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Digital cellular telecommunications system (Phase 2+);
Radio network planning aspects
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A GLOBAL INITIATIVE

GLOBAL SYSTEM FOR MOBILE COMMUNICATIONS

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650 Route des Lucioles
F-06921 Sophia Antipolis Cedex - FRANCE

Tel.: +33 4 92 94 42 00 Fax: +33 4 93 65 47 16

Siret N° 348 623 562 00017 - NAF 742 C
Association à but non lucratif enregistrée à la
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Contents

Foreword

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1 Scope

The present document is a descriptive recommendation to be helpful in cell planning.

1.1 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
- For a specific reference, subsequent revisions do not apply.
- For a non-specific reference, the latest version applies.

[1] GSM 01.04: "Digital cellular telecommunications system (Phase 2+); Abbreviations and acronyms".

[2] 3GPP TS 45.002: "Digital cellular telecommunications system (Phase 2+); Multiplexing and multiple access on the radio path".

[3] 3GPP TS 45.005: "Digital cellular telecommunications system (Phase 2+); Radio transmission and reception".

[4] 3GPP TS 45.008: "Digital cellular telecommunications system (Phase 2+); Radio subsystem link control".

[5] CCIR Recommendation 370-5: "VHF and UHF propagation curves for the frequency range from 30 MHz to 1000 MHz".

[6] CCIR Report 567-3: "Methods and statistics for estimating field strength values in the land mobile services using the frequency range 30 MHz to 1 GHz".

[7] CCIR Report 842: "Spectrum-conserving terrestrial frequency assignments for given frequency-distance seperations".

[8] CCIR Report 740: "General aspects of cellular systems".

1.2 Abbreviations

Abbreviations used in the present document are given clause 6 (Glossary) and in GSM 01.04 [1].

2 Traffic distributions

2.1 Uniform

A uniform traffic distribution can be considered to start with in large cells as an average over the cell area, especially in the country side.

2.2 Non-uniform

A non-uniform traffic distribution is the usual case, especially for urban areas. The traffic peak is usually in the city centre with local peaks in the suburban centres and motorway junctions.

A bell-shaped area traffic distribution is a good traffic density macro model for cities like London and Stockholm. The exponential decay constant is on average 15 km and 7,5 km respectively. However, the exponent varies in different directions depending on how the city is built up. Increasing handheld traffic will sharpen the peak.

Line coverage along communication routes as motorways and streets is a good micro model for car mobile traffic. For a maturing system an efficient way to increase capacity and quality is to build cells especially for covering these line concentrations with the old area covering cells working as umbrella cells.

Point coverage of shopping centres and traffic terminals is a good micro model for personal handheld traffic. For a maturing system an efficient way to increase capacity and quality is to build cells on these points as a complement to the old umbrella cells and the new line covering cells for car mobile traffic.

3 Cell coverage

3.1 Location probability

Location probability is a quality criterion for cell coverage. Due to shadowing and fading a cell edge is defined by adding margins so that the minimum service quality is fulfilled with a certain probability.

For car mobile traffic a usual measure is 90 % area coverage per cell, taking into account the minimum signal-to-noise ratio Ec/No under multipath fading conditions. For lognormal shadowing an area coverage can be translated into a location probability on cell edge (Jakes, 1974).

For the normal case of urban propagation with a standard deviation of 7 dB and a distance exponential of 3.5, 90 % area coverage corresponds to about 75 % location probability at the cell edge. Furthermore, the lognormal shadow margin in this case will be 5 dB, as described in CEPT Recommendation T/R 25-03 and CCIR Report 740.

3.2 Ec/No threshold

The mobile radio channel is characterized by wideband multipath propagation effects such as delay spread and Doppler shift as defined in 3GPP TS 45.005 annex C. The reference signal-to-noise ratio in the modulating bit rate bandwidth (271 kHz) is Ec/No = 8 dB including 2 dB implementation margin for the GSM system at the minimum service quality without interference. The Ec/No quality threshold is different for various logical channels and propagation conditions as described in 3GPP TS 45.005.

3.3 RF-budgets

The RF-link between a Base Transceiver Station (BTS) and a Mobile Station (MS) including handheld is best described by an RF-budget. Annex A consists of 7 such budgets; A.1 for GSM 900 MS class 4; A.2 for GSM 900 MS class 2, A.3 for DCS 1800 MS classes 1 and 2, A.4 for GSM 900 class 4 in small cells, A.5 for GSM 400 class 4 in small cells, A.6 for GSM 700 class 4 and A.7 for DCS 1800 MS class 1. GSM 900 RF-budgets should be used for 850 band.

The Mean Effective Gain (MEG) of handheld MS in scattered field representing the cell range taking into consideration absorption, detuning and mismatch of the handheld antenna by the human body (MEG = -antenna/body loss) of -13 dBi for GSM 400, -10dBi for GSM 700, -9 dBi for GSM 900 and -6 dBi for DCS 1800 is incorporated in annex A.1, A.3, A.4 and A.5 as shown from measurements in Tdoc SMG2 1075/99.

At 900 MHz, the indoor loss is the field strength decrease when moving into a house on the bottom floor on 1.5 m height from the street. The indoor loss near windows (< 1 m) is typically 12 dB. However, the building loss has been measured by the Finnish PTT to vary between 37 dB and -8 dB with an average of 18 dB taken over all floors and buildings (Kajamaa, 1985). See also CCIR Report 567.

At 1800 MHz, the indoor loss for large concrete buildings was reported in COST 231 TD(90)117 and values in the range 12 - 17 dB were measured. Since these buildings are typical of urban areas a value of 15 dB is assumed in annex A.3. In rural areas the buildings tend to be smaller and a 10 dB indoor loss is assumed.

The isotropic power is defined as the RMS value at the terminal of an antenna with 0 dBi gain. A quarter-wave monopole mounted on a suitable earth-plane (car roof) without losses has antenna gain 2 dBi. An isotropic power of -113 dBm corresponds to a field strength of 23.5 dBuV/m for 925 MHz and 29.3 dBuV/m at 1795 MHz, see CEPT

Recommendation T/R 25-03 and 3GPP TS 45.005 section 5 for formulas. GSM900 BTS can be connected to the same feeders and antennas as analog 900 MHz BTS by diplexers with less than 0.5 dB loss.

3.4 Cell ranges

3.4.1 Large cells

In large cells the base station antenna is installed above the maximum height of the surrounding roof tops; the path loss is determined mainly by diffraction and scattering at roof tops in the vicinity of the mobile i.e. the main rays propagate above the roof tops; the cell radius is minimally 1 km and normally exceeds 3 km. Hata"s model and its extension up to 2000 MHz (COST 231-Hata model) can be used to calculate the path loss in such cells (see COST 231 TD (90) 119 Rev 2 and annex B).

The field strength on 1.5 m reference height outdoor for MS including handheld is a value which inserted in the curves of CCIR Report 567-3 Figure 2 (Okumura) together with the BTS antenna height and effective radiated power (ERP) yields the range and re-use distance for urban areas (section 5.2).

The cell range can also be calculated by putting the maximum allowed path loss between isotropic antennas into the Figures 1 to 3 of annex C. The same path loss can be found in the RF-budgets in annex A. The figures 1 and 2 (GSM 900) in annex C are based on Hata"s propagation model which fits Okumura"s experimental curves up to 1500 MHz and figure 3 (DCS 1800) is based on COST 231-Hata model according to COST 231 TD (90) 119 Rev 2. GSM 900 models should be used for 850 band range calculation.

The example RF-budget shown in annex A.1 for a GSM900 MS handheld output power 2 W yields about double the range outdoors compared with indoors. This means that if the cells are dimensioned for handhelds with indoor loss 10 dB, the outdoor coverage for MS will be interference limited, see section 4.2. Still more extreme coverage can be found over open flat land of 12 km as compared with 3 km in urban areas outdoor to the same cell site.

For GSM 900 the Max EIRP of 50 W matches MS class 2 of max peak output power 8 W, see annex A.2.

An example RF budget for DCS 1800 is shown in annex A.3. Range predictions are given for 1 W and 250 mW DCS 1800 MS with BTS powers which balance the up- and down- links.

The propagation assumptions used in annex A1, A2, A3 are shown in the tables below:

For GSM 900:

	Rural (Open Area)	**Rural (Quasi-open)**	**Urban**
Base station height (m)	100	100	50
Mobile height (m)	1.5	1.5	1.5
Hata"s loss formula (d in km)	90.7+31.8log(d)	95.7+31.8log(d)	123.3+33.7log(d)
Indoor Loss (dB)	10	10	15

For DCS 1800:

	Rural (Open Area)	Rural (Quasi-Open)	Urban (*)
Base station height (m)	60	60	50
Mobile height (m)	1.5	1.5	1.5
COST 231 Hata"s loss formula (d in km)	100.1+33.3log(d)	105.1+33.3log(d)	133.2+33.8log (d)
Indoor Loss (dB)	10	10	15

(*) medium sized city and suburban centres (see COST 231 TD (90) 119 Rev2). For metropolitan centres add 3 dB to the path loss.

NOTE 1: The rural (Open Area) model is useful for desert areas and the rural (Quasi-Open) for countryside.
NOTE 2: The correction factors for Quasi-open and Open areas are applicable in the frequency range 100-2000 MHz (Okumura,1968).

3.4.2 Small cells

For small cell coverage the antenna is sited above the median but below the maximum height of the surrounding roof tops and so therefore the path loss is determined by the same mechanisms as stated in section 3.4.1. However large and small cells differ in terms of maximum range and for small cells the maximum range is typically less than 1-3 km. In the case of small cells with a radius of less than 1 km the Hata model cannot be used.

The COST 231-Walfish-Ikegami model (see annex B) gives the best approximation to the path loss experienced when small cells with a radius of less than 5 km are implemented in urban environments. It can therefore be used to estimate the BTS ERP required in order to provide a particular cell radius (typically in the range 200 m - 3 km).

The cell radius can be calculated by putting the maximum allowed path loss between the isotropic antennas into figure 4 of annex C.

The following parameters have been used to derive figure 4:

Width of the road, w = 20 m
Height of building roof tops, Hroof = 15 m
Height of base station antenna, Hb = 17 m
Height of mobile station antenna, Hm = 1.5 m
Road orientation to direct radio path, Phi = 90°
Building separation, b = 40 m

For GSM 900 the corresponding propagation loss is given by:

Loss (dB) = 132.8 + 38log(d/km)

For DCS 1800 the corresponding propagation loss is given by:

Loss (dB) = 142,9 + 38log(d/km) for medium sized cities and suburban centres
Loss (dB) = 145,3 + 38log(d/km) for metropolitan centres

An example of RF budget for a GSM 900 Class 4 MS in a small cell is shown in annex A.4.

3.4.3 Microcells

COST 231 defines a microcell as being a cell in which the base station antenna is mounted generally below roof top level. Wave propagation is determined by diffraction and scattering around buildings i.e. the main rays propagate in street canyons. COST 231 proposes the following experimental model for microcell propagation when a free line of sight exists in a street canyon:

Path loss in dB (GSM 900) = 101,7 + 26log(d/km) d > 20 m
Path loss in dB (DCS 1800) = 107,7 + 26log(d/km) d > 20 m

The propagation loss in microcells increases sharply as the receiver moves out of line of sight, for example, around a street corner. This can be taken into account by adding 20 dB to the propagation loss per corner, up to two or three corners (the propagation being more of a guided type in this case). Beyond, the complete COST231-Walfish-Ikegami model as presented in annex B should be used.

Microcells have a radius in the region of 200 to 300 metres and therefore exhibit different usage patterns from large and small cells. They can be supported by generally smaller and cheaper BTS"s. Since there will be many different microcell environments, a number of microcell BTS classes are defined in 3GPP TS 45.005. This allows the most appropriate microcell BTS to be chosen based upon the Minimum Coupling Loss expected between MS and the microcell BTS. The MCL dictates the close proximity working in a microcell environment and depends on the relative BTS/MS antenna heights, gains and the positioning of the BTS antenna.

In order to aid cell planning, the micro-BTS class for a particular installation should be chosen by matching the measured or predicted MCL at the chosen site with the following table.

The microcell specifications have been based on a frequency spacing of 6 MHz between the microcell channels and the channels used by any other cell in the vicinity. However, for smaller frequency spacings (down to 1.8 MHz) a larger MCL must be maintained in order to guarantee successful close proximity operation. This is due to an increase in wideband noise and a decrease in the MS blocking requirement from mobiles closer to the carrier.

Micro-BTS class	Recommended MCL (GSM 900)		Recommended MCL (DCS 1800)	
	Normal	Small freq. spacing	Normal	Small freq. spacing
M1	60	64	60	68
M2	55	59	55	63
M3	50	54	50	58

Operators should note that when using the smaller frequency spacing and hence larger MCL the blocking and wideband noise performance of the micro-BTS will be better than necessary.

Operators should exercise caution in choosing the microcell BTS class and transmit power. If they depart from the recommended parameters in 45.005 they risk compromising the performance of the networks operating in the same frequency band and same geographical area.

4 Channel re-use

4.1 C/Ic threshold

The C/Ic threshold is the minimum co-channel carrier-to-interference ratio in the active part of the timeslot at the minimum service quality when interference limited. The reference threshold C/Ic = 9 dB includes 2 dB implementation margin on the simulated residual BER threshold The threshold quality varies with logical channels and propagation conditions, see 3GPP TS 45.005.

4.2 Trade-off between Ec/No and C/Ic

For planning large cells the service range can be noise limited as defined by Ec/No plus a degradation margin of 3 dB protected by 3 dB increase of C/Ic, see annex A.

For planning small cells it can be more feasible to increase Ec/No by 6 dB corresponding to an increase of C/Ic by 1 dB to cover shadowed areas better. C/(I+N) = 9 dB represents the GSM limit performance.

To permit handheld coverage with 10 dB indoor loss, the Ec/No has to be increased by 10 dB outdoors corresponding to a negligible increase of C/Ic outdoors permitting about the same interference limited coverage for MS including handhelds. The range outdoors can also be noise limited like the range indoors as shown in section 3.4 and annex A.1.

4.3 Adjacent channel suppressions

Adjacent channel suppression (ACS) is the gain (Ia/Ic) in C/I when wanted and unwanted GSM RF-signals co-exist on adjacent RF channels whilst maintaining the same quality as in the co-channel case, i.e. ACS = C/Ic - C/Ia. Taking into account frequency errors and fading conditions in the product of spectrum and filter of wanted and unwanted GSM RF-signals, ACS = 18 dB is typical as can be found in 3GPP TS 45.005.

1st ACS >= 18 dB, i.e. C/Ia1 <= -9 dB for C/Ic = 9 dB in 3GPP TS 45.005, imposes constraints of excluding the 1st adjacent channel in the same cell. However, the 1st adjacent channel can be used in the 1st adjacent cell, as C/Ic <= 12 dB and ACS >= 18 dB gives an acceptable handover- margin of >= 6 dB for signalling back to the old BTS as shown in 3GPP TS 45.008. An exception might be adjacent cells using the same site due to uplink interference risks.

2nd ACS >= 50 dB, i.e. C/Ia2 <= -41 dB for C/Ic = 9 dB in 3GPP TS 45.005, implies that due to MS power control in the uplink, as well as intra-cell handover, it is possible that the 2nd adjacent channel can be used in the same cell. Switching transients are not interfering due to synchronized transmission and reception of bursts at co-located BTS.

4.4 Antenna patterns

Antenna patterns including surrounding masts, buildings, and terrain measured on ca 1 km distance will always look directional, even if the original antenna was non-directional. In order to achieve a front-to-back ratio F/B of greater than 20 dB from an antenna with an ideal F/B > 25 dB, backscattering from the main lobe must be suppressed by using an antenna height of at least 10 m above forward obstacles in ca 0.5 km. In order to achieve an omni-directional pattern with as few nulls as possible, the ideal non-directional antenna must be isolated from the mast by a suitable reflector. The nulls from mast scattering are usually in different angles for the duplex frequencies and should be avoided because of creating path loss imbalance.

The main lobe antenna gains are typically 12-18 dBi for BTS, and 2-5 dBi for MS. Note that a dipole has the gain 0 dBd = 2 dBi.

4.5 Antenna heights

The height gain under Rayleigh fading conditions is approximately 6 dB by doubling the BTS antenna height. The same height gain for MS and handheld from reference height 1.5 m to 10 m is about 9 dB, which is the correction needed for using CCIR Recommendation 370.

4.6 Path loss balance

Path loss balance on uplink and downlink is important for two-way communication near the cell edge. Speech as well as data transmission is dimensioned for equal quality in both directions. Balance is only achieved for a certain power class (section 3.4).

Path loss imbalance is taken care of in cell selection in idle mode and in the handover decision algorithms as found in 3GPP TS 45.008. However, a cell dimensioned for 8 W MS (GSM 900 class 2) can more or less gain balance for 2 W MS handheld (GSM 900 class 4) by implementing antenna diversity reception on the BTS.

4.7 Cell dimensioning

Cell dimensioning for uniform traffic distribution is optimized by at any time using the same number of channels and the same coverage area per cell.