffraction in Pi County, Chengdu, China, aiming at obtaining the basic law of reflection and diffraction. Especially, impacts of polarization effect and attenuation were the key focus points. Separate microwave device at 23 GHz with single polarization (256 QAM@56 MHz) parabolic antenna with diameter 0,3 m were used. The polarization direction could be configured to V for verticality and H for horizontality.

A.1.1 Diffraction test

1) Test scenario (shown in figure A.1):

Two devices were separately placed onto roofs of two buildings (U2 and U3 as shown in figure A.1) with height difference. The outside wall in U2 which is relatively higher was used as diffraction object. Antenna on the roof of U2 was placed in several places along the route shown in figure A.1 (#1 is LoS, #2 is nLoS, and the rest are NLoS). Two polarization combinations (VV/HH) were used in each test point, and then there were total 12 test cases to observe diffraction law in different polarization conditions and different block conditions.



NOTE: D #1~#6 = 97 m, 101 m, 111 m, 120 m, 130 m, 138 m;
h = 1,7 m;
h1 = 6,7 m;
h2 = 18,7 m

Figure A.1: Series of diffraction test scenarios

2) Test result:

a) Diffraction loss increased from #1 to #6;

b) There was no obvious loss difference between VV and HH combinations in LoS scenario (#1), while there was obvious loss difference between VV and HH combinations in nLoS (#2) and NLoS scenarios (from #3 to #6) (shown in table A.1).

Table A.1: Test data

		V:V(U2:U3)		H:H(U2:U3)	
	TX Power(dBm)	U2 Rx power (dBm)	U3 Rx power (dBm)	U2 Rx power (dBm)	U3 Rx power (dBm)
#1	10	-20.2	-20.2	-20.1	-20.0
#2		-33.8	-34.6	-38.9	-38.9
#3		-43.3	-42.3	-53.7	-53.5
#4		-46.7	-45.6	-58.1	-58.5
#5		-49.4	-48.1	-61.5	-61.7
#6		-51.2	-49.9	-62.5	-62.8

3) Test analysis:

The same diffraction surface produces different attenuation according to different polarization direction. This is the depolarization effect in diffraction scenario. If polarization direction is not vertical nor horizontal, and then the horizontal component and vertical component would suffer from different diffractions, so the polarization direction of electromagnetic wave would deflect after diffraction. As a result, receiving level decreases further.

A.1.2 Reflection test

1) Test scenario (shown in figure A.2):

Two devices were separately placed at two corners of a wall. The wall was used as reflection surface. Left/right antennas were moved symmetrically to build the test scenarios with different horizontal angles (11/15/30/45/60/64/65/69/72/75°). Two polarization combinations (VV/HH) were used in each test point, and then there were total 20 test cases to observe the reflection law.

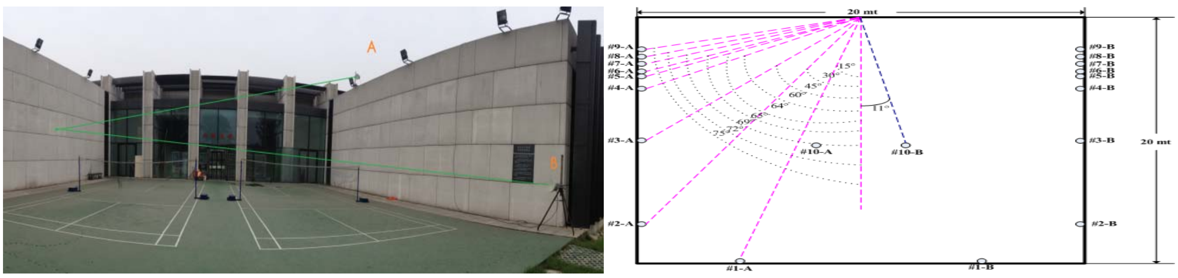
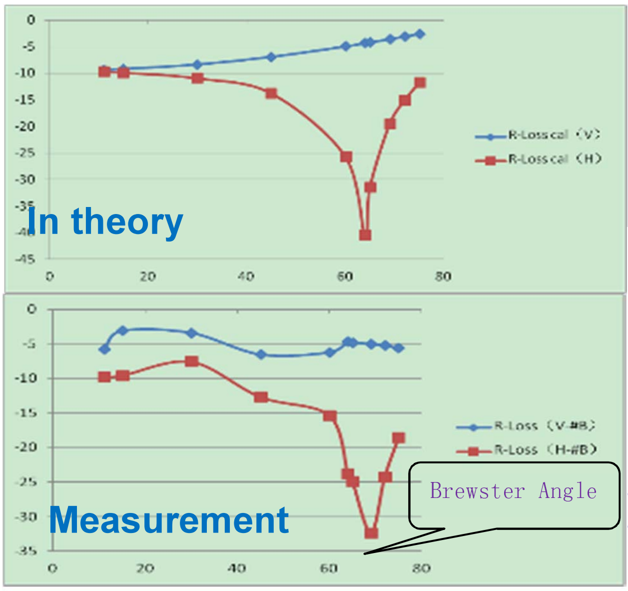


Figure A.2: Series of reflection scenarios inside research institute

2) Test result (shown in figure A.3):

The reflection loss in HH polarization combination fluctuated a lot. The maximum loss occurred when incident angle reached 69°.



$$\Gamma_{\perp} = \frac{\cos\theta_i - \sqrt{\varepsilon_2/\varepsilon_1 - \sin^2\theta_i}}{\cos\theta_i + \sqrt{\varepsilon_2/\varepsilon_1 - \sin^2\theta_i}} \qquad ①$$

$$\Gamma_{//} = \frac{(\varepsilon_2/\varepsilon_1)\cos\theta_i - \sqrt{(\varepsilon_2/\varepsilon_1) - \sin^2\theta_i}}{(\varepsilon_2/\varepsilon_1)\cos\theta_i + \sqrt{(\varepsilon_2/\varepsilon_1) - \sin^2\theta_i}} \qquad ②$$

a) b)

NOTE 1: a): Blue line is VV polarization combination and red line is HH polarization combination.
NOTE 2: b): Upper is for vertical incidence and lower is for horizontal incidence.

Figure A.3: a) Reflection loss change with incident angle
b) Reflection coefficient calculation formula

3) Test analysis:

When incident angle increases in HH polarization combination, there is severe depolarization effect. Reflection energy will completely disappear when incident angle equals to Brewster angle. This is because the reflection coefficient of vertical incidence is different from that of horizontal incidence (shown in figure A.3 right, ① is reflection coefficient formula of vertical incidence and ② is reflection coefficient of horizontal incidence). In our test scenarios, VV polarization combination corresponds to vertical incidence and HH polarization combination corresponds to horizontal incidence. If there is oblique incidence, the polarization direction of electromagnetic wave after reflection would deflect as the vertical component and horizontal component produce different reflection loss. As a result, the receiving level decreases. When incident angle reaches Brewster angle, there will be severe reflection deflection, and then the receiving level will go below the receiving sensitivity.

A.1.3 Tree leaf penetration scenario

This scenario would be more complex. Further test and further analysis are needed.

A.2 Impact of depolarization effect in NLoS

As different polarization direction produces different polarization loss in NLoS scenarios, antenna polarization direction should be taken into consideration in NLoS deployment in order to acquire best transmission effect:

1) Polarization direction would be adjusted according to field test and simulation result. However, labour cost and difficulties of installation/test would also be increased.

2) As the antenna beam shape is not the same in vertical direction and horizontal direction, polarization direction cannot be adjusted freely.

3) When diffraction/reflection surface is not 100 % vertical or horizontal, the polarization direction would deflect. As a result, receiving level would accordingly decrease. Then the ability of adjustment of polarization direction is needed.

As NLoS scenario suffers more loss than LoS scenario (20 ~ 40 dB+), it is very important to decrease loss in NLoS deployment. Solving depolarization effect would be a key item in the present document.

A.3 Insight in Physical Phenomena on Depolarization

A.3.1 Overview

A.3.1.0 General

In general, it can be assumed that differences between VV combinations and HH combinations, that have been measured, can be related to the specific analysed test scenario.

A.3.1.1 Reflection scenario

Some clarifications are thereafter reported:

- **Vertical polarization** refers to that the polarization direction is vertical to horizon.
- **Horizontal polarization** refers to that the polarization direction is parallel to horizon.
- **VV combination** refers to transmitting signals using vertical polarization waves and receiving signals using vertical polarization waves.
- **HH combination** refers to transmitting signals using horizontal polarization waves and receiving signals using horizontal polarization waves.
- There are two kinds of incidence:
  - **Normal incidence** which refers to the direction of wave's propagation is vertical to a media boundary plane.
  - **Oblique incidence** refers to the EM wave incident at an oblique angle on a media boundary plane.

In the measured NLOS scenarios, only oblique incidence should be considered.

In oblique incidence, there are two cases to be discussed:

- **Parallel polarization** refers to that incident electric field (polarization direction) is parallel to the plane of incidence, which should use equation 2 shown in figure A.4 to calculate the reflection coefficient.
- **Perpendicular polarization** refers to that incident electric field (polarization direction) is perpendicular to the plane of incidence, which should use equation 1 shown in figure A.4 to calculate the reflection coefficient.

$$\Gamma_{\perp} = \frac{\cos\theta_i - \sqrt{\varepsilon_2/\varepsilon_1 - \sin^2\theta_i}}{\cos\theta_i + \sqrt{\varepsilon_2/\varepsilon_1 - \sin^2\theta_i}} \qquad ①$$

$$\Gamma_{//} = \frac{(\varepsilon_2/\varepsilon_1)\cos\theta_i - \sqrt{(\varepsilon_2/\varepsilon_1) - \sin^2\theta_i}}{(\varepsilon_2/\varepsilon_1)\cos\theta_i + \sqrt{(\varepsilon_2/\varepsilon_1) - \sin^2\theta_i}} \qquad ②$$

Figure A.4: Two equations

In the test shown in figure A.5, the plane of incidence is horizontal. When horizontal polarization has been used and polarization direction is parallel to the plane of incidence then equation 2 should be used to calculate the reflection coefficient.

The theoretical result matches the test measurements and confirmed that there is severe depolarization effect in this test scenario. Furthermore the Brewster angle, where the maximum attenuation value is reached, has been measured in accordance to the theory.

In other hand, when vertical polarization has been used and polarization direction is perpendicular to the plane of incidence, the equation 1 should be used to calculate the reflection coefficient. The measurements match the theoretical results and show that the depolarization effect is relatively much less than in the horizontal case.

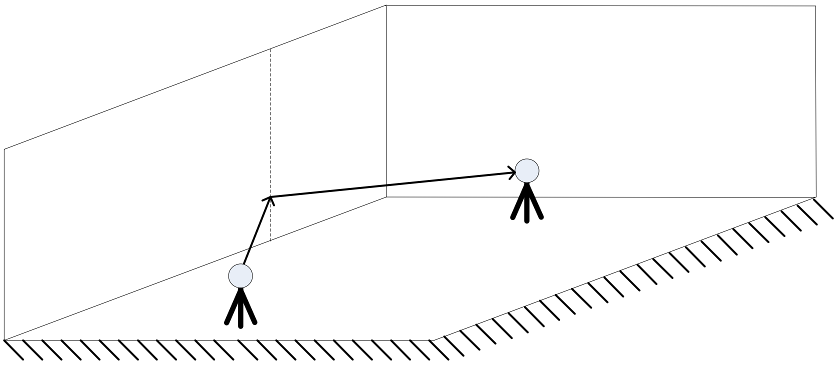


Figure A.5: Field test scenario

Then the test scenario is changed in the way that the plane of incidence results now vertical, as shown in figure A.6. In this case when horizontal polarization has been used and polarization direction is perpendicular to the plane of incidence, equation 1 should be used to calculate the reflection coefficient.

In case when polarization direction is parallel to the plane of incidence but it is not vertical polarization because the polarization direction has an oblique angle respect to the vertical line, the equation 2 should be used to calculate the reflection coefficient.

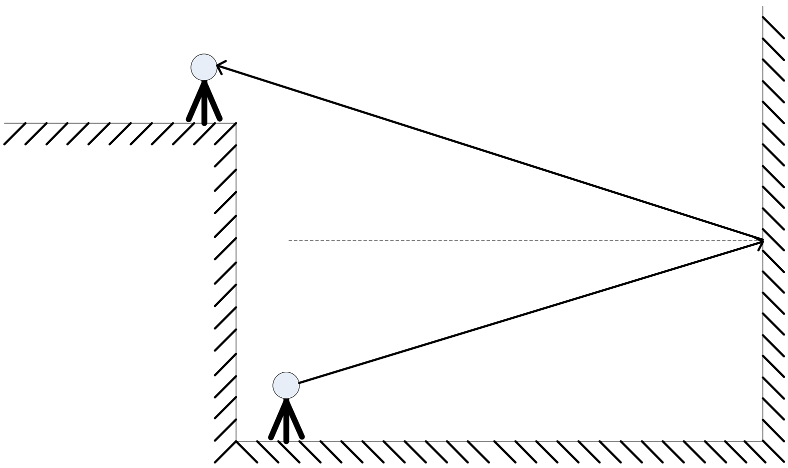


Figure A.6: Test scenario

Finally expected results should show that the depolarization effect of HH combinations is now better than that of perpendicular polarization (which is not strictly a VV combination). However, this is just theoretical assumption, because the tests have not been performed yet.

A.3.1.2 Diffraction scenario

In the previous test, the diffraction surface is horizontal edge, and then the depolarization effect of VV combinations is better than that of HH combinations. It can also assumed that if the diffraction surface is vertical edge, the test result would be reversed with the depolarization effect of HH combinations is better than that of VV combinations.

A.3.1.3 Further analysis

Further, in both reflection and diffraction scenarios, if it is neither parallel polarization nor perpendicular polarization, the polarization direction should be decomposed to perpendicular direction and parallel direction. As the depolarization effects are different in perpendicular or parallel direction, the total depolarization effect may vary significantly and also the polarization direction after reflection/diffraction would vary, especially when incidence angle reaches to Brewster angle.

A.4 Conclusion

From above measurements it can be assumed that depolarization effect should be related to the space relationship between signal polarization direction and reflection/diffraction objects. Further field test should be made to prove it. As the application scenarios would be very complex in street level, the depolarization effect would vary significantly and also the polarization direction after reflection/diffraction would vary, and then NLOS equipment should be able to handle all kinds of reflection/diffraction scenarios in order to reach commercial production application.

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History

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