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Coverage Estimation for Converging Co-Located Mobile/Wireless Communication Systems

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"*Victory belongs to those who persevere firmly in their own efforts*"

Daisaku Ikeda

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Abstract

This report deals with radio propagation issues, concerning their influence on the mobile radio environment.

The objective is to evaluate the path-loss with and without slow and fast fading influence for narrowband and wideband systems, and to estimate, through several propagation models, the cell-range for different systems (GSM, UMTS and HIPERLAN) in several environments.

Main emphasis is given to the characterisation of wideband multipath fading, concerning the dependence on system bandwidth and environments characteristics, since this is a topic that is not yet well studied and only a few approaches can be found in literature.

In fact, for UMTS and HIPERLAN, which are wideband systems, the impact of the fast fading is considerable and the well known models for fast fading (Rayleigh and Rice distributions) are not longer appropriate. Therefore, one has decided to present in more detail a new model that describes this wideband multipath fading phenomenon (Cardoso model).

Cardoso model is used to estimate the fading depth in several environments and for different systems, which represents the most important part of the work, since it represents a new approach in this field.

Another innovative aspect of this work concerns the presentation of a modified Cardoso model for two particular scenarios. Results regarding average path-loss, slow and fast fading, are reported. Link budgets for different systems working in different environments are presented and discussed.

Finally, the cell-range estimation for the average path loss and when considering the fading margins obtained by the application of COST 231-Hata, COST 231-WI and Multi-wall models are presented and discussed.

Considering that the most interesting case is the cell-range evaluation with the influence of the slow and fast fading margins, some comparisons are made on them. Concerning the results obtained with COST 231-Hata model, one of the main observation is that the cell.range evaluation in rural/sub-urban environment is greater than in urban one, in fact, in the fistr case the range is for GSM 900 is $0.67 \leq d \leq 3.10$ km, for GSM 1800 is $0.40 \leq d \leq 2.61$ km and for UMTS is $0.37 \leq d \leq 5.57$ km. In urban environment, the cell-range estimation is, for GSM 900, $0.20 \leq d \leq 0.98$ km, for GSM 1800 is $0.10 \leq d \leq 0.34$ km and for UMTS is $0.10 \leq d \leq 1.10$ km. These ranges are wrote independently on the particular service and one observes that the greater one is for UMTS system.

Comparing the results obtained with COST 231-Hata model and with COST 231-WI, in NLoS case, one observes that in the second case the value are lower, in fact the range for GSM 900 is $0.20 \leq d \leq 0.64$ km, for GSM 1800 is $0.07 \leq d \leq 0.22$ km and for UMTS is $0.07 \leq d \leq 0.63$ km. It depends on the fact that COST 231-WI is more precise that COST 231-Hata model, bcause of the additional parameters.

More specific comparisons are presented in chapter for making a distinction on the type of the service, too.

Keywords

Propagation model, Path loss, Wideband system, Fading margins, Cell-range, Cardoso model

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List of Acronyms

AMR	Adaptive Multirate (speech codec)
ATM	Asynchronous Transfert Mode
AUC	Authentication Centre
BCC	Broadcasting Control Channel
BER	Bit Error Rate
BS	Base Station
BSC	Base Station Sub Controller
BSS	Base Station System
BTS	Base Transceiver Station
CDF	Cumulative Distribution Function
CDMA	Code Division Multiple Access
CN	Core Network
DL	Downlink
DS	Direct Sequence
DTE	Data Terminal Equipment
EQ	Equalisation Testing
EIRP	Equivalent Isotropic Radiated Power
ETSI	European Telecommunications Standards Institute
FER	Frame Error Ratio
FDD	Frequency Division Duplex
FSK	Frequency Shift Keying
GMM	GPRS Mobility Management
GMSK	Gaussian Minimum Shift Keying
GPRS	General Radio Packet Service

GSM	Global System for Mobile Communications
HBR	High Bit Rate
HIMM	High Interactive Multimedia
HIPERLAN	High Performance Radio Local Area Network
HLR	Home Location Register
HM	High Multimedia
HO	Handover
HT	Hilly Terrain
IMSI	International Mobile Subscriber Identity
IP	Internet Protocol
ISDN	Integrated Services Digital Network
MC	Multicarrier
MS	Mobile Station
MT	Mobile Termination
NER	Nominal Error Rate
OFDMA	Orthogonal Frequency Division Multiple Access
OHG	Operator Harmonisation Group
OQPSK	Offset Quadrature Phase Shift Keying
PCU	Packet Control Unit
PDN	Packet Data Network
PLMN	GSM-Public Land Mobile Network
PS	Packet Switched
PSTN	Public Switched Telephone Network
QPSK	Quadrature Phase Shift Keying
RA	Rural Area
RAN	Radio Access Network

RBER	Residual Bit Error Rate
RF	Radio Frequency
RNC	Radio Network Controller
S	Speech
SD	Switched Data
SGSN	Serving GPRS Support Node
SM	Session Management
TCH/F	Full-rate Traffic Channel
TCH/H	Half-rate Traffic Channel
TCH/FS	Full-rate Traffic Channel speech
TCH/HS	Half-rate Traffic Channel speech
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
TE	Terminal Equipment
TU	Typical Urban
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunications System
USIM	UMTS Subscriber Identity Module
UTRAN	UMTS Terrestrian Radio Access Network
VLR	Visitor Location Register
WCDMA	Wideband Code Division Multiple Access
WLAN	Wireless Local Area Network
WAP	Wireless Application Protocol

List of Symbols

$\Delta \phi$	Phase difference
ΔL_{max}	Maximum difference in propagation path length
$2\Delta f$	System bandwidth
Δw_{eq}	Equivalent received bandwidth
$\overline{\varepsilon}_r$	Mean relative error
φ	Road orientation with respect to the direct radio path
γ	Received signal level
Γ_i	Reflection coefficients
λ	Wavelength
v	Relative velocity of the mobile
θ	Angle between the direction of motion of the mobile and the direction of arrival of scattered waves
θ_i	Incident angle of the transmitted wave
ρ	Roll-off factor
σ	Standard deviation
σ^2	Average power of the received signal
σ_r^2	Variance of the Rayleigh distribution
σ_τ	*rms* delay spread
w	Width of road
A	Peak amplitude of the dominant signal
A_i	Amplitude of *i-th* arriving wave

b_d	Building separation
B_c	Coherence bandwidth
B_d	Doppler spread
C_m	Correction factor
d	Distance between the transmitter and the receiver
d_0	Close-in reference distance
d_f	Far-field distance
d_p	Perpendicular distance for a path of obstructed by internal walls
D_p	Perpendicular distance of the external antenna
E_b	Received energy per information bit
f	Carrier frequency
f_d	Doppler shift
f_{DL}	Carrier frequency in downlink direction
f_m	Doppler shift
f_{UL}	Carrier frequency in uplink direction
F	Receiver noise figure
G_{FH}	Total floor height gain
G_h	Height gain per height
G_{n_f}	Height gain per floor level
G_r	Receiver antenna gain
G_t	Transmitter antenna gain
h_{BS}	BS antenna height
h_f^1	Height relative to reference outdoors height

h_{MS}	MS antenna height
h_r	Receiver antenna gain
h_{Roof}	Buildings height
h_t	Transmitter antenna gain
I_0	Interference power density
I_0	Modified Bessel function of the first kind and zero-th order
IR	Information Rate
j	Total effective noise plus interference density
k_{fj}	Number of penetrated floors of type j
k_{wi}	Number of penetrated walls of type i
K	Rice factor
l	Required Carrier to noise plus interference ratio
L_o	Free-space loss
L_{bsh}	Correction factor for the BS height
L_c	Constant loss
L_{f_1}	Attenuation caused due to a single floor
L_{fj}	Loss between adjacent floors
L_{msd}	Multiple screen diffraction loss
L_{Ori}	Empirical correction factor
L_p	Path loss
$\overline{L_{\mathrm{p}}}$	Mean path-loss
$L_p(d)$	Path-loss at distance d
L_{rst}	Roof-top to street diffraction and scatter
L_{wo}	Attenuation wall factor
m	Number of cells in a cluster

n	Generic channel
n_f	Floor level
N	Thermal Noise Density
N_0	Total effective noise
P	Lower limit for fading depth evaluation
$p(\cdot)$	Probability density function
P_t	Transmitted power
r_{mean}	Mean value of the Rayleigh distribution
r_{median}	Median of the Rayleigh distribution
R_b	Bit Rate
RS	Reference sensitivity level
S	Physical separation distance between the external antenna and the external wall from the considered floor
SF	Spreading factor
T_c	Coherence time
W_e	External wall attenuation assuming perpendicular penetration
W_{ge}	Additional external wall attenuation
W_i	Internal walls attenuation
X_σ	Zero-mean Gaussian distributed random variable

1. Introduction

Mobile and wireless communication systems are becoming convergent, so the users have the possibility to choose which system to use for a specific service. First of all, it is necessary to develop technique to enable the convergence of multiple wireless standards, and to demonstrate how a user with a Mobile Terminal (MT) can be simultaneous connected to several networks operating, according to different standards. This in turn will enable the consumer to access a wider variety of services. This vision of the feature wireless communication system led some European projects, such as Flows project, to investigate on this argument. In fact, Flow project is studying the benefit to the service provider of adopting a converged multi-standard approach. So, one of the main aims in Flows project is to define scenarios that are common to standard such as GSM, UMTS and HIPERLAN/s, and to establish a common set of parameters for the system evaluation and network simulations. The approach that is adopted is to see how services can be mapped to standards. The used common standards in this work and in Flows project are GSM, UMTS and HIPERLAN/s.

The main objectives of the Global System for Mobile Communications (GSM) are to provide a wide range of services and facilities, both data and video, that are compatible with other type of network, such as Public Switched Telephone Network (PSTN) and Integrated Service Digital Network (ISDN), and to give compatibility of access to the GSM network for any mobile user.

The Universal Mobile Telecommunication System (UMTS) is designed for multimedia communication: Person-to-person communication can be enhanced with high quality images and video and access to information and services on public and private networks will be enhanced with higher data rates and new flexible communication capabilities.

High Performance Radio Local Area Network (HIPERLAN) is a family of standards on digital high speed communication. HIPERLAN standard describe a common air interface and a physical layer for wireless communications equipment. The family is composed by four variants: HIPERLAN type 1 (HIPERLAN/1), HIPERLAN type 2 (HIPERLAN/2) IPERACCESS and HIPERLINK. HIPERLAN/1 is a standard for high speed communications for portable devices, HIPERLAN/2 offers high speed access to different type of networks, HIPERACCESS is a service for residential and small business users and HIPERLINK provides an interconnection of HIPERLAN/s and HIPERACCESS with high speed.

As for GSM, its key service (telephony) is well known, but lately, with the emergence of WAP and GPRS, some new services supported on data are being implemented, and starting to appear. The main UMTS services and applications have already been identified; which include the ones of GSM, and can be listed as: Speech, Simple messaging(SM), Switched Data (SD), Medium Multimedia (MM), High Multimedia (HMM), High Interactive Multimedia (HIMM). In some way, HIPERLAN/s will provide services that will be include in this classification as well. Frequency band and channel spacing parameters of these common standards are important to underline the huge variety of multi-band and multi-mode terminals that are needed. Terminals that support GSM 900 MHz and 1800 MHz are already available. Currently, terminals that will also support the 2000 MHz UMTS, as well as 5000 MHz HIPERLAN/s are being developed.

This report resumes eight months of work on radio propagation issues concerning their influence on the mobile radio environment because a complete characterization of the mobile environment is needed. The main aim is to evaluate the path-loss with and without slow and fast fading influence for narrowband and wideband systems, and to estimate, through several propagation models, the cell-range for different systems (GSM, UMTS and HIPERLAN/s) in several environments.

In this report, a brief description of path-loss and fading models is presented. Moreover, general considerations about shadowing and multipath fading are drawn, and recent work about the fading dependence on system characteristics, such as bandwidth, and scenario specific feature is presented. Results for the fading depth observed by GSM, UMTS and HIPERLAN, working in different environments are presented and discussed.

Main emphasis is given to the characterization of wideband multipath fading, concerning the dependence on system bandwidth and environments characteristics; since this is a topic that is not already well studied and only a few approaches can be found in literature.

In fact, UMTS and HIPERLAN systems, which are wideband systems, present a bandwidth that is much larger than the one usually considered in current second generation (2G) systems. For these systems, the impact of the fast fading is considerable and the well known models for fast fading (Rayleigh and Rice distributions) are not longer applicable. Therefore, one has decided to present in more detail a new model that describes this wideband multipath fading phenomenon (Cardoso model).

This report is organised as follows:

In Chapter 2 one can find a general description of mobile/wireless communication systems: GSM, UMTS and HIPERLAN, in terms of network structure, frequency bands and channel arrangement, transmitted and received power, that are the main parameters that are needed to achieve the aim of this work. Different scenarios and applications for each system are presented and finally a link budget estimation that is essential in the dimensioning activities, e.g. coverage analysis, capacity estimation is performed.

Chapter 3 is devoted to theoretical propagation models. Typical path-loss models for outdoor and indoor environments, namely COST 231 Hata, COST 231 Walfish-Ikegami, Multi-wall and COST 231 indoor model, are presented and discussed. Moreover, general considerations about slow fading and fast fading are made with a presentation of well known models (Log-normal, Rayleigh and Ricean distributions). Finally, Cardoso model description is made, which represents a new approach for studying the fast fading influence in wideband systems.

In Chapter 4 one can find how Cardoso model was used to estimate the fading depth in several environments and for different systems; which represents the most important part of the work since it represents a new approach in this field. Another innovative aspect of this work concerns the presentation of a modified Cardoso model for two particular scenarios. Results regarding average path-loss and the estimation of slow fading by Log-normal distribution and of fast fading, obtained by Cardoso model, are reported. The evaluation of the path-loss with the fading margins is shown and discussed. Finally, the cell-range estimation for the average path loss and when considering the fading margins obtained by the application of COST 231 Hata, COST 231-WI and Multi-wall models are presented and discussed.

Chapter 5 provides the reader the main conclusions extracted form this work.

In Annex, detailed calculations … are provided.

2. Systems and Applications

In this chapter a description of GSM, UMTS HIPERLAN systems is done, concerning (frequency band, bit rate, power), scenarios, applications and link budget aspects.

2.1. GSM

2.1.1. Network structure

The simplified structure of a typical GSM network with the functional entities of the system and their logical interconnections is presented in Figure 2.1.

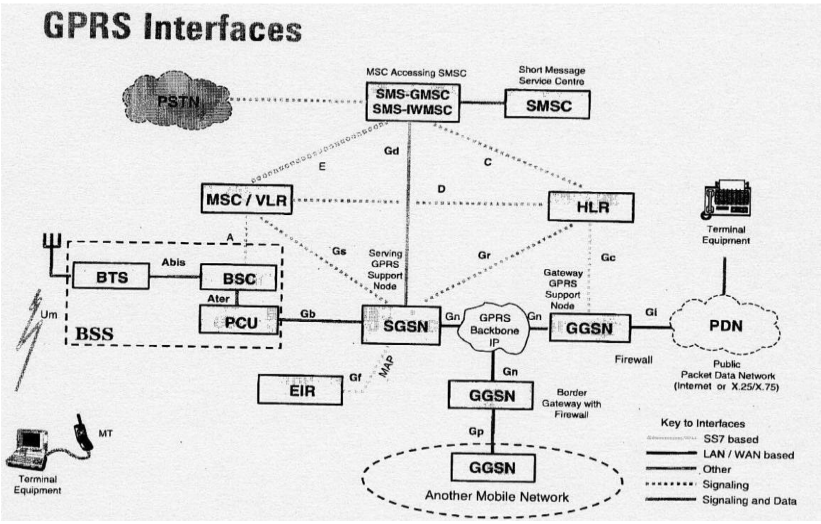


Figure 2.1-Simplified structure of a GSM/GPRS network (extracted from [Agil01]).

The main functional blocks are as follows:

- The Mobile Station (MS), is the equipment used by a subscriber to access the services offered by the system. Functionally the MS includes a Mobile Termination (MT), and the Terminal Equipment (TE), which may consist of several types of equipment such as a telephone set and Data Terminal Equipment (DTE).
- The MT that performs functions needed to support the physical channel between the MS and the Base Station (BS), radio channel management, channel coding/decoding, speech encoding/decoding, and so forth.

- The Base Station Sub-system (BSS) is divided functionally into a Base Transceiver Station (BTS) and Base Station Controller (BSC), interconnected by an A-bis interface.
- The BS is associated with the radio channel management including channel allocation, link quality supervision, transmission of associated signalling information and broadcast messages, as well as controlling transmitted power levels and frequency hopping.
- The BTS is the transmission equipment used to give radio coverage for a specific cell. All control functions in the base station are performed by the BSC. The radio equipment in a BS may serve more than one cell, in which case the BS will consist of several BTS's under the control of one BSC.
- The Mobile Switching Centre (MSC), linked to the BS via an A interface, performs all the switching functions needed for the operation of the mobile stations in the group of cells it serves.

One important feature in GSM is Handover (HO), which is the process of re-assigning the MS communication to a different BS, when the MS move outside the range of the serving BS. The functions of an MSC include call routing and call control; procedure related to the mobile station's mobility management such as paging to receive a call, location updating while roaming and authentication to prevent unauthorised access; as well as procedures required to implement handovers. Home Location Register (HLR) is a data base unit for the management of the mobile subscribers. The BS serving the cell allocates a traffic channel and the MSC routes the call to its destination, the handover take place under the controlled of BSC when the BSs are controlled by the same BSC otherwise BSs are under the MSC.

Part of the mobile location information is stored in HLR. The MS has to periodically inform the PLMN about its geographic location by updating the contents of the HLR. To assist this process, the PLMNs are divided into disjoint geographic areas characterised by unique identifiers broadcast regularly to all MSs via the so-called Broadcasting Control Channel (BCCHs) conveyed over reserved RF carriers. Should the MS observe a change of identifier, it issues a location update request. The HLR contains the International Mobile Subscriber Identity (IMSI) number that is used for the authentication of the subscriber by his Authentication Centre (AUC). This enables the system to confirm that the subscriber is allowed to access it.

The Visitor Location Register (VLR) is the functional unit that attends to a MS operating outside the area of its HLR. The visiting MS is automatically registered at the nearest MSC and the VLR is informed of the MS arrival. A roaming number is assigned to the MS and this enables calls to be routed to it.

In this context is simple to compare the GSM architecture with the General Packet Radio Service (GPRS) one because to support GPRS technology only two new nodes are required: the Serving GPRS Support Node (SGSN) and the Gateway GPRS Support Node (GGSN). The GGSN acts as a gateway between the GPRS network and the public PDN (Packet Data network) or other GPRS networks. It also provides authentication and location management functions and connection to the HLR (Home Location Register). The SGSN controls all aspects of the connection between the network and the MS by providing Session Management (SM) and GPRS Mobility Management (GMM) functions such as handover and paging. It is connected to the HLR and MSC/VLR. Both GGSN and SGSN count the number of the packets and route them to provide accurate billing.

PCU functions include converting the packet data into a format that can be transferred over the air interface, radio resource management and Quality of service measurements, namely throughput, delay, reliability and priority.

2.1.2. Frequency bands and channel arrangement

GSM [Stee92] was first devised as a cellular system in a specific 900 MHz band, called “ the primary band”. This primary band includes two sub-bands of 25 MHz each, [890, 915] MHz for uplink transmission and [935, 960] MHz for downlink transmission. A portion of this band is usually given to an operator, since most countries have several operators. However, every MS must be able to use the full band, in order not to impose constraints upon roaming. In 1990, a second frequency band was specified, divided in two sub-bands with 75 MHz, bandwidth [1710, 1785] MHz and [1805, 1880] MHz.

In GSM, speech and data are mapped onto timeslots of TDMA frames, 8 time-slots per carrier. The central frequencies of the frequency slots are spread evenly every 200 kHz within these bands, starting 200 kHz away from the band borders. There are 124 different radio channel for the 900 MHz band, and 375 for 1800 MHz band. The radio channel power spectrum is somewhat wider than 200 kHz, resulting in some level of interference between bursts on simultaneous slots, or on adjacent frequency slots. The border frequencies are usually avoided and so the number of frequency slots, which can be used in the 900 MHz band is usually limited to 122, while in the 1800 MHz one, it is usually limited to 373. Thus, the carrier frequencies in the two bands for the *n-th* duplex radio channel will be

$$f_{UL} = 890.2 + 0.2\,(n - 1) \quad \text{[MHz]} \tag{2.1}$$

$$f_{DL} = f_{UL} + 45 \quad \text{[MHz]} \tag{2.2}$$

for the 900 MHz band, and

$$f_{UL} = 1710.2 + 0.2\,(n - 1) \quad \text{[MHz]} \tag{2.3}$$

$$f_{DL} = f_{UL} + 75 \quad \text{[MHz]} \tag{2.4}$$

for the 1800 MHz band, where f_{UL} and f_{DL} are the carrier frequencies in uplink and downlink directions, respectively.

The elaborate design of the MS-BS radio interface is motivated by the needs of providing appropriate signalling and traffic channels. A feasible solution to efficient networking is provided by the set of logical control channels defined by GSM. As one can see from Table 2.1, there are two general forms of speech and data traffic channels: the full-rate traffic channels (TCH/F), which carry information at a gross rate of 22.8 kbit/s, and the half rate traffic channels (TCH/H), which communicate at a gross rate of 11.4 kbit/s. A physical channel carries either a full rate channel, or two half-rate traffic channels. In the former the traffic channel occupies one timeslot, while in the latter the two half-rate traffic channels are mapped onto the same timeslot, but in alternative frames. The bit rate in the full-rate traffic channel for speech (TCH/FS) is 13 kbit/s, becoming 22.8 kbit/s after embedded channel coding. The channel code data rate in the half-rate speech channel (TCH/HS) is 11.4 kbit/s. The traffic channels may carry a wide variety of users information, but not signalling information.

The error rate performance of the RF subsystem is specified in the GSM system for various propagation environments, which are presented by different channel models. The propagation models, defined by ETSI [Stee92], are: Rural Area (RAx), Hilly Terrain (HTx), Typical Urban Area (TUx), and the profile for Equalisation Testing (EQx) with x representing the speed of the MS. Additive white Gaussian noise channel is also considered. Depending on the type of traffic or control channel, the performance is described in terms of Frame Erasure Rate (FER), Bit Error Rate (BER), or Residual Bit Error Rate (RBER).

Table 2.1-Available bit rate in GSM (extracted from [Stee92]).

Speech	Data
TCH/F 22.8 kbit/s	TCH/F9.6 TCH/F4.8 TCH/F2.4 22.8 kbit/s
TCH/H 11.4 kbit/s	TCH/H4.8 TCH/H2.4 11.4 kbit/s

The RBER is defined as the ratio between the number of errors detected and the number of the bits in a “good” frame.

In GSM three different types of error rates are defined. One is concerned with the conditions of operation at reasonable signal levels and in the absence of interference, another applies when the receiver is operating with signal levels close to its noise floor, and the third category applies for operation in the presence of interference. The Nominal Error Rates (NER) applies to propagation conditions, when there is no interference and the received RF signal level is equal to -85 dBm. Under these conditions the chip error rate (channel BER), which is equivalent to the bit error rate of the non-protected C2 bits of a full rate traffic channel for speech, is specified as presented in Table 2.2.

Table 2.2-Chip Error Rate (BER) for different type of channels (extracted from [Stee92]).

CHANNEL	**BER**
Static	$< 10^{4}$
Rural (RA250)	$\leq 4\ 10^{4}$
Typical Urban (TU3)	$\leq 4\ 10^{4}$
Equalisation Testing	10^{2}

2.1.3. Power considerations

In GSM, the BS and the MS are classified according to the transmitter output power and to the band in which they are working,

Table 2.3 and 2.4.

Table 2.3-GSM BS power characteristics (extracted from [ETSI99]).

Parameter	Value/Interval	
	GSM900	**GSM1800**
Maximum Transmission power [dBm]		
Power class 1:	[55.0, 58.0[	[43.0, 46.0[
Power class 2:	[52.0, 55.0[	[40.0, 43.0[
Power class 3:	[49.0, 52.0[	[36.9, 40.0[
Power class 4:	[46.0, 49.0[	[33.9, 36.9[
Power class 5:	[43.0, 46.0[	
Power class 6:	[40.0, 43.0[	
Power class 7:	[36.9, 40.0[	
Power class 8:	[33.9, 36.9[	
Micro BTS Maximum Transmission Power [dBm]		
Power class M1	]19.0, 24.0]	]27.0, 32.0]
Power class M2	]14.0, 19.0]	]22.0, 27.0]
Power class M3	]09.0, 14.0]	]17.0, 22.0]

Table 2.4-GSM MS power characteristics (extracted from [ETSI99]).

Parameter	Value/Interval	
	GSM900	**GSM1800**
Maximum Transmission power [dBm]		
Power class 1:	39	30
Power class 2:	37	24
Power class 3:	33	36
Power class 4:	29	
Power class 5:		

Adaptive RF power control is mandatory for the MS, but optional for the BS. This feature reduces co-channel interference while maintaining the quality of the radio channel. It also decreases the power consumption, which is important for hand-held MSs. Provisions are made for 16 different power control levels with 2 dB spacing between adjacent steps. The lowest power level for all MS, regardless of their power class, is 13 dBm (20 mW) and the highest power level is equal to the maximum peak power corresponding to the class of the particular mobile station. In the BS, the same 16 steps of 2 dB-spaced power levels are provided to achieve adaptive RF power.

The output power of the BS can be reduced from its maximum level in at least six steps of 2 dB (with each step accurate to ± 0.5 dB) to adjust the radio coverage by the network operator. This RF output adjustment is provided in every BS. These permitted emission levels decrease to 2 nW (-57 dBm) and 20 nW (-47 dBm) in the corresponding bands when the MS is in its idle mode.

The MS receiver performance is assessed in terms of a reference sensitivity level, which is the RF signal level at the receiver input assuming a specific propagation channel, for which the required error rate performance is achieved. For hand portable receivers the reference sensitivity level is -102 dBm and -104 dBm for all other MSs and BSs.

2.2. UMTS

2.2.1. Network structure

UMTS is based on the same well-known architecture that has been used by all main second-generation system and even by some first generation ones. It consists of a number of logical network elements with specified functionality. In the standards, network elements are defined at the logical level, but this quite often results in a similar physical implementation, especially since there are a number of open interfaces. Functionally network elements are grouped into the Radio Access Network (RAN, UMTS Terrestrial RAN = UTRAN) that handles all radio-related functionally, and the Core Network (CN), which is responsible for switching and routing calls and data connections to external networks. Finally the User Equipment (UE) that interfaces with the user and the radio interface is defined. UTRAN is based on Wideband Code Division Multiple Access (WCDMA) radio technology, while the definition of CN is adopted from GSM. UMTS elements can be subdivided into sub-networks, as presented in Figure 2.2.

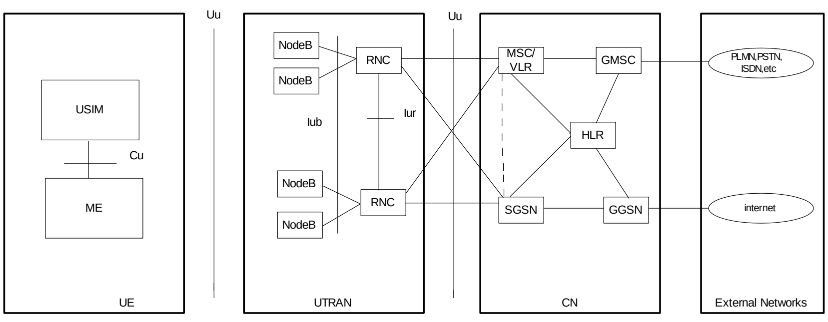


Figure 2.2-Network elements in a UMTS (extracted from [HoTo00]).

UMTS is modular, in the sense that is possible to have several network elements of the same type (the minimum requirement for a fully featured and operational network is to have at least one logical network elements of each type).

The UE consists on the Mobile Equipment (ME), i.e., is the radio terminal used for radio communication over the Uu interface, and the Subscriber Identity Module (USIM) that is a smartcard that holds the subscribers identity, performs authentication algorithms, stores authentication and encryption keys and some additional subscription information needed at the terminal. UTRAN is composed of two main blocks: the Node B converts the data flow between the Iub and Uu interface, while providing radio resource management. The Radio Network Controller (RNC) owns and controls the radio resources in its domain (the Nodes B connected to it). The RNC is the service access point for all services that UTRAN provides to the CN. The external network can be divided into circuit-switched networks, like the existing telephony service (e.g. ISDN and PSTN), and packet switched networks that provide connections for packet data services, e.g. Internet.

2.2.2. Frequency bands and channel arrangement

The radio spectrum is not an unlimited natural resource, but rather it is extremely scarce. Although, advanced systems exploit the available radio spectrum more efficiently, nevertheless, rapid growth in demand for wireless services increases the scarcity of the spectrum. For this reason, it has been decided (in mid-1999 by Operator Harmonisation Group (OHG)) that UMTS will have two DS-CDMA variants in use. These are: Frequency Division Duplex-Wideband Code Division Multiple Access (FDD-WCDMA) and Time Division Duplex- Time Division Wideband Code Division Multiple Access (TDD-TDWCDMA). These variants use similar bandwidths: FDD uses the frequency band of [2110, 2170] MHz for the downlink, and [1920, 1980] MHz for the uplink, and the duplex distance is 190 MHz; the TDD variant uses a frequency band located in both sides of the FDD uplink, [1900, 1920] MHz and [2010, 2025] MHz.

System Chip Rate is a constant value for all WCDMA variants and is expressed as 3.84 Mc/s. The Spreading Factor, *SF*, gives a measure of how much the user signal is spread onto the channel, Table 2.4.

Table 2.4- Relationship between Spreading Factor, Symbol Rate and Bit Rate (extracted from [KALN01]).

Spreading Factor	**Uplink**		**Dowlink**	
	Symbol Rate [ks/s]	Channel Bit Rate [kb/s]	Symbol Rate [ks/s]	Channel Bit Rate [kb/s]
512	-	-	7.5	15.0
256	15.0	15.0	15.0	30.0
128	30.0	30.0	30.0	60.0
64	60.0	60.0	60.0	120.0
32	120.0	120.0	120.0	240.0
16	240.0	240.0	240.0	480.0
8	480.0	480.0	480.0	960.0
4	960.0	960.0	960.0	1920.0

2.2.3. Power Considerations

Usually, the power transmitted by the BS is higher than the power transmitted by the MS. Typical values of maximum output power, power control step size (standardized values are indicated for FDD and TDD), reference sensitivity level, noise power density, noise figure and cable loss and are presented in

Table 2.5 and 2.6.

The "Output power" for the BS is the mean power of one carrier delivered to a load with resistance equal to the nominal load impedance of the transmitter during one slot, and the Maximum output power for the BS, is the mean power level per carrier that the manufacturers has declared to be available at the antenna connector.

Reference sensitivity is the signal level needed at the receiver input that just satisfies the required carrier to noise plus interference ratio:

$$l = Eb / (No + Io) \tag{2.5}$$

where Eb is the received energy per information bit, N_0 is the total effective noise and I_0 is the interference power density needed.

Table 2.5-Characteristics of the BS (extracted from [3GPP01], [HoTo00]).

Parameter	**Value/interval**		
	Macro - Cell	Micro - Cell	Pico - Cell
Maximum output power [dBm]	[20, 43]	[20, 33]	[20, 33]
Power control step Size [dB]	1 (0.5 optional) (FDD) {1, 2, 3} (TDD)		
Reference sensitivity [dBm]	12.2 kbps voice (FDD)	144 kbps real-time data (FDD)	384kbps non-real-time data (FDD)
	-120	-113	-109.2
Noise power density [dBm/Hz]	- 174		
Noise Figure	[3, 5]		
Cable loss	[1, 3]		

Table 2.6-Characteristics of the MS (extracted from [Fern99], [Kott99]).

Parameter	**Value/Interval**	
	FDD	TDD
EIRP [dBm]	[10, 33]	
Output power [dBm] Power class 1: Power class 2: Power class 3: Power class 4:	 [- 50, + 33] [- 50, + 27] [- 50, + 24] [- 50, + 21]	 [- 44, + 27] [- 44, + 21]

Thus, the reference sensitivity can be evaluated from [ETSI97]:

$$RS\text{[dBm]} = j\ \text{[dBm/Hh]} + IR\text{[dBHz]} + l\ \text{[dB]} \tag{2.6}$$

where j is the total effective noise plus interference density, defined as

$$j = 10\log(10^{((F+N)/10)} + I) \tag{2.7}$$

where F is the Receiver Noise Figure (5 dB is considered), and N is the Thermal Noise Density (- 174 dBm/Hz being considered). IR is the Information Rate, defined as:

$IR = 10 \log (Rb)$ [dBHz], (2.8)

with Rb is representing the Bit Rate.

Typical values of Reference sensitivity for the transmission of voice at 12.2 kbps, for the transmission of real-time data at 144 kbps and the transmission of non-real-time data at 384 kbps are presented in Table 2.5. These values [HoTo00] are referred to uplink direction (in means that are for BS) because it is more range limited than downlink in UMTS, therefore, the study of uplink is most important.

2.3. HIPERLAN

2.3.1. Network structure

High Performance Radio Local Area Network (HIPERLAN) is a set of Wireless Local Area Network (WLAN) communication standards. These standards are proposed by the European Telecommunications Standard Institute (ETSI)

As previously referred, there are four diferent variants of HIPERLAN: HIPERLAN/1, HIPERLAN/2, HIPERACCESS and HIPERLINK, Table 2.7.

Table 2.7-HIPERLAN family (extracted from [Sky00]).

	HIPERLAN/1	HIPERLAN/2		HIPERACCESS	HIPERLINK
Description	Wireless LAN	Wireless ATM		Wireless ATM Remote Access	Broadband interconnect
		Lower	Upper		
Frequency band [GHz]	5.15-5.3	5.15-5.30	5.47-5.73	40.5-43.5	17
Bit Rate [Mb/s]	24	≤ 54		25	155

HIPERLAN/1 is designed to provide high-speed communications between portable devices in the 5 GHz range. It can be used to allow flexible wireless data networks and as an extension of a wired LAN. HIPERLAN/2 (short-range variant) will offer high-speed access (up to 54 Mbit/s) to a variety of networks including UMTS n, ATM (Asynchronous Transfer Mode) and IP (Internet Protocol) based networks. HIPERACCESS (long-range variant) is intended for point-to-multipoint and high speed access (25 Mbit/s typical data rate) by residential and small business users to a wide variety of networks including the UMTS, ATM and IP based ones. HIPERLINK variant provides short-range very high-speed interconnection of HIPERLANs and HIPERACCESS, e.g., up to 155 Mbit/s over distances up to 150 m.

2.3.2. Frequency bands and channel arrangement

In HIPERLAN/1 system five channels are available. All HIPERLAN/1 equipments can operate in all of these. The nominal radio frequency band allocated to HIPERLAN is [5.15, 5.30] GHz.

The bit rate, in HIPERLAN/1, depends on the type of transmitted data and the modulation scheme. Indeed data packets are modulated with Gaussian Minimum Shift Keying (GMSK) and transmitted at a high bit rate (HBR) of 23,5294 Mbit/s; while Frequency Shift Keying (FSK) is used for the acknowledgements that are transmitted at a low bit rate (LBR) of 1.4706 Mbit/s. The deviation in signal rate shall be accurate to be within the range of ± 235 bit/sec for high rate transmissions and of ± 15 bit/sec for low rate transmission. The selected radio frequency can only deviate a maximum 10^{-5} from the mid-frequency as shown in Table 2.8.

Table 2.8-Physical characteristics of the physical layer (extracted from [Walk99]).

	High-bit-rate-data	**Low-bit-rate-data**
Frame	Data packet	Ackonoledgement
Signal rate [MHz]	23.5294	1.4707
Deviation in signal rate [bit/s]	±235	± 15
Modulation procedure	GMSK	FSK
ρ	0.3	-

where ρ is the roll-off factor.

As shown in Table 2.9 each carrier has its own carrier number [ETSI9b].

Table 2.9-Nominal carrier centre frequencies (extracted from [ETSI96b]).

Carrier number	Centre Frequency [MHz]
0	5176,468 0
1	5199,997 4
2	5223,526 8
3	5247,056 2
4	5270,585 1

HIPERLAN/2 operates in two frequency bands, usually called lower frequency band and upper frequency band. The allocated band for the former is [5 150, 5 350] MHz, while for the latter is [5 470, 5 725] MHz. The channeling is implemented by Orthogonal Frequency Division Multiplexing (OFDM). Hence, data is divided into several interleaved, parallel bit streams with each bit stream modulating a separate carrier. The channel spacing is 23.5 MHz and 52 sub-carriers are used per channel (48 sub-carriers for data and 4 sub-carriers for tracking the phase for coherent demodulation) [Tml99].

HIPERLAN/2 has a very high transmission rate up to 54 Mbit/s. This is achieved by making use OFDM modulation method. OFDM provides flexibility considering the realization of different modulation alternatives; some of them are shown in .

Table 2.10.

Table 2.10-Physical layer mode for HIPERLAN/2 (extracted from [Tml99]).

Mode	**Modulation**	**PHY bit rate [**Mb/s]	**Bytes/OFDM**
1	BPSK	6	3.0
2	BPSK	9	4.5
3	QPSK	12	6.0
4	QPSK	18	9.0
5	16-QAM	27	13.5
6	16-QAM	36	18.0
7	64-QAM	54	27.0

The available frequency for HIPERACCESS is [40.5, 43.5] GHz and in this band will be used TDMA as multiple access scheme and a single carrier modulation scheme.

Finally, spectrum for HIPERLINK is available in the 17 GHZ range. HIPERACCESS utilizes the same bit rate available for HIPERLA/2, while for HIPERLINK the maximum bit rate is 155 Mbps.

2.3.3. Power Considerations

The combinations of three categories of receiving and transmitting classes assess the receiver sensitivity. Three classes A, B and C have been defined according to the allowed combinations of the classes with the minimum receiver power level, Table 2.11.

Table 2.11-Allowed combinations of transmitter and receiver classes (extracted from [Walk99]).

Receiver class	Transmitter class		
	A (+ 10 dBm)	B (+ 20 dBm)	C(+ 30 dBm)
A (- 50 dBm)	Allowed	-	-
B (- 60 dBm)	Allowed	Allowed	-
C (- 70 dBm)	Allowed	Allowed	Allowed

In HIPERLAN/2 the transmission power range is [-15, 30] dBm for MT, but the maximum value chosen is 23 dBm (200 mW), because it enables to cover all indoor applications [ETSI01]. In this type of systems the receiver sensitivity [ETSI01] change on the base of the nominal bit rate, for this reason it is possible to give a range for the minimum receiver sensitivity: [-85, -68] dBm.

2.4. Scenarios and Applications

2.4.1. GSM

In GSM, the cells are grouped into clusters with m BSs, (typically m = 4). This architecture represents an intelligent way for the frequency reuse in order to improve the system capacity: the smaller the cells, the more efficiently the radio spectrum is used but the cost of the system increases at the same time because more base BSs are needed. The usual planning cell shape is hexagonal, but, in general, it depends on the terrain, buildings, directivity of the antennas, radiated power level, among many other parameters, Figure 2.3.

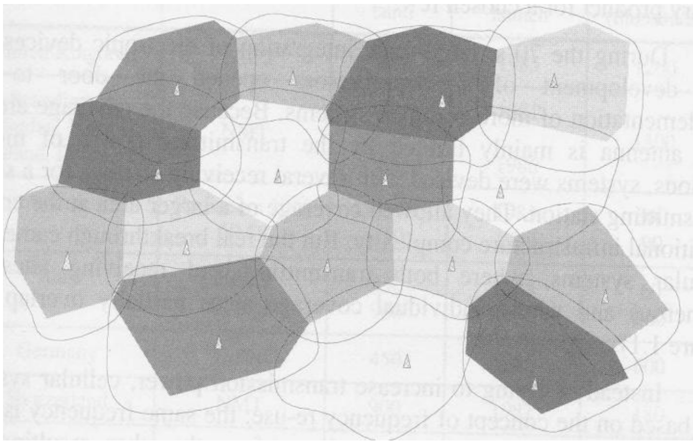


Figure 2.3-Example of irregular cell shape (extracted form [MoPa92]).

The cell range in GSM900 is limited to 35 km in rural areas, while in urban areas this limit decreases to 10 km, except for handheld stations, for which the limit is greater [MoPa92].

Since the density of the population in a country is so varied, different types of cells are used according different systems requirements: macrocells, microcells, selective cells and umbrella cells. While, macrocells are large cells for remote and sparsely populated areas, microcells are used for densely populated areas. By splitting the existing areas into smaller cells, the number of available channels increases thus, increasing the system capacity. The power level of the transmitters in these cells is then decreased, reducing the possibility of interference between neighboring cells. Selective cells are used when cells with a particular shape and coverage are needed. A typical example are the cells that are located at the entrances of tunnels where a coverage of 360 degrees is not needed. Umbrella cells cover several Microcells. They are important to solve the problem of handover between the different neighboring of the cells.

GSM supplies speech and data applications, like: SMS, voicemail and WAP. Another technology that could be seen like an application of GSM is GPRS. This is possible because it involves overlaying a packet-based network on the existing circuit switched GSM network [Agil01]. GPRS is a packet switched data network and so it allows to use a data transfer rate faster than conventional GSM: the theoretical maximum speed is up to 171.2 kbps against 9.6 kbps [Agil01]. All these things imply that several new applications are allowed: the overcoming of the limitation due to the length of the Short Message Service (160 characters in GSM). Even if this new technology offers many advantages, it presents several limitations, too.

2.4.2. UMTS

In UMTS one usually considers three types of cells: macrocell, microcell and picocell. The first one is used to cover wide areas and for high-speed mobiles, it is also characterized by three-sector cell, whereas for microcell and picocell are usually employed omnidirectional antennas. Microcells and picocells are used to provide extra capacity with respect to macrocells where the traffic density is too much. Microcells are used for outdoor coverage, instead picocells are used mainly in indoor areas where high data rate services are required.

The capacity of the cells depends on the service bit rate and on the use of low/high mobility terminals, e.g., in microcells 2 Mbit/s may be possible in a low mobility environment close to the BS, Table 2.12.

Table 2.12-Assumed BS distances, cell areas and mobility class (extracted form [Garc00]).

Cell type	Distance [km]	Cell area [km^2]	Mobility class
Macro	1.000	0.288	High
Micro	0.400	0.138	High/Low
Pico	0.075	0.005	Low

From the environment point of view, six operational environments can be identified [Vele00], Table 2.13.

Table 2.13-Operating environments and corresponding cell types (extracted from [Vele00]).

Operational Environment	Cell Type
City Business District (in building)	Micro/Pico
Suburban (in building or on street)	Macro
Home (in building)	Pico
Urban (pedestrian)	Macro/Micro
Urban (vehicular)	Macro/Micro
Rural in - & - out - door	Macro

It can be seen from Table 2.14, that the cell size depends on the operating environment.

Table 2.14-Cell dimensions per operating environment (extracted from [Vele00]).

Operational Environment	2005		2010	
	Cell radius [km]	Area of hexagon sector [km^2]	Cell radius [km]	Area of hexagon sector [km^2]
City Business District (in building)	0.075	0.005	0.075	0.005
Suburban (in building or on street)	3.000	7.790	2.000	3.460
Home (in building)	0.020	0.001	0.020	0.001
Urban (pedestrian)	0.700	0.424	0.600	0.312
Urban (vehicular)	0.700	0.424	0.600	0.312
Rural in - & - out - door	8.000	55.430	8.000	55.400

Six main service classes are considered [ETSI99b]:

- **Speech (S):** teleconferencing services and voicemail
- **Simple messaging(SM):** SMS and paging, email delivery, broadcast and public information messaging, ordering/payment (for simple electronic commerce).
- **Switched Data (SD):** low speed dial-up LAN access, Internet/Intranet access Fax, legacy services- mainly using radio modems such as PCMCIA cards (are not expected to be very significant by 2005)
- **Medium multimedia:** Asymmetric services that tend to be “bursty” in nature, require moderate data rates, and are characterized by a typical file size of 0.5 Mbytes, with a tolerance to a range of delays. They are classed as packet switched services: LAN and Internet/Intranet access, application sharing (collaborative working), interactive

games, lottery and betting services, sophisticated broadcast and public information messaging, simple online shopping and banking (electronic commerce) services.

- **High Media (HMM):** Asymmetric services that tend to be “bursty” in nature, require moderate data rates, and are characterized by a typical file size of 10 Mbyte, with a tolerance to a range of delays. They are classed as packet switched services. Applications include: fast LAN and Internet/Intranet access, video clips on demand, audio clips on demand, online shopping.
- **High Interactive Multimedia (HIMM):** Symmetric services which require reasonably continuous and high-speed data rates with a minimum of delay. Applications include: video telephony and video conferencing, collaborative working and telepresence.

2.4.3. HIPERLAN

In HIPERLAN the following scenarios are identified [Vele00]:

- Office
- Industry
- Studio

For each scenario a different set of applications is defined:

- Office:
    - Audio Distribution, 8 channels;
    - High quality audio uplink, 1 stereo channels;
    - Telephone headsets, 10 lines;
    - Radio microphone, 30 off;
    - High quality video distribution, 8 channels;
    - High quality video uplink, 1 channel.
- Studio:
    - Video Applications: multimedia conference (large display), general video conferencing, asymmetric video;
    - Telephone;
    - General network computing applications: Data transmission, Document Retrieval, E-mail, Processing (Host 0.5 MIPS), Processing (Host 5.0 MIPS), Mono chrome Laser Printing;
    - Multimedia database;

- Security and monitoring;
- Internet and Intranet browsing;
- Teleworking;

- Indusry:
  - File transfer;
  - Software transfer;
  - Configuration data;
  - Control data;
  - Alarm;
  - Surveillance;
  - Monitoring;
  - Video multi - point monitoring;
  - High bandwidth video multi - point monitoring.

2.5. Link Budgets

Link budget evaluation is essential for system design and evaluation purposes, e.g., coverage and interference analysis. Basically, it consists of estimating the power at the receiver:

$$P_{r\,[\mathrm{dB}]} = P_{t\,[\mathrm{dB}]} + G_{r\,[\mathrm{dBi}]} + G_{t\,[\mathrm{dBi}]}] - L_{p\,[\mathrm{dB}]} \qquad (2.9)$$

where P_t and and P_r corresponds to the transmitted and received power, respectively; G_r and G_t represent the total gain at the transmitter and the receiver, respectively (it includes antenna gains plus additional factors such as cable and body losses); L_p is the path loss between the transmitter and the receiver.

Some useful parameters for GSM link budget evaluation purposes are presented in . Table 2.15.

Table 2.15-Parameters for GSM.

	GSM				**Reference**
Parameters	**Uplink**		**Downlink**		
Max. transmitted power [dBm]	**GSM 900**	**GSM 1800**	**GSM 900**	**GSM 1800**	
	Class1: 39 Class4: 29	Class1: 30 Class3: 36	Class1: [55, 58[Class8: [34, 37[	Class1: [43, 46[Class4: [34, 37[	[ETSI99]
Antenna gain for MT [dBi]	**Speech**	**Data**	**Speech**	**Data**	
	[0,2]				
Body loss [dB]	3	0	3	0	[HoTo00]
Minimum receiver power [dBm]	-104		-102		[ETSI99]
Cable loss [dB]	2				[HoTo00]
Antenna gain for BS [dBi]	[0, 13]				
Thermal noise density [dBm/Hz]	-174				

Link budgets for UMTS are usually evaluated for three typical UMTS services: 12.2 kbps voice service; 144 kbps real-time data service, and 384 kbps non-real-time data service.

The calculations, Table 2.16, are made considering, for the moment, the same value for the noise figure (F) and the required E_b/N_0 in uplink and downlink directions. Even if the first depends on the equipment (indeed F is lower for BS than for MS), while the last parameter depends on the bit rate, service, multipath profile, mobile speed, receiver algorithms and BS antenna structure.

Table 2.16-Parameters for UMTS.

<table>
<tr><th colspan="2" rowspan="2">Parameters</th><th colspan="3">UMTS</th><th>Reference</th></tr>
<tr><td>12.2 kbps voice</td><td>144 kbps real-time data</td><td>384 kbps non-real time data</td><td rowspan="2"></td></tr>
<tr><td colspan="2">Antenna gain for MS [dBi]</td><td>[0, 2]</td><td colspan="2">[0, 2]</td></tr>
<tr><td colspan="2">Minimum receiver power [dBm]</td><td>-120</td><td>-113</td><td>-109</td><td rowspan="4">[HoTo00]</td></tr>
<tr><td colspan="2">Processing gain [dB]</td><td>25</td><td>14.3</td><td>10.0</td></tr>
<tr><td colspan="2">Body loss [dB]</td><td>3</td><td colspan="2">0</td></tr>
<tr><td colspan="2">Cable loss [dB]</td><td colspan="3">2</td></tr>
<tr><td colspan="2">Antenna gain for BS [dBi]</td><td colspan="3">[0, 13]</td><td></td></tr>
<tr><td colspan="2">Thermal noise density [dBm/Hz]</td><td colspan="3">-174</td><td rowspan="4">[HoTo00]</td></tr>
<tr><td colspan="2">BS receiver noise figure [dB]</td><td colspan="3">5</td></tr>
<tr><td colspan="2">Interference margin [dB]</td><td colspan="3">3</td></tr>
<tr><td colspan="2">Required Eb/N0 [dB]</td><td>5</td><td>1.5</td><td>1.0</td></tr>
<tr><td rowspan="2">Max. transmitted power [dBm]</td><td>Uplink</td><td>21</td><td colspan="2">24</td><td>[HoTo00][Fern01]</td></tr>
<tr><td>Downlink</td><td colspan="3">43</td><td>[Kott01]</td></tr>
</table>

In HIPERLAN, the link budget depends on the combinations of the classes at the transmitter and at the receiver, and so it is the same in uplink and downlink directions, Table 2.17.

Table 2.17-Parameters for HIPERLAN.

<table>
<tr><td></td><td colspan="3">HIPERLAN/1</td><td>HIPERLAN/2</td><td>Reference</td></tr>
<tr><td>Parameters</td><td colspan="4">Uplink/Downlink</td><td rowspan="3">[Walk99]</td></tr>
<tr><td>Max. transmitted power [dBm]</td><td>CLASS:A
10</td><td>CLASS:B
20</td><td>CLASS:C
30</td><td>[-15, 30]</td></tr>
<tr><td>Antenna gain for BS [dBi]</td><td colspan="4">[0, 13]</td></tr>
<tr><td>Body loss [dB]</td><td colspan="4">3</td><td>[HoTo00]</td></tr>
<tr><td>Minimum receiver power [dBm]</td><td>CLASS:A
-50</td><td>CLASS:B
-60</td><td>CLASS:C
-70</td><td>[-85, -68]</td><td>[Walk99]
[ETSI99]</td></tr>
<tr><td>Cable loss [dB]</td><td colspan="4">2</td><td rowspan="2">[HoTo00]</td></tr>
<tr><td>Antenna gain for MS [dBi]</td><td colspan="4">[0, 2]</td></tr>
</table>

3. Path-loss models and fading statistics

Propagation Models are important because they permit to simplify the prediction data to characterize the propagation phenomena in a mobile radio environment, e.g. the mean signal strength for an arbitrary transmitter-receiver separation distance, which is used to estimate the radio coverage area. Hence, different types of Propagation Models for GSM, UMTS and HIPPERLAN/s are presented.

3.1. General Propagation

Wave propagation depends on several interactions, such as reflection, diffraction, absorption and scattering. All these effects together with others as influence of vegetation, terrain variations and atmospheric effects have an important impact on mobile communication systems because of decay in the transmitted waves.

Reflection occurs when waves impinge on objects of large dimensions when compared with the wavelength of the propagation wave. The reflected and transmitted waves are related to the incident wave in the medium of origin through the Fresnel reflection coefficient, Γ, which depend on the material properties, wave polarization, angle of incidence and working frequency.

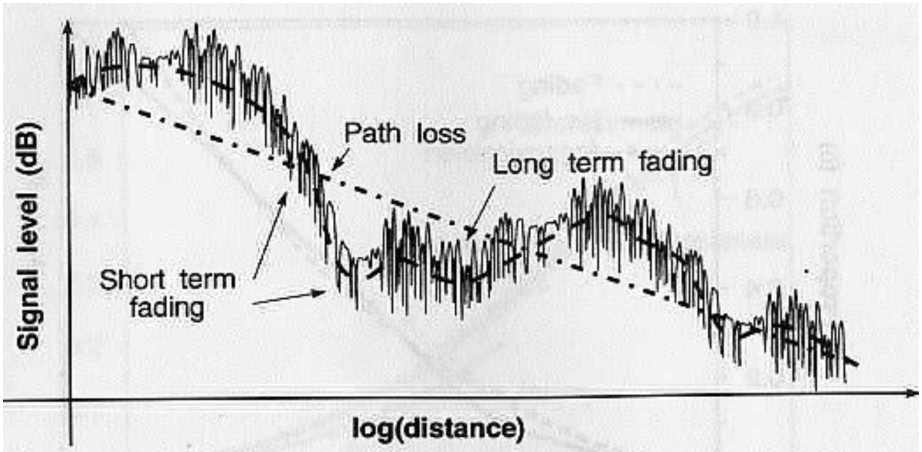
Diffraction is a phenomenon that occurs when the path between the transmitter and the receiver is obstructed by a surface with sharp irregularities (edges), like buildings. When a single object causes shadowing, the attenuation can be estimated treating the obstacle as a diffracting knife-edge; in this way the estimation can be made using the classical Fresnel solution for the field behind the knife-edge. If there is more than one obstacle it can be replaced (or usually is) by a single equivalent obstacle so that it is possible to use a single knife-edge model.

Scattering phenomena occurs when the medium through which the wave travels is composed of objects with small dimensions, when compared to the wavelength, and where the number of obstacles is large. Scattered waves are produced when waves impinge in rough surfaces, foliage and small objects in general.

Absorption (or penetration) losses results from the path obstruction in indoor and outdoor environments by a multiplicity of natural and man-made elements objects such as walls, furniture, buildings and trees. When considering outdoors also atmospheric elements can cause an extra absorption, nevertheless it can be neglected for the range of frequencies under study.

The path-loss between the transmitter and the receiver depends on these phenomena, being significantly dependent on the environment characteristics. As one can see from Figure 3.1, the rusultant signal is strongly influenced by solw and fast fading interactions.

Figure 3.1-The total fading signal (extracted from [Yaco93]).



Usually it is necessary to provide additional power in order to achieve the desired link quality. Considering that:

- Mean signal decreases with distance *d* as $d^{-\alpha}$, where α is a parameter typically in the range 2-4, depending on the environment.
- Slow fading due to shadowing has an approximately lognormal distribution with standard deviation in the range 4-13 dB.
- Fast fading due to multipath propagation has a Rayleigh distribution. Within buildings, where both multipath and LoS waves can be found, the fast fading follows a Ricean distribution.

The received signal cannot be treated only by a deterministic methods because it fades due to the statistical fluctuations.

Thus, in the next sections, some models for outdoors and indoor path-loss estimation are presented.

It is possible classify two types of prediction models: Slow propagation models and Fast propagation models. The first predicts the mean signal strength over large T-R separation distances (several hundreds or thousands of meters), while the last characterizes the rapid fluctuation of the received signal strength over very short travel distances or short time durations, when compared to the wavelength of the transmitted signal.

3.2. Outdoor path-loss models

The path loss (L_p) is defined as the difference between the effective transmitted power and the received power.

Free-space propagation (without obstructions between the transmitter and the receiver) represents the easiest model. The path-loss is given by the Friis formula:

$$L_{o[\mathrm{dB}]} = 32.44 + 20 \log (d_{[\mathrm{km}]}) + 20 \log (f_{[\mathrm{MHz}]}) \tag{3.1}$$

where d is the T-R separation distance and f is the working frequency. This formula is only valid for values of d, which are in the far-field of the transmission antenna (Fraunhofer region) so to be in this region d must satisfy two conditions: $d >> D$ and $d >> \lambda$,with D representing the largest physical linear dimension of the antenna and λ the wavelength. The presence of free space between the transmitter and the receiver is seldom, so this model in the most of the cases is inaccurate.

The 2-ray ground reflection model is a useful propagation model that is based on geometric optics and considers both the direct path and a ground reflected propagation path. It is accurate to predict the signal strength over distances of several kilometers for mobile radio systems and for line-of-sight micro-cell channels in urban environments. The path loss for this model (with antenna gains) is expressed by [Rapp96]:

$$L_{p[dB]} = 40 \log d_{[m]} - (10 \log G_{t[dBi]} + 10 \log G_{r[dBi]} + 20 \log h_{t[m]} + 20 \log h_{r[m]}) \tag{3.2}$$

where G_t is the transmitter antenna gain, Gr is the receiver antenna gain, d is the T-R separation distance and h_t, h_r, are the transmitter and receiver antenna heights, respectively. At large distances ($d >> \sqrt{h_t h_r}$) the received power falls off with a rate of 40 dB/decade, so this is much more rapid compared with the path loss in free space.

3.2.1. COST 231-Hata-model

The Hata model [Hata80] is an empirical formulation of the graphical path loss data provided by Okumura et. al. **Error! Reference source not found.**, and is valid from 150 MHz to 1500 MHz. Hata presented the urban area propagation loss as a standard formula and supplied correction equations for application to other situations. Although Hata’s model does not have any of the path-specific corrections that are available in Okumura’s model, the expressions of Hata have significant practical value. The predictions of the Hata model is closely related to the original Okumura model, as long as distance exceeds 1 km. Therefore, this model is well suited for large cell mobile systems (cell radius above 1 km; but it provides good results only for *d* > 5 km).

Within the COST-231 project an extended version of the Hata model was developed. COST-231 proposes an extension of Hata's model to the frequency band 1 500 ≤ f [MHz] ≤ 2 000 by analysing Okumura's propagation curves in the upper frequency band. This combination is called "COST 231-Hata model"[DaCo99]. It is restricted to large and small macro-cells, *i.e.*, BS antenna heights above rooftop levels adjacent to the BS. The proposed model for path-loss is [DaCo99]:

$$\begin{aligned} L_p[\mathrm{dB}] = {} & 46.3 + 33.9\log(f[\mathrm{MHz}]) - 13.82\log(h_{BT}[\mathrm{m}]) - a(h_{MT}[\mathrm{m}]) + \\ & (44.9 - 6.55\log(h_{BT}[\mathrm{m}]))\log(d[\mathrm{km}]) + C_m \end{aligned} \tag{3.3}$$

Five parameters are used in input to estimate the propagation loss: frequency, distance, base station antenna height, mobile station antenna height and the correction factor C_m
with

$$C_m = \begin{cases} 0 & \text{dB for medium sized city and suburban centres with medium tree density} \\ 3 & \text{dB for metropolitan centres} \end{cases}$$

and

$$a(h_{MT}) = (1.1\log f[\mathrm{MHz}] - 0.7)h_{BT}[\mathrm{m}] - (1.56\log f[\mathrm{MHz}] - 0.8) \tag{3.4}$$

where h_{BS} and h_{MT} correspond to the BS and MT heights, respectively. The function $a(h_{MT})$ is a correction factor for effective mobile antenna height, which depends on the size of the coverage area. Parameter C_m is an additional correction factor that depends on the type of environment. The restricted field in which to work is showed in Table 3.1.

In this particular model the estimation of the path-loss depends on the specific scenario. The (3.3) equation is valid only for the urban environmet. For the sub-urban and rural scenarios some factors depending on the working frequency have to be added to that equation.

In the sub-urban case, the equation is:

$$\begin{aligned} L_p[\mathrm{dB}] = {} & 46.3 + 33.9\log(f[\mathrm{MHz}]) - 13.82\log(h_{BT}[\mathrm{m}]) - a(h_{MT}[\mathrm{m}]) + \\ & (44.9 - 6.55\log(h_{BT}[\mathrm{m}]))\log(d[\mathrm{km}]) + C_m - K_{sub}[\mathrm{dB}] \end{aligned} \tag{3.5}$$

where K_{sub} is the additional factor:

$$K_{sub\,[dB]} = 2\log^2(f_{[MHz]}/28) + 5.4 \tag{3.6}$$

In the rural case, the equation is:

$$L_{p\,[dB]} = 46.3 + 33.9\log(f_{[MHz]}) - 13.82\log(h_{BT\,[m]}) - a(h_{MT\,[m]}) + (44.9 - 6.55\log(h_{BT\,[m]}))\log(d_{[m]}) + C_m - K_{rur\,[dB]} \tag{3.7}$$

where K_{rur} is the additional factor:

$$K_{rur\,[dB]} = 4.78\log^2(f_{[MHz]}) - 18.33\log(f_{[MHz]}) + 35.9 \tag{3.8}$$

3.2.2. COST 231-Walfish-Ikegami-model

The COST 231-Walfisch-Ikegami model [DaCo99] allows to improve the estimation of the path loss in a urban environment by considering additional environment data, namely: height of buildings h_{Roof},, width of roads w, building separation, b, and road orientation with respect to the direct radio path, φ. Moreover, this model is also valid when the BS antenna is positioned below the rooftop level. Additionally, it distinguishes between line-of-sight (LoS) and non-line-of-sight (NLoS) conditions.

For the LoS case, within a street canyon, the path loss is evaluated from:

$$L_{p[dB]} = 42.6 + 26\log(d_{[m]}) + 20\log(f_{[MHz]}) \qquad \text{for } d \geq 20 \text{ m} \tag{3.9}$$

With two input parameters: frequency and distance of which the values are in Table 3.1. The constant is determined in such a way that is equal to free space loss for d = 20 m.

For the last case (NLOS), the formula of path loss is a sum of three terms:

$$L_{p\,[dB]} = \begin{cases} L_{o\,[dB]} + L_{rts\,[dB]} + L_{msd\,[dB]} & \text{for } L_{rts} + L_{msd} \geq 0 \\ L_{o\,[dB]} & \text{for } L_{rts} + L_{msd} \leq 0 \end{cases} \tag{3.10}$$

where L_o is the free space loss, L_{msd} is the multiple screen diffraction loss. The parameter L_{rst} describes the coupling of the wave propagating along the multiple-screen path into the street where the mobile station is located:

$$L_{rts[dB]} = -16.9 - 10\log w_{[m]} + 20\log f_{[MHz]} + 20\log \Delta h_{MT[m]} + L_{Ori[dB]} \tag{3.11}$$

where L_{Ori} is an empirical correction factor, obtained from a few experimental measurements:

$$L_{Ori} = \begin{cases} -10 + 0.354\,\varphi_{[^\circ]} & \text{for } 0^\circ \leq \varphi < 35^\circ \\ 2.5 - 0.075\,(\varphi_{[^\circ]} - 35) & \text{for } 35^\circ \leq \varphi < 55^\circ \\ 4.0 - 0.114\,(\varphi_{[^\circ]} - 55) & \text{for } 55^\circ \leq \varphi < 90^\circ \end{cases} \tag{3.12}$$

and

$$\Delta h_{\mathrm{MT}\,[\mathrm{m}]} = h_{Roof\,[\mathrm{m}]} - h_{MT\,[\mathrm{m}]} \tag{3.13}$$

$$\Delta\ h_{\mathrm{BT}\,[\mathrm{m}]} = h_{BT\,[\mathrm{m}]} - h_{Roof\,[\mathrm{m}]} \tag{3.14}$$

where h_{MT} is the high of the mobile antenna, h_{BT} is the high of the base station antenna and h_{Roof} is the high of the buildings.

The multiple screen diffraction loss, L_{msd}, is defined as:

$$L_{msd[dB]} = L_{bsh} + k_a + k_d \log d_{[km]} + k_f \log f_{[MHz]} - 9\log b_{[m]} \tag{3.15}$$

where

$$L_{bsb\,[dB]} = \begin{cases} -18\log\left(1 + \Delta h_{MT\,[m]}\right) & \text{for } h_{BS} > h_{Roof} \\ 0 & \text{for } h_{BS} \le h_{Roof} \end{cases} \tag{3.16}$$

$$k_a = \begin{cases} 54 & \text{for } h_{BS} > h_{Roof} \\ 54 - 0.8\Delta h_{BS\,[m]} & \text{for } d \ge 0.5\,\text{km and } h_{BS} \le h_{Roof} \\ 54 - 0.8\Delta h_{BS\,[m]}\dfrac{d_{[km]}}{0.5} & \text{for } d < 0.5\,\text{km and } h_{BS} \le h_{Roof} \end{cases} \tag{3.17}$$

$$k_d = \begin{cases} 18 & \text{for } h_{BS} > h_{Roof} \\ 18 - 15\dfrac{\Delta h_{BS}}{h_{Roof}} & \text{for } h_{BS} \le h_{Roof} \end{cases} \tag{3.18}$$

$$k_f = -4 + \begin{cases} 0.7\left(\dfrac{f_{[MHz]}}{925}\right) - 1 & \text{for medium sized city and suburban centres with medium tree density} \\ 1.5\left(\dfrac{f_{[MHz]}}{925}\right) - 1 & \text{for metropolitan centres} \end{cases} \tag{3.19}$$

The parameter k_a represents the increase of the path loss for BS antennas below the rooftops of the adjacent buildings; k_d and k_f controls the dependence of the multi-screen diffraction loss versus distance and radio frequency.When buildings and roads data are unknown, default values are recommended:

$$h_{Roof} = 3\text{ m} \times \{\text{number of floors}\} + \text{roof-height} \tag{3.20}$$

with

$$\text{roof-height} = \begin{cases} 3\text{ m} & \text{pitched} \\ 0\text{ m} & \text{flat} \end{cases} \tag{3.21}$$

also:

$b_d = 20\ldots50$ m, $w = \dfrac{b_d}{2}$, $\varphi = 90^{o}$.

The input parameters in which this model works are represented in Table 3.1.

The estimation of path loss agrees rather well with the measurements for BS antenna heights above rooftop level. The mean error is in the range of $+3$ dB and the standard deviation is about 4 to 8 dB **Error! Reference source not found.**. However, the prediction error becomes large for $h_{Base} \approx h_{Roof}$ compared to situations where $h_{Base} >> h_{Roof}$. Furthermore, the performance of the model is poor for $h_{Base} << h_{Roof}$. The parameters b, w and φ are not considered in a physically meaningful way for micro-cells. Therefore the prediction error for micro-cells may be quite large. The model does not consider multipath propagation, and the reliability of path-loss estimation also decreases, if terrain is not flat or the land cover is inhomogeneous

3.3. Indoor path-loss models

The prediction of the propagation characteristics inside buildings, offices and other types of indoor environments is important for the design of indoors cellular systems with indoors It is necessary to consider that radio indoor channels differ from outdoor ones because the distances covered between the transmitter and the receiver antennas are much smaller. Moreover, attenuation is higher caused by the internal walls and low transmitter powers. Another reason is because the variability of the environment is much greater for a much smaller range of T-R separation distances. The attenuation is strongly influenced by the layout of buildings, types of materials and buildings types, e.g. types of partitions (soft or hard partitions) and multy-floor buildings. In general it is difficult to predict the exact model for indoor environments, for this reason some generalizations are made:

1. signal strength received inside building increases with height.
2. at lower floor the attenuation is greater caused by urban clutter.

3.3.1. Multi-Wall Model

The Multi-Wall Model (MWM) [DaCo99] is an empirical narrowband model. The path loss is given by the sum of the free space loss plus additional losses introduced by walls and floors:

$$L_{p\,[\mathrm{dB}]} = L_{o\,[\mathrm{dB}]} + L_{c\,[\mathrm{dB}]} + \sum_{i=1}^{I} k_{wi}\, L_{wi\,[\mathrm{dB}]} + k_{fj}^{\left[\frac{k_f+2}{kf+1}-b\right]} L_{fj\,[\mathrm{dB}]}$$

(3.22)

with:

$$L_{w\,[\mathrm{dB}]}(k_f) = L_{w0\,[\mathrm{dB}]} \cdot 10^{\frac{k_f^2}{a}} \qquad (3.23)$$

$$L_{f\,[\mathrm{dB}]}(k_f) = \frac{L_{f1\,[\mathrm{dB}]}}{k_f\left(b - \frac{1}{1+k_f}\right)} \qquad (3.24)$$

where L_o is the free space loss between transmitter and receiver, L_c is a constant loss, k_{wi} is the number of penetrated walls of type i, k_{fi} is the number of penetrated type i floors, L_{wi} is the loss of wall type i and L_{fj} is the type j floor attenuation. L_f and L_w are functions of the number of floors, k_f, between the transmitter and the receiver. L_{w0} is the wall attenuation factor for $k_f = 0$ and L_{f1} is the attenuation caused by a single floor. Parameters a and b are empirical factors. One important characteristic of all factors is that implicitly they include the effect of furniture as well as the effect of signal paths guided through corridors because they are model coefficients, which can be optimised with path loss data from measurements.

3.3.2. COST 231 Model

The COST 231 indoor model [DaCo99] gives a more complete characterisation of signal impinging to a certain building. It takes into account the angle of incidence of the transmitted wave, θ, and it makes a distinction between the LoS and NLoS situations. The model was developed for the frequency band of [900, 1800] MHz and distances above 500 m. Isotropic antennas are assumed, both for LoS and NLoS cases. The path-loss for the LoS case is evaluated from:

$$L_p[\mathrm{dB}] = 32.4 + 20\log(f[\mathrm{GHz}]) + 20\log(S[\mathrm{m}] + d[\mathrm{m}]) + W_e[\mathrm{dB}] + W_{ge}[\mathrm{dB}]\left(1 - \frac{D[\mathrm{m}]}{S[\mathrm{m}]}\right) + \max(\varGamma_1, \varGamma_2)$$

(3.25)

with

$$\varGamma_1 = W_i[\mathrm{dB}] \cdot t \qquad (3.26)$$

and

$$\varGamma_2 = \alpha\,(d[\mathrm{m}] - 2)\left(1 - \frac{D}{S}\right)^2 \qquad (3.27)$$

where D and d corresponds to the perpendicular distance of the external antenna to the external wall and the perpendicular one for a path obstructed by internal walls, respectively. $\varGamma_i$ are reflection coefficients, S is a physical separation distance between the external antenna and the external wall from the considered floor, W_e is the external wall attenuation assuming perpendicular penetration ($\theta = 90$º), W_{ge} is the additional external wall attenuation for $\theta = 0$º, W_i represents the attenuation from the internal walls and t is the number of penetrated walls.

As demonstrated by several measurement campaigns [DaCo99], penetration losses may decay as the floor level, n_f, increases. This effect is due to diffraction in neighbouring buildings; typical values are within 1.5 and 2 dB for 1800 MHz band. Assuming a floor height of 3 m, the total floor height gain G_{FH} is given by [DaCo99]:

$$G_{FH}(n_f) = 2.9\,n_f - 1.16 \qquad \text{for } n_f > 0 \qquad (3.28)$$

This aspect is considered fot the calculation of the path loss for the NLoS case. The total attenuation, relative to the reference level of outdoors attenuation, L_o, in then:

$$L[dB] = L_0[dB] + W_e[dB] + W_{ge}[dB] + \max(\varGamma_1, \varGamma_3) - G_{FH}[dB] \qquad (3.29)$$

with

$$\varGamma_3 = \alpha\, d_p \qquad (3.30)$$

and

$$G_{FH} = \begin{cases} n_f G_{nf} \\ \\ h_f^1 G_h \end{cases} \tag{3.31}$$

where W_e, W_{ge}, Γ_1 and d_p are the same as for the LoS case. G_{FH} is the total floor height gain, G_{nf} is height gain per floor level, G_h is height gain per height, h_f^1 is the height relative to reference outdoors height.

Table 3.1-Outdoor propagation models.

Types of models	**Input parameters**		**Work Range**	**Comments**
Friis model	f, d_p		Fraunhofer region: $d_f \gg D$	It is used only in free space (LoS).
2-ray model	G_t, G_r, d, h_t, h_r		Large distances $d_f \gg \sqrt{h_t h_r}$	It is valide over distances of several kms and for LoS in urban environments.
COST 231 Hata model	f, h_{BT}, h_{MT}, d		f : [1500-2000]MHz h_{BT}: [30-200]m h_{MT} :[1-10]m d : [1-20]km	It is limited to large/small macro-cells.
COST 231-WI	LoS	f, d	f : [800-2000]MHz d : [0.02-5]km	It is good for large cities and large/small macro-cells.
	NLoS	$f, w, \Delta h_{BT}$, $\Delta h_{MT}, b$	f : [800-2000]MHz h_{BS} : [4-50]m h_{MS} :[1-3]m d :[0.02-5]km	

Table 3.2-Indoor propagation models

Types of models	**Input parameters**	**Work Range**	**Comments**
Multy-wall model	b, f, d	f : 1800 MHz	$L_{p[dB]}$ is given by a sum of free space loss and losses do to walls and floors.

COST 231 model	LoS	f, S, d_p, D_p	f : [900, 1800] MHz d_p : > 500 m	It gives a complete characterization of signal impinging to a certain building.

3.4. Slow-fading

The average path loss could be expressed as a function of an arbitrary distance between the transmitter and the receiver, by:

$$\overline{L_p} \propto \left(\frac{d}{d_o}\right)^{\alpha} \tag{3.32}$$

with d representing the distance between transmitter and receiver, α the power decay rate d_o a reference distance. One must remember that there are limits to the applicability of this expression for small distances between the transmitter and the receiver, when compared to the wavelength of the transmitted wave. If expressed in logarithmic units (3.32) becomes:

$$\overline{L_p}(d)[\mathrm{dB}] = \overline{L_p}(d_0)[\mathrm{dB}] + 10\,\alpha\log\left(\frac{d}{d_0}\right) \tag{3.33}$$

Besides the dependence of α on the scenario characteristics, the model (3.32) does not consider the effect of shadowing along the measured path, leading to theoretical values of path loss that can be significantly different from the measured ones. For free-space, a value of $\alpha = 2$ is obteined. In wireless and mobile environments typical value of α are usually between 1.6 and 6.0, depending on the environment characteristics.

Measurements at the UHF band, reported in [Rapp96] show that the path loss at a particular location is random and lognormal distributed about the mean distance-dependent value calculated from (3.33). This behaviour is usually called slow fading. The path loss is then given by:

$$L_p(d)[dB] = \overline{L_p}(d_o)[\mathrm{dB}] + 10n\log\left(\frac{d}{d_o}\right) + X_\sigma \tag{3.34}$$

where $X_\sigma[\mathrm{dB}]$ is a zero-mean Gaussian random variable expressed in dB, with standard deviation σ, also expressed in dB.

Since the path loss has a lognormal distribution in dB, so has the received power $P_r(d)$. The probability that the received signal level will exceed (or fall bellow) a particular level γ, is obtained form the Q-function or error function (*erf*) as:

$$Prob\left[P_r(d) > \gamma\right] = Q\left(\frac{\gamma - \overline{P_r}(d)}{\sigma}\right) \qquad (3.35)$$

where

$$Q(z) = \frac{1}{\sqrt{2\pi}}\int_z^{\infty} e^{-\frac{x^2}{2}}dx = \frac{1}{2}\left[1 - \mathrm{erf}\left(\frac{z}{\sqrt{2}}\right)\right] \qquad (3.36)$$

Typical values of σ at the UHF band are around 7-9 dB for outdoor environments and 1.5-16.3 dB for indoors [Rapp96]. Values of σ between 1.0-5.7 dB and 0.3-3.6 dB are reported from indoor measurements at 1.9 and 2.4 GHz respectively [PaLe95].

3.5. Fast-fading.

3.5.1. General considerations

Fast fading is a phenomenon that describes the rapid fluctuations in signal amplitude over a short period of time or a small distance; in this context large-scale path loss effects are neglected. As previously referred, fading is caused by the existence of the multipath between the transmitter and the receiver due to reflections from the ground and surrounding structures. These fluctuations depend on the time delay of the received signal: the random waves (in amplitude and phase) are combined vectorially in a constructive or destructive way. Fading is considered purely a spatial phenomenon when all objects in the radio channel are static, while it is considered as a temporal variation when the mobile moves through the multipath field. There are three important effects of the multipath in the radio channel:

- Rapid changes in signal strength over a small travel distance or time interval.
- Random frequency modulation due to varying Doppler shifts on different multipath signals.
- Time dispersion (echoes) caused by multipath propagation delays.

The Doppler shift is a variation of the phase in the received signal due to the difference in path lengths:

$$f_d = \frac{v}{\lambda}\cos\theta \qquad (3.37)$$

where v is the relative velocity of the mobile and θ is the angle between the direction of motion of the mobile and the direction of arrival of scattered waves. The doppler spread and the coherence time are parameters that describe the time varying nature of the channel in a small-scale region. The doppler spread (B_d) is the range of frequencies in which the received doppler spectrum is essentially non-zero. The coherence time T_c is the time domain dual of the doppler spread and it is used to characterise the time varying nature of the frequency dispersiveness of the channel in the time domain, if defined as the time over which the time correlation function is above 0.5, then:

$$T_c \approx \frac{9}{16\pi\ f_d} \tag{3.38}$$

Thus, coherence time is the time duration over which two received signals have a strong potential for amplitude correlation. This means that two signals arriving with a time separation greater than T_c are affected different by the channel. A rule of thumb for the evaluation of the coherence time in a mobile communication systems is:

$$T_c = \sqrt{\frac{9}{16\pi\ f_d{}^2}} = \frac{0.423}{f_d} \tag{3.39}$$

The coherence bandwidth B_c is a statistical measure of the maximum frequency difference for which signals are strongly correlated in amplitude, so it is the range of frequencies over which the channel can be considered flat (channel that passes all spectral components with approximately equal gain and linear phase). If the coherence bandwidth is defined as the bandwidth over which the frequency correlation is above 90 %, then

$$B_c \approx \frac{1}{50\sigma_\tau} \tag{3.40}$$

while if the frequency correlation is above 50 % the bandwidth is approximately:

$$B_c \approx \frac{1}{5\sigma_\tau} \tag{3.41}$$

where σ_τ is the rms delay spread. The small-scale variations can be directly related to the impulse response of the radio channel, which may be modeled as a linear filter with a time varying impulse response, which is due to receiver motion in space. The impulse response is a useful characterisation of the channel because it contains all information to simulate any type of radio transmission through the channel. There are different types of fading because it depends on the nature of the transmitted signal with respect to the characteristics of the channel and the velocity of the mobile. In order to understand how fading depends on the channel bandwidth, two types of channel are usually referred: narrowband and wideband channels. In the former case, the signal transmitted bandwidth is smaller then the coherence bandwidth of the propagation channel thus, the received signal spectrum profile is not distorted. Typically, GSM is considered as an example of a narrowband system. On the contrary, in wideband channels, the signal transmitted bandwidth is greater then the coherence bandwidth of the propagation channel, so the spectrum profile is not preserved at the receiver because it includes multiple versions of the transmitted wave, which are attenuated and delayed in time. In this case the received signal is distorted. Typically, UMTS and HIPERLAN are considered as wideband systems. In this context several types of probabilistic distributions are adopted. Usually, for narrowband systems Rayleigh and Ricean distribution are used, while for wideband systems they are not longer applicable, hence a new approach is adopted. This approach is called Cardoso model [Card01]. More emphasis will be given to this model, because the others are already well known in literature, and because wideband systems are being considered in this work.

3.5.2. Rayleigh distribution

The Rayleigh distribution [Rapp96] is commonly used to describe the statistical time varying nature of the received signal envelope when there are a large number of indirect paths between the transmitter and the receiver (NLoS).

The Rayleigh Probability Density Function (PDF) is given by:

$$p(r) = \begin{cases} \frac{r}{\sigma^2}\exp\left(-\frac{r^2}{2\sigma^2}\right) & (0 \le r \le \infty) \\ 0 & (r < 0) \end{cases} \tag{3.42}$$

where σ^2 is the average power of the received signal before envelope detection, and r is the signal level.

The Cumulative Distribution Function (CDF) gives the probability that the envelope of the received signal does not exceed a specified value r, being given by:

$$P(R) = P_{prob}(r \le R) = \int_0^{\infty} p(r)\,dr = 1 - \exp\left(-\frac{R^2}{2\sigma^2}\right) \tag{3.43}$$

the mean value of this distribution is:

$$r_{mean} = E[r] = \int_0^{\infty} r\,p(r)\,dr = \sigma\sqrt{\frac{\pi}{2}} = 1.2533\,\sigma \tag{3.44}$$

its variance is:

$$\sigma_r^2 = E\left[r^2\right] - E^2\left[r\right] = \int_0^\infty r^2\, p(r)\, dr - \frac{\sigma^2\pi}{2} = \sigma^2\left(2 - \frac{\pi}{2}\right) = 0.4292\sigma^2 \qquad (3.45)$$

and the median is:

$$r_{median} = 1.177\sigma \qquad (3.46)$$

3.5.3. Ricean distribution

This distribution [Rapp96] is used when there is a LoS propagation path between the transmitter and the receiver. In such situation, random multipath components arriving at different angles are imposed on a stationary dominant signal; hence, the effect is like adding a dc component to the random multipath:

$$p(r) = \begin{cases} \dfrac{r}{\sigma^2} e^{-\frac{\left(r^2 + A^2\right)}{2\sigma^2}} \mathrm{I}_0\left(\dfrac{Ar}{\sigma^2}\right) & \text{for } (A \geq 0, r \geq 0) \\ 0 & \text{for } (r \leq 0) \end{cases} \qquad (3.47)$$

The parameter A denotes the peak amplitude of the dominant signal and I_0 is the modified Bessel function of the first kind and zero-order. This distribution is generally expressed as a function of the Rice factor K, which is defined as the ratio between the deterministic signal power and the variance of the multipath:

$$K[\mathrm{dB}] = 10\log\frac{A^2}{2\sigma^2} \qquad (3.48)$$

When A = 0 the dominant path decays in amplitude and the Ricean distribution degenerates on the Rayleigh distribution.

3.5.4. Dependence on system bandwidth

Cardoso model [Card01] provides a simple and computationally inexpensive analytical approach to study the signal level characteristics. It is based on the fitting of simulation results obtained form a theoretical model [KoSN96]. The advantage is that to have a determination of the fading depth it is not necessary to make huge computer simulations, because its evaluation is made through a simple equation. The mathematical equation, derived from fitting simulated data from a model in literature [KoSN96], is given by:

$$FD(K,\Delta w_{eq}) = \begin{cases} S_1(K) & , \Delta w_{eq} \leq w_b \\ \dfrac{S(K) - A_1(K)}{1 + A_2(K) \times \left[\log\left(\dfrac{\Delta w_{eq}}{w_b}\right)\right]^{A_3(K)}} + A_1(K) & , \Delta w_{eq} > w_b \end{cases} \tag{3.49}$$

where $FD\ (K,\Delta w_{eq})$ is the fading depth measured between p and 50 % of the CDF of the received power, and $w_{b,p}$ is the breakpoint, defined as the value of Δw_{eq} for which the fading depth starts to decrease. The equivalent received bandwidth, Δw_{eq}, is a new parameter that permits to simultaneously consider the dependence on system bandwidth and scenario features. It is defined as the product between the system bandwidth, $2\Delta f$ and the maximum possible difference in propagation path length, ΔL_{max}. The mathematical functions, $S_1(K)$, $A_1(K)$, $A_2(K)$ and $A_3(K)$ must be chosen to be simple enough, in order not to unnecessarily increase the mathematical complexity of the proposed approach while giving accurate results. The breakpoint $w_{b,p}$, is assumed as 4, 10 and 40 MHz.m for p = 0.1, 1, 10 % respectively. Thus, for each value of p it is possible to evaluate $S_p(K)$, $A_1(K)$, $A_2(K)$ and $A_p(K)$,Table 3.3.

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Table 3.3-Fitted parameters and associated error (extracted from [Card01]).

Parameter	p [%]	$K_{[dB]}$					
		0	3	5	7	10	20
$S_{[dB]}$	0.1	28.220	26.010	22.380	15.440	8.380	1.950
	1.0	17.810	15.980	12.980	9.410	5.860	1.510
	10.0	7.680	6.510	5.300	4.180	2.870	0.840
$A_{1[dB]}$	0.1	-1.440	-0.670	-0.040	0.000	0.000	0.000
	1.0	-0.840	-0.530	-0.270	-0.080	-0.050	-0.040
	10.0	-0.520	-0.320	-0.240	-0.170	-0.100	-0.030
A_2	0.1	0.315	0.317	0.258	0.135	0.072	0.045
	1.0	0.414	0.423	0.348	0.236	0.163	0.113
	10.0	0.973	1.009	0.950	0.848	0.757	0.637
A_3	0.1	2.259	2.473	2.867	3.310	3.523	3.530
	1.0	2.427	2.575	2.850	3.218	3.403	3.392
	10.0	2.019	2.251	2.349	2.533	2.702	2.842
$\sqrt{\varepsilon^2}_{[dB]}$	0.1	0.500	0.40	0.430	0.400	0.230	0.060
	1.0	0.150	0.15	0.160	0.050	0.110	0.030

	10.0	0.080	0.07	0.070	0.060	0.040	0.010
$\overline{\varepsilon_r}$ [%]	0.10	-0.800	0.800	2.500	4.300	4.200	2.900
	1.0	-0.600	-0.700	-0.400	0.200	0.500	0.400
	10.0	-6.400	-6.400	-5.300	-5.200	-7.000	-7.700

The root mean square error is given by:

$$\sqrt{\overline{\varepsilon^2}} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\varepsilon_i^2} \tag{3.50}$$

and the mean relative error is evaluated from:

$$\overline{\varepsilon_r} = \frac{1}{n}\sum_{i=1}^{n}\frac{\varepsilon_i}{y_i} \tag{3.51}$$

with ε_i defined as:

$$\varepsilon_i = (y_i - \hat{y}_i) \tag{3.52}$$

where y_i corresponds to the value obtained from simulation, and $\hat{y}_i$ to the one estimated from (3.42). The parameter w stands for the number of interpolation points.

The fitting process to evaluate $S_1(K)$, $A_1(K)$, $A_2(K)$ and $A_3(K)$ was implemented in two steps: first, the range of variation of y_i is identified, and second, $\hat{y}_i$ is estimated as the one that minimizes the mean square error. $S_p(K)$, $A_{1,p}(K)$, $A_{2,p}(K)$ and $A_{3,p}(K)$ are obtained as a function of K from:

$$S_1(K)\rvert_{B} = \frac{(b_1 - b_2)}{1 + b_3 \times \left(\frac{K\rvert_{B}}{10} - b_4\right)^{b_5}} + b_2 \tag{3.53}$$

$$A_{1(K)}\rvert_{B} = c_{11} \times \arctan(c_{12} \times K\rvert_{B} - c_{13}) - c_{14} \tag{3.54}$$

$$A_2 = c_{21} \times \left(\frac{\pi}{2} - \arctan(c_{22} \times K\rvert_{B} - c_{23})\right) + c_{24} \tag{3.55}$$

$$A_3 = c_{31} \times \arctan(c_{32} \times K\rvert_{B} - c_{33}) + c_{34} \tag{3.56}$$

where parameters b_i $\{i = 1, \ldots, 5\}$ and c_{jk} $\{j = 1, \ldots, 3;\ k = 1, \ldots, 4\}$ depend on the value of p.

The parameters b_i and c_{jk}, derived from the fitting of data in Table 3.3, with p = 1 %, are presented in Table 3.4 and Table 3.5.

Table 3.4-Fitting of A_i and associated error, p = 1 %(extracted from [Card01]).

	$A_1(K)$ [dB]	$A_2(K)$	$A_3(K)$
C_{i1}	0.328	0.118	0.351
C_{i2}	0.553	0.486	0.720
C_{i3}	1.810	3.020	3.750
C_{i4}	0.489	0.099	2.907
$\sqrt{\overline{\varepsilon^2}}$	0.020	0.012	0.026
$\overline{\varepsilon_r}$ [%]	1.300	-0.200	0.000

Table 3.5-Fitting of S1(K) and associated error, p = 1 %(extracted from [Card01]).

$S_p(K)$						
b_1	b_2	b_3	b_4	b_5	$\sqrt{\overline{\varepsilon^2}}$ [dB]	$\overline{\varepsilon_r}$ [%]
18.089	0.569	0.939	-0.298	3.593	0.13	-0.6

4. Cell Radius Evaluation

The maximum path-loss and the fading depths observed by GSM, UMTS and HIPERLAN in different environments are presented. Thus, allowing to predict cellular coverages in different environments

4.1. Fading depth

Cardoso model is developed to evaluate the influence of the fading depth in wideband systems, since, as previously refered, well known models (Rayleigh and Rice distributions) are not longer applicable.

The channel bandwidth has a huge influence in the fast fading behaviour of wideband systems; in fact, as the system bandwidth increases the fading depth decreases. Globally, the fading depth depends on the system bandwidth and also on the specific features of the environments. One of the considerations is that the fading margins for different systems must be determined by considering the influence of the system bandwidth and that different fading margins must be considered for different environments.

Hence, the fast fading depth dependence on system bandwidth and environment specific features is evaluated form Cardoso model.

In order to study the dependence of the fading depth on $B \cdot \sigma_\tau$, where B is the bandwidth of the system and σ_τ is the *rms* delay spread of a typical environment, the first step consists of fitting simulated data for several scenarios such as: GSM Rural Area, GSM Typical Urban, GSM Hilly Terrain, UMTS Indoor-A and B, UMTS Pedestrian-A and B, UMTS Vehicular-A and B, UMTS Rural Area, UMTS Typical Urban, UMTS Hilly Terrain, finally HIPERLAN A, B, C, D and E.

The main aim was to fit these ideal values with the best fitting curve obtained by the equation of Cardoso model. Generally, through the characterisation of $A11$, $A12$, $A13$ and $S11$ parameters of (3.43) the fitting curves are obtained.

Some assumptions to find these parameters were made to characterise each environment from the point of view of the *rms* delay spread. One considers Non-Directional channel models (in which only dispersion in time is present). In this case several channel models for each system are proposed. For GSM model Type 1 channel models are chosen, Table 4.1, for UMTS channel A and B are considered, Table 4.2 and Table 4.3 and, finally for HIPERLAN/2 five channel models (A, B, C, D and E) are considered.

Table 4.1-Average *rms* delay spread for GSM environments [ETSI96].

Channel model	Cell type	Average *rms* delay spread [ns]	
		Type 1	Type 2
Rural Area	Macro–cell	98	126
Hilly Terrain	Macro–cell	5 100	4 984
Typical Urban	Macro–cell	1 026	1 000

Table 4.2-Average *rms* delay spread for UMTS environments [ETSI96].

Environment	Cell Type	Average *rms* delay spread [ns]	
		Channel A	**Channel B**
Indoor Office	Pico–cell	35	100
Outdoor to Indoor and Pedestrian	Micro–cell	45	750
Vehicular - High Antenna	Macro–cell	370	4 000

Table 4.3-Average *rms* delay spread for UMTS environments [3GPP00].

Environment	Cell Type	Average *rms* delay spread [ns]
Rural Area	Macro–cell	100
Hilly Terrain	Macro–cell	3 000
Typical Urban	Macro–cell	500

Table 4.4-Average *rms* delay spread for different environments [MeSc98].

Environment	Cell Type	Average *rms* delay spread [ns]
Model A	Pico–indoor	50
Model B	Pico–indoor	100
Model C	Pico–indoor	150
Model D	Pico–indoor	140
Model E	Pico–indoor	250

In GSM, Rural Area, Typical Urban and Hilly Terrain macro-cellular environments are used. In the former the short-term fading can be modelled either as Ricean or Rayleigh, depending on the existence of a LoS component, while in the last two the short-term fading is modelled as Rayleigh. In UMTS system, the Indoor channel model is adequate to describe environments characterised by small cells (pico-cellular) and low transmit power, with both the antennas and the users located indoor. The short-term fading can be modelled either as Ricean or Rayleigh depending on the existence of LoS. The Pedestrian models apply to both micro- and pico-cellular environments and low transmit powers. The antennas are located outdoors at low heights, and the users can be on the streets or inside buildings; in this case the short-term fading can be modelled either as Ricean or Rayleigh depending on the existence of LoS, too. The Vehicular channel models, the Rural Area, the Typical Urban and the Hilly Terrain are applied to macro-cellular environments. In HIPERLAN, model A corresponds to a typical office environment. Model B corresponds to a typical large open space environment with NLoS conditions or an office environment with large delay spread. Model C and E correspond to a typical large open space indoor and outdoor environments with large delay spread, while model D correspond to LoS conditions in a large open space indoor or an outdoor environment.

The majority of the considered environments show a typical trend of the fitting curve that is represented in Figure 4.1 for GSM Rural Area. Note that under NLoS the fading depth remains practically constant for $B{\cdot}\sigma_\tau$ below 0.02 Hz·s and then decreases with increasing $B{\cdot}\sigma_\tau$. This product between the system bandwidth and the *rms* delay spread of the propagation channel corresponds to the coherence bandwidth of the propagation channel, when defined for a correlation of 90%. Under LoS, the fading depth decrease rate above $B{\cdot}\sigma_\tau$ decreases with increasing values of *K*. Considering this specific example (GSM Rural Area) and considering the relative values for *B* and σ_τ, the product is 0.02 Hz·s.

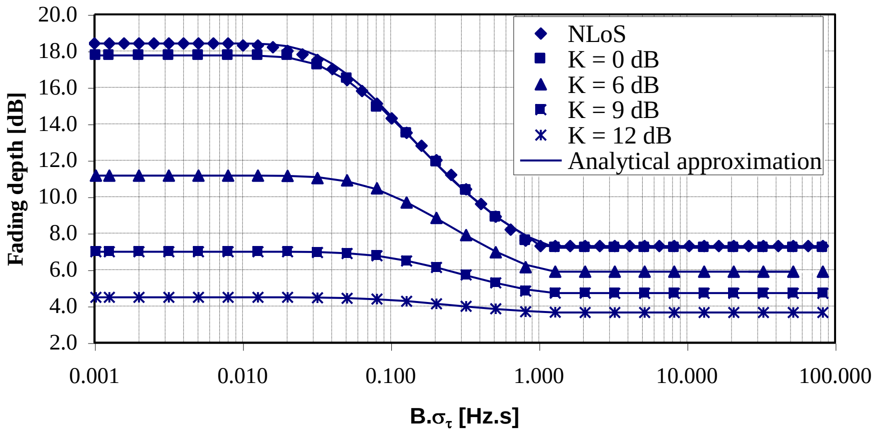

Figure 4.1-Evaluation of fading depth, in GSM Rural Area.

The product between the system bandwidth and the *rms* delay spread allows to distinguish two different behaviours; the first one, corresponding to a system bandwidth below the coherence bandwidth of the propagation channel, which is usually referred as a narrowband case, and the second, corresponding to the wideband case, i.e., the system bandwidth is above the coherence bandwidth of the propagation channel. In the former, the fading depth depends only on the value of K rather then on the system bandwidth; for the latter, besides the dependence on K, the fading depth decreases with increasing system bandwidths. Also, as the system bandwidth increases, the fading depth becomes less sensible to the value of K, since for different values of K the curves become closer. For this typical behaviour the values of of A_{11}, A_{12}, A_{13} and S_{11} are shown in Table 4.5.

Table 4.5- Estimation of A_{11}, A_{12}, A_{13} and S_{11} for GSM Rural Area.

NLoS	**S_{11} [dB]**	**A_{11} [dB]**	**A_{12}**	**A_{13}**	$\sqrt{\overline{\varepsilon^2}}$ **[dB]**	$\overline{\varepsilon_r}$ **[%]**
***K*= 0 dB**	17.17	3.8	0.32	3.14	0.07	-0.07
***K*= 6 dB**	11.16	3.9	0.17	3.85	0.03	-0.07
***K*= 9 dB**	6.98	3.9	0.12	4.36	0.02	-0.09
***K*= 12 dB**	4.48	3.4	0.16	4.11	0.01	-0.40
NLoS	18.40	3.8	0.37	3.00	0.12	-0.23

The fitting curves, in this general case, are characterized by two breakpoints that allow to distinguish between the linear and non linear trend. The first one, corresponding to the product between the system bandwidth and the *rms* delay spread, is equal to 0.02 Hz·s, the other one is 1.00 Hz·s.

A different behavior is observed in UMTS Hilly Terrain and UMTS Vehicular-B. In these cases the equation (3.43) is not very accurate, so it is necessary to find another equation that allows a reasonable fitting of simulation data. As one can see from Table 4.2 not only two breakpoints exist but other fourth: $B{\cdot}\sigma_\tau$ equals to 0.02 Hz·s, $B{\cdot}\sigma_\tau$ equals to 0.2 Hz·s, 0.3 Hz·s and 200 Hz·s.

The observations are the same of the previous case but, in this situation there is a constant trend of the curve below the first breakpoint, after the curves decrease until the second breakpoint, and from this point on they are still constant until the third for a small range and finally they decrease another time until the fourth, form which the curves are constant until the end.

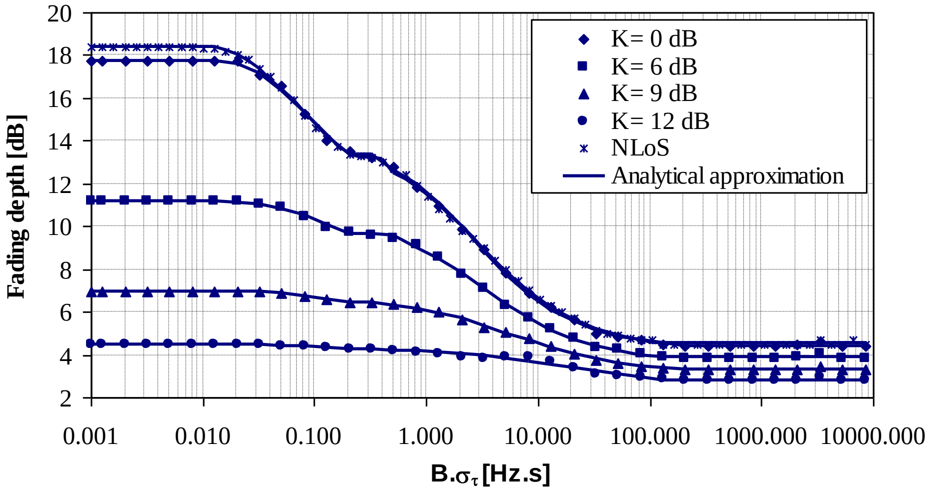

Figure 4.2- Evaluation of Fading Depth in UMTS Hilly Terrain.

It means that the equation can be written as:

$$FD_p(K,\Delta w_{eq}) = \begin{cases} S_{11}(K) & ,\Delta w_{eq} \le w_{b1} \\ \dfrac{S_{11}(K) - A_{11}(K)}{1 + A_{12}(K) \times \left[\log\left(\dfrac{\Delta w_{eq}}{w_{b1}}\right)\right]^{A_{13}(K)}} + A_{11}(K) & ,w_{b1} < \Delta w_{eq} \le w_{b2} \\ S_{21}(K) & ,w_{b2} < \Delta w_{eq} \le w_{b3} \\ \dfrac{S_{21}(K) - A_{21}(K)}{1 + A_{22}(K) \times \left[\log\left(\dfrac{\Delta w_{eq}}{w_{b2}}\right)\right]^{A_{23}(K)}} + A_{21}(K) & ,w_{b3} < \Delta w_{eq} \le w_{b4} \\ S_{31}(K) & ,\Delta w_{eq} > w_{b4} \end{cases} \quad (4.1)$$

where $w_{b1,}\ w_{b2,}\ w_{b3}\ w_{b4}$ are the breakpoints, S_{11}, $A_{11,}\ A_{12,}\ A_{13}$ are the parameters to determine the non linear fitting curve below $w_{b1,}$ while S_{21}, $A_{21,}\ A_{22,}\ A_{23}$ are the parameters to determine the non linear fitting curve below w_{b3}.

Fitting results for UMTS Vehicular-B are shown in Table 4.6.

Table 4.6- Estimation of the parameters for UMTS Vehicular-B.

NLoS	S_{11} [dB]	A_{12} [dB]	A_{13} [dB]	A_{13}	S_{21} [dB]	A_{21} [dB]	A_{22}	A_{23}	$\sqrt{\overline{\varepsilon^2}}$ [dB]	$\overline{\varepsilon_r}$ [%]
	18.40	7.50	0.57	2.60	5.56	3.60	0.0011	5.60	0.09	-0.006

The values of these parameters that allow drawing the best fitting-curve for UMTS Hilly Terrain are shown in Table 4.7.

Table 4.7- Estimation of the parameters for UMTS Hilly Terrain.

LoS	S_{11} [dB]	A_{12} [dB]	A_{13} [dB]	A_{13}	S_{21} [dB]	A_{21} [dB]	A_{22}	A_{23}	$\sqrt{\overline{\varepsilon^2}}$ [dB]	$\overline{\varepsilon_r}$ [%]
***K*=0 dB**	17.74	9.9	0.53	3.0	13.36	4.0	0.0031	6.21	0.097	-0.07
***K*= 6 dB**	11.16	3.9	0.13	2.7	9.64	3.50	0.0021	6.30	0.062	0.11
***K*= 9 dB**	6.98	6.0	0.43	3.5	6.45	3.00	0.0020	5.88	0.042	-0.01
***K*= 12 dB**	4.48	4.0	0.37	3.2	4.25	1.60	0.0021	4.50	0.055	-0.09
NLoS	18.40	4.9	0.36	2.1	13.25	3.90	0.0040	5.80	0.094	-0.14

4.2. Path-Loss estimation

4.2.1. Average Case

This subsection deals with calculations about the available maximum path loss to ensure the communications respecting the minimum receiver sensitivity between the Tx and the Rx in GSM, UMTS and HIPERLAN. The simulations are made evaluating the maximum path loss range in function of the maximum transmitted power, the minimum receiver sensitivity and considering a range of values for the antenna gains. The range chosen for these parameters are, as already reported in Table 2.15, 2.19 and 2.20, [0, 2] dBi for the MS and [0, 13] dBi for the BS. By changing the combination of the gains, the lowest and the highest values of the path loss are found. The lowest value is obtained when the values of the gains at the MS and at the BS are at the lowest levels e.g., G_{MS} = 0 dBi and G_{BS} = 0 dBi, on the contrary the highest value is obtained when both the gains are at the highest levels e.g., G_{MS} = 2 dBi and G_{BS} = 13 dBi. For each system different services are considered (e.g.,data, voice).

Firstly, the idea was considered a range of values also for the maximum transmitted power, observing how the path loss changes in function of it. The second approach was considered the specific case for hand-held portable. This type of studies are important for these devices due to the maximum transmitted power, hence, for GSM 900 the considered transmitted power is 33 dBm, for GSM 1800 and UMTS it is 30 dBm and for HIPERLAN/2 is 24 dBm. So, for all the systems this second approach was carried on always in uplink direction because the transmitted power in portable devices is more restrictively then BS. The two extreme sensitivities is being taken for HIPERLAN/2: HS (High Sensitivity) for P_r = -85 dBm, and LS (Low Sensitivity) for P_r = - 68 dBm.

$\overline{L}_{p\max}$ is evaluated, by considering (2.9), as:

$$\overline{L}_{p\max\,[\mathrm{dB}]} = -P_{rmin[\mathrm{dBm}]} + P_{tmax[\mathrm{dBm}]} + G_{MS\,[\mathrm{dBi}]} + G_{BS[\mathrm{dBi}]} \tag{4.2}$$

Table 4.8- Estimation of $\overline{L}_{p\max}$.

$\overline{L}_{p\max}$ [dB]	G_{BS} = 0 dBi		G_{BS} = 13 dBi	
	G_{MS} = 0 dBi	G_{MS} = 2 dBi	G_{MS} = 0 dBi	G_{MS} = 2 dBi
GSM 900 data	135	137	148	150
GSM 1800 data	132	134	145	147
GSM 900 voice	132	134	145	147
GSM 1800 voice	129	131	142	144
UMTS 12.2 kbps	145	147	158	160
UMTS 144 kbps	141	143	154	156
UMTS 384 kbps	131	133	144	146
HIPERLAN/2-HS	107	109	120	122
HIPERLAN/2-LS	90	92	103	105

As one can see from Table 4.8, the maximum range of $\overline{L}_{p\max}$, for the voice service in GSM-900 (uplink direction) is [132, 147] dB, in GSM-1800 is [129, 144] dB, for the data service in GSM-900 (uplink direction) is [135, 150] dB, in GSM-1800 is [132, 147] dB. Generally, as one can say that the maximum range in GSM system for $\overline{L}_{p\max}$ is [129, 150] dB. In UMTS, one can observe that when the bit rate increases, the maximum range decreases; in fact, in UMTS 12.2 kbps the range is [145, 160] dB, in UMTS 144 kbps the range is [141, 156] kbps and in UMTS 384 kbps it is [131, 146] dB hence, the maximum range for UMTS is [131, 160] dB. For HIPERLAN/2, considering both sensitivities, the maximum range is [90, 122] dB. The values are quite similar in GSM and UMTS, except in HIPERLAN/2 case where they are lower.

4.2.2. Slow-fading margin

The slow-fading margin is usually obtained from the Log-normal distribution:

$$M^{SF}{}_{[dB]} = X_{\sigma}[\mathrm{dB}] \cdot u_{[dB]} \tag{4.3}$$

where $X_{\sigma}[\mathrm{dB}]$ is the zero-mean Gaussian random variable expressed in dB and u is a normal parameter, expressed as the ratio between the difference of the signal and the mean value of the signal, and σ. The slow fading margin is evaluated at 90 and 99 %, and u is equal to 1.282 and 2.326, respectively.

The slow fading margin depends on the particular propagation model used and on the system. For COST 231-Hata-model, the slow fading must be determined by considering the system and the scenario (urban, sub-urban or rural) because X_{σ} depends on them, as shown in (4.4) and (4.5).

$$X_{\sigma\ [dB]} = 0.98\log^2(f[MHz]) - 3.40\log(f[\mathrm{MHz}]) + 11.88 \tag{4.4}$$

$$X_{\sigma\ [dB]} = 0.70\log^2(f[\mathrm{MHz}]) - 2.50\log(f[\mathrm{MHz}]) + 11.10 \tag{4.5}$$

and X_{σ} is evaluated in the same way for sub-urban and rural environments.

Table 4.9-Slow-fading margin for COST 231-Hata-model at 90% and 99%.

$M^{SF}{}_{[dB]}$		GSM 900	GSM 1800	UMTS	HIPERLAN/2
90 %	Urban	13.32	14.30	14.49	16.40
	Sub-urban	12.60	13.27	13.40	14.73
	Rural	12.60	13.27	13.40	14.73
99 %	Urban	24.27	25.95	26.30	29.76
	Sub-urban	22.85	24.08	24.31	26.72
	Rural	22.85	24.08	24.31	26.72

Obviously, the slow fading margin increases with the frequency because of the behaviour of X_{σ}, as one can see form Table 4.9.

In COST 231-WI and Multi-Wall Model slow fading margin is independent on the particular scenario, so it depends only on the system and on the σ value. In COST 231-WI typical values for σ are 7.0, 9.0 and 5.3 dB in GSM 900, in GSM 1800 and UMTS and HIPERLAN/2, respectively, the results for COST 231-WI are reperted in Table 4.10.

Table 4.10- Slow-fading margin for COST 231 WI at 90% and 99%.

$M^{SF}{}_{[dB]}$	GSM 900	GSM 1800	UMTS	HIPERLAN/2

90 %	8.97	11.54	11.54	6.79
99 %	16.28	20.93	20.93	12.33

In the Multi-wall model to find the slow fading margin σ = 5.3 dB is used, a typical value for indoor environments.

Table 4.11- Slow-fading margin for Multi-wall model at 90% and 99%.

M^{SF} [dB]	UMTS Indoor A/B	HIPERLAN/2
90 %	14.49	16.40
99 %	16.29	29.76

4.2.3. Fast-fading margin

The fast fading margin evaluation is obtained from Cardoso model. From Figure 4.1 and 4.3 it is possible to read the fading depth for GSM Rural Area and for UMTS Hilly Terrain, corresponding to the product between the system bandwidth and the *rms* delay spread. The values are assumed being 0.02 Hz·s and 1.02 Hz·s, respectively. In Table 4.12 are presented the values of the fading margin for each environment in NLoS and in LoS case when K = 0 dB. The other results in Annex 2.2 are reported. The process of fitting the simulated data for each value of K and for each environment are made and a complete list of the results is shown in Annex 2.2.

Table 4.12- Fast-fading evaluation in NLoS case for different environments.

	B.σ_τ [Hz·s]	**NLoS**
GSM Rural Area	0.02	18.40
GSM Typical Urban	0.20	11.80
GSM Hilly Terrain	1.02	10.30
UMTS Indoor A	0.17	12.10
UMTS Indoor B	0.50	9.00
UMTS Pedestrian A	0.22	12.30
UMTS Pedestrian B	3.75	6.30
UMTS Vehicular A	1.85	7.40
UMTS Vehicular B	20.00	7.70
UMTS Rural Area	0.50	8.70
UMTS Typical Urban	2.50	5.10
UMTS Hilly Terrain	15.00	6.00
HIPERLAN/A	1.18	6.30

HIPERLAN/B	2.35	4.70
HIPERLAN/C	2.53	4.00
HIPERLAN/D	3.29	4.20
HIPERLAN/E	5.88	3.60

Globally, one can say that the fading depth decreases as the system bandwidth increases; besides, for wideband systems, in which there is a dependence on *K*, as the system bandwidth increases the fading depth becomes less sensible to the value of *K*, since for different values of *K* the curves become closer. These observations can be easily extrapolated to any value of *K*; as it is shown in Table 4.13.

Table 4.13- Fast-fading evaluation in LoS case when *K*= 6 dB for different environments.

	$\mathbf{B.\sigma_{\tau}}$ **[Hz·s]**	**LoS (K=6 dB)**
GSM Rural Area	0.02	11.16
UMTS Indoor A	0.17	9.20
UMTS Indoor B	0.50	6.90
UMTS Pedestrian A	0.22	9.00
UMTS Pedestrian B	3.75	5.20
UMTS Vehicular A	1.18	5.90
UMTS Rural Area	0.50	6.80
UMTS Typical Urban	2.50	4.50
UMTS Hilly Terrain	15.00	5.00
HIPERLAN/A	1.18	4.00
HIPERLAN/D	3.29	3.70

Comparing the obtained results, one observes that they are quite similar for NLoS and for LoS case when K = 0 dB and that the fading depth decreases when K increases. From now on, when referring to the LoS case, ones considers K = 6 dB.

4.2.4. Path-Loss evaluation considering slow- and fast-fading

The next step is to give an estimation of the path-loss by considering fading components, one chose to evaluate the slow fading margin at 90 and 99 % from (4.3) and the fast fading from the results obtained by Cardoso model, Table 4.12 and 4.13.

This estimation depends on the type of the adopted propagation model. In the particular case of COST 231-Hata model, in fact, there is a little variation in X_{σ} values if it is considered urban, sub-urban or rural environment (as shown from equations (4.4) and (4.5)). In Table 4.14, the values of the path-loss are represented and obetined from (3.3), (3.5) and (3.7), by considering all the effects previously presented, for GSM Rural Area in NLoS case with a slow fading estimation at 90 and 99 %, with COST 23-Hata model.

Table 4.14-Evaluation of L_{pmax} in GSM Rural Area, NLoS case, COST231-Hata model.

$\bar{L}_{p\max} + M^{SF}{}_{[dB]} + M^{FF}{}_{[dB]}$		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}= 0 dBi	G_{MT}= 2 dBi	G_{MT}= 0 dBi	G_{MT}= 2 dBi
90 %	GSM 900 data	103.97	105.97	116.97	118.97
	GSM 1800 data	100.34	102.34	113.34	115.34
	GSM 900 voice	101.01	103.01	114.01	116.01
	GSM 1800 voice	97.34	99.34	110.34	112.34
99 %	GSM 900 data	93.76	95.76	106.76	108.76
	GSM 1800 data	89.53	91.53	102.53	104.53
	GSM 900 voice	90.76	92.76	103.76	105.76
	GSM 1800 voice	86.53	88.53	99.53	101.53

From Table 4.14, a general behaviour can be observed: in the case of 90 % the path-loss values are higher with respect to the 99 %, due to the fact for that in the estimation of slow fading at the 99 % the additional power that one considers to ensure the desired link budget is bigger than in the 90 % case. This effect is normal because when the additional power increases, at the same time, the path-loss decreases and the distance, too. This typical behaviour occurs in each system, for each value of K and for each model.

By considering the results reported in Table 4.14, another aspect is that the path-loss for data service is 3 dB higher than the path-loss for voice service, hence, as aspect, the cell-range estimation will be greater for data service. The maximum path-loss range for GSM 900 is [100.01, 118.97] dB and for GSM 1800 is [97.34, 115.34] dB with slow fading at 90 %; while the maximum path-loss range , when the slow fading is evaluated at 99 %, is [90.76, 108.76] dB for GSM 900, and [86.53, 104.53] dB for GSM 1800. From now on, the comparisons will be done only between values evaluated with slow fading at 90 % because the results obtained with slow fading at 99 % are smaller, but the bahaviour is the same.

In Table 4.15 the results obtained, always, with COST 231-Hata model, in NLoS case at 90 % and 99 % are reported, for UMTS, in order to understand how this typical behaviour is valid also for another system, similar results are reported in Annes 3, 4 and 5.

Table 4.15-Evaluation of L_{pmax} in UMTS Rural Area, NLoS, COST 231-Hata model.

$\bar{L}_{p\max} + M^{SF}{}_{[dB]} + M^{FF}{}_{[dB]}$		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}= 0 dBi	G_{MT}= 2 dBi	G_{MT}= 0 dBi	G_{MT}= 2 dBi
90 %	UMTS 12.2 kbps	122.86	126.86	135.86	137.86
	UMTS 144 kbps	118.86	120.86	134.86	136.86
	UMTS 384 kbps	108.86	110.86	121.86	123.86
99 %	UMTS 12.2 kbps	111.95	113.95	124.95	126.95
	UMTS 144 kbps	107.95	109.95	120.95	122.95
	UMTS 384 kbps	97.95	99.95	110.95	112.95

As one can see, from Table 4.15, when the bit rate of the service increases, the path-loss decreases, as it is already possible to observe from Table 4.8 for the average case. One can aspects that the cell-range will be greater for UMTS at 12.2 kbps than for UMTS at 384 kbps; it means that if one wants to provide a service with higher bit rate, the capacity of the cells might be smaller. The difference in terms of path-loss is about 4 dB between voice service and rela-time data service, while it is 14 dB between voice service and non-real-time data service. As shown in Table 4.15, the maximum path-loss range in UMTS rural area is [108.86, 137.86] dB.

When comparing the results reported in Table 4.8 on the mean value of the path-loss with the results in Table 4.14 for GSM, one can see that the path-loss evaluated by adding the slow and the fast fading margins is lower than the mean value case, due to the considered tolerance bandwidth being wider when the fading margins are considered. The difference is about 31 dB for data and voice services when the slow fading is evaluated at 90 %, and about 41 dB when the slow fading is evaluated at 90 %.

A similar behaviour occurs when the results reported in Table 4.8 and in Table 4.15, for UMTS, are compared. In fact, in this case the difference is 20 dB when the slow fading is evaluated at 90 % and 30 dB at 99%.

In Table 4.16 the path-loss estimation for GSM Rural Area under LoS, yet with COST 231-Hata model is reported.

Table 4.16-Evaluation of L_{pmax} in GSM Rural Area, LoS, COST 231-Hata model.

$\overline{L}_{p\max} + M^{SF}{}_{[dB]} + M^{FF}{}_{[dB]}$		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}= 0 dBi	G_{MT}= 2 dBi	G_{MT}= 0 dBi	G_{MT}= 2 dBi
90 %	GSM 900 data	112.20	124.20	113.20	126.20
	GSM 1800 data	107.57	120.57	109.57	122.57
	GSM 900 voice	108.24	121.24	110.24	123.24
	GSM 1800 voice	104.57	117.57	106.57	119.57
99 %	GSM 900 data	100.99	113.99	102.99	115.99
	GSM 1800 data	96.76	109.76	98.76	111.76
	GSM 900 voice	97.99	110.99	99.99	112.99
	GSM 1800 voice	93.76	109.76	95.76	108.76

Comparing the results in Table 4.16, with the ones in Table 4.14, one observes that for the LoS case the values of the path-loss are higher than the NLoS case. This is to the fact that when K increases, the fast fading depth decreases, as already mentioned in section 4.2.1. In fact, the maximum path-loss range in GSM 900 is [108.24, 126.20] dB, and in GSM 1800 is [104.57, 1122.57] dB. One observes that between NLoS and LoS case, the difference in terms of maximum path-loss is about 7 dB. Considering the results reported in Annex 3 for UMTS Rural Area, in LoS case, the maximum range is [110.80, 139.80] dB, thus a difference of 2 dB occurs.

Considering COST 231-Hata model, one shows how the path-loss values changing in function of the particular environment hence, Table 4.17 and 4.18 are reported.

Table 4.17-Evaluation of the path-loss in Typical Urban Area, NLoS, COST 231-Hata model, for GSM and UMTS.

$\overline{L}_{p\max} + M^{SF}{}_{[dB]} + M^{FF}{}_{[dB]}$		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}= 0 dBi	G_{MT}= 2 dBi	G_{MT}= 0 dBi	G_{MT}= 2 dBi
90 %	GSM 900 data	109.87	111.87	122.87	124.87
	GSM 1800 data	105.89	107.89	118.89	120.89
	GSM 900 voice	100.29	102.29	113.29	115.29
	GSM 1800 voice	102.89	104.89	115.89	117.89
	UMTS 12.2 kbps	125.41	127.41	138.41	140.41
	UMTS 144 kbps	121.41	123.41	134.41	136.41
	UMTS 384 kbps	111.41	113.41	124.41	126.41
99 %	GSM 900 data	99.02	101.02	112.02	114.02
	GSM 1800 data	94.24	96.24	107.24	109.24
	GSM 900 voice	96.02	98.02	109.02	111.02
	GSM 1800 voice	91.24	93.24	104.24	106.24
	UMTS 12.2 kbps	113.61	115.61	126.61	128.61
	UMTS 144 kbps	109.61	111.61	122.61	124.61
	UMTS 384 kbps	99.61	101.61	112.61	114.61

Table 4.18-Evaluation of the path-loss with COST 231-Hata model, in Hilly Terrain, for GSM and UMTS.

$\overline{L}_{p\max} + M^{SF}{}_{[\mathrm{dB}]} + M^{FF}{}_{[\mathrm{dB}]}$		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}= 0 dBi	G_{MT}= 2 dBi	G_{MT}= 0 dBi	G_{MT}= 2 dBi
90 %	GSM 900 data	112.06	114.06	125.06	127.06
	GSM 1800 data	108.43	110.43	121.43	123.43
	GSM 900 voice	109.10	111.10	122.10	124.10
	GSM 1800 voice	111.43	113.43	124.43	126.43
	UMTS 12.2 kbps	125.60	127.60	138.60	140.60
	UMTS 144 kbps	121.60	123.60	134.60	136.60
	UMTS 384 kbps	111.60	113.60	124.60	126.60
99 %	GSM 900 data	101.85	103.85	114.85	116.85
	GSM 1800 data	97.62	99.62	110.62	112.62
	GSM 900 voice	98.85	100.85	111.85	113.85
	GSM 1800 voice	100.62	102.62	113.62	115.62
	UMTS 12.2 kbps	114.69	116.69	127.69	129.69
	UMTS 144 kbps	110.69	122.69	123.69	125.69
	UMTS 384 kbps	100.69	102.69	113.69	115.69

From Table 4.17 and 4.18, one observes that the path-loss in Sub-urban environments is higher than in Urban Area ones, because in this case there are much more objects that cause shadowing, so the slow fading is greater in this environment. The same occurs when comparing the results obtained for rural environment with sub-urban one. In fact, considering the urban case, the maximum path-loss range in GSM 900 is [100.29, 124.87] dB, and in GSM 1800 is [102.89, 120.89] dB; while considering sub-urban (Hilly Terrain)case, the range is [109.10, 127.06] dB in GSM 900 and [111.43, 123.43] dB in GSM 1800.

To give a complete view, now, some examples for COST 213-WI and for Multi-wall models are presented.

COST-WI model is used only for urban environments, thus in order to compare the results for different systems, the calculations for GSM and for UMTS Typical Urban environments are considered, Table 4.19 and 4.20. Additional results on the cases of UMTS Vehicular-A and B, UMTS Pedestrian-A and B can be found in Annex 3.

Table 4.19-Evaluation of L_{pmax} in Typical Urban, NLoS, COST 231-WI model.

$\bar{L}_{p\max} + M^{SF}{}_{[dB]} + M^{FF}{}_{[dB]}$		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}= 0 dBi	G_{MT}= 2 dBi	G_{MT}= 0 dBi	G_{MT}= 2 dBi
90 %	GSM 900 data	114.22	116.22	127.22	129.22
	GSM 1800 data	108.65	110.65	121.65	123.65
	GSM 900 voice	111.22	113.22	124.22	126.22
	GSM 1800 voice	105.65	107.65	118.65	120.65
	UMTS 12.2 kbps	128.36	130.36	141.36	143.36
	UMTS 144 kbps	124.36	126.36	137.36	139.36
	UMTS 384 kbps	114.36	116.36	127.36	129.36
99 %	GSM 900 data	106.91	108.91	119.91	121.91
	GSM 1800 data	69.26	71.26	82.26	84.26
	GSM 900 voice	103.91	105.91	116.91	118.91
	GSM 1800 voice	96.26	98.26	109.26	111.26
	UMTS 12.2 kbps	118.97	120.97	131.97	133.97
	UMTS 144 kbps	114.97	116.97	127.97	129.97
	UMTS 384 kbps	104.97	106.97	117.97	119.97

Comparing the results in Table 4.17 with the ones in Table 4.19, one observes that the estimation of the maximum path-loss range, with COST 231-WI is greater than the estimation of the maximum path-loss range with COST 231-Hata model. In fact, considering GSM 900 data service the maximum path-loss range is [109.87, 124.87] dB with COST 231-Hata model, while with COST 231-WI is [114.22, 129.22] dB hence, COST 231-WI range is about 3 dB greater than the range evaluated with COST 231-Hata model. A similar behaviour occurs comparing the results obtained for UMTS, in fact, the maximum path-loss range for UMTS at 12.2 kbps is [125.41, 140.41] dB with COST 231-Hata model, while with COST 231-WI is [128.36, 143.36] dB. In this case the difference is about 3 dB, too. The same bahaviour for the other services is checked.

In general, the results obtained with COST 231-WI are more accurate respect with the results obtained with COST 231-Hata model because the path-loss estimation, in the previous case, considering more data to describe the characters of the urban environmet, is made.

COST 231-WI model can be apply for LoS case, too, by (3.9), In this context some results for UMTS Indoor-A and B environments and for HIPERLAN/2 are made and shown in Annex 4.

General considerations on the differences of the difference path-loss range, between LoS and NLoS casen are the same made for COST 231-Hata model.

Usually, Multi-wall model is used for Indoor environments, thus it is used only for UMTS Indoor-A and B environments and HIPERLAN/2. Besides, because of the penetrated walls and floors only NLoS case is considered. In this section only the results for UMTS Indoor-A, Table 4.20, and HIPERLAN/2-HS, Table 4.21, are presented. Other results in Annex 5 are reported.

Table 4.20 -Evaluation of L_{pmax} in UMTS Indoor-A, NLoS, with Multi-wall model.

$\overline{L}_{p\max} + M^{SF}{}_{[dB]} + M^{FF}{}_{[dB]}$		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}= 0 dBi	G_{MT}= 2 dBi	G_{MT}= 0 dBi	G_{MT}= 2 dBi
90 %	UMTS 12.2 kbps	118.41	120.41	131.41	133.41
	UMTS 144 kbps	114.41	116.41	127.41	129.41
	UMTS 384 kbps	104.41	106.41	117.41	119.41
99 %	UMTS 12.2 kbps	106.61	108.61	119.61	121.61
	UMTS 144 kbps	102.61	104.61	115.61	117.61
	UMTS 384 kbps	92.61	94.61	105.61	107.61

As aspected, one observes form Table 4.20, that the general behaviour between the servie bit rate and the maximum path-loss range is respected in multi-wall model, too..

Table 4.21 -Evaluation of L_{pmax} in HIPERLAN/2-HS, NLoS, Multi-wall model.

$\overline{L}_{p\max} + M^{SF}{}_{[dB]} + M^{FF}{}_{[dB]}$		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}= 0 dBi	G_{MT}= 2 dBi	G_{MT}= 0 dBi	G_{MT}= 2 dBi
90 %	HIPRLAN/2_A	84.16	86.16	97.16	99.16
	HIPRLAN/2_B	85.76	87.76	98.76	100.76
	HIPRLAN/2_C	86.46	88.46	99.46	101.46
	HIPRLAN/2_D	86.26	88.26	99.26	101.26
	HIPRLAN/2_E	86.86	88.86	99.86	101.86
99 %	HIPRLAN/2_A	70.70	72.70	83.70	85.70
	HIPRLAN/2_B	72.30	74.30	85.30	87.30
	HIPRLAN/2_C	73.00	75.00	86.00	88.00
	HIPRLAN/2_D	72.80	74.80	85.80	87.80
	HIPRLAN/2_E	73.40	75.40	86.40	88.40

The path-loss values in HIPERLAN/2-HS (but also in HIPERLAN/2-LS) are smaller respect with the other systems, such as in the $\overline{L}_{p\max}$ case, as shown in Table 4.8.

From Table 4.21, one observes that the maximum path-loss range corresponding to the channel characterised by the greatest *rms* delay spread (channel A) is lower than the channel characterised by the lowest *rms* delay spread (channel E); this is an effect due to the fact that when the *rms* delay spread increases, Table 4.4, at the same time, the fast fading margin decreases, as previously shown in Table 4.12. However, the maximum path-loss range is quite similar for each considered channel.

4.3. Cell Range evaluation

In this section the values of the cell-range estimated through COST 231-Hata, COST 231-WI and Multi-wall model for different systems and environments are presented and discussed.

4.3.1. Average Case

Cell-range estimation corresponding to $\overline{L}_{p\max}$ values reported in Table 4.8 evaluated by COST 231-Hata model in Urban, Sub-urban and Rural environments, are shown in what follow.

From (3.3) one obtains:

$$d_{[\mathrm{km}]} = \left(\left(\begin{array}{l} L_{p\max\,[\mathrm{dB}]} - 46.3 - 33.9\log\left(f_{[\mathrm{MHz}]}\right) + a\left(h_{MT\,[\mathrm{m}]}\right) + \\ 13.82\log\left(h_{BT\,[\mathrm{m}]}\right) - C_m \end{array} \right) / \left(44.9 + 66.5\log\left(h_{BT\,[\mathrm{m}]}\right)\right) \right) \quad (4.6)$$

hence, one can evaluate the cell-range for urban environmet as presented in Table 4.22.

Table 4.22 -Cell-range evaluation for $\overline{L}_{p\max}$, COST 231-Hata model, Urban environment.

$d_{\text{[km]}}$	G_{BS}= 0 dBi		G_{BS}= 13 dBi	
	G_{MT}= 0 dBi	G_{MT}= 2 dBi	G_{MT}= 0 dBi	G_{MT}= 2 dBi
GSM 900 data	1.90	2.17	4.45	5.07
GSM 1800 data	0.71	0.80	1.65	1.88
GSM 900 voice	1.56	1.70	3.31	4.17
GSM 1800 voice	0.58	0.66	1.36	1.55
UMTS 12.2 kbps	1.49	1.70	3.48	3.97
UMTS 144 kbps	1.15	1.31	2.68	2.68
UMTS 384 kbps	0.60	0.68	1.39	1.59

As referred in Table 4.22, the maximum cell-range in GSM 900 data is [1.90, 5.07] km and in GSM 1800 is [0.71, 1.88] km, while for voice service, in GSM 900 it is [1.56, 4.17] km and in GSM 1800 is [0.58, 1.55]. Thus, one observes that the values for different services are quite similar in the same working frequency, hence, concerning the average case; one can say that the maximum cell-range in GSM 900 is [1.56, 5.07] km and in GSM 1800 is [0.58, 1.88] km.

For UMTS, the cell-range coverage devreases when the bit rate increasing, thus the mximum cell-range evaluation with COST 231-Hata model is [0.60, 3.97] km.

From (3.5) one obtains:

$$d_{[\mathrm{km}]} = \left(\begin{pmatrix} L_{p\max}{}_{[\mathrm{dB}]} - 46.3 - 33.9\log\left(f_{[\mathrm{MHz}]}\right) + a\left(h_{MT}{}_{[m]}\right) + \\ 13.82\log\left(h_{BT}{}_{[m]}\right) - C_m + k_{sub}{}_{[\mathrm{dB}]} \end{pmatrix} / \left(44.9 + 66.5\log\left(h_{BT}{}_{[m]}\right)\right) \right) \quad (4.7)$$

hence, one can evaluate the cell-range for sub-urban environmet as presented in Table 4.23.

Table 4.23 -Cell range evaluation for $\overline{L}_{p\max}$, COST 231-Hata model, Sub-urban environment.

$d_{[\mathrm{km}]}$	G_{BS}= 0 dBi		G_{BS}= 13 dBi	
	G_{MT}= 0 dBi	G_{MT}= 2 dBi	G_{MT}= 0 dBi	G_{MT}= 2 dBi
GSM 900 data	3.65	4.16	8.53	9.72
GSM 1800 data	1.53	1.74	3.58	4.08
GSM 900 voice	3.00	3.11	6.04	7.99
GSM 1800 voice	1.26	1.43	2.94	3.35
UMTS 12.2 kbps	3.30	3.76	7.73	8.81
UMTS 144 kbps	2.54	2.90	5.95	6.78
UMTS 384 kbps	1.32	1.50	3.09	3.53

From Table 4.23, one can refers that in sub-urban case the maximum cell-range in GSM 900 is [3.00, 9.72] km and in GSM 1800 is [1.26, 4.08] km. Therefore, respect with the urban case, the maximum cell-range is increasing. A similar behaviour is verified in UMTS and for each other system.

From (3.7) one obtains:

$$d_{[\mathrm{km}]} = \left(\begin{pmatrix} L_{p\max}{}_{[\mathrm{dB}]} - 46.3 - 33.9\log\left(f_{[\mathrm{MHz}]}\right) + a\left(h_{MT}{}_{[m]}\right) + \\ 13.82\log\left(h_{BT}{}_{[m]}\right) - C_m + k_{rur}{}_{[\mathrm{dB}]} \end{pmatrix} / \left(44.9 + 66.5\log\left(h_{BT}{}_{[m]}\right)\right) \right) \quad (4.8)$$

hence, one can evaluate the cell-range for rural environmet as presented in Table 4.23

Table 4.24 -Cell-range evaluation for $\overline{L}_{p\max}$, COST 231-Hata model, Rural environment.

d [km]	G_{BS}= 0 dBi		G_{BS}= 13 dBi	
	G_{MT}= 0 dBi	G_{MT}= 2 dBi	G_{MT}= 0 dBi	G_{MT}= 2 dBi
GSM 900 data	8.83	10.06	20.65	23.54
GSM 1800 data	4.05	4.61	9.47	10.79
GSM 900 voice	7.26	7.04	13.67	19.34
GSM 1800 voice	3.33	3.79	7.78	8.87
UMTS 12.2 kbps	8.89	10.13	20.79	23.69
UMTS 144 kbps	6.84	7.80	16.01	18.24
UMTS 384 kbps	3.56	4.06	8.33	9.49

In rural environment, Table 4.24, the cell-range estimations are much more great than in urban and sub-urban ones; in fact, in GSM 900, the cell-range estimation is [7.26, 23.54] km, in GSM 1800 is [3.33, 10.79] km and in UMTS is [3.56, 23.69] km.

Therefore, as it is expected, the cell-range coverage in urban environment is smaller than in sub-urban and rural ones, and the same situation occurs between sub-urban and rural environments. This comes from the fact that propagation loss in rural environments is lower than in urban and sub-urban.

The next step is to compare the cell-ranges obtained with COST 231-Hata model and COST 231-WI models. Obviously, this comparison is done only in urban environments, because of the COST 231-WI validity. In Table 4.25, the results for GSM Typical Urban and UMTS Typical Urban are presented for COST 231-WI model.

From (3.10) one obtains:

$$d_{[\mathrm{km}]} = 10^\wedge\left(\left(\begin{array}{l} L_{p\max\,[dB]} - 32.4 - (20+k_f)\log(f_{[\mathrm{dB}]}) - L_{rts\,[\mathrm{dB}]} - L_{bsh\,[\mathrm{dB}]} \\ + k_a + 9\log(b_{[\mathrm{km}]}) \end{array}\right) / (20+k_d)\right) \tag{4.9}$$

hence, one can evaluate the cell-range for rural environmet as presented in Table 4.25.

Table 4.25-Cell-range evaluation for $\overline{L}_{p\max}$, COST 231-WI model, Typical Urban scenario.

d [km]	G_{BS}= 0 dBi		G_{BS}= 13 dBi	
	G_{MT}= 0 dBi	G_{MT}= 2 dBi	G_{MT}= 0 dBi	G_{MT}= 2 dBi
GSM 900 data	0.90	1.02	1.98	2.24
GSM 1800 data	0.37	0.41	0.80	0.90
GSM 900 voice	0.75	0.85	1.66	1.87
GSM 1800 voice	0.31	0.34	0.67	0.76
UMTS 12.2 kbps	0.70	0.80	1.53	1.73
UMTS 144 kbps	0.55	0.62	1.20	1.36
UMTS 384 kbps	0.30	0.34	0.66	0.74

As one can observe that the values obtained by COST 231-Hata model are approximately twice the ones obtained by COST 231-WI. One should remember that the COST 231-WI model allows improving the path-loss estimation by considering more parameters to describe the urban environment.; in fact in this case the maximum cell-range in GSM 900 is [0.75, 2.24] km, in GSM 1800 is [0.31, 0.90] km and in UMTS is [0.30, 1.74] km.

In Multi-wall model the estimation of the cell-range depends on the number of the penetrated walls and floors, as shown in (4.9):

$$d_{[\mathrm{km}]} = 10 \wedge \left(\begin{pmatrix} L_{p\max\,[dB]} - 32.4 - 20\log\left(f_{[\mathrm{MHz}]}\right) - L_{c\,[\mathrm{dB}]} - \sum_{i=1}^{I} k_{wi}\, L_{wi\,[dB]} - \\ k_{fj}^{\left[\frac{kf+2}{kf+1}-b\right]} L_{fj\,[dB]} \end{pmatrix} / 20 \right) \tag{4.10}$$

hence, one can evaluate the cell-range for multi-wall model as presented in
Table 4.26.

The simulations with this model are made for three cases: when the number of penetrated walls and floors are equal to 1, 2 and 3. In
Table 4.26, the results for each of this three cases are shown.

Table 4.26 -Cell range evaluation for $\overline{L}_{p\max}$, Multi-wall model, in HIPERLAN/2.

d [km]		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}= 0 dBi	G_{MT}= 2 dBi	G_{MT}= 0 dBi	G_{MT}= 2 dBi
k_{wi}= k_{fj}=1	HIPERLAN/2-HS	0.600	0.760	2.690	3.390
	HIPERLAN/2-LS	0.090	0.110	0.380	0.480
k_{wi}= k_{fj}=2	HIPERLAN/2-HS	0.070	0.080	0.300	0.380
	HIPERLAN/2-LS	0.009	0.085	0.042	0.380
k_{wi}= k_{fj}=3	HIPERLAN/2-HS	0.002	0.002	0.009	0.001
	HIPERLAN/2-LS	< 0.001	0.002	0.001	0.010

As one can see, from Table 4.26, the values of the maximum cell-range in HIPERLAN/2, are very small; in fact, considering both receiver sensitivities, when k_{wi}= k_{fj}=1, the maximum range is [0.09, 3.39] km, when k_{wi}= k_{fj}=2 is [0.009, 0.38] km and when k_{wi}= k_{fj}=3 is [< 0.001, 0.001] km. These ranges are valid because HIPERLAN/2 is mainly used for indoor environments. Obviously, when the number of penetrated floors and walls increases, the maximum cell-range decreases because of the penetration loss is greater.

4.3.2. Path-Loss evaluation considering slow- and fast-fading

Finally, one presents the cell-range estimation for the environments that were considered in section 4.2.4, to have a direct corrispondence between the maximum path-loss range and the maximum cell-range estimation. Thus, first of all it is presented the estimation of the cell-range by COST 231-Hata model, in NLoS, for GSM Rural Area.The values presented in Table 4.27, are obtained by (4.8) considering the maximum path-loss range with the influence of the slow and the fast fading margins.

Table 4.27-Cell range evaluation for L_{pmax}, GSM Rural Area, NLoS, COST 231-Hata model.

d [km]		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}= 0 dBi	G_{MT}= 2 dBi	G_{MT}= 0 dBi	G_{MT}= 2 dBi
90 %	GSM 900 data	1.16	1.30	2.52	3.10
	GSM 1800 data	0.98	1.12	2.29	2.61
	GSM 900 voice	0.96	1.08	2.10	2.55
	GSM 1800 voice	0.42	0.48	0.98	1.12
99 %	GSM 900 data	0.59	0.70	1.36	1.59
	GSM 1800 data	0.48	0.55	1.13	1.29
	GSM 900 voice	0.49	0.58	1.13	1.31
	GSM 1800 voice	0.21	0.24	0.48	0.55

As it is expected, the cell-range coverage decreases when the path-loss decreases, as already explain in Section 4.2.4. Therefore, the coverage evaluated with slow fading at 90 % is greater than slow fading evaluated at 99 %. Of course, this second case is demanding because it means that for the most of the time the signal power must be sufficient to ensure the communication between MS and BS. Comparing the results obtained for different services, one observes that the cell-range estimation for data is greater than for voice one; in fact, in the first case, when the slow fading estimation is done at 90 %, the range is [0.98, 3.10] km, while in the second case is [0.42, 2.55] km.

The 3 dB difference between data and voice services in terms of path-loss, as observed in Section 4.2.4, corresponds to 0.6 km in terms of cell-range coverage. In general, the cell-range for GSM 900 is [0.96, 3.10] km and for GSM 1800 is [0.42, 2.61] km.

InTable 4.28, are presented the results obtained for UMTS, in order to show how the general behaviour concerning the difference between the evaluation of the slow fading at 90 % and at 99 % is, yet, respected.

Table 4.28 -Cell range evaluation for L_{pmax}, UMTS Rural Area, NloS, COST 231-Hata model.

d [km]		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}= 0 dBi	G_{MT}= 2 dBi	G_{MT}= 0 dBi	G_{MT}= 2 dBi
90 %	UMTS 12.2 kbps	2.10	2.38	4.89	5.57
	UMTS 144 kbps	1.61	1.83	3.76	4.29
	UMTS 384 kbps	0.84	0.95	1.96	2.23
99 %	UMTS 12.2 kbps	1.02	1.17	2.39	2.73
	UMTS 144 kbps	0.79	0.90	1.84	2.10
	UMTS 384 kbps	0.41	0.47	0.96	1.09

Can be observed, from Table 4.28, that the cell-range evaluation is greater when the bit rate of the service is lower. For UMTS at 12.2 kbps, the cell-range estimation is [2.10, 5.57] km, for UMTS at 144 kbps is [1.61, 4.29] km and for UMTS at 384 kbps is [0.84, 2.23] km, hence, the 4 dB difference in terms of maximum path-loss range between voice and real-time data service, corresponds to 0.50 km in terms of cell-range coverage, and at 14 dB difference between voice and non-real-time service corresponds to 1.26 km in terms of cell-range evaluation. The same bahaviour is verified when the slow fading is evaluated at 99 %.

Comparing the cell range in the same system and environment but changing from NLoS case to LoS case when K = 6 dB. it is expect that since the path-loss increases, the same occurs with the cell-range, Table 4.29. Only the GSM Rural Area case is shown because the same behaviour occurs for other systems.

Table 4.29- Cell range evaluation for L_{pmax}, GSM Rural Area, LoS, COST 231-Hata model.

d [km]		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}= 0 dBi	G_{MT}= 2 dBi	G_{MT}= 0 dBi	G_{MT}= 2 dBi
90 %	GSM 900 data	1.86	2.00	3.89	4.97
	GSM 1800 data	1.57	1.79	3.67	4.19
	GSM 900 voice	1.53	1.67	3.26	4.09
	GSM 1800 voice	0.67	0.77	1.58	1.80
99 %	GSM 900 data	0.96	1.08	2.10	2.55
	GSM 1800 data	0.77	0.88	1.81	2.07
	GSM 900 voice	0.79	0.90	1.75	2.00
	GSM 1800 voice	0.33	0.39	0.77	0.88

In this case, the maximum cell-range for GSM 900 is [1.53, 4.97] km, and for GSM 1800 is [0.67, 4.19] km, evaluated with slow fading at 90 %. Comparing the ranges obtained with NLoS case, one can observe that the maximum cell-range is greater in LoS case respect with NLoS one, and this is agree with the general bahaviour of the path-loss, how already explain in Section 4.2.4.

Another comparison is based on the difference between rural, sub-urban and urban. For this reason Table 4.30 and 4.31 are reported. The values presented in Table 4.30 are found by (4.7), while the ones in Table 4.31 are found by (4.6).

Table 4.30 -Cell range evaluation for L_{pmax}, Hilly Terrain, NLoS, COST 231-Hata model.

d [km]		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}= 0 dBi	G_{MT}= 2 dBi	G_{MT}= 0 dBi	G_{MT}= 2 dBi
90 %	GSM 900 data	0.81	0.93	1.81	2.17
	GSM 1800 data	0.63	0.72	1.47	1.76
	GSM 900 voice	0.67	0.78	1.51	1.79
	GSM 1800 voice	0.40	0.45	0.93	1.06
	UMTS 12.2 kbps	0.93	1.06	2.17	2.48
	UMTS 144 kbps	0.71	0.81	1.67	1.90
	UMTS 384 kbps	0.37	0.42	0.87	0.99
99 %	GSM 900 data	0.42	0.50	0.98	1.11
	GSM 1800 data	0.31	0.35	0.73	0.83
	GSM 900 voice	0.34	0.42	0.82	0.91
	GSM 1800 voice	0.20	0.22	0.46	0.52
	UMTS 12.2 kbps	0.45	0.52	1.06	1.21
	UMTS 144 kbps	0.35	0.40	0.82	0.93
	UMTS 384 kbps	0.18	0.21	0.43	0.48

Table 4.31-Cell range evaluation for L_{pmax}, Typical Urban, NLoS, COST 231-Hata model.

d [km]		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}= 0 dBi	G_{MT}= 2 dBi	G_{MT}= 0 dBi	G_{MT}= 2 dBi
90 %	GSM 900 data	0.37	0.45	0.87	0.98
	GSM 1800 data	0.13	0.15	0.30	0.34
	GSM 900 voice	0.20	0.25	0.50	0.52
	GSM 1800 voice	0.10	0.12	0.25	0.28
	UMTS 12.2 kbps	0.41	0.47	0.97	1.10
	UMTS 144 kbps	0.32	0.36	0.74	0.85
	UMTS 384 kbps	0.16	0.19	0.39	0.44
99 %	GSM 900 data	0.18	0.23	0.45	0.48
	GSM 1800 data	0.06	0.07	0.14	0.16
	GSM 900 voice	0.15	0.19	0.38	0.40
	GSM 1800 voice	0.05	0.07	0.12	0.13
	UMTS 12.2 kbps	0.19	0.22	0.45	0.51
	UMTS 144 kbps	0.15	0.17	0.34	0.39
	UMTS 384 kbps	0.08	0.09	0.18	0.20

Also considering the influence of the fading margins, the cell-range estimation in sub-urban environment is higher than than in urban one, in fact, in GSM 900 it is [0.20, 0.98] km, while in sub-urban (Hilly Terrain) it is [0.67, 2.1] km. The same happands comparing rural and sub-urban values, for different systems, too.

To give a complete view, some examples for COST 231-WI and Multi-wall model are presented, assuming that the general observations made for COST231-Hata model are the same. The values shown in Table 4.32 are found by (4.9).

Table 4.32 -Cell range evaluation for L_{pmax} ,Typical Urban, NLoS, COST 231-WI model.

d [km]		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}= 0 dBi	G_{MT}= 2 dBi	G_{MT}= 0 dBi	G_{MT}= 2 dBi
90 %	GSM 900 data	0.26	0.29	0.56	0.64
	GSM 1800 data	0.09	0.10	0.19	0.22
	GSM 900 voice	0.21	0.24	0.47	0.53
	GSM 1800 voice	0.07	0.08	0.16	0.18
	UMTS 12.2 kbps	0.26	0.30	0.58	0.66
	UMTS 144 kbps	0.21	0.23	0.46	0.52
	UMTS 384 kbps	0.11	0.13	0.25	0.43
99 %	GSM 900 data	0.16	0.19	0.36	0.41
	GSM 1800 data	0.01	0.01	0.02	0.02
	GSM 900 voice	0.14	0.15	0.30	0.34
	GSM 1800 voice	0.04	0.05	0.09	0.10
	UMTS 12.2 kbps	0.15	0.17	0.33	0.37
	UMTS 144 kbps	0.12	0.13	0.26	0.29
	UMTS 384 kbps	0.06	0.07	0.14	0.16

Comparing the results in Table 4.32 with the onea in Table 4.31, as one can observe the values obtained by COST 231-Hata model are very closely to the ones obtained with COST 231-WI. In fact, the ranges obtained with COST 231-WI are: for GSM 900, [0,21, 0.64] km, for GSM 1800, [0.07, 0.22] km, for UMTS, [0.11, 0.66] km, Table 4.32, and the ranges obtained with COST 231-Hata model are: fpr GSM 900, [0.20, 0.98] km, for GSM 1800, [0.10, 0.34] km, for UMTS, [0.16, 0.10] km, Table 4.31.

The last example is reported for Multi-wall model. In this case the calculation are made for three cases of penetrated walls and floors. The calculations being done for three cases on the base of penetrated walls and floors. Only the results for which this number is equal to three are reported here, the others results being presented in Annex 5.

Table 4.33 -Cell-range evaluation in HIPERLAN/2-HS, NLoS, with Multi-wall model.

d [km]		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}= 0 dBi	G_{MT}= 2 dBi	G_{MT}= 0 dBi	G_{MT}= 2 dBi
90 %	HIPRLAN/2_A	0.04	0.05	0.18	0.23
	HIPRLAN/2_B	< 0.001	< 0.001	< 0.001	< 0.001
	HIPRLAN/2_C	< 0.001	< 0.001	< 0.001	0.001
	HIPRLAN/2_D	< 0.001	< 0.001	< 0.001	< 0.001
	HIPRLAN/2_E	0.06	0.07	0.26	0.33
99 %	HIPRLAN/2_A	0.009	0.01	0.039	0.05
	HIPRLAN/2_B	< 0.001	< 0.001	< 0.001	< 0.001
	HIPRLAN/2_C	< 0.001	< 0.001	< 0.001	< 0.001
	HIPRLAN/2_D	< 0.001	< 0.001	< 0.001	< 0.001
	HIPRLAN/2_E	0.012	0.01	0.05	0.07

The maximum cell-range in HIPERLAN/2-HS, considering all the channels, is [<0.001, 0.07] km. Obviously, the cell-range for channel E is greater than the cell-range for channel A, how shown in Table 4.33, because of the maximum path-loss range is higher in this second channel instead of the first one, as already presented in Section 4.2.4. Comparing the values reported in Table 4.33 with Table 4.26, one observes that they don’t change in a deep way because of the small distances. A significant difference in terms of distances can be survey comparing the values between different cases of penetrated walls and floors, Annex 5.

Finally, a general view on the differences between the considered systems, in terms of cell-range coverage is given. The most important case is represented by the cell-range evaluation with the influence of the fading margins, because it is more restrictive than the average case and the case considering only slow fading influence. The comparisons are going on for the values found with slow fading margin evaluated at 90 %, because the same behaviour occurs when the slow fading is evaluated at 99 %, but with smaller values.

The first step is to compare the values on the base of the particular environment with COST 231-Hata model. As one can observe, referring to the tables reported in in Annex 3, that the obtained values for sub-urban are quite similar with the ones of the rural environment, hence, the comparison is made considering only two different types of scenario: rural/sub-urban and urban for each system.

The cell-range estimation, in NLoS case with COST 231 Hata model, for GSM 900 is $0.67 \leq d \leq 3.10$ km, for GSM 1800 is $0.40 \leq d \leq 2.61$ km and for UMTS is $0.37 \leq d \leq 5.57$

km. In urban environment, the cell-range estimation is, for GSM 900, $0.20 \leq d \leq 0.98$ km, for GSM 1800 is $0.10 \leq d \leq 0.34$ km and for UMTS is $0.10 \leq d \leq 1.10$ km. These ranges are obtained independently on the particular service and one observes that the greater one is for UMTS system. As expected, the values found for rural and sub-urban environment are greater than urban one, in fact for GSM 900 the difference is [0.47, 2.21] km, for GSM 1800 is [0.30, 2.27] km and for UMTS is [0.27, 4.47] km.

If the comparison is made considering different types of models, the first one is between the values found with COST 231-Hata model and COST 231-WI. Considering, yet, NLoS caset, he range found with COST231-WI for GSM 900 is $0.20 \leq d \leq 0.64$ km, for GSM 1800 is $0.07 \leq d \leq 0.22$ km and for UMTS is $0.07 \leq d \leq 0.63$ km. In this case the values are smaller than the first one because COST 231-WI keeps into account more parameters, indeed it is much restrictively respect with COST 231-Hata model, but the values are more precise.

The COST 231-WI model considers the LoS case, too. The values found in this case can be compared with the ones found with Multi-wall model, because in this case UMTS Indoor and HIPERLAN/2 are considered.

With COST 231-WI, the found range for UMTS is too big, due to the fact that LoS case is not a realistic situation concerning propagation issues. The range is $1.79 \leq d \leq 28.68$ km for UMTS and for HIPERLAN/2 is $0.03 \leq d \leq 0.57$ km, in this case the both sensitivity levels are considered.

If the Multi-wall is considered, different ranges are obtained on the base of the number of penetrated walls and floors. When this number is equal to one, the range for UMTS is $1.28 \leq d \leq 51.69$ km, and for HIPERLAN/2 is $0.006 \leq d \leq 0.33$ km. When the number of penetrated walls and floors is two, the range for UMTS is $0.14 \leq d \leq 5.81$ km, for HIPERLAN/2 is $<0.001 \leq d \leq 0.04$ km. The difference range between these two cases is significant, because when the number of penetrated walls and floors increases, the penetration loss is greater. The worst case is when three penetrated walls and floors are considered. In this case the range for UMTS is $0.003 \leq d \leq 0.17$ km, and for HIPERLAN/2 the distances are so small that the precise values are not significant, thus one can consider a reference distance as < 0.001 km. The found range with COST 231-WI are similar with the values found by Multi-wall model, even if, in this case, they are greater. The same happens with HIPERLAN/2, but when the number of penetrated walls and floors is, while the values are quite different when the number of penetrated walls and floors is three. In this case, they are significantly smaller, due to the greater penetration loss.

5. Conclusions

-The main aim of this work is to evaluate the maximum path loss with and without the influence of the slow and fast fading for narrowband and wideband systems, and to estimate, through several propagation models, the corresponding cell-range for different systems (GSM, UMTS and HIPERLAN) in several environments. This type of study is needed because of the convergence of several mobile and wireless communication systems.

First of all, a characterisation of the systems, is presented, considering the main parameters such as frequency band, maximum transmitter power, minimum transmitted power and others. Moreover, their applications fields and typical environments with link budget estimation is addressed, in order to have a complete view of their performances.

Steering the attention on the propagation aspects, some propagation models are described. Mainly, the attention is focused on some of outdoor and indoor models, such as COST 231-Hata, COST 231 WI, Multi-wall and COST 231 indoor model, respectively. Through these models, it is possible to evaluate the maximum path loss considering firstly the average case, and after the influence of the slow and fast fading.

The main conclusion about the results obtained for the maximum path loss, is that it depends on the particular model considered. Two different behaviors can be observed, if one considers slow or fast fading influence. Considering slow fading, the estimation of the maximum path-loss is higher than at 99 %. Considering fast fading, the maximum path-loss in the NLoS case is higher than in the LoS case for any value of *K*, and in the LoS one when *K* increases the maximum path-loss increases too. These two aspects usually occur for each system and for each environment.

In this report more emphasis is given to the characterisation of wideband multipath fading concerning the dependence on system bandwidth and environments characteristics, since this is a topic that is not yet well studied and only a few approaches can be found in literature. More detail is given to a new model that describes this wideband multipath fading phenomenon (Cardoso model). One of the innovative aspects was to find values that characterise the parameters that are in Cardoso model equation, for different scenarios, for NloS and LoS case, and in the latter for different values of *K*. It is possible to draw the best fitting curves of the simulations data, and to read the value of the fading depth. In the most of the considered scenarios, the best fitting curve follows a typical course and that respect Cardoso model equation. The most important conclusion is that the fading depth decreases as the system bandwidth increases; besides, for wideband systems in which there is a dependence on K, as the system bandwidth increases the fading depth becomes less sensitive to the value of K, because for different value of K the curves become closer. Another innovative aspect was that this general behaviour is not respected in two cases, so, a presentation of a modified Cardoso model is provided. The equation that describes this bahaviour developed, by making an analysis step by step between the constant and decreasing parts of the curves.

The last step is to present the estimation of the maximum path-loss taking into account these new values for these particular scenarios, and to evaluate the maximum cell-range for the average case and when slow and fast fading occur. Some general observations on the cell-range estimation are a directly consequence of the maximum path-loss behavior. General conclusions about the cell-range estimation considering the maximum cell-range corresponding at the maximum path-loss with slow and fast fading effects : by considering the cell-range with COST 231-Hata model, one can observe that it depends on the particular environment considered and that in urban area the cell-range is smaller then in sub-urban and rural, the same occur between suburban and rural, even if for these two environments the found values are very similar, thus one considers as one environment. The cell-range estimation, in NLoS case with COST 231 Hata model, for GSM 900 is $0.67 \leq d \leq 3.10$ km, for GSM 1800 is $0.40 \leq d \leq 2.61$ km and for UMTS is $0.37 \leq d \leq 5.57$ km. In urban environment, the cell-range estimation is, for GSM 900, $0.20 \leq d \leq 0.98$ km, for GSM 1800 is $0.10 \leq d \leq 0.34$ km and for UMTS is $0.10 \leq d \leq 1.10$ km. These ranges are considered independently on the particular service and one observes that the greater one is for UMTS system. All the calculations are made for COST 231-Hata, COST 213 Walfish-Ikegami and Multi-wall model because they are the most interesting, and the general observation that are reported, are valid for each one. Comparing the results obtained with COSt 231-Hata model and COST 231-WI, is observed that, in the NLoS case the range found with COST231-WI for GSM 900 is $0.20 \leq d \leq 0.64$ km, for GSM 1800 is $0.07 \leq d \leq 0.22$ km and for UMTS is $0.07 \leq d \leq 0.63$ km. In this case the values are smaller than the first one because COST 231-WI takes into account more parameters, indeed it is much restrictively respect with COST 231-Hata model, but the values are more precise. Comparing the results obtained with COST 231-WI for the LoS case with the ones obtained with Multi-wall model, one observes that for the first model, the range is $1.79 \leq d \leq 28.68$ km for UMTS and for HIPERLAN/2 is $0.03 \leq d \leq 0.57$ km, in this case the both sensitivity levels are considered. Similar results are obtained with Multi-wall model, when the nimber of penetrated walls and floors is equal to one, the range for UMTS is $1.28 \leq d \leq 51.69$ km, and for HIPERLAN/2 is $0.006 \leq d \leq 0.33$ km. The values becomes quite different when the muber of walls and floors is greater, in fact the worst case is represented by $k_{fj} = k_{wi}$=3, in which the range for UMTS is $0.003 \leq d \leq 0.17$ km, and for HIPERLAN/2 the distances are so small that the precise values are not significant, thus one can consider a reference distance as < 0.001 km. They are significantly smaller, due to the greater penetration loss.

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Annex 1

This annex represents the best fitting curve for each considered scenario.

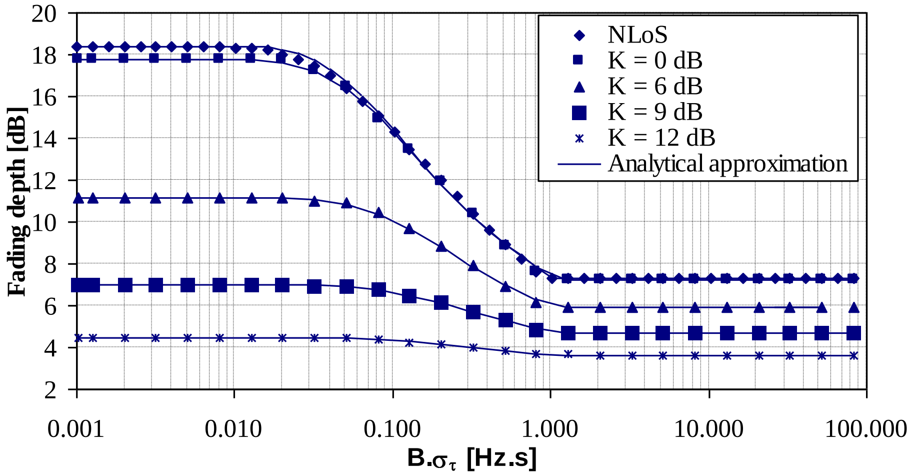

Figure A1.1-Fitting curves for GSM Rural Area.

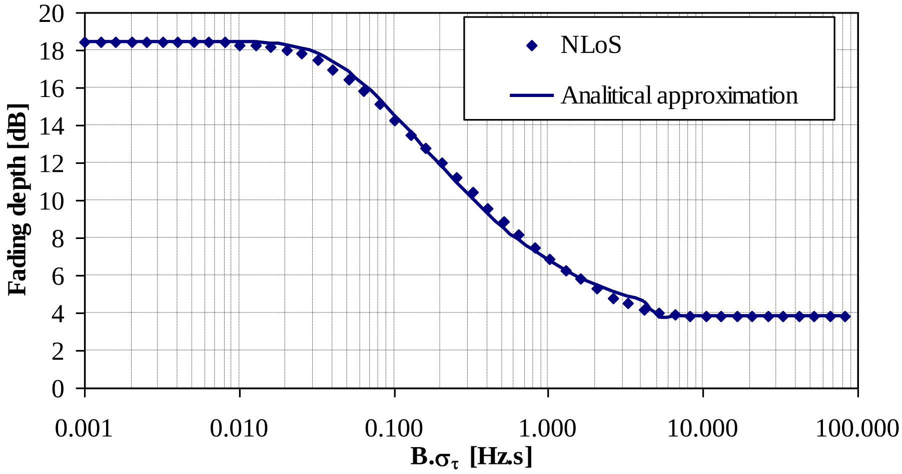

Figure A1.2-Fitting curves for GSM Typical Urban.

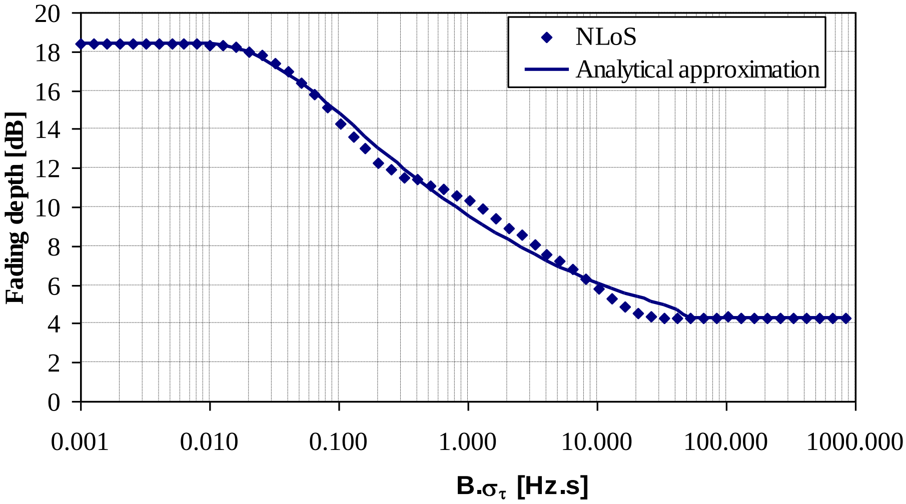

Figure A1. 3 -Fitting curves for GSM Hilly Terrain.

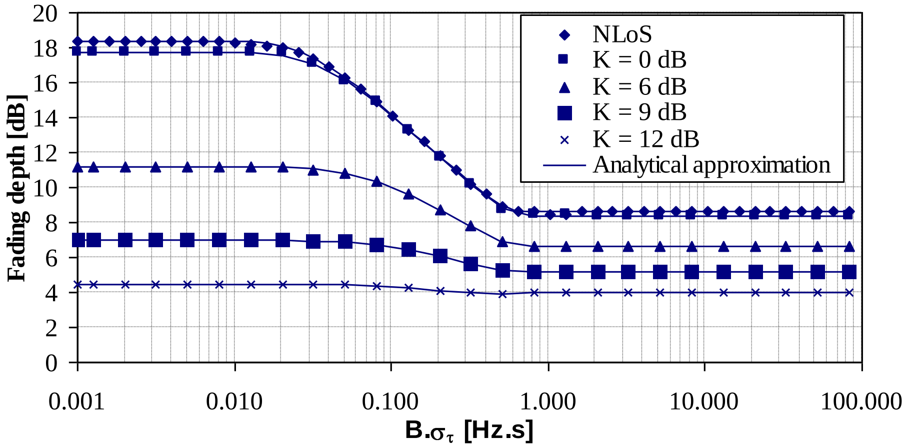

Figure A1. 4 -Fitting curves for UMTS Indoor-A.

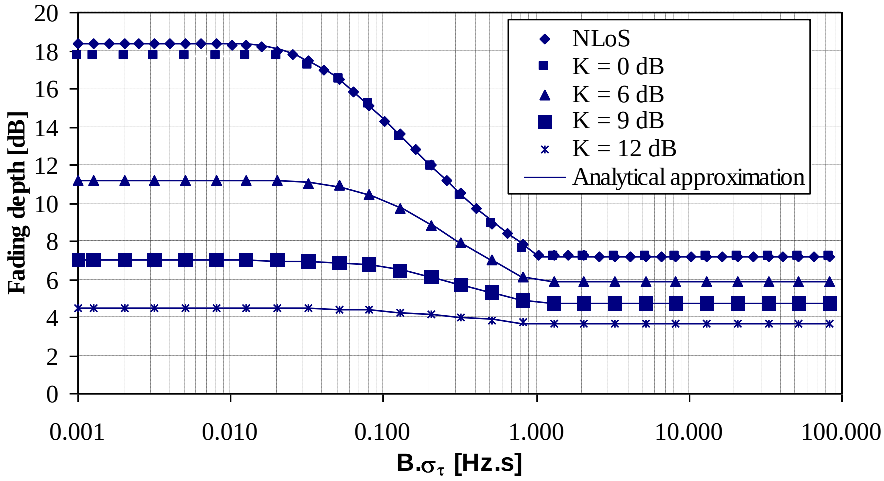

Figure A1. 5 -Fitting curves for UMTS Indoor-B.

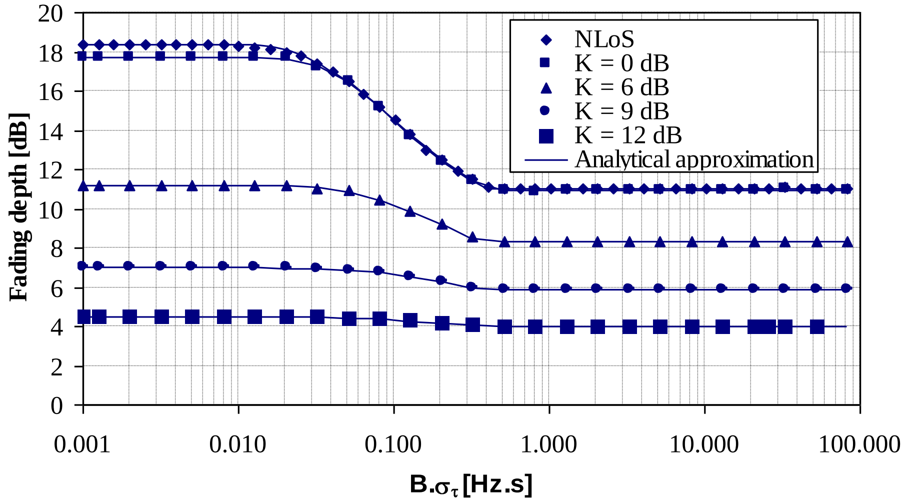

Figure A1. 6 -Fitting curves for Pedestrian-A.

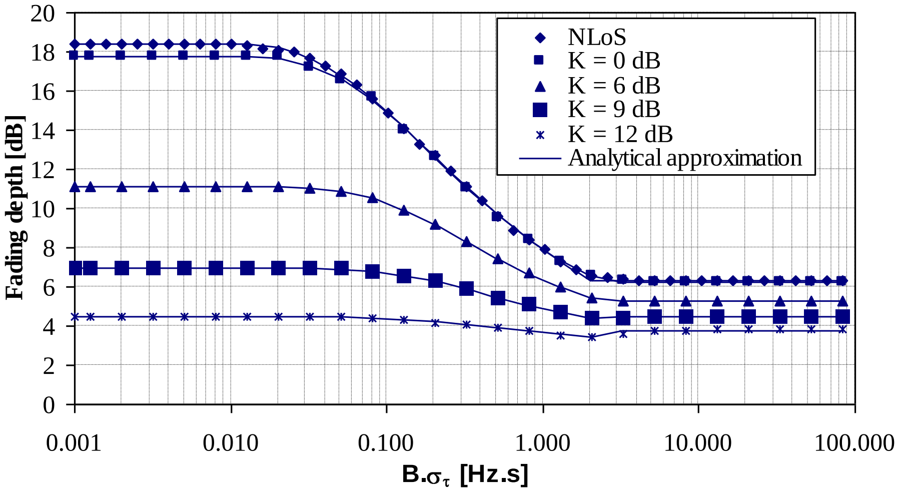

Figure A1. 7 -Fitting curves for Pedestrian-B.

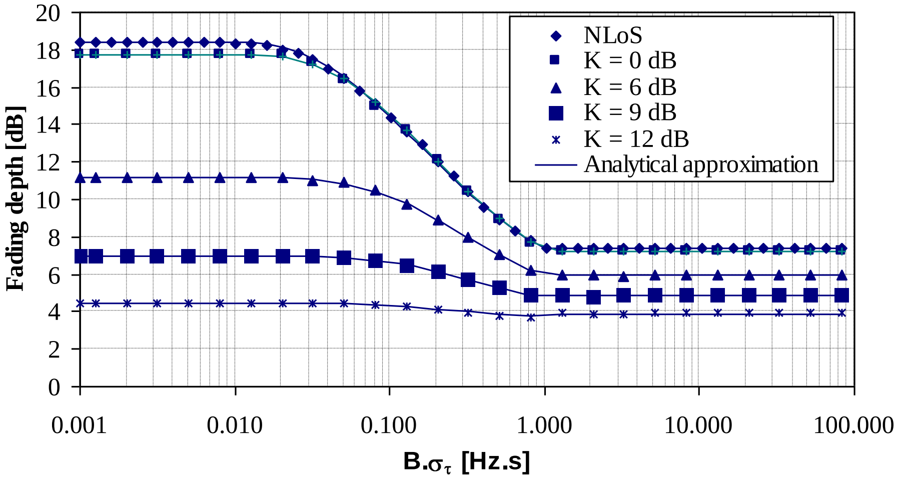

Figure A1. 8 -Fitting curves for UMTS Vehicular-A.

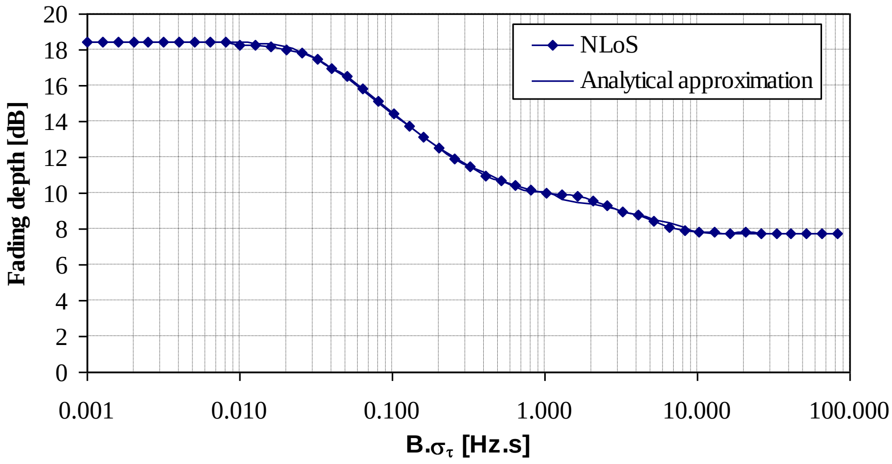

Figure A1. 9 -Fitting curves for UMTS Vehicular-B.

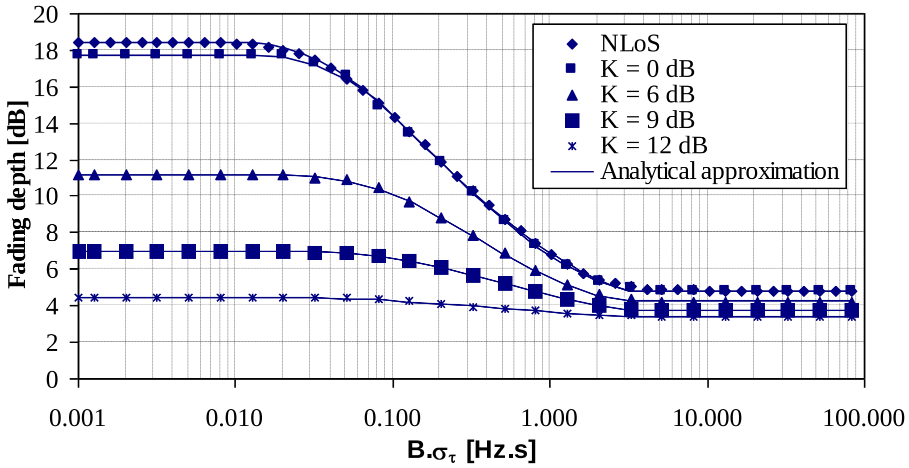

Figure A1. 10 -Fitting curves for UMTS Rural Area.

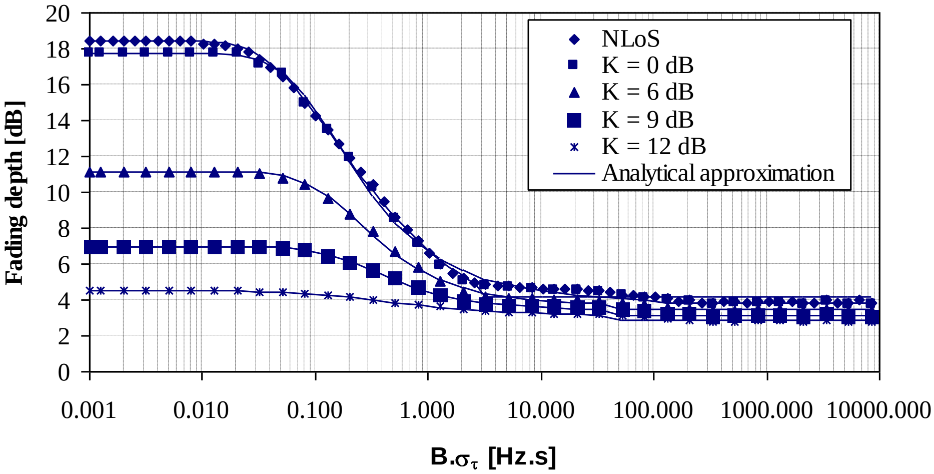

Figure A1. 11 -Fitting curves for UMTS Typical Urban.

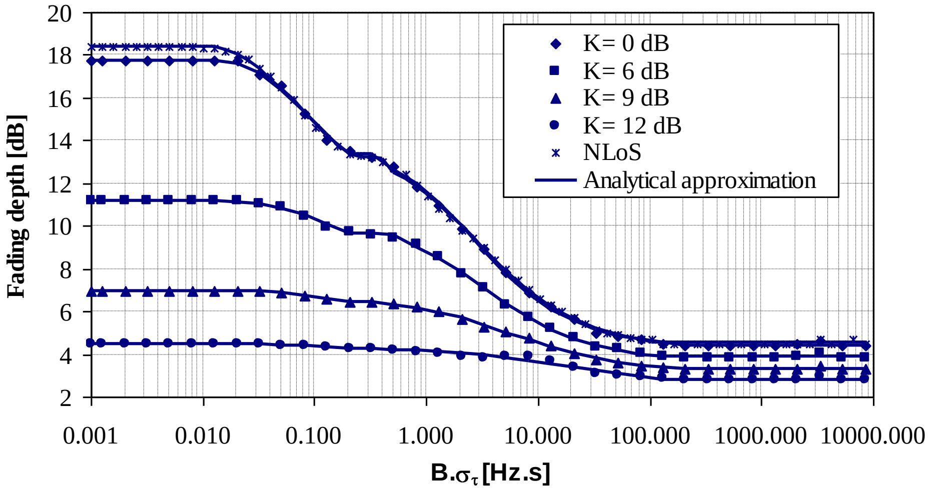

Figure A1. 12 -Fitting curves for UMTS Hilly Terrain.

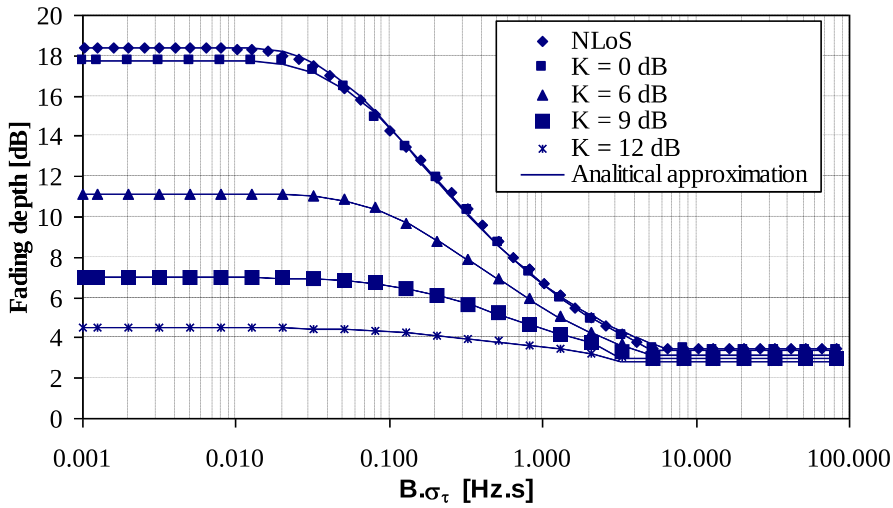

Figure A1. 13 -Fitting curves for HIPERLAN/2, channel A.

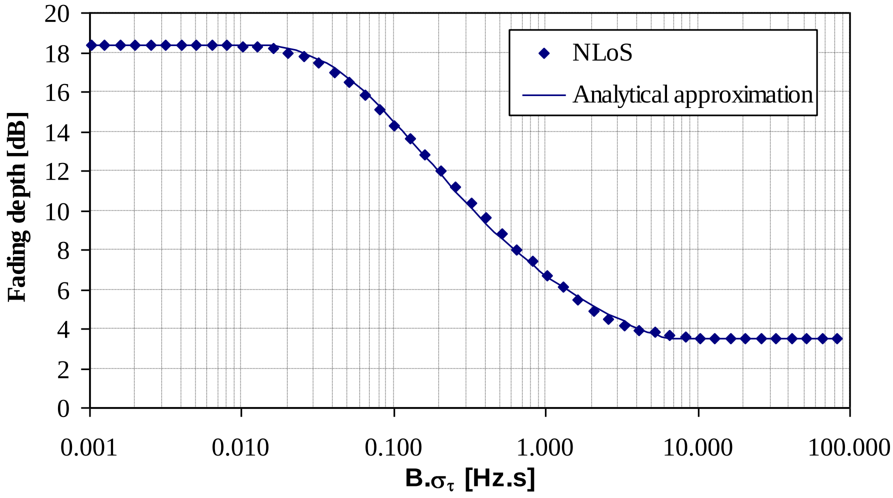

Figure A1. 14 -Fitting curves for HIPERLAN/2, channel B.

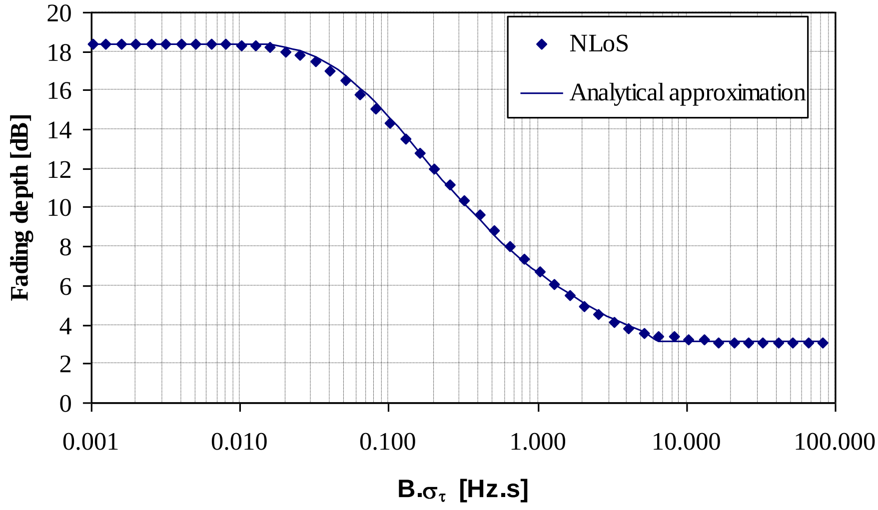

Figure A1. 15 -Fitting curves for HIPERLAN/2, channel C.

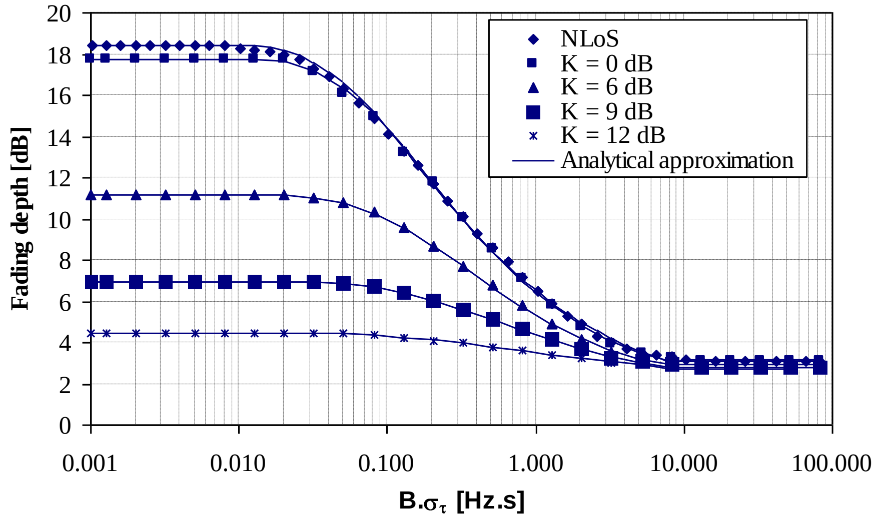

Figure A1. 16 -Fitting curves for HIPERLAN/2, channel D.

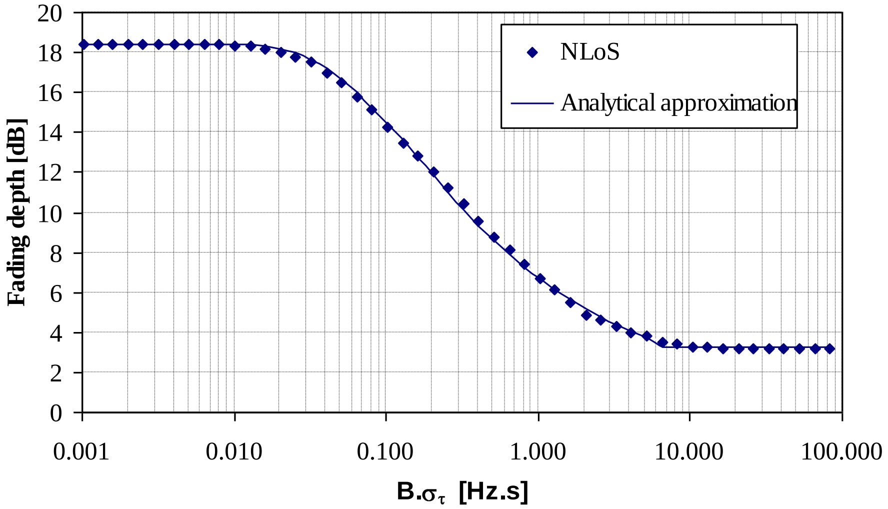

Figure A1. 17 -Fitting curves for HIPERLAN/2, channel E.

Annex 2

This annex presents the parameters to characterise the best fitting curves with Cardoso model and fading depth value for NLoS and LoS case, for each value of K in the environments previously reported.

Table 2. 1-Parameters in GSM Rural Area.

LoS	S_{11} [dB]	A_{11} [dB]	A_{12}	A_{13}	$\sqrt{\overline{\varepsilon^2}}$ [dB]	$\overline{\varepsilon_r}$ [%]
***K*= 0 dB**	17.74	3.80	0.32	3.14	0.07	-0.07
***K*= 6 dB**	11.16	3.90	0.17	3.85	0.03	-0.07
***K*= 9 dB**	6.98	3.90	0.12	4.36	0.02	-0.09
***K*= 12 dB**	4.48	3.40	0.16	4.11	0.01	-0.40
NLoS	18.40	3.80	0.37	3.00	0.12	-0.23

Table 2. 2-Parameters in GSM Typical Urban.

NLoS	S_{11} [dB]	A_{11} [dB]	A_{12}	A_{13}	$\sqrt{\overline{\varepsilon^2}}$ [dB]	$\overline{\varepsilon_r}$ [%]
	18.40	2.00	0.30	3.00	0.20	-0.48

Table 2. 3-Parameters in GSM Hilly Terrain.

NLoS	S_{11} [dB]	A_{11} [dB]	A_{12}	A_{13}	$\sqrt{\overline{\varepsilon^2}}$ [dB]	$\overline{\varepsilon_r}$ [%]
	18.40	0	0.24	1.92	0.38	-0.78

Table A2. 1-Parameters in UMTS Indoor-A.

LoS	S_{11} [dB]	A_{11} [dB]	A_{12}	A_{13}	$\sqrt{\overline{\varepsilon^2}}$ [dB]	$\overline{\varepsilon_r}$ [%]
***K*= 0 dB**	17.75	2.2	0.30	2.80	0.47	-4.90
***K* = 6 dB**	11.17	3.7	0.18	3.70	0.75	-6.30
***K* = 9 dB**	6.99	3.6	0.13	3.90	0.53	6.80
***K* = 12 dB**	4.49	3.6	0.24	4.10	0.14	2.30
NLoS	18.40	1.7	0.34	2.50	0.86	-7.20

Table A2. 2-Parameters in UMTS Indoor-B.

LoS	S_{11} [dB]	A_{11} [dB]	A_{12}	A_{13}	$\sqrt{\overline{\varepsilon^2}}$ [dB]	$\overline{\varepsilon_r}$ [%]
***K*= 0 dB**	17.75	2.30	0.21	3.00	0.038	-0.01
***K* = 6 dB**	11.16	2.90	0.14	3.70	0.025	-0.06
***K* = 9 dB**	6.98	3.20	0.10	3.90	0.007	-0.02
***K* = 12 dB**	4.48	3.30	0.15	3.50	0.012	-0.05
NLoS	18.40	0.60	0.21	2.50	0.047	-0.07

Table A2. 3-Parameters in UMTS Pedestrian-A.

LoS	S_{11} [dB]	A_{11} [dB]	A_{12}	A_{13}	$\sqrt{\overline{\varepsilon^2}}$ [dB]	$\overline{\varepsilon_r}$ [%]
***K*= 0 dB**	17.74	8.80	0.57	3.50	0.030	0.01
***K* = 6 dB**	11.16	5.80	0.21	3.70	0.020	0.01
***K* = 9 dB**	6.98	4.70	0.16	3.80	0.004	-0.01
***K*= 12 dB**	4.48	3.80	0.28	3.90	0.004	-0.01
NLoS	18.40	5.07	0.44	2.50	0.057	-0.07

Table A2. 4-Parameters in UMTS Pedestrian-B.

LoS	S_{11} [dB]	A_{11} [dB]	A_{12}	A_{13}	$\sqrt{\overline{\varepsilon^2}}$ [dB]	$\overline{\varepsilon_r}$ [%]
***K* = 0 dB**	17.74	2.60	0.23	3.00	0.05	-0.05
***K* = 6dB**	11.16	3.50	0.13	3.70	0.02	0.08
***K*= 9dB**	6.98	3.40	0.08	4.10	0.02	-0.01
***K*= 12 dB**	4.48	2.70	0.07	3.60	0.04	-0.23
NLoS	18.40	0.65	0.24	2.6	0.07	-0.01

Table A2. 5-Parameters in UMTS Vehicular-A.

LoS	S_{11} [dB]	A_{11} [dB]	A_{12}	A_{13}	$\sqrt{\overline{\varepsilon^2}}$ [dB]	$\overline{\varepsilon_r}$ [%]
***K* = 0 dB**	17.74	2.00	0.26	3.00	0.06	-0.04
***K* = 6 dB**	11.16	3.00	0.14	3.80	0.02	-0.02
***K* = 9 dB**	6.98	3.00	0.09	4.00	0.01	0.00
***K* = 12 dB**	4.48	3.00	0.14	3.50	0.02	-0.17
NLoS	18.40	1.00	0.30	2.60	0.06	-0.06

Table A2. 6-Parameters in UMTS Vehicular-B.

NLoS	S_{11} [dB]	A_{11} [dB]	A_{12}	A_{13}	S_{21} [dB]	A_{21} [dB]	A_{22}	A_{23}	$\sqrt{\overline{\varepsilon^2}}$ [dB]	$\overline{\varepsilon_r}$ [%]
	18.40	7.50	0.57	2.60	5.56	3.60	0.0011	5.60	0.09	-0.006

Table A2. 7-Parameters in UMTS Ruarl Area.

LoS	S_{11} [dB]	A_{11} [dB]	A_{12}	A_{13}	$\sqrt{\overline{\varepsilon^2}}$ [dB]	$\overline{\varepsilon_r}$ [%]
***K* = 0 dB**	17.74	1.30	0.25	3.00	0.08	0.05
***K* = 6 dB**	11.16	2.30	0.13	3.70	0.03	0.01
***K* = 9 dB**	06.98	2.80	0.09	3.90	0.02	- 0.05
***K* = 12 dB**	04.48	3.00	0.15	3.00	0.02	0.08
NLoS	18.40	0.19	0.28	2.60	0.08	0.00

Table A2. 8-Parameters in UMTS Typical Urban.

LoS	S_{11} [dB]	A_{11} [dB]	A_{12}	A_{13}	$\sqrt{\overline{\varepsilon^2}}$ [dB]	$\overline{\varepsilon_r}$ [%]
***K*= 0 dB**	17.74	3.71	0.28	3.70	0.21	-0.13
***K*=6 dB**	11.16	3.60	0.14	4.50	0.11	0.39
***K*= 9 dB**	06.98	3.40	0.08	4.90	0.08	-0.08
K= 12 dB	04.48	3.00	0.12	3.40	0.06	0.09
NLoS	18.40	0.61	0.29	2.70	0.27	- 0.49

Table A2. 9-Parameters in UMTS Hilly Terrain.

LoS	S_{11} [dB]	A_{11} [dB]	A_{12}	A_{13}	S_{21} [dB]	A_{21} [dB]	A_{22}	A_{23}	$\sqrt{\overline{\varepsilon^2}}$ [dB]	$\overline{\varepsilon_r}$ [%]
***K*= 0 dB**	17.74	09.90	0.53	3.00	13.36	4.09	0.0031	6.21	0.097	-0.07
***K*= 6 dB**	11.16	03.90	0.13	2.70	09.64	3.50	0.0021	6.3	0.062	0.11
***K*= 9 dB**	06.98	06.00	0.43	3.50	06.45	3.00	0.002	5.88	0.042	-0.01
***K*= 12 dB**	04.48	04.00	0.37	3.20	04.25	1.60	0.0021	4.5	0.055	-0.09
NLoS	18.40	04.90	0.36	2.10	13.25	3.90	0.004	5.8	0.094	-0.14

Table A2. 10-Parameters in HIPERLAN/2, channel A.

LoS	S_{11} [dB]	A_{11} [dB]	A_{12}	A_{13}	$\sqrt{\overline{\varepsilon^2}}$ [dB]	$\overline{\varepsilon_r}$ [%]
***K*= 0 dB**	17.74	0.15	0.23	2.90	0.09	-0.01
***K*= 6 dB**	11.16	0.65	0.11	3.40	0.02	0.11
***K*= 9 dB**	6.98	1.31	0.07	3.50	0.06	0.45
***K*= 12 dB**	4.48	1.60	0.06	3.00	0.04	0.31
NLoS	18.4	0.011	0.27	2.70	0.13	- 0.27

Table A2. 11-Parameters in HIPERLAN/2, channel B.

NLoS	S_{11} [dB]	A_{11} [dB]	A_{12}	A_{13}	$\sqrt{\overline{\varepsilon^2}}$ [dB]	$\overline{\varepsilon_r}$ [%]
	18.40	0.05	0.27	2.70	0.13	-0.23

Table A2. 12-Parameters in HIPERLAN/2, channel C.

NLoS	S_{11} [dB]	A_{11} [dB]	A_{12}	A_{13}	$\sqrt{\overline{\varepsilon^2}}$ [dB]	$\overline{\varepsilon_r}$ [%]
	18.40	0.20	0.26	2.8	0.16	-0.48

Table A2. 13-Parameters in HIPERLAN/2, channel D.

LoS	S_{11} [dB]	A_{11} [dB]	A_{12}	A_{13}	$\sqrt{\overline{\varepsilon^2}}$ [dB]	$\overline{\varepsilon_r}$ [%]
***K*= 0 dB**	17.74	0.50	0.24	3.00	0.11	-0.23
***K*= 6 dB**	11.16	1.10	0.13	3.40	0.05	0.13
***K*= 9 dB**	6.98	1.70	0.08	3.60	0.04	0.01
***K*= 12 dB**	4.48	1.90	0.07	3.10	0.03	0.00
NLoS	18.4	0.00001	0.28	2.70	0.15	0.77

Table A2. 14-Parameters in HIPERLAN/2, channel E.

NLoS	**S_{11} [dB]**	**A_{11} [dB]**	**A_{12}**	**A_{13}**	$\sqrt{\overline{\varepsilon^2}}$ **[dB]**	$\overline{\varepsilon_r}$ **[%]**
	18.4	0.095	0.27	2.70	0.1291	-0.0024

Table A2. 15-Fast fading evaluation in NLoS case for different environments.

	$B.\sigma_\tau$ [Hz.s]	**NLoS**
GSM Rural Area	0.02	18.40
GSM Typical Urban	0.20	11.80
GSM Hilly Terrain	1.02	10.30
UMTS Indoor A	0.17	12.10
UMTS Indoor B	0.50	9.00
UMTS Pedestrian A	0.22	12.30
UMTS Pedestrian B	3.75	6.30
UMTS Vehicular A	1.85	7.40
UMTS Vehicular B	20.00	7.70
UMTS Rural Area	0.50	8.70
UMTS Typical Urban	2.50	5.10
UMTS Hilly Terrain	15.00	6.00
HIPERLAN/A	1.18	6.30
HIPERLAN/B	2.35	4.70
HIPERLAN/C	2.53	4.00
HIPERLAN/D	3.29	4.20
HIPERLAN/E	5.88	3.60

Table A2. 16-Fast fading evaluation in Los case when K = 0 dB, for different environments.

	B.σ_τ [Hz.s]	***K* = 0 dB**
GSM Rural Area	0.02	17.90
UMTS Indoor A	0.17	12.50
UMTS Indoor B	0.50	9.00
UMTS Pedestrian A	0.22	12.30
UMTS Pedestrian B	3.75	6.30
UMTS Vehicular A	1.85	7.20
UMTS Rural Area	0.50	8.60
UMTS Typical Urban	2.50	5.00
UMTS Hilly Terrain	15.00	6.30
HIPERLAN/A	1.18	5.00
HIPERLAN/D	3.29	4.90

Table A2. 17-Fast fading evaluation in LoS when K = 6 dB, for different environments.

	B.σ_τ [Hz.s]	***K*=6 dB**
GSM Rural Area	0.02	11.16
UMTS Indoor A	0.17	9.20
UMTS Indoor B	0.50	6.90
UMTS Pedestrian A	0.22	9.00
UMTS Pedestrian B	3.75	5.20
UMTS Vehicular A	1.18	5.90
UMTS Rural Area	0.50	6.80
UMTS Typical Urban	2.50	4.50
UMTS Hilly Terrain	15.00	5.00
HIPERLAN/A	1.18	4.00
HIPERLAN/D	3.29	3.70

Table A2. 18- Fast fading evaluation in LoS when K = 9 dB, for different environments.

	B.σ_τ [Hz.s]	***K*=9 dB**
GSM Rural Area	0.02	6.90
UMTS Indoor A	0.17	6.30
UMTS Indoor B	0.50	5.20
UMTS Pedestrian A	0.22	6.20
UMTS Pedestrian B	3.75	4.50
UMTS Vehicular A	1.85	4.84
UMTS Rural Area	0.50	5.20
UMTS Typical Urban	2.50	3.90
UMTS Hilly Terrain	15.00	4.10
HIPERLAN/A	1.18	6.20
HIPERLAN/D	3.29	3.30

Table A2. 19- Fast fading evaluation in LoS when K = 12 dB, for different environments.

	B.σ_τ [Hz.s]	***K*=6 dB**
GSM Rural Area	0.02	4.48
UMTS Indoor A	0.17	4.10
UMTS Indoor B	0.50	4.10
UMTS Pedestrian A	0.22	4.10
UMTS Pedestrian B	3.75	3.80
UMTS Vehicular A	1.85	3.90
UMTS Rural Area	0.50	3.80
UMTS Typical Urban	2.50	3.40
UMTS Hilly Terrain	15.00	3.40
HIPERLAN/A	1.18	3.30
HIPERLAN/D	3.29	3.00

Annex 3

In here, the results about the evaluation of the maximum path loss and the maximum cell-range are reported, for COST 231 Hata model.

Table A3. 1-Estimation of $\overline{L}_{p\max}$, COST 231-Hata, COST 231-WI and Multi-Wall model.

$\overline{L}_{p\max}$ [dB]	G_{BS}= 0 dBi		G_{BS}= 13 dBi	
	G_{MT}= 0 dBi	G_{MT}= 2 dBi	G_{MT}= 0 dBi	G_{MT}= 2 dBi
GSM 900 data	135	137	148	150
GSM 1800 data	132	134	145	147
GSM 900 voice	132	134	145	147
GSM 1800 voice	129	131	142	144
UMTS 12.2 kbps	145	147	158	160
UMTS 144 kbps	141	143	154	156
UMTS 384 kbps	131	133	144	146
HIPERLAN/2-HS	107	109	120	122
HIPERLAN/2-LS	90	92	103	105

Table A3. 2-Cell range evaluation for $\overline{L}_{p\max}$, COST 231-Hata model, Urban environment.

d [km]	G_{BS}= 0 dBi		G_{BS}= 13 dBi	
	G_{MT}= 0 dBi	G_{MT}= 2 dBi	G_{MT}= 0 dBi	G_{MT}= 2 dBi
GSM 900 data	1.90	2.17	4.45	5.07
GSM 1800 data	0.71	0.80	1.65	1.88
GSM 900 voice	1.56	1.70	3.31	4.17
GSM 1800 voice	0.58	0.66	1.36	1.55

Table A3. 3-Cell range evaluation for $\overline{L}_{p\max}$, COST 231-Hata model, Sub-urban environment.

d [km]	G_{BS}= 0 dBi		G_{BS}= 13 dBi	
	G_{MT}= 0 dBi	G_{MT}= 2 dBi	G_{MT}= 0 dBi	G_{MT}= 2 dBi
GSM 900 data	3.65	4.16	8.53	9.72
GSM 1800 data	1.53	1.74	3.58	4.08
GSM 900 voice	3.00	3.11	6.04	7.99
GSM 1800 voice	1.26	1.43	2.94	3.35

Table A3. 4-Cell range evaluation for $\overline{L}_{p\max}$, COST 231-Hata model, in Rural environment.

d [km]	G_{BS}= 0 dBi		G_{BS}= 13 dBi	
	G_{MT}= 0 dBi	G_{MT}= 2 dBi	G_{MT}= 0 dBi	G_{MT}= 2 dBi
GSM 900 data	8.83	20.65	10.06	23.54
GSM 1800 data	4.05	9.47	4.61	10.79
GSM 900 voice	7.26	13.67	7.04	19.34
GSM 1800 voice	3.33	7.78	3.79	8.87

Table A3. 5-Evaluation of path loss, COST 231-Hata model in Urban environment.

$\overline{L}_{p\max} + M^{SF}$ [dB]		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}= 0 dBi	G_{MT}= 2 dBi	G_{MT}= 0 dBi	G_{MT}= 2 dBi
90 %	GSM 900 data	121.68	123.68	134.68	136.68
	GSM 1800 data	117.70	119.70	130.70	132.70
	GSM 900 voice	118.68	120.68	131.68	133.68
	GSM 1800 voice	114.70	116.70	127.70	129.70
	UMTS 12.2 kbps	130.51	132.51	143.51	145.51
	UMTS 144 kbps	126.51	128.51	139.51	141.51
	UMTS 384 kbps	116.51	118.51	129.51	131.51
99 %	GSM 900 data	110.83	112.83	123.83	125.83
	GSM 1800 data	106.05	108.05	111.05	121.05
	GSM 900 voice	107.83	109.83	120.83	122.83
	GSM 1800 voice	103.05	105.05	116.05	118.05
	UMTS 12.2 kbps	118.71	120.71	131.71	133.71
	UMTS 144 kbps	114.71	116.71	127.71	129.71
	UMTS 384 kbps	104.71	106.71	117.71	119.71

Table A3. 6-Evaluation of path loss, COST 231-Hata model in Sub-urban/Rural environment.

$\overline{L}_{p\max} + M^{SF}$ [dB]		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}= 0 dBi	G_{MT}= 2 dBi	G_{MT}= 0 dBi	G_{MT}= 2 dBi
90 %	GSM 900 data	122.36	124.36	135.36	137.36
	GSM 1800 data	118.73	120.73	131.73	133.73
	GSM 900 voice	119.40	121.40	132.40	134.40
	GSM 1800 voice	115.73	117.73	128.73	130.73
	UMTS 12.2 kbps	131.60	133.60	144.60	146.60
	UMTS 144 kbps	127.60	129.60	140.60	142.60
	UMTS 384 kbps	117.60	119.60	130.60	132.60
99 %	GSM 900 data	112.15	114.15	125.15	127.15
	GSM 1800 data	107.92	109.92	120.92	122.92
	GSM 900 voice	109.15	111.15	122.15	124.15
	GSM 1800 voice	104.92	106.92	117.92	119.92
	UMTS 12.2 kbps	120.69	122.69	133.69	135.69
	UMTS 144 kbps	116.69	118.69	121.69	131.69
	UMTS 384 kbps	106.69	108.69	119.69	129.69

Table A3. 7-Evaluation of distance, COST 231-Hata mode in Urban environment.

d [km]		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}= 0 dBi	G_{MT}= 2 dBi	G_{MT}= 0 dBi	G_{MT}= 2 dBi
90 %	GSM 900 data	0.80	0.91	1.78	2.12
	GSM 1800 data	0.28	0.32	0.65	0.71
	GSM 900 voice	0.65	0.76	1.48	1.74
	GSM 1800 voice	0.23	0.26	0.53	0.61
	UMTS 12.2 kbps	0.58	0.66	1.35	1.54
	UMTS 144 kbps	0.44	0.50	1.04	1.18
	UMTS 384 kbps	0.23	0.26	0.54	0.62
99 %	GSM 900 data	0.39	0.47	0.92	1.04
	GSM 1800 data	0.13	0.15	0.18	0.36
	GSM 900 voice	0.32	0.40	0.77	0.86
	GSM 1800 voice	0.10	0.12	0.25	0.28
	UMTS 12.2 kbps	0.27	0.30	0.62	0.71
	UMTS 144 kbps	0.21	0.23	0.48	0.56
	UMTS 384 kbps	0.11	0.12	0.25	0.28

Table A3. 8-Evaluation of distance, COST 231-Hata mode, in Sub-urban environment.

d [km]		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}= 0 dBi	G_{MT}= 2 dBi	G_{MT}= 0 dBi	G_{MT}= 2 dBi
90 %	GSM 900 data	1.60	1.74	3.37	4.25
	GSM 1800 data	1.23	1.40	2.88	3.20
	GSM 900 voice	1.31	1.45	2.82	3.50
	GSM 1800 voice	0.53	0.60	1.24	1.41
	UMTS 12.2 kbps	1.38	1.57	3.22	3.67
	UMTS 144 kbps	1.06	1.21	2.48	2.82
	UMTS 384 kbps	0.55	0.63	1.29	1.47
99 %	GSM 900 data	0.82	0.94	1.82	2.18
	GSM 1800 data	0.61	0.69	1.42	1.62
	GSM 900 voice	0.67	0.78	1.52	1.79
	GSM 1800 voice	0.26	0.30	0.61	0.70
	UMTS 12.2 kbps	0.67	0.77	1.58	1.80
	UMTS 144 kbps	0.52	0.59	1.21	1.38
	UMTS 384 kbps	0.27	0.31	0.63	0.72

Table A3. 9-Evaluation of distance, COST 231 Hata model, in Rural environment.

d [dB]		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}= 0 dBi	G_{MT}= 2 dBi	G_{MT}= 0 dBi	G_{MT}= 2 dBi
90 %	GSM 900 data	3.86	3.93	7.64	10.30
	GSM 1800 data	2.68	3.05	6.26	7.14
	GSM 900 voice	3.18	3.29	6.38	8.49
	GSM 1800 voice	1.40	1.60	3.27	3.73
	UMTS 12.2 kbps	3.70	4.22	8.66	9.87
	UMTS 144 kbps	2.85	3.25	6.67	7.60
	UMTS 384 kbps	1.48	1.69	3.47	3.95
99 %	GSM 900 data	1.98	2.12	4.12	5.28
	GSM 1800 data	1.61	1.83	3.76	4.28
	GSM 900 voice	1.69	1.77	3.44	4.34
	GSM 1800 voice	0.69	0.79	1.61	1.82
	UMTS 12.2 kbps	1.81	2.10	4.24	4.84
	UMTS 144 kbps	1.40	1.51	3.27	3.72
	UMTS 384 kbps	0.73	0.83	1.70	1.94

Table A3. 10-Evaluation of path loss, in NLoS, with COST 231-Hata model, in GSM System.

$\overline{L}_{p\max} + M^{SF}{}_{[dB]} + M^{FF}{}_{[dB]}$		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}=		G_{MT}=	
		0 dBi	2 dBi	0 dBi	2 dBi
90 %	GSM 900 Rural Area (data)	103.97	105.97	116.97	118.97
	GSM 1800 Rural Area (data)	100.34	102.34	113.34	115.34
	GSM 900 Rural Area (voice)	101.01	103.01	114.01	116.01
	GSM 1800 Rural Area (voice)	97.34	99.34	110.34	112.34
	GSM 900 Typical Urban (data)	109.87	111.87	122.87	124.87
	GSM 1800 Typical Urban (data)	105.89	107.89	118.89	120.89
	GSM 900 Typical Urban (voice)	100.29	102.29	113.29	115.29
	GSM 1800 Typical Urban (voice)	102.89	104.89	115.89	117.89
	GSM 900 Hillly Terrain (data)	112.06	114.06	125.06	127.06
	GSM 1800 Hillly Terrain (data)	105.43	107.43	118.43	120.43
	GSM 900 Hillly Terrain (voice)	109.10	111.10	122.10	124.10
	GSM 1800 Hillly Terrain (voice)	111.43	113.43	124.43	126.43
99 %	GSM 900 Rural Area (data)	93.76	95.76	106.76	108.76
	GSM 1800 Rural Area (data)	89.53	91.53	102.53	104.53
	GSM 900 Rural Area (voice)	90.76	92.76	103.76	105.76
	GSM 1800 Rural Area (voice)	86.53	88.53	99.53	101.53
	GSM 900 Typical Urban (data)	99.02	101.02	112.02	114.02
	GSM 1800 Typical Urban (data)	94.24	96.24	107.24	109.24
	GSM 900 Typical Urban (voice)	96.02	98.02	109.02	111.02
	GSM 1800 Typical Urban (voice)	91.24	93.24	104.24	106.24
	GSM 900 Hillly Terrain (data)	101.85	103.85	114.85	116.85
	GSM 1800 Hillly Terrain (data)	97.62	99.62	110.62	112.62
	GSM 900 Hillly Terrain (voice)	98.85	100.85	111.85	113.85
	GSM 1800 Hillly Terrain (voice)	100.62	102.62	113.62	115.62

Table A3. 11-Evaluation of path loss, in LoS when K = 6 dB, COST 231 Hata model

$\overline{L}_{p\max} + M^{SF}{}_{[90\%]} + M^{FF}$		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}=		G_{MT}=	
		2 dBi	0 dBi	2 dBi	0 dBi
90 %	GSM 900 Rural Area (data)	111.20	113.20	124.20	126.20
	GSM 1800 Rural Area (data)	107.57	109.57	120.57	122.57
	GSM 900 Rural Area (voice)	108.24	110.24	121.24	123.24
	GSM 1800 Rural Area (voice	104.57	106.57	117.57	119.57
99 %	GSM 900 Rural Area (data)	100.99	102.99	113.99	115.99
	GSM 1800 Rural Area (data)	96.76	98.76	109.76	111.76
	GSM 900 Rural Area (voice)	97.99	99.99	110.99	112.99
	GSM 1800 Rural Area (voice)	93.76	95.76	106.76	108.76

Table A3. 12-Evaluation of distance, in NLoS case, with COST 231-Hata model, in GSM.

d [km]		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}=		G_{MT}=	
		0 dBi	2 dBi	0 dBi	2 dBi
90 %	GSM 900 Rural Area (data)	1.16	1.30	2.52	3.10
	GSM 1800 Rural Area (data)	0.98	1.12	2.29	2.61
	GSM 900 Rural Area (voice)	0.96	1.08	2.10	2.55
	GSM 1800 Rural Area (voice)	0.42	0.48	0.98	1.12
	GSM 900 Typical Urban (data)	0.37	0.45	0.87	0.98
	GSM 1800 Typical Urban (data)	0.13	0.15	0.30	0.34
	GSM 900 Typical Urban (voice)	0.20	0.25	0.50	0.52
	GSM 1800 Typical Urban (voice)	0.10	0.12	0.25	0.28
	GSM 900 Hillly Terrain (data)	0.81	0.93	1.81	2.17
	GSM 1800 Hillly Terrain (data)	0.63	0.72	1.47	1.76
	GSM 900 Hillly Terrain (voice)	0.67	0.78	1.51	1.79
	GSM 1800 Hillly Terrain (voice)	0.40	0.45	0.93	1.06
99 %	GSM 900 Rural Area (data)	0.59	0.70	1.36	1.59
	GSM 1800 Rural Area (data)	0.48	0.55	1.13	1.29
	GSM 900 Rural Area (voice)	0.49	0.58	1.13	1.31
	GSM 1800 Rural Area (voice)	0.21	0.24	0.48	0.55
	GSM 900 Typical Urban (data)	0.18	0.23	0.45	0.48

	GSM 1800 Typical Urban (data)	0.06	0.07	0.14	0.16
	GSM 900 Typical Urban (voice)	0.15	0.19	0.38	0.40
	GSM 1800 Typical Urban (voice)	0.05	0.07	0.12	0.13
	GSM 900 Hillly Terrain (data)	0.42	0.50	0.98	1.11
	GSM 1800 Hillly Terrain (data)	0.31	0.35	0.73	0.83
	GSM 900 Hillly Terrain (voice)	0.34	0.42	0.82	0.91
	GSM 1800 Hillly Terrain (voice)	0.20	0.22	0.46	0.52

Table A3. 13-Evaluation of distance, in LoS when K = 6 dB with COST 231-Hata model, in GSM.

d [dB]		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}=		G_{MT}=	
		2 dBi	0 dBi	2 dBi	0 dBi
90 %	GSM 900 Rural Area (data)	1.86	2.00	3.89	4.97
	GSM 1800 Rural Area (data)	1.57	1.79	3.67	4.19
	GSM 900 Rural Area (voice)	1.53	1.67	3.26	4.09
	GSM 1800 Rural Area (voice	0.67	0.77	1.58	1.80
99 %	GSM 900 Rural Area (data)	0.96	1.08	2.10	2.55
	GSM 1800 Rural Area (data)	0.77	0.88	1.81	2.07
	GSM 900 Rural Area (voice)	0.79	0.90	1.75	2.00
	GSM 1800 Rural Area (voice)	0.33	0.39	0.77	0.88

Table A3. 14-Evaluation of path loss, in NLoS case, with COST 231-Hata model, in UMTS.

$\overline{L}_{p\max} + M^{SF}{}_{[dB]} + M^{FF}{}_{[dB]}$		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}= 0 dBi	G_{MT}= 2 dBi	G_{MT}= 0 dBi	G_{MT}= 2 dBi
90 %	UMTS Pedestrian-A 12.2 kbps	118.21	120.21	131.21	133.21
	UMTS Pedestrian-A 144 kbps	114.21	116.21	127.21	129.21
	UMTS Pedestrian-A 384 kbps	104.21	106.21	117.21	119.21
	UMTS Pedestrian-B 12.2 kbps	124.21	120.86	137.21	139.21
	UMTS Pedestrian-B 144 kbps	120.21	122.21	133.21	135.21
	UMTS Pedestrian-B 384 kbps	110.21	112.21	123.21	125.21
	UMTS Vehicular-A 12.2 kbps	123.11	125.11	136.11	138.11
	UMTS Vehicular-A 144 kbps	119.11	121.11	132.11	134.11
	UMTS Vehicular-A 384 kbps	109.11	127.60	122.11	124.11
	UMTS Vehicular-B 12.2 kbps	122.81	124.81	135.81	137.81
	UMTS Vehicular-B 144 kbps	118.81	120.81	131.81	133.81
	UMTS Vehicular-B 384 kbps	108.81	110.81	121.81	123.81
	UMTS Rural Area 12.2 kbps	122.86	124.86	135.86	137.86
	UMTS Rural Area 144 kbps	118.86	120.86	131.86	133.86
	UMTS Rural Area 384 kbps	108.86	110.86	121.86	123.86
	UMTS Typical Urban 12.2 kbps	125.41	127.41	138.41	140.41
	UMTS Typical Urban 144 kbps	121.41	123.41	134.41	136.41
	UMTS Typical Urban 384 kbps	111.41	113.41	124.41	124.41
	UMTS Hilly Terrain 12.2 kbps	125.60	127.60	138.60	140.60
	UMTS Hilly Terrain 144 kbps	121.60	123.60	134.60	136.60
	UMTS Hilly Terrain 384 kbps	111.60	113.60	124.60	126.60
99 %	UMTS Pedestrian-A 12.2 kbps	106.41	108.42	119.41	121.41
	UMTS Pedestrian-A 144 kbps	102.41	104.41	115.41	117.41
	UMTS Pedestrian-A 384 kbps	92.41	94.41	105.41	107.41
	UMTS Pedestrian-B 12.2 kbps	112.41	114.41	125.41	127.41
	UMTS Pedestrian-B 144 kbps	108.41	110.41	121.41	123.41
	UMTS Pedestrian-B 384 kbps	98.41	100.41	111.41	113.41
	UMTS Vehicular-A 12.2 kbps	111.31	113.31	124.31	126.31
	UMTS Vehicular-A144 kbps	107.31	109.31	120.31	122.31

	UMTS Vehicular-A 384 kbps	97.31	99.31	110.31	112.31
	UMTS Vehicular-B 12.2 kbps	111.01	113.01	124.01	126.01
	UMTS Vehicular-B 144 kbps	107.01	109.01	120.01	122.01
	UMTS Vehicular-B 384 kbps	97.01	99.01	110.01	112.01
	UMTS Rural Area 12.2 kbps	111.95	113.95	124.95	126.95
	UMTS Rural Area 144 kbps	107.95	109.95	120.95	122.95
	UMTS Rural Area 384 kbps	97.95	99.95	110.95	112.95
	UMTS Typical Urban 12.2 kbps	113.61	115.61	126.61	128.61
	UMTS Typical Urban 144 kbps	109.61	111.61	122.61	124.61
	UMTS Typical Urban 384 kbps	99.61	101.61	112.61	114.61
	UMTS Hilly Terrain 12.2 kbps	114.69	116.69	127.69	129.69
	UMTS Hilly Terrain 144 kbps	110.69	122.69	123.69	125.69
	UMTS Hilly Terrain 384 kbps	100.69	102.69	113.69	115.69

Table A3. 15-Evaluation of path loss, in LoS with K=6 dB, with COST 231-Hata model, in UMTS

$\overline{L}_{p\max} + M^{SF}{}_{[dB]} + M^{FF}{}_{[dB]}$		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}= 0 dBi	G_{MT}= 2 dBi	G_{MT}= 0 dBi	G_{MT}= 2 dBi
90 %	UMTS Pedestrian-A 12.2 kbps	121.51	123.51	134.51	136.51
	UMTS Pedestrian-A 144 kbps	117.51	119.51	130.51	132.51
	UMTS Pedestrian-A 384 kbps	107.51	109.51	120.51	122.51
	UMTS Pedestrian-B 12.2 kbps	125.31	127.31	138.31	140.31
	UMTS Pedestrian-B 144 kbps	121.31	123.31	134.31	136.31
	UMTS Pedestrian-B 384 kbps	111.31	113.31	124.31	126.31
	UMTS Vehicular-A 12.2 kbps	124.61	126.61	137.61	139.61
	UMTS Vehicular-A144 kbps	120.61	122.61	133.61	135.61
	UMTS Vehicular-A 384 kbps	110.61	112.61	123.61	125.61
	UMTS Rural Area 12.2 kbps	124.80	126.80	137.80	139.80
	UMTS Rural Area 144 kbps	120.80	122.80	133.80	135.80

	UMTS Rural Area 384 kbps	110.80	112.80	123.80	125.80
	UMTS Typical Urban 12.2 kbps	126.01	128.01	139.01	141.01
	UMTS Typical Urban 144 kbps	122.01	124.01	135.01	137.01
	UMTS Typical Urban 384 kbps	112.01	114.01	125.01	127.01
	UMTS Hilly Terrain 12.2 kbps	126.60	128.60	139.60	141.60
	UMTS Hilly Terrain 144 kbps	122.60	124.60	135.60	137.60
	UMTS Hilly Terrain 384 kbps	112.60	114.60	126.60	127.60
99 %	UMTS Pedestrian-A 12.2 kbps	109.71	111.71	122.71	124.71
	UMTS Pedestrian-A 144 kbps	105.71	107.71	118.71	120.71
	UMTS Pedestrian-A 384 kbps	95.71	97.71	108.71	110.71
	UMTS Pedestrian-B 12.2 kbps	113.51	115.51	126.51	128.51
	UMTS Pedestrian-B 144 kbps	109.51	111.51	122.51	124.51
	UMTS Pedestrian-B 384 kbps	99.51	101.51	112.51	114.51
	UMTS Vehicular-A 12.2 kbps	112.81	114.81	125.81	127.81
	UMTS Vehicular-A144 kbps	108.81	110.81	121.81	123.81
	UMTS Vehicular-A 384 kbps	98.81	100.81	111.81	113.81
	UMTS Rural Area 12.2 kbps	113.89	115.89	126.89	128.89
	UMTS Rural Area 144 kbps	109.89	111.89	122.89	124.89
	UMTS Rural Area 384 kbps	99.89	101.89	112.89	114.89
	UMTS Typical Urban 12.2 kbps	126.61	128.61	139.61	141.61
	UMTS Typical Urban 144 kbps	122.52	124.52	135.52	137.52
	UMTS Typical Urban 384 kbps	112.52	114.52	125.52	127.52
	UMTS Hilly Terrain 12.2 kbps	127.50	129.50	140.50	142.50
	UMTS Hilly Terrain 144 kbps	123.50	125.50	136.50	138.50
	UMTS Hilly Terrain 384 kbps	113.50	115.50	126.50	128.50

Table A3. 16-Evaluation of distance, in NLoS case, COST 231-Hata model, in UMTS

d [dB]		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}=		G_{MT}=	
		0 dBi	2 dBi	0 dBi	2 dBi
90 %	UMTS Pedestrian-A 12.2 kbps	0.26	0.29	0.60	0.69
	UMTS Pedestrian-A 144 kbps	0.20	0.29	0.47	0.53
	UMTS Pedestrian-A 384 kbps	0.10	0.12	0.24	0.27
	UMTS Pedestrian-B 12.2 kbps	0.38	0.44	0.89	1.02
	UMTS Pedestrian-B 144 kbps	0.29	0.33	0.69	0.78
	UMTS Pedestrian-B 384 kbps	0.15	0.17	0.36	0.41
	UMTS Vehicular-A 12.2 kbps	0.36	0.40	0.83	0.94
	UMTS Vehicular-A144 kbps	0.27	0.31	0.64	0.73
	UMTS Vehicular-B 384 kbps	0.14	0.16	0.33	0.38
	UMTS Vehicular-B 12.2 kbps	0.35	0.40	0.82	0.93
	UMTS Vehicular-B 144 kbps	0.27	0.31	0.63	0.72
	UMTS Vehicular-B 384 kbps	0.14	0.16	0.33	0.37
	UMTS Rural Area 12.2 kbps	2.10	2.38	4.89	5.57
	UMTS Rural Area 144 kbps	1.61	1.83	3.76	4.29
	UMTS Rural Area 384 kbps	0.84	0.95	1.96	2.23
	UMTS Typical Urban 12.2 kbps	0.41	0.47	0.97	1.10
	UMTS Typical Urban 144 kbps	0.32	0.36	0.74	0.85
	UMTS Typical Urban 384 kbps	0.16	0.19	0.39	0.44
	UMTS Hilly Terrain 12.2 kbps	0-93	1.06	2.17	2.48
	UMTS Hilly Terrain 144 kbps	0.71	0.81	1.67	1.90
	UMTS Hilly Terrain 384 kbps	0.37	0.42	0.87	0.99
99 %	UMTS Pedestrian-A 12.2 kbps	0.12	0.14	0.28	0.32
	UMTS Pedestrian-A 144 kbps	0.09	0.10	0.21	0.24
	UMTS Pedestrian-A 384 kbps	0.05	0.06	0.11	0.13
	UMTS Pedestrian-B 12.2 kbps	0.18	0.20	0.41	0.47
	UMTS Pedestrian-B 144 kbps	0.14	0.16	0.32	0.36
	UMTS Pedestrian-B 384 kbps	0.07	0.08	0.16	0.19
	UMTS Vehicular-A 12.2 kbps	0.16	0.19	0.38	0.44
	UMTS Vehicular-A 144 kbps	0.13	0.14	0.30	0.34
	UMTS Vehicular-A 384 kbps	0.06	0.07	0.15	0.17

	UMTS Vehicular-B 12.2 kbps	0.16	0.18	0.38	0.43
	UMTS Vehicular-B 144 kbps	0.12	0.14	0.29	0.33
	UMTS Vehicular-B 384 kbps	0.06	0.07	0.15	0.17
	UMTS Rural Area 12.2 kbps	1.02	1.17	2.39	2.73
	UMTS Rural Area 144 kbps	0.79	0.90	1.84	2.10
	UMTS Rural Area 384 kbps	0.41	0.47	0.96	1.09
	UMTS Typical Urban 12.2 kbps	0.19	0.22	0.45	0.51
	UMTS Typical Urban 144 kbps	0.15	0.17	0.34	0.39
	UMTS Typical Urban 384 kbps	0.08	0.09	0.18	0.20
	UMTS Hilly Terrain 12.2 kbps	0.45	0.52	1.06	1.21
	UMTS Hilly Terrain 144 kbps	0.35	0.40	0.82	0.93
	UMTS Hilly Terrain 384 kbps	0.18	0.21	0.43	0.48

Table A3. 17-Evaluation of distance, in LoS case with K = 6 dB, COST 231-Hata model, in UMTS

d [dB]		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}=		G_{MT}=	
		0 dBi	2 dBi	0 dBi	2 dBi
90 %	UMTS Pedestrian-A 12.2 kbps	0.32	0.36	0.75	0.85
	UMTS Pedestrian-A 144 kbps	0.25	0.28	0.58	0.65
	UMTS Pedestrian-A 384 kbps	0.13	0.15	0.30	0.34
	UMTS Pedestrian-B 12.2 kbps	2.45	2.80	5.74	6.54
	UMTS Pedestrian-B 144 kbps	0.32	0.36	0.74	0.84
	UMTS Pedestrian-B 384 kbps	0.16	0.19	0.38	0.44
	UMTS Vehicular-A 12.2 kbps	0.39	0.45	0.92	1.05
	UMTS Vehicular-A144 kbps	0.30	0.34	0.71	0.81
	UMTS Vehicular-A 384 kbps	0.16	0.18	0.37	0.42
	UMTS Rural Area 12.2 kbps	2.37	2.70	5.55	6.33
	UMTS Rural Area 144 kbps	1.83	2.08	4.27	4.87
	UMTS Rural Area 384 kbps	0.95	1.08	2.22	2.53
	UMTS Typical Urban 12.2 kbps	0.43	0.49	1.00	1.15
	UMTS Typical Urban 144 kbps	0.33	0.38	0.77	0.88
	UMTS Typical Urban 384 kbps	0.17	0.20	0.40	0.46
	UMTS Hilly Terrain 12.2 kbps	0.99	0.13	2.17	2.64

	UMTS Hilly Terrain 144 kbps	0.76	0.87	1.79	2.04
	UMTS Hilly Terrain 384 kbps	0.40	0.45	0.93	1.06
99 %	UMTS Pedestrian-A 12.2 kbps	0.15	0.17	0.35	0.39
	UMTS Pedestrian-A 144 kbps	0.11	0.13	0.27	0.30
	UMTS Pedestrian-A 384 kbps	0.06	0.007	0.14	0.16
	UMTS Pedestrian-B 12.2 kbps	1.13	1.29	2.66	3.02
	UMTS Pedestrian-B 144 kbps	0.15	0.17	0.34	0.39
	UMTS Pedestrian-B 384 kbps	0.08	0.09	0.19	0.20
	UMTS Vehicular-A 12.2 kbps	0.18	0.20	0.42	0.48
	UMTS Vehicular-A 144 kbps	0.14	0.16	0.33	0.37
	UMTS Vehicular-A 384 kbps	0.07	0.08	0.17	0.19
	UMTS Rural Area 12.2 kbps	1.16	1.32	2.72	3.10
	UMTS Rural Area 144 kbps	0.89	1.02	2.09	2.39
	UMTS Rural Area 384 kbps	0.47	0.53	1.09	1.24
	UMTS Typical Urban 12.2 kbps	0.20	0.23	0.46	0.53
	UMTS Typical Urban 144 kbps	0.15	0.17	0.36	0.41
	UMTS Typical Urban 384 kbps	0.08	0.09	0.19	0.21
	UMTS Hilly Terrain 12.2 kbps	0.49	0.55	1.14	1.30
	UMTS Hilly Terrain 144 kbps	0.37	0.42	0.87	0.99
	UMTS Hilly Terrain 384 kbps	0.19	0.22	0.45	0.52

Annex 4

This annex presents the results obtained with COST 231 Walfish-Ikegami.

Table A4. 1-Evaluation of the path loss, with COST 231 WI.

$\overline{L}_{p\max} + M^{SF}_{[90\%]}$		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}= 0 dBi	G_{MT}= 2 dBi	G_{MT}= 0 dBi	G_{MT}= 2 dBi
90 %	GSM 900 data	126.03	128.03	139.03	141.03
	GSM 1800 data	120.46	122.46	133.46	135.46
	GSM 900 voice	123.03	125.03	136.03	138.03
	GSM 1800 voice	117.46	119.46	130.46	132.46
	UMTS 12.2 kbps	133.46	135.46	146.46	148.46
	UMTS 144 kbps	129.46	131.46	142.46	144.46
	UMTS 384 kbps	119.46	121.46	132.46	134.46
	HIPERLAN/2-HS	100.20	102.20	113.20	115.20
	HIPERLAN/2-LS	83.20	85.20	96.20	98.20
99 %	GSM 900 data	118.72	120.72	131.72	133.72
	GSM 1800 data	111.07	113.07	124.07	126.07
	GSM 900 voice	115.72	117.72	128.72	130.72
	GSM 1800 voice	108.07	110.07	121.07	123.07
	UMTS 12.2 kbps	124.07	126.07	137.07	139.07
	UMTS 144 kbps	120.07	122.07	133.07	135.07
	UMTS 384 kbps	110.07	112.07	123.07	125.07
	HIPERLAN/2-HS	94.67	96.67	107.67	109.67
	HIPERLAN/2-LS	77.67	76.67	90.67	92.67

Table A4. 2-Evaluation of the distance, with COST 231 WI.

d [km]		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}= 0 dBi	G_{MT}= 2 dBi	G_{MT}= 0 dBi	G_{MT}= 2 dBi
90 %	GSM 900 data	0.52	0.59	1.15	1.30
	GSM 1800 data	0.18	0.20	0.40	0.45
	GSM 900 voice	0.44	0.49	0.96	1.08
	GSM 1800 voice	0.15	0.17	0.33	0.38
	UMTS 12.2 kbps	0.35	0.39	0.76	0.86
	UMTS 144 kbps	0.27	0.31	0.59	0.67
	UMTS 384 kbps	0.15	0.17	0.33	0.37
	HIPERLAN/2-HS	0.21	0.26	0.68	0.81
	HIPERLAN/2-LS	0.05	0.06	0.15	0.18
99 %	GSM 900 data	0.34	0.38	0.74	0.84
	GSM 1800 data	0.10	0.12	0.23	0.25
	GSM 900 voice	0.28	0.32	0.62	0.70
	GSM 1800 voice	0.08	0.09	0.19	0.21
	UMTS 12.2 kbps	0.14	0.16	0.31	0.35
	UMTS 144 kbps	0.15	0.17	0.34	0.38
	UMTS 384 kbps	0.08	0.09	0.18	0.21
	HIPERLAN/2-HS	0.13	0.16	0.42	0.50
	HIPERLAN/2-LS	0.03	0.03	0.09	0.11

Table A4. 3-Evaluation of path loss, in NLoS, with COST 231-WI model.

$\bar{L}_{p\max} + M^{SF}{}_{[dB]} + M^{FF}{}_{[dB]}$		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}=		G_{MT}=	
		0 dBi	2 dBi	0 dBi	2 dBi
90 %	GSM 900 Typical Urban (data)	114.22	116.22	127.22	129.22
	GSM 1800 Typical Urban (data)	108.65	110.65	121.65	123.65
	GSM 900 Typical Urban (voice)	111.22	113.22	124.22	126.22
	GSM 1800 Typical Urban (voice)	105.65	107.65	118.65	120.65
	UMTS Pedestrian-A 12.2 kbps	121.16	123.16	134.16	136.16
	UMTS Pedestrian-A 144 kbps	117.16	119.16	130.16	132.16
	UMTS Pedestrian-A 384 kbps	107.16	109.16	120.16	122.16
	UMTS Pedestrian-B 12.2 kbps	127.16	129.16	140.16	142.16
	UMTS Pedestrian-B 144 kbps	123.16	125.16	136.16	138.16
	UMTS Pedestrian-B 384 kbps	113.16	125.16	126.16	128.16
	UMTS Vehicular-A 12.2 kbps	126.06	128.06	139.06	141.06
	UMTS Vehicular-A 144 kbps	122.06	124.06	135.06	137.06
	UMTS Vehicular-A 384 kbps	112.06	114.06	125.06	127.06
	UMTS Vehicular-B 12.2 kbps	125.76	127.76	138.76	140.76
	UMTS Vehicular-B 144 kbps	121.76	123.76	134.76	136.76
	UMTS Vehicular-B 384 kbps	111.76	113.76	124.76	126.76
	UMTS Typical Urban 12.2 kbps	128.36	130.36	141.36	143.36
	UMTS Typical Urban 144 kbps	124.36	126.36	137.36	139.36
	UMTS Typical Urban 384 kbps	114.36	116.36	127.36	129.36
99 %	GSM 900 Typical Urban (data)	106.91	108.91	119.91	121.91
	GSM 1800 Typical Urban (data)	69.26	71.26	82.26	84.26
	GSM 900 Typical Urban (voice)	103.91	105.91	116.91	118.91
	GSM 1800 Typical Urban (voice)	96.26	98.26	109.26	111.26
	UMTS Pedestrian-A 12.2 kbps	111.77	113.77	124.77	126.77
	UMTS Pedestrian-A 144 kbps	107.77	109.77	120.77	122.77
	UMTS Pedestrian-A 384 kbps	97.77	99.77	110.77	112.77
	UMTS Pedestrian-B 12.2 kbps	117.77	119.77	130.77	132.77
	UMTS Pedestrian-B 144 kbps	113.77	115.77	126.77	128.77
	UMTS Pedestrian-B 384 kbps	103.77	105.77	116.77	118.77
	UMTS Vehicular-A 12.2 kbps	116.67	118.67	129,67	131.67

	UMTS Vehicular-A 144 kbps	112.67	114.67	125.67	127.67
	UMTS Vehicular-A 384 kbps	102.67	104.67	115.67	117.67
	UMTS Vehicular-B 12.2 kbps	116.37	118.37	129.37	131.37
	UMTS Vehicular-B 144 kbps	112.37	114.37	125.37	127.37
	UMTS Vehicular-B 384 kbps	102.37	104.37	115.37	117.37
	UMTS Typical Urban 12.2 kbps	118.97	120.97	131.97	133.97
	UMTS Typical Urban 144 kbps	114.97	116.97	127.97	129.97
	UMTS Typical Urban 384 kbps	104.97	106.97	117.97	119.97

Table A4. 4-Evaluation of path loss, in LoS when K = 6 dB, with COST 231-WI model.

$\overline{L}_{p\max} + M^{SF}{}_{[\mathrm{dB}]} + M^{FF}{}_{[\mathrm{dB}]}$		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}=		G_{MT}=	
		0 dBi	2 dBi	0 dBi	2 dBi
90 %	UMTS Indoor-A 12.2 kbps	129.00	131.00	142.00	144.00
	UMTS Indoor-A 144 kbps	125.00	127.00	138.00	140.00
	UMTS Indoor-A 384 kbps	115.00	117.00	128.00	130.00
	UMTS Indoor-B 12.2 kbps	131.30	133.30	144.30	146.30
	UMTS Indoor-B 144 kbps	127.30	129.30	140.30	142.30
	UMTS Indoor-B 384 kbps	117.30	119.30	130.30	132.30
	HIPERLAN/2_A-HS	96.20	98.20	109.20	111.20
	HIPERLAN/2_D-HS	95.50	98.50	109.50	111.50
	HIPERLAN/2_A-LS	79.20	81.20	92.20	94.20
	HIPERLAN/2_D-LS	79.50	81.50	92.50	94.50
99 %	UMTS Indoor-A 12.2 kbps	123.47	125.47	136.47	138.47
	UMTS Indoor-A 144 kbps	119.47	121.47	132.47	134.47
	UMTS Indoor-A 384 kbps	109.47	111.47	122.47	124.47
	UMTS Indoor-B 12.2 kbps	125.77	127.77	138.77	140.77
	UMTS Indoor-B 144 kbps	121.77	123.77	134.77	136.77
	UMTS Indoor-B 384 kbps	111.77	113.77	124.77	126.77
	HIPERLAN/2_A-HS	90.67	92.67	103.67	105.67
	HIPERLAN/2_D-HS	90.97	92.97	103.97	105.97
	HIPERLAN/2_A-LS	73.67	75.67	86.67	88.67
	HIPERLAN/2_D-LS	73.97	75.97	86.97	88.97

Table A4. 5-Evaluation of distance, in NLoS case with COST 231-WI model.

d [km]		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}=		G_{MT}=	
		0 dBi	2 dBi	0 dBi	2 dBi
90 %	GSM 900 Typical Urban (data)	0.26	0.29	0.56	0.64
	GSM 1800 Typical Urban (data)	0.09	0.10	0.19	0.22
	GSM 900 Typical Urban (voice)	0.21	0.24	0.47	0.53
	GSM 1800 Typical Urban (voice)	0.07	0.08	0.16	0.18
	UMTS Pedestrian-A 12.2 kbps	0.16	0.18	0.36	0.41
	UMTS Pedestrian-A 144 kbps	0.13	0.14	0.28	0.32
	UMTS Pedestrian-A 384 kbps	0.07	0.08	0.15	0.17
	UMTS Pedestrian-B 12.2 kbps	0.24	0.27	0.52	0.59
	UMTS Pedestrian-B 144 kbps	0.18	0.21	0.41	0.46
	UMTS Pedestrian-B 384 kbps	0.10	0.11	0.22	0.25
	UMTS Vehicular-A 12.2 kbps	0.22	0.25	0.49	0.55
	UMTS Vehicular-A 144 kbps	0.17	0.19	0.38	0.43
	UMTS Vehicular-A 384 kbps	0.09	0.11	0.21	0.23
	UMTS Vehicular-B 12.2 kbps	0.22	0.24	0.48	0.54
	UMTS Vehicular-B 144 kbps	0.17	0.19	0.37	0.42
	UMTS Vehicular-B 384 kbps	0.09	0.10	0.20	0.23
	UMTS Typical Urban 12.2 kbps	0.25	0.29	0.56	0.63
	UMTS Typical Urban 144 kbps	0.20	0.22	0.44	0.49
	UMTS Typical Urban 384 kbps	0.11	0.12	0.24	0.27
99 %	GSM 900 Typical Urban (data)	0.16	0.19	0.36	0.41
	GSM 1800 Typical Urban (data)	0.008	0.009	0.02	0.02
	GSM 900 Typical Urban (voice)	0.14	0.15	0.30	0.34
	GSM 1800 Typical Urban (voice)	0.04	0.05	0.09	0.10
	UMTS Pedestrian-A 12.2 kbps	0.09	0.10	0.20	0.23
	UMTS Pedestrian-A 144 kbps	0.07	0.08	0.16	0.18
	UMTS Pedestrian-A 384 kbps	0.04	0.04	0.09	0.10
	UMTS Pedestrian-B 12.2 kbps	0.13	0.15	0.29	0.33
	UMTS Pedestrian-B 144 kbps	0.11	0.12	0.23	0.26
	UMTS Pedestrian-B 384 kbps	0.06	0.06	0.13	0.14

	UMTS Vehicular-A 12.2 kbps	0.12	0.14	0.27	0.31
	UMTS Vehicular-A 144 kbps	0.10	0.11	0.22	0.24
	UMTS Vehicular-A 384 kbps	0.05	0.06	0.12	0.13
	UMTS Vehicular-B 12.2 kbps	0.12	0.14	0.27	0.30
	UMTS Vehicular-B 144 kbps	0.10	0.11	0.21	0.24
	UMTS Vehicular-B 384 kbps	0.05	0.06	0.11	0.13
	UMTS Typical Urban 12.2 kbps	0.14	0.16	0.32	0.36
	UMTS Typical Urban 144 kbps	0.11	0.13	0.25	0.28
	UMTS Typical Urban 384 kbps	0.06	0.07	0.13	0.15

Table A4. 6-Evaluation of distance,in LoS case with K = 6 dB, with COST 231-WI model.

d [km]		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}=		G_{MT}=	
		0 dBi	2 dBi	0 dBi	2 dBi
90 %	UMTS Indoor-A 12.2 kbps	6.20	7.40	19.60	23.40
	UMTS Indoor-A 144 kbps	4.35	5.19	13.75	16.42
	UMTS Indoor-A 384 kbps	1.79	2.14	5.67	5.77
	UMTS Indoor-B 12.2 kbps	7.60	9.07	24.03	28.68
	UMTS Indoor-B 144 kbps	5.33	6.36	16.86	20.13
	UMTS Indoor-B 384 kbps	2.20	2.62	6.95	8.30
	HIPERLAN/2_A-HS	0.15	0.18	0.48	0.57
	HIPERLAN/2_D-HS	0.15	0.18	0.50	0.58
	HIPERLAN/2_A-LS	0.03	0.04	0.11	0.13
	HIPERLAN/2_D-LS	0.03	0.04	0.11	0.13
99 %	UMTS Indoor-A 12.2 kbps	3.80	4.53	12.01	14.34
	UMTS Indoor-A 144 kbps	2.66	3.18	8.43	10.06
	UMTS Indoor-A 384 kbps	1.10	1.31	3.48	4.15
	UMTS Indoor-B 12.2 kbps	4.66	5.56	14.72	17.58
	UMTS Indoor-B 144 kbps	3.27	3.90	10.33	12.33
	UMTS Indoor-B 384 kbps	1.35	1.61	4.26	5.09
	HIPERLAN/2_A-HS	0.09	0.11	0.29	0.35
	HIPERLAN/2_D-HS	0.09	0.40	0.30	0.36
	HIPERLAN/2_A-LS	0.02	0.02	0.06	0.08
	HIPERLAN/2_D-LS	0.02	0.02	0.07	0.08

Annex 5

This Annex presents all the results obtained with Multi-wall model.

Table A5. 1-Evaluation of the path loss, with Multi-wall model.

$\overline{L}_{p\max} + M^{SF}$ [dB]		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}= 0 dBi	G_{MT}= 2 dBi	G_{MT}= 0 dBi	G_{MT}= 2 dBi
90%	GSM 900 data	121.68	123.68	134.68	136.68
	GSM 1800 data	117.70	119.70	130.70	132.70
	GSM 900 voice	118.68	120.68	131.68	133.68
	GSM 1800 voice	114.70	116.70	127.70	129.70
	UMTS 12.2 kbps	130.51	132.51	143.51	145.51
	UMTS 144 kbps	126.51	128.51	139.51	141.51
	UMTS 384 kbps	116.51	118.51	129.51	131.51
	HIPERLAN/2-HS	90.46	92.46	103.46	105.46
	HIPERLAN/2-HS	73.46	75.46	86.46	88.46
99 %	GSM 900 data	110.83	112.83	123.83	125.83
	GSM 1800 data	106.05	108.05	111.05	121.05
	GSM 900 voice	107.83	101.83	120.83	122.83
	GSM 1800 voice	103.05	105.05	116.05	118.05
	UMTS 12.2 kbps	118.71	120.71	131.71	133.71
	UMTS 144 kbps	114.71	116.71	127.71	129.71
	UMTS 384 kbps	104.71	106.71	117.71	119.71
	HIPERLAN/2-LS	77.00	79.00	90.00	92.00
	HIPERLAN/2-LS	60.00	62.00	73.00	75.00

Table A5. 2-Evaluation of the path loss. Multi-wall model when k_{fj}=k_{wi}=1.

d [km]		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}= 0 dBi	G_{MT}= 2 dBi	G_{MT}= 0 dBi	G_{MT}= 2 dBi
90 %	GSM 900 data	20.26	25.50	90.48	113.91
	GSM 1800 data	6.62		29.55	
	GSM 900 voice	14.34	18.05	64.05	80.64
	GSM 1800 voice	4.68	5.90	20.92	26.34
	UMTS 12.2 kbps	25.91	32.62	115.73	147.70
	UMTS 144 kbps	16.35	20.58	73.02	91.93
	UMTS 384 kbps	5.17	6.51	23.09	29.07
	HIPERLAN/2-HS	0.09	0.11	0.40	0.50
	HIPERLAN/2-LS	0.01	0.01	0.06	0.07
99 %	GSM 900 data	5.81	7.31	25.94	32.66
	GSM 1800 data	1.73	2.18	3.08	9.63
	GSM 900 voice	4.11	5.18	18.37	23.12
	GSM 1800 voice	1.22	1.54	5.47	6.89
	UMTS 12.2 kbps	6.66	8.38	29.75	37.45
	UMTS 144 kbps	4.20	5.29	18.77	23.63
	UMTS 384 kbps	1.33	1.67	5.93	7.47
	HIPERLAN/2-HS	0.02	0.02	0.08	0.11
	HIPERLAN/2-LS	0.003	0.003	0.01	0.01

Table A5. 3-Evaluation of distance, with Multi-wall model when k_{fj}=k_{wi}=2.

d [km]		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MS}= 0 dBi	G_{MS}= 2 dBi	G_{MS}= 0 dBi	G_{MS}= 2 dBi
90 %	GSM 900 data	121.68	123.68	134.68	136.68
	GSM 1800 data	117.70	119.70	130.70	132.70
	GSM 900 voice	118.68	120.68	131.68	133.68
	GSM 1800 voice	114.70	116.70	127.70	129.70
	UMTS 12.2 kbps	2.91	3.66	12.30	16.36
	UMTS 144 kbps	1.84	2.31	8.20	10.32
	UMTS 384 kbps	0.58	0.73	2.59	3.26
	HIPERLAN/2-HS	0.01	0.01	0.04	0.06

	HIPERLAN/2-LS	0.001	0.02	0.06	0.008
99 %	GSM 900 data	0.65	0.82	2.91	3.67
	GSM 1800 data	0.19	0.24	0.34	1.10
	GSM 900 voice	0.46	0.58	2.06	2.60
	GSM 1800 voice	0.14	0.17	0.61	0.77
	UMTS 12.2 kbps	0.75	0.94	3.34	4.21
	UMTS 144 kbps	0.47	0.59	2.11	2.65
	UMTS 384 kbps	0.15	0.19	0.67	0.84
	HIPERLAN/2-HS	0.002	0.003	0.009	0.01
	HIPERLAN/2-LS	<0.001	<0.001	0.001	0.002

Table A5. 4-Evaluation of distance, with Multi-wall model when $k_{fj}=k_{wi}=3$.

d [km]		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}= 0 dBi	G_{MT}= 2 dBi	G_{MT}= 0 dBi	G_{MT}= 2 dBi
90 %	GSM 900 data	0.06	0.08	0.29	0.37
	GSM 1800 data	0.02	0.03	0.09	0.12
	GSM 900 voice	0.05	0.06	0.21	0.26
	GSM 1800 voice	0.02	0.02	0.07	0.08
	UMTS 12.2 kbps	0.08	0.10	0.37	0.47
	UMTS 144 kbps	0.04	0.05	0.18	0.23
	UMTS 384 kbps	0.01	0.02	0.16	0.07
	HIPERLAN/2-HS	<0.001	<0.001	0.001	0.002
	HIPERLAN/2-LS	<0.001	<0.001	<0.001	<0.001
99 %	GSM 900 data	0.02	0.02	0.08	0.10
	GSM 1800 data	0.005	0.007	0.01	0.03
	GSM 900 voice	0.01	0.02	0.06	0.07
	GSM 1800 voice	0.004	0.005	0.02	0.02
	UMTS 12.2 kbps	0.02	0.03	0.10	0.12
	UMTS 144 kbps	0.01	0.01	0.05	0.06
	UMTS 384 kbps	0.003	0.004	0.01	0.02
	HIPERLAN/2-HS	<0.001	<0.001	<0.001	<0.001
	HIPERLAN/2-LS	<0.001	<0.001	<0.001	<0.001

Table A5. 5-Evaluation of the path loss,in NLoS case, with Multi-wall model.

$\bar{L}_{p\max} + M^{SF}{}_{[dB]} + M^{FF}{}_{[dB]}$		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}=		G_{MT}=	
		0 dBi	2 dBi	0 dBi	2 dBi
90 %	UMTS Indoor-A 12.2 kbps	118.41	120.41	131.41	133.41
	UMTS Indoor-A 144 kbps	114.41	116.41	127.41	129.412
	UMTS Indoor-A 384 kbps	104.41	106.41	117.41	119.41
	UMTS Indoor-B 12.2 kbps	121.51	123.51	134.51	136.51
	UMTS Indoor-B 144 kbps	117.51	119.51	130.51	132.51
	UMTS Indoor-B 384 kbps	197.51	109.51	120.51	122.51
	HIPERLAN/2_A-HS	84.16	86.16	97.16	99.16
	HIPERLAN/2_B-HS	85.76	87.76	98.76	100.76
	HIPERLAN/2_C-HS	86.26	88.26	99.26	101.26
	HIPERLAN/2_D-HS	86.76	88.76	99.76	101.76
	HIPERLAN/2_E-HS	86.86	88.86	99.86	101.86
	HIPERLAN/2_A-LS	67.16	69.16	80.16	82.16
	HIPERLAN/2_B-LS	68.66	70.76	81.76	83.76
	HIPERLAN/2_C-LS	69.26	71.26	82.26	84.26
	HIPERLAN/2_D-LS	69.46	71.46	82.26	84.46
	HIPERLAN/2_E-LS	69.86	71.46	82.86	84.86
99 %	UMTS Indoor-A 12.2 kbps	106.61	108.61	119.61	121.61
	UMTS Indoor-A 144 kbps	102.61	104.61	115.61	117.61
	UMTS Indoor-A 384 kbps	92.61	94.61	105.61	107.61
	UMTS Indoor-B 12.2 kbps	109.71	111.71	122.71	124.71
	UMTS Indoor-B 144 kbps	105.71	107.71	118.71	120.71
	UMTS Indoor-B 384 kbps	95.71	97.71	108.71	110.71
	HIPERLAN/2_A-HS	70.70	72.70	83.70	85.70
	HIPERLAN/2_B-HS	72.30	74.30	85.30	87.30
	HIPERLAN/2_C-HS	72.80	74.80	85.80	87.80
	HIPERLAN/2_D-HS	73.00	75.00	86.00	88.00
	HIPERLAN/2_E-HS	73.40	75.40	86.40	88.40
	HIPERLAN/2_A-LS	53.70	55.70	66.70	68.70
	HIPERLAN/2_B-LS	55.30	57.30	68.30	70.30

	HIPERLAN/2_C-LS	55.80	57.80	68.80	70.80
	HIPERLAN/2_D-LS	56.00	58.00	69.00	71.00
	HIPERLAN/2_E-LS	56.40	58.40	69.40	71.40

Table A5. 6-Evaluation of distance, in NLoS case, with Multi-wall model, when k_{fj}=k_{wi}=1.

d [km]		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MS}=		G_{MS}=	
		0 dBi	2 dBi	0 dBi	2 dBi
90 %	UMTS Indoor-A 12.2 kbps	6.43	8.10	28.74	36.18
	UMTS Indoor-A 144 kbps	4.06	5.11	18.13	22.83
	UMTS Indoor-A 384 kbps	1.28	1.62	5.73	7.22
	UMTS Indoor-B 12.2 kbps	9.19	11.57	41.06	51.69
	UMTS Indoor-B 144 kbps	5.80	7.30	25.91	32.62
	UMTS Indoor-B 384 kbps	1.83	2.31	8.19	10.31
	HIPERLAN/2_A-HS	0.04	0.05	0.19	0.24
	HIPERLAN/2_B-HS	0.05	0.06	0.23	0.24
	HIPERLAN/2_C-HS	0.05	0.07	0.25	0.31
	HIPERLAN/2_D-HS	0.06	0.07	0.25	0.31
	HIPERLAN/2_E-HS	0.06	0.07	0.26	0.33
	HIPERLAN/2_A-LS	0.006	0.008	0.03	0.03
	HIPERLAN/2_B-LS	0.007	0.009	0.03	0.04
	HIPERLAN/2_C-LS	0.008	0.01	0.03	0.04
	HIPERLAN/2_D-LS	0.008	0.01	0.03	0.04
	HIPERLAN/2_E-LS	0.008	0.01	0.04	0.05
99 %	UMTS Indoor-A 12.2 kbps	1.65	2.08	7.39	9.30
	UMTS Indoor-A 144 kbps	1.49	1.88	6.66	8.38
	UMTS Indoor-A 384 kbps	0.47	0.59	2.11	2.65
	UMTS Indoor-B 12.2 kbps	2.36	2.97	10.55	13.29
	UMTS Indoor-B 144 kbps	1.49	1.88	6.66	8.38
	UMTS Indoor-B 384 kbps	0.47	0.59	2.11	2.65
	HIPERLAN/2_A-HS	0.009	0.01	0.04	0.05
	HIPERLAN/2_B-HS	0.01	0.01	0.05	0.06
	HIPERLAN/2_C-HS	0.01	0.01	0.05	0.07

	HIPERLAN/2_D-HS	0.01	0.01	0.05	0.07
	HIPERLAN/2_E-HS	0.01	0.01	0.06	0.07
	HIPERLAN/2_A-HS	0.001	0.002	0.006	0.007
	HIPERLAN/2_B-HS	0.002	0.002	0.007	0.009
	HIPERLAN/2_C-HS	0.002	0.002	0.007	0.009
	HIPERLAN/2_D-HS	0.002	0.002	0.007	0.009
	HIPERLAN/2_E-HS	0.002	0.002	0.008	0.01

Table A5. 7-Evaluation of the distance, in NLoS cas, with Multi-wall model, when k_{fj}=k_{wi}=2.

d [km]		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}=		G_{MT}=	
		0 dBi	2 dBi	0 dBi	2 dBi
90 %	UMTS Indoor-A 12.2 kbps	0.70	0.91	3.23	4.06
	UMTS Indoor-A 144 kbps	0.46	0.57	2.04	2.56
	UMTS Indoor-A 384 kbps	0.14	0.18	0.64	0.81
	UMTS Indoor-B 12.2 kbps	1.03	1.30	4.61	5.81
	UMTS Indoor-B 144 kbps	0.65	0.82	2.91	3.66
	UMTS Indoor-B 384 kbps	0.21	0.26	0.92	1.16
	HIPERLAN/2_A-HS	0.005	0.006	0.02	0.03
	HIPERLAN/2_B-HS	0.006	0.007	0.03	0.04
	HIPERLAN/2_C-HS	0.006	0.007	0.03	0.03
	HIPERLAN/2_D-HS	0.006	0.008	0.03	0.04
	HIPERLAN/2_E-HS	0.007	0.008	0.03	0.04
	HIPERLAN/2_A-LS	< 0.001	< 0.001	0.003	0.004
	HIPERLAN/2_B-LS	< 0.001	0.001	0.004	0.005
	HIPERLAN/2_C-LS	< 0.001	0.001	0.004	0.005
	HIPERLAN/2_D-LS	< 0.001	0.001	0.004	0.005
	HIPERLAN/2_E-LS	< 0.001	0.001	0.004	0.005
99 %	UMTS Indoor-A 12.2 kbps	0.18	0.23	0.83	1.04
	UMTS Indoor-A 144 kbps	0.17	0.21	0.75	0.94
	UMTS Indoor-A 384 kbps	0.05	0.07	0.24	0.30
	UMTS Indoor-B 12.2 kbps	0.26	0.33	1.18	1.49
	UMTS Indoor-B 144 kbps	0.17	0.21	0.75	0.94
	UMTS Indoor-B 384 kbps	0.05	0.07	0.24	0.30

	HIPERLAN/2_A-HS	0.001	0.001	0.005	0.006
	HIPERLAN/2_B-HS	0.001	0.001	0.005	0.007
	HIPERLAN/2_C-HS	0.001	0.001	0.006	0.007
	HIPERLAN/2_D-HS	0.001	0.002	0.006	0.008
	HIPERLAN/2_E-HS	0.001	0.002	0.006	0.008
	HIPERLAN/2_A-HS	<0.001	<0.001	<0.001	<0.001
	HIPERLAN/2_B-HS	<0.001	<0.001	<0.001	0.001
	HIPERLAN/2_C-HS	<0.001	<0.001	<0.001	0.001
	HIPERLAN/2_D-HS	<0.001	<0.001	<0.001	0.001
	HIPERLAN/2_E-HS	<0.001	<0.001	<0.001	0.001

Table A5. 8-Evaluation of distance, in NLoS case, with Multi-wall model, when $k_{fj}=k_{wi}=3$.

d [km]		G_{BS}= 0 dBi		G_{BS}= 13 dBi	
		G_{MT}=		G_{MT}=	
		0 dBi	2 dBi	0 dBi	2 dBi
90 %	UMTS Indoor-A 12.2 kbps	0.02	0.03	0.09	0.12
	UMTS Indoor-A 144 kbps	0.01	0.01	0.05	0.06
	UMTS Indoor-A 384 kbps	0.003	0.004	0.01	0.02
	UMTS Indoor-B 12.2 kbps	0.003	0.004	0.13	0.17
	UMTS Indoor-B 144 kbps	0.01	0.02	0.06	0.08
	UMTS Indoor-B 384 kbps	0.004	0.006	0.02	0.02
	HIPERLAN/2_A-HS	<0.001	<0.001	<0.001	<0.001
	HIPERLAN/2_B-HS	<0.001	<0.001	<0.001	<0.001
	HIPERLAN/2_C-HS	<0.001	<0.001	<0.001	<0.001
	HIPERLAN/2_D-HS	<0.001	<0.001	<0.001	<0.001
	HIPERLAN/2_E-HS	<0.001	<0.001	<0.001	<0.001
	HIPERLAN/2_A-LS	<0.001	<0.001	<0.001	<0.001
	HIPERLAN/2_B-LS	<0.001	<0.001	<0.001	<0.001
	HIPERLAN/2_C-LS	<0.001	<0.001	<0.001	<0.001
	HIPERLAN/2_D-LS	<0.001	<0.001	<0.001	<0.001
	HIPERLAN/2_E-LS	<0.001	<0.001	<0.001	<0.001
99 %	UMTS Indoor-A 12.2 kbps	0.005	0.007	0.02	0.03
	UMTS Indoor-A 144 kbps	0.004	0.005	0.02	0.02
	UMTS Indoor-A 384 kbps	0.001	0.001	0.005	0.007

	UMTS Indoor-B 12.2 kbps	0.007	0.010	0.03	0.04
	UMTS Indoor-B 144 kbps	0.004	0.005	0.02	0.02
	UMTS Indoor-B 384 kbps	0.001	0.001	0.005	0.006
	HIPERLAN/2_A-HS	<0.001	<0.001	<0.001	<0.001
	HIPERLAN/2_B-HS	<0.001	<0.001	<0.001	<0.001
	HIPERLAN/2_C-HS	<0.001	<0.001	<0.001	<0.001
	HIPERLAN/2_D-HS	<0.001	<0.001	<0.001	<0.001
	HIPERLAN/2_E-HS	<0.001	<0.001	<0.001	<0.001
	HIPERLAN/2_A-HS	<0.001	<0.001	<0.001	<0.001
	HIPERLAN/2_B-HS	<0.001	<0.001	<0.001	<0.001
	HIPERLAN/2_C-HS	<0.001	<0.001	<0.001	<0.001
	HIPERLAN/2_D-HS	<0.001	<0.001	<0.001	<0.001
	HIPERLAN/2_E-HS	<0.001	<0.001	<0.001	<0.001