European Radiocommunications Committee (ERC)
within the European Conference of Postal and Telecommunications Administrations (CEPT)

A COMPARISON OF THE MINIMUM COUPLING LOSS METHOD, ENHANCED MINIMUM COUPLING LOSS METHOD, AND THE MONTE-CARLO SIMULATION

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EXECUTIVE SUMMARY

WG- SE has been requested by the ERC to recommend a unified method for evaluating the minimum frequency separation between two systems operating in adjacent frequency bands. Three methods were identified for comparison. These were the Minimum Coupling Loss (MCL) method, the Enhanced Minimum Coupling Loss (E-MCL) method and the Monte Carlo method.

The most important characteristics of the MCL method are:

- the result generated is isolation in dB, which may be converted into a physical separation if an appropriate path loss formula is chosen
- it is simple to use and does not require a computer for implementation
- it is a worst case analysis and produces a spectrally inefficient result
- the victim receiver is assumed to be operating 3 dB above reference sensitivity
- a single interferer transmitting at fixed (usually the maximum) power and using a single channel is considered.

The most important characteristics of the E-MCL method are:

- the result generated is isolation in dB, which may be converted into a physical separation and subsequently into a probability of interference
- it does not require a computer for implementation
- the victim receiver has a fixed wanted signal strength margin dependent upon system availability
- interferers are assumed to be uniformly distributed across a circular cell system
- a fixed victim to interferer frequency offset is assumed
- The path loss figures used by the E-MCL method include fading on the victim's wanted signal link (assuming the curves derived by W.C.Jakes are used) but do not include slow fading in the interferer to victim link.
- The results of initial E-MCL calculations indicate results that are of the same order of magnitude as those generated by the Monte Carlo method.
- Power control may or may not be taken into account.

The most important characteristics of the Monte Carlo method are:

- the result generated is a probability of interference
- it is a statistical technique, which requires the use of a computer
- it allows the user to model realistic scenarios and evaluate appropriate minimum frequency separations
- an appropriate path loss model is required
- the victim receiver has variable wanted signal strength
- multiple interferers using multiple channels may be considered
- the effect of features such as power control may be included.

The main points to be considered are:

- the MCL approach is relatively straight forward, modelling only a single interferer-victim pair. It provides a result which, although spectrally inefficient, guards against the worst case scenario.
- the Monte Carlo approach is a statistical technique, which models a victim receiver amongst a population of interferers. It is capable of modelling highly complex systems including CDMA. The result is spectrally efficient but requires careful interpretation.
- the E-MCL approach provides a useful bridge between the MCL and Monte Carlo methodologies. For relatively simplistic scenarios the results of the E-MCL methodology are of the same order of magnitude as the Monte Carlo. However the methodology is not likely to compare so favourably for all interference scenarios e.g. CDMA scenarios. As in the case of Monte Carlo, the result requires careful interpretation.

Each of the methodologies has its merits and drawbacks. The appropriate choice depends upon the criteria used and on the tool available to the user. The increasing penetration of wireless communications is leading to increased congestion in the radio spectrum. This indicates that one criterion should be the ability to evaluate spectrum efficiency. Radio systems are becoming more and more complex as the range of services offered is increased. This indicates that another criteria should be the ability to model complex scenarios realistically and with flexibility. Finally, the advent of high-density systems has led to the concept of soft capacity i.e. capacity is a function of inter and intra system interference, this concept is fundamental to the case of CDMA systems. Thus the last criteria is the ability to evaluate capacity in a system. In summary the criteria are:

- the ability of evaluating spectrum efficiency.
- ability to model complex scenarios realistically.
- Flexibility.
- ability to evaluate system performance for high density or CDMA systems.

Considering these criteria and the following study, the recommended method for evaluating minimum frequency separations is the Monte Carlo simulation. Users of the Monte Carlo simulation should be aware of the following factors:

- the accuracy of the result obtained will rely upon accurate values being assigned to each simulation parameter and upon how these parameters are introduced in the simulation.
- Furthermore, the simulation by an MC tool of particular features available in some systems may require dedicated software modules or code.
- simulation parameters may be assigned using values from the relevant radio system standard or using typical equipment values. Care has to be taken in the interpretation of the results, particularly when values of both types have been used.
- an appropriate path loss model must be used.
- system hot spots may exist where there are unusually high densities of active users potentially generating increased levels of interference.
- radio functions such as power control should be included if used in practice. In addition special channel types such as control channels should also be modelled.
- the probability of interference, which is acceptable, will vary from system to system and user to user and needs to be carefully interpreted.

It has to be noted that what the Monte Carlo simulation is computing will depend upon the scenario being modelled. For simulations where the victims are all treated equally and do not have restrictions placed upon their positions then each will experience the same level of interference. In this case the meaning of the result is that 100 % of the users experience a P % probability of being disturbed. For simulations where the position of some or all of the victims is restricted then it is possible that some victims will experience more interference than others. In this case the meaning of the result will be somewhere between 100 % of the users experiencing a P % probability of being disturbed and P % of users experiencing a 100 % probability of being disturbed.

When interpreting a simulation result in terms of what it means in the real world, a great deal of care needs to be taken. In reality each mobile user is likely to have an individual pattern of mobile terminal usage. This is likely to be related to where that user lives and works. This means that one user may commonly pass through an area of poor signal quality whereas another user may very rarely experience poor signal quality. In this case the P % probability of interference should be interpreted as somewhere between 100 % of the users experiencing a P % probability of being disturbed and P % of users experiencing a 100 % probability of being disturbed.

In addition, it should be kept in mind that Monte Carlo simulations should be used to model hotspots or areas of high mobile terminal usage. It is important to recognise that the result produced is specific to that hotspot and does not apply to all areas or to all users.

WG SE has released a specification for a Monte Carlo based radio system compatibility tool. This tool has been named the ‘Spectrum Engineering Advanced Monte Carlo Analysis Tool’ (SEAMCAT). It is referred to in document WG SE(97)30 ‘Monte Carlo Radio Compatibility Tool’ [1]. SEAMCAT is more sophisticated than the Monte Carlo radio compatibility tool used in this study. It is recommended that once SEAMCAT is available, CEPT administrations use it to evaluate minimum frequency separations between adjacent systems.

It is important to realise that care will have to be taken in using the SEAMCAT tool and in ensuring that it is applicable to the scenario being modelled. The first version of the tool may not be applicable to all system scenarios e.g. CDMA systems. Each scenario should therefore be considered on a case by case basis to ensure that the relevant system aspects are being modelled accurately.

Discussions were held in the project team on which could or should be the allowable percentage of interference: no specific figure is recommended, because this has to be chosen depending on the systems and services involved and the specific scenario which has been considered for the compatibility study. It is strongly recommended that such figure is carefully identified on a case by case basis, by the relevant Working Groups and Task Groups of the CEPT, based on both technical elements and economical/operational constraints (including safety requirements).

[1] CEPT ERC Report 68 Monte Carlo Radio Compatibility Tool, http://www.ero.dk/eroweb/SEAMCAT/SEAMCAT.html . The Monte Carlo results in this document have been produced with several different Monte Carlo tools. Those results are proposed only with the purpose of proposing examples for the reader.

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1 INTRODUCTION

This report has been proposed as a result of a request by the ERC to WG-SE to develop a unified method for the determination of minimum frequency separation. The purpose being to allow CEPT member states the ability to adopt a harmonised band plan framework with provision for national requirements.

This follows on from work carried out on adjacent band compatibility using Minimum Coupling Loss (a link budget methodology), where excessively large minimum frequency separations were produced.

In the past, WG SE adjacent band compatibility studies utilised the Minimum Coupling Loss (MCL) method, based upon minimum receiver sensitivity, to determine both minimum frequency separation and, by the application of an appropriate propagation model, interference distances. However, concerns were raised regarding the pessimistic results given by this method, particularly since real systems operating on an uncoordinated basis, operate apparently quite satisfactorily with much reduced minimum separation distances. More recent proposals include the statistical Monte Carlo method and the Enhanced Minimum Coupling Loss (E-MCL) method. The E-MCL method is aimed at bridging the gap between the MCL and Monte Carlo methods.
The way forward therefore was to implement a comparison study to compare the MCL, E-MCL and Monte Carlo methods.

2 STUDY

The study took the form of an assessment of the essential differences between the three fundamental approaches, namely the minimum coupling loss (MCL) method, the Enhanced Minimum Coupling Loss (E-MCL) method and the Monte Carlo (MC) simulation. For ease of comparisons this study considers mobile to mobile scenarios. For Minimum Coupling Loss the base to base case is also included. Recommendations are made for the method to be used in each case.

For each interference scenario, the following need to be considered:

- unwanted emissions, i.e. any off-channel noise of the interfering equipment falling within the receive band of the victim receiver, thus acting as co-channel interference to the wanted signal. In general, this sort of interference can only be removed at the source.
- blocking, i.e. a strong signal off the receive band of a victim receiver, desensitising its reception. In general, this sort of interference can only be removed at the victim. However, in most cases the adoption of power control for the interferer and good site engineering can improve the situation.
- adjacent channel rejection
- transmitter intermodulation
- receiver intermodulation
- In order to compare like with like, the same propagation model should be adopted for all three methods. For the purpose of this comparison, one of the models developed within WG SE has been used. A number of other models, which could be used, are listed in Appendix C.

Technological advantages such as dynamic channel selection, intra-cell handover, error correction, frequency hopping, etc., which can, in some cases, ease the coexistence between different systems, have not been taken into account in this analysis of the different methods. Some of the reasons for this choice are the need for an approach which ensures the long term usability of spectrum, and the inclusion of such features in the different systems make it controversial to generalise on the mutual effect of such features on adjacent systems using different technologies. Knowledge of such features could however be useful when interpreting the results of an analysis, or when estimating the acceptable probability of interference to be used in an analysis. It is noted also that in the case of hot spots the traffic can be so high that the overall level of interference (internal and external) becomes larger than the level acceptable (threshold) by the system even taking into account the improvement of resistance to interference introduce by these specific features.

For inter-system interference scenarios, unwanted emissions and blocking are the prime mechanisms that may give rise to compatibility problems.

It may be noted that from a 'systems' point of view, unwanted emissions and blocking refer to each end of the 'interference link' associated with a scenario. Thus for 'intra-system' interference design, ideally the two should be balanced. For inter-system interference considerations however, calculations may show that one is dominant, depending upon the specifications involved.

Note. Unwanted emissions must be converted into the bandwidth of the victim receiver, whereas no bandwidth conversions are applied in calculating blocking exposure, assuming receiver blocking is dependant only on the total power of the interfering signal.

2.1 Minimum Coupling Loss Theory

The Minimum Coupling Loss (MCL) method calculates the isolation required between interferer and victim to ensure that there is no interference. The method is simple to use and does not require a computer for implementation. The primary drawback is that it is a worst case analysis and produces a spectrally inefficient result for scenarios of a statistical nature.

The victim receiver is assumed to be continually operating 3 dB above reference sensitivity. Interference must be limited to the noise floor to maintain the victim's protection ratio. A path loss formula must be chosen to determine how much isolation can be attained through physical separation (see examples on page 8). The median path loss is used and no account has been taken of fading. There is also no statistical distribution of interferers used by the method.

Two MCL equations are used for the scenarios considered in this report. These include the interference effects of :

- unwanted emissions
- receiver blocking.

The unwanted emissions analysis equation is:

$$\text{Isolation} = P_{INT} + dB_{BW} + MC_{INT} + G_{VICT} + G_{INT} - (S_{VICT} - C/I_{VICT}) + f(dBc_{INT,},P_{INT})$$

where:

P_{INT}	is the maximum transmit power of the interferer
dB_{BW}	is the bandwidth conversion factor between interferer and victim
MC_{INT}	is the multiple carrier margin to account for when the interferer is a base site and has more than a single carrier being transmitted
G_{VICT}	is the gain of the victim antenna (inc. cable loss)
G_{INT}	is the gain of the interferer antenna (inc. cable loss)
S_{VICT}	is the sensitivity of the victim
C/I_{VICT}	is the protection ratio of the victim
$f(dBc_{INT,},P_{INT})$	is a function defining the power of the wideband noise at the frequency offset being considered relative to the interferer's carrier power

The receiver blocking analysis equation is:

$$\text{Isolation} = P_{INT} + MC_{INT} + G_{VICT} + G_{INT} - f(B_{VICT},S_{VICT})$$

where:

P_{INT}	is the maximum transmit power of the interferer
MC_{INT}	is the multiple carrier margin to account for when the interferer is a base site and has more than a single carrier being transmitted
G_{VICT}	is the gain of the victim antenna (inc. cable loss)
G_{INT}	is the gain of the interferer antenna (inc. cable loss)
$f(B_{VICT},S_{VICT})$	is the blocking performance of the victim receiver at the frequency offset being considered.

2.1.1 Interpretation of the Results

The result of an MCL calculation is an isolation figure which, can then subsequently be converted into a physical separation having chosen an appropriate path loss model. Care must be taken when attempting to interpret this figure. It is the isolation/physical separation required between an interferer and victim 'when' the victim is receiving 3 dB above sensitivity and the interferer is transmitting at fixed (usually the maximum) power at the assumed frequency offset. Nothing is known about what percentage of time or over what percentage of the cell area this isolation requirement occurs. It is possible that in reality the isolation computed is never required.

2.1.2 Minimum Coupling Loss Example

It is possible that spectrum allocations for radio systems A and B lead to the uplink band of radio system A meeting the downlink band of radio system B. the following interference scenarios would result:

- System A mobile station transmissions causing interference to a System B mobile station receiver
- System B base station transmissions causing interference to a System A base station receiver

The occurrence of interference can be limited by imposing a minimum frequency separation between the two systems. Spectrum efficiency requirements dictate that this separation should be as small as possible. The following two sub-sections apply the MCL wideband noise and receiver blocking analysis equations to the base to base interference scenario.

2.1.2.1 Unwanted Emissions MCL Analysis – Base Station to Base Station

The relevant radio parameters required by the analysis are provided in Table 1.

Parameter	Value
Interferer Transmit Power	44 dBm
Bandwidth Conversion Factor	10.5 dB
Multiple Carrier Margin	6 dB
Base Antenna Gains	10 dBi
Victim Sensitivity	- 104 dBm
Victim Protection Ratio	9 dB

Table 1
Radio System Parameters for Unwanted Emissions MCL Analysis

The isolation requirement in dB is given by:

$$\text{Isolation} = P_{INT} + dB_{BW} + MC_{INT} + G_{VICT} + G_{INT} - (S_{VICT} - C/I_{VICT}) + f(dBc_{INT,},P_{INT})$$

$$= 44 + 10.5 + 6 + 10 + 10 - (-104 - 9) + f(dBc_{INT,},P_{INT}) = 193.5 + f(dBc_{INT,},P_{INT})$$

It has been assumed that there are four carriers continuously active on the System B base station leading to a 6 dB increase in unwanted emissions. This is a worst case assumption and in practice duplex filtering may reduce the figure. Antenna gains of 10 dBi are being used to represent directional antennas in a sectorised cell structure. A gain of 10 dBi represents a 14 dBi antenna with 3 dB cable and connector loss and 1 dB of loss due to downtilt meaning that the main lobe of one antenna is not pointing directly at the main lobe of the other antenna.

The isolation is computed as (193.5 + $f(dBc_{INT,},P_{INT})$) dB. This isolation may be achieved through a physical separation, a frequency separation, some standard site engineering or most likely, a combination of these. Table 2 shows the assumed wideband noise characteristic for a system B base station.

Frequency Offset	**Wideband Noise Relative to Carrier**
25 kHz ≤ f_{offset} < 50 kHz	- 60 dBc
50 kHz ≤ f_{offset} < 100 kHz	- 70 dBc
100 kHz ≤ f_{offset} < 250 kHz	- 80 dBc
250 kHz ≤ f_{offset} < 500 kHz	- 85 dBc
500 kHz ≤ f_{offset}	- 90 dBc
at any frequency offset the minimum requirement is - 70 dBm	

Table 2
The Wideband Noise Characteristic for a System B Base Station

These figures may be applied to the wideband noise MCL analysis result to provide the isolation required as a function of frequency offset. This has been done in Table 3.

Frequency Offset	**Isolation**
25 kHz ≤ f_{offset} < 50 kHz	133.5 dB
50 kHz ≤ f_{offset} < 100 kHz	123.5 dB
100 kHz ≤ f_{offset} < 250 kHz	113.5 dB
250 kHz ≤ f_{offset} < 500 kHz	108.5 dB
500 kHz ≤ f_{offset}	103.5 dB

Table 3
The Isolation required for different System A to System B Base Station Frequency Offsets (BS to BS)

These isolations can be achieved through physical separation and standard site engineering. In the first case assuming that no site engineering is used, the only isolation comes from physical separation. The figures 1a and 1b illustrate the free space and urban Working Group Spectrum Engineering (WGSE) path loss characteristics assuming a frequency of 915 MHz (in the cases BS to BS and BS to MS).

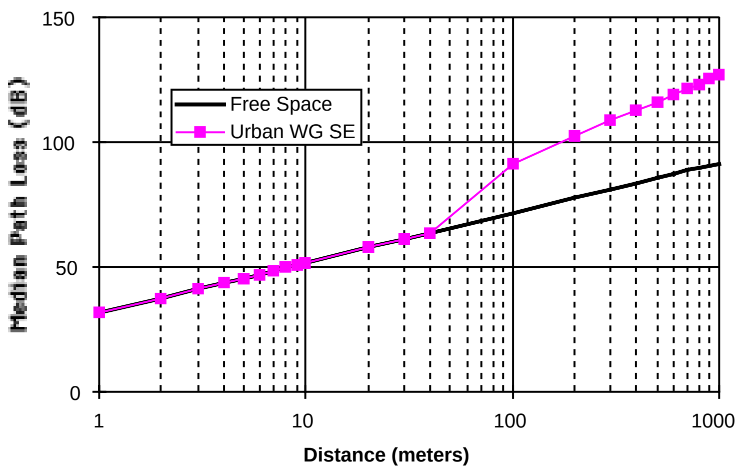

Figure 1a
The Free Space and WG SE Path Loss Characteristic assuming 915 MHz (case BS to MS)

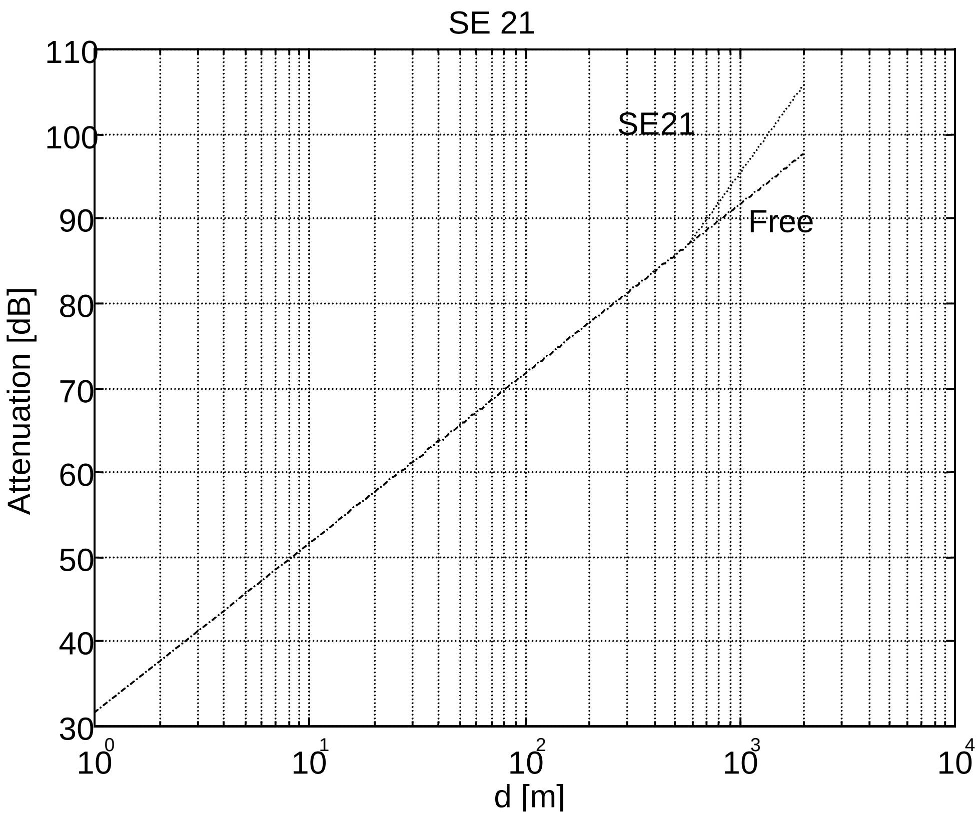

Figure 1b
The Free Space and WG SE Path Loss Characteristic assuming 915 MHz (case BS to BS)

Care should be taken in selecting the appropriate propagation model. Figure 1 can be used to convert isolation at a given frequency offset into a physical separation. This is done in Table 4 assuming that no site engineering is used.

Frequency Offset	Physical Separation assuming Free Space model	Physical Separation assuming WG SE model
25 kHz ≤ f_{offset} < 50 kHz	124 km	12 km
50 kHz ≤ f_{offset} < 100 kHz	39 km	6.3 km
100 kHz ≤ f_{offset} < 250 kHz	12 km	3.3 km
250 kHz ≤ f_{offset} < 500 kHz	7 km	2.4 km
500 kHz ≤ f_{offset}	4 km	1.7 km

Table 4
The Variation in Physical Separation with Frequency Offset assuming no Site Engineering is used (BS to BS)

The distances vary quite considerably with frequency offset reflecting the steps in the radio system A base station unwanted emissions characteristic.

2.1.2.2 Receiver Blocking MCL Analysis – Base Station to Base Station

The relevant radio parameters required by the analysis are provided in Table 5.

Parameter	Value
Interferer Transmit Power	44 dBm
Multiple Carrier Margin	0 dB
Base Antenna Gains	10 dBi
Victim Sensitivity	- 104 dBm
Victim Protection Ratio	9 dB

Table 5 - Radio System Parameters for Receiver Blocking MCL Analysis

Applying the receiver blocking analysis MCL equation to the base to base interference scenario the isolation required is:

$$\text{Isolation (dB)} = P_{INT} + MC_{INT} + G_{VICT} + G_{INT} - f(B_{VICT}, S_{VICT})$$
$$= 44 + 0 + 10 + 10 - f(B_{VICT}, S_{VICT}) = 64 - f(B_{VICT}, S_{VICT})$$

In this case the multiple carrier margin has been set to zero. This is because of the assumed radio system B blocking characteristic having a 10 dB step at 800 kHz. Assuming the minimum frequency separation to be 600 kHz then the next possible channel is 800 kHz away which the radio system B base station blocks with 10 dB more effectiveness. This means that the single carrier at a 600 kHz minimum frequency separation is dominant. Table 6 illustrates the radio system B base station blocking characteristic.

Frequency Offset	BS Receiver Blocking Performance
600 kHz ≤ f_{offset} < 800 kHz	- 26 dBm
800 kHz ≤ f_{offset} < 3 MHz	- 16 dBm
3 MHz ≤ f_{offset}	- 13 dBm

Table 6
The Victim Radio System A Base Station Blocking Characteristics

These blocking levels assume that the radio system B receiver is operating 3 dB above sensitivity and that when the blocking signal is present performance is reduced to that which would be obtained if the receiver were operating at sensitivity without an interfering signal. Applying these figures to the isolation result
($64 - f(B_{VICT}, S_{VICT})$), generates the figures in Table 7.

Frequency Offset	BS Isolation	Physical Separation assuming Free Space model	Physical Separation assuming WG SE model
600 kHz ≤ f_{offset} < 800 kHz	90 dB	830 m	700 m
800 kHz ≤ f_{offset} < 3 MHz	80 dB	265 m	263 m
3 MHz ≤ f_{offset}	77 dB	190 m	186 m

Table 7
The Isolation Required for different Radio System A BS to Radio System B BS Frequency Offsets

Comparing these isolation figures with those in Table 3 it is clear that wideband noise is the dominant interference mechanism for a radio system A base station using frequencies adjacent to a radio system B base station. In this case the wideband noise analysis would be used to determine a minimum frequency separation.

2.2 Enhanced Minimum Coupling Loss Theory

As for MCL, the Enhanced Minimum Coupling Loss (E-MCL) method calculates the isolation required between interferer and victim to ensure that there is no interference. The method is simpler than Monte Carlo but more complex than MCL. It is semi-analytical and can be implemented using a calculator, a computer or both.

The main improvements with respect to the classical MCL approach are:

- To introduce as an input, the link availability (quality of coverage) within the interfering system, in terms of the form of the maximum transmit power of interferers.

In fact this maximum transmit power is a function of the cell radius and of the intrinsic (only noise limitation) link availability within the overall cell of the interfering system. The results of the W.C. Jakes method (Microwave Mobile Communications) are used to estimate this maximum power value.

- To introduce a power control mechanism in the interfering system.

Concerning the victim system, the MCL as well as the E-MCL approaches, implicitly introduce power control within the victim system because the useful signal level at the input of the victim receiver is assumed to be constant, independently of all the other victim parameters (transmitter characteristics, propagation model, separation between transmitter and receiver). But if necessary, to be more in line with the considered scenario or to allow comparison with the MC method, the removal of power control is also possible (see section 2.2.3).

- To introduce a link availability figure also within the victim system.

In fact, the victim receiver is assumed to be operating N dB (instead of 3 for MCL) above its reference sensitivity. Interference must be limited such that the linear summation of the receiver noise floor and the interferer received level maintains the victim's protection ratio taking into account that the useful signal is N dB above the victim reference sensitivity. The N figure is related to the link availability within the victim system, the larger N, then the higher the link availability.

The WG SE median path loss formula is inversed[2] to determine the separation distance between victim and interferer corresponding to the required isolation. A uniform distribution of interferers is assumed in the case where power control is applied. In that case an isolation and its corresponding separation distance is calculated for each interferer transmit power figure and a mean separation distance can be obtained by weighted summation.

As for the classical MCL method, two equations are used to calculate the required isolation, one for the unwanted emission analysis, the other for the blocking analysis.

The equation for unwanted emission is :

$$\text{Isolation} = P_{INT} + dB_{BW} + MC_{INT} + G_{VICT} + G_{INT} - (S_{VICT} - C/I_{VICT}) + f(dBc_{INT,},P_{INT}) - 10 \log (10^{N/10}-1)$$ [3]

where:

P_{INT}	is the maximum transmit power of the interferer
dB_{BW}	is the bandwidth conversion factor between interferer and victim
MC_{INT}	is the multiple carrier margin to account for when the interferer is a base site and has more than a single carrier being transmitted
G_{VICT}	is the gain of the victim antenna (inc. cable loss)
G_{INT}	is the gain of the interferer antenna (inc. cable loss)
S_{VICT}	is the sensitivity of the victim
C/I_{VICT}	is the protection ratio of the victim
$f(dBc_{INT,},P_{INT})$	is a function defining the power of the wideband noise at the frequency offset being considered relative to the interferer's carrier power

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[2] *A more elaborate method using the full inversion of the log.normal distribution of the path loss can be introduced to estimate the separation distance corresponding to a certain attenuation L, e.g. to a certain percentage P % of the cases (using the median path loss corresponds to 50%). Further elements on this point are provided in Annex 1.*

[3] See Annex 3 for explanation of the term 10 log ($10^{N/10}$-1)

N is the factor used to take account of victim system availability

The equation for blocking is:

$$\text{Isolation} = P_{INT} + MC_{INT} + G_{VICT} + G_{INT} - f(B_{VICT},S_{VICT}) - 10 \log (10^{N/10}-1)$$

where:

P_{INT}	is the maximum transmit power of the interferer
MC_{INT}	is the multiple carrier margin to account for when the interferer is a base site and has more than a single carrier being transmitted
G_{VICT}	is the gain of the victim antenna (inc. cable loss)
G_{INT}	is the gain of the interferer antenna (inc. cable loss)
$f(B_{VICT},S_{VICT})$	is the blocking performance of the victim receiver at the frequency offset being considered
N	is the factor used to take account of victim system availability

The isolation equation for blocking assumes that blocking can be considered as a linear phenomena. This is correct when the disturbance level is not too high and the blocking (desensitisation) effect is an increase of the local oscillator noise level in the receiver channel due to the presence of the interferer at the receiver input.

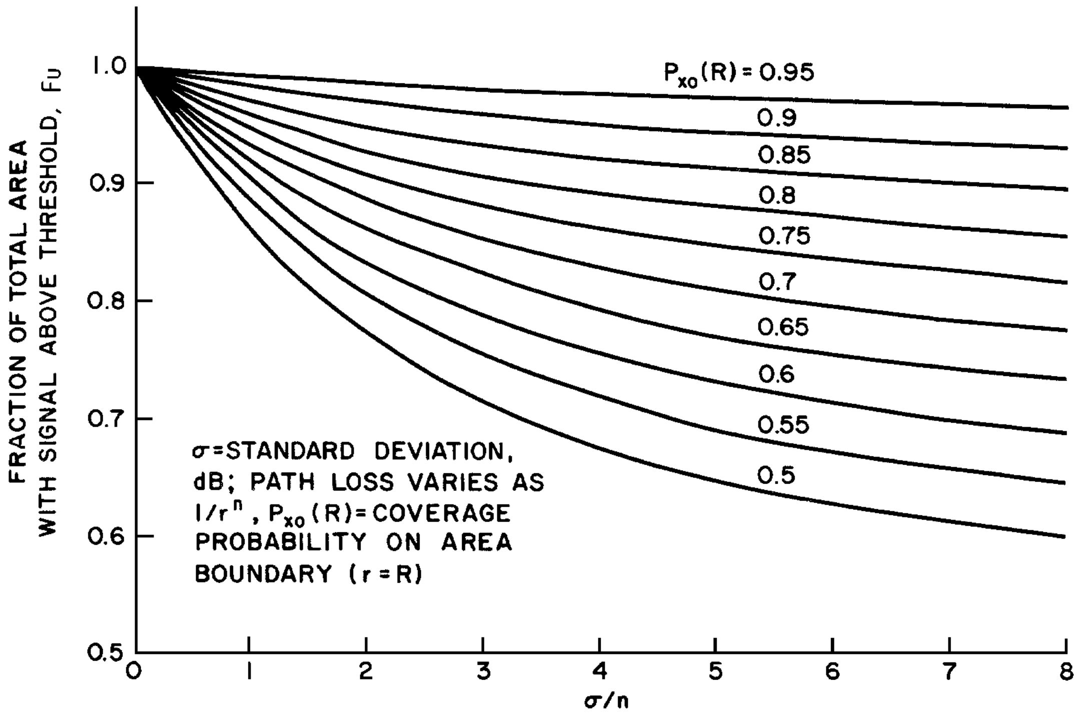
2.2.1 Link Availability Estimation "Jakes Method"

The reference used here is from the book 'Microwave Mobile Communications' by W.C. Jakes [1] and thus in the following sections the methodology used for estimating the link availability will be referred to for simplicity as the 'Jakes Method'.

Assuming that the mean propagation model is of the form χ = a - 10 nlog (r/R),

χ	= mean received signal level (dBm)
a	= factor depending upon the equipment characteristics (antenna gains, transmit power etc ...)
n	= propagation exponent (Jakes notation)
R	= cell radius
r	= current distance between the transmitter and receiver

In addition, assuming that shadowing is defined by a log normal distribution characterised by a mean value χ dBm and standard deviation σ dB,
W.C. JAKES in the chapters 2.5.2 and 2.5.3. of his book 'Microwave Mobile Communications' deduces a set of curves – shown below in Figure 2, where the x axis variable is the ratio σ/n, the Y axis represents the overall link availability (quality of coverage) within the cell (fraction of the total area where the received signal is above a given threshold x_0), each curve is characterised by $P_{x_0}(R)$, the quality of coverage at the border of the cell (fraction of the border line where the received signal is above the threshold , x_0 , R being the radius of the cell).



Fraction of total area with signal above threshold, F_u.

Figure 2
Curves Derived by W.C. Jakes, which can be used to estimate the Mean Signal Strength Margin Assuming a Specific System Availability

For a given σ/n value, this set of curves associates each wanted overall quality of coverage to a quality of coverage at the border $P_{x_0}(R)$. As the received level (in dB) are gaussian distributed, to each $P_{x_0}(R)$ value corresponds a $\left(\frac{(x_0 - \bar{x}(R))}{\sigma}\right)$ value :

$$P_{x_0}(R) = \tfrac{1}{2} - \tfrac{1}{2} erf\left(\frac{x_0 - \bar{x}}{\sigma\sqrt{2}}\right)$$

where: $(\bar{x}(R) - x_0)$ represents the dB margin to obtain the wanted coverage quality.

x_0 is the received signal threshold level, with the above margin figure, $\bar{x}(R)$ can be deduced and using the mean propagation model, the radius (R) of the cell can be determined. For example, with n = 3.5 and σ = 9 dB, an overall quality of coverage of 95% corresponds to $P_{x_0}(R) =$ 0.87 using the set of curves, this value correspond to a margin of around 1.125 σ (gaussian distribution) and as σ = 9 dB the margin is equal to approximately 10 dB. This means that at the border of the cell $\bar{x}(R)$ shall be equal to $x_0 + 10dB$ and the maximum transmit power can be calculated (issued from the 'a' parameter in the above mean propagation model).

Note that in the above explanation the down link has been considered but in addition the method is also applicable to the uplink.

Also note that due to the introduction of the threshold (reference sensitivity) as well in the W.C. Jakes calculation as in the E-MCL or Monte Carlo methods and supposing that power control is normally working[4] and that the actual maximum power is equal to the one issued from the W.C. Jakes calculation, the intrinsic availability figure is the same with or without power control, the fraction of the cell area where signal is above (or below) the threshold being the same in the two cases.

[4] 'normally' means that if the PC algorithm asks for a transmit level below the maximum power, with this level value the received signal will be above the receiver sensitivity.

2.2.2 Power Control in the E-MCL Method (interfering system)

In most mobile radio systems, the power of the mobile station transmitters are automatically controlled using a power control algorithm. It is important in any analysis that the effect of power control is accounted for.

For the E-MCL approach, a simplified method is given by :

1. Consider the radius of each cell (R_0) within the interfering system.

2. Consider the propagation attenuation behaviour with the distance given by -

$$A = 10\,\alpha \log d + K$$

where:

A = attenuation (dB)
d = transmitter - receiver distance
α = propagation exponent (classical notation)
K = constant depending on environmental hypothesis.

3. Determine the maximum mobile power (PM) as a function of the above radius and of the other input hypothesis, in particular the availability of coverage or the link budget margin in the interfering system (W.C. Jakes method)

4. Consider the quantisation step, q and the dynamic range, D of the power control algorithm to determine the set of MS powers within the cell:

$$PM, PM\text{-}q \ldots PM\text{-} (i\text{-}1)q \ldots PM - Lq(=PM\text{-}D)$$

where:

PM is in dBm
q and D are in dB
i and L are integers

5. For each power Pi = PM - (i-1)q, the corresponding separation distance (ds_i) is determined using the appropriate propagation model, the characteristics of the victim receiver and disturbing transmitters (see the isolation equations above) and the operating margin of the victim link.

6. The cell is approximated by a circle of radius R_0 and is split in L rings and one small remaining circle. In the first ring (border of the cell), delimited by R_0 and R_1, the power is P_1 = PM. In the i^{st} ring, deliminated by R_{i-1} and R_i, the power is P_i = PM - (i-1)q. In the last (L^{th}) ring, deliminated by R_{L-1} and R_L, the power is :

$$P_L = PM\text{-}(L\text{-}1)q \quad \text{with } L = D/q$$

Around the centre of the cell, a small circle remains of radius R_L and where the power is P_{L+1} = PM - Lq.
The radius R_i are determined by:

$$q = 10\,\alpha \log (R_{i-1} / R_i) \quad \text{with } i = 1 \text{ to } L$$

The area S_i of the ith ring relative to the overall cell area SC is equal to:

$$S_i = (R^2_{(i-1)} - R^2_i) / R^2_0$$

$$(\text{for the remaining circle } R_{i-1} = R_L \text{ and } R_i = 0)$$

7. Finally, the mean separation distance is determined by:

$$\text{aver.}(ds) = \Sigma\, S_i.ds_i \quad (i = 1 \text{ to } L + 1)$$

In this equation a uniform distribution of interferers is assumed. Note that when power control is not activated aver. (ds) = ds_1, ds_1 being only a function of PM.

2.2.3 Victim System without Power Control in the E-MCL Approach

Considering the coverage area of a transmitter within the victim system, its transmit power, PT is assumed to be constant (no power control), the radius R_0 of this area is mainly determined by PT and by the expected quality of coverage within the area using for example the W.C. Jakes approach. At the border, that means at a distance R_0 from the transmitter the corresponding link margin is N_0 dB (N_0 = (mean received level for a distance R_0) - (intrinsic receiver sensitivity level)) and this N_0 value is used in the isolation formula in the case of usual E-MCL approach and this leads to power control implicitly being included in the victim system.

To eliminate power control (i.e. for the purpose of comparison with the Monte Carlo results in this report) the circle of radius R_0 is split in a set of rings, the external radius of these rings are $R_0 < R_1 < R_2$ .... R_L the remaining sub area being a small circle of radius R_L around the transmitter.

The values R_1, R_2 ... are such that if for R_0 the link margin is N_0, for R_1 it is $(N_0 + n)$dB, for R_2 : $(N_0 + 2n)$dB ... for R_L : $(R_0 + Ln)$dB.

The figures n and L are arbitrarily chosen such that as a priori the larger L and the smaller n are, the more accurate the calculation.

The values R_0, R_1 ... R_l ... R_L are such that $n = 10\ \alpha \log (R_{l-1} - R_l)$ α being the propagation exponent.

The relative area of each ring with respect to the one of the radius R_0 circle is

$$S_l = (R^2_{(l-1)} - R^2_{\_l})/R^2_0$$

It is obvious that S_l is decreasing when l is increasing.

The victim link margin within the ring l is approximated by $(N_0 + (2l - 1)\ n/2)$ and the margin within the remaining circle of radius RL is supposed infinite (optimistic hypothesis).

Now considering the interfering mechanism and the corresponding necessary isolation equation (spurious case):

$$ISO = P_{INT} + dBc_{INT} + MC_{INT} + G_{INT} + G_{VICT} - (S_{VICT} - C/I_{VICT}) + dB_{BW} - 10 \log(10^{N/10}-1).$$

In this equation N is now replaced by $(N_0 + (2l-1)n/2)$ with l = 1 to L and for each l figure an aver(ds_l) value or a ds_l value is calculated according to whether a power control mechanism is implemented within the interfering system or not.

For the last remaining circle aver(ds) = ds =0 is stated.

Now considering the victim receivers likely distributed over the victim coverage area (circle of radius R_0), a weighted summation of the set of aver (ds_l) or ds_l values can be made to estimate the averaged effect to have not activated power control within the victim system.

$$ds_{NPC} = \Sigma\ ds_l\ .\ S_l$$

$$\text{or } aver(ds)_{NPC} = \Sigma\ aver\ (ds_l)\ .\ S_l$$

$$\text{With } l = 1 \text{ to } L$$

Note that the method used to consider ‘no power control’ within the victim system is in fact very similar to the one to consider ‘power control’ within the interfering system. The differences being that in the first case N (victim margin) is variable and how to split the victim coverage is arbitrary and only depending of the wanted calculation accuracy, on the contrary in the second one P_T (interferer power) is variable and how the interfering coverage is split is a function of the interferer power control algorithm (step size and dynamic range) and of the spurious limits characteristics (in dBc or in dBm).

2.2.4 Limit Mask Consideration in the E-MCL method

The aim of this chapter is to illustrate how the E-MCL method can be extended.

2.2.4.1 The Basic E-MCL Scenario

In the E-MCL method each basic scenario is defined by a set of input parameters :

1. propagation model
2. frequency separation between the victim channel and the interfering channel
3. interferers characteristics:
   - the maximum power as a function of the cell size and the relevant technical equipment characteristics (antenna gains, antenna heights, receiver sensitivity) taking into account the quality of coverage within the disturbing system
   - the power control mechanism = range and step size
   - the spurious transmit level (in dBc) or the blocking performance of the victim (in dBm) as a function of the above mentioned frequency separation and perhaps also of each actual interferer transmit power in the case of spurious emissions.
4. victim characteristics:
   - sensitivity
   - C/I threshold
   - level of the wanted signal at the victim receiver input depending on the quality of coverage within the victim system.

For each transmit power a necessary isolation is calculated as is the corresponding separation distance. Using the power control algorithm, a distribution of these transmit powers and therefore also of the separation distances is estimated.

Finally, the mean separation distance for that basic scenario is calculated. This basic scenario corresponds in particular to one frequency separation between the victim receiver and the disturbing transmitters.

2.2.4.2 The Spurious Limit

In practice within a given geographical area the disturbing transmitters use in fact different channels depending of the local frequency plan and to each channel corresponds a frequency separation with respect to the victim channel depending of the respective frequency allocations for the victim and for the interfering system.

On the other hand, the spurious limit mask is characterised by a step function (indicating limit values), with each value being associated to a frequency band on both sides of each transmit frequency.

If f_T is the central frequency of a transmitter the mask is defined as:

- a limit LA for the frequency bands from f_T to ($f_T \pm df_A$),
- a limit LB for the frequency bands from ($f_T - df_B$) to ($f_T - df_A$) and from ($f_T + df_A$) to ($f_T + df_B$)
- and so on.

It is clear that if the victim central frequency f_R is now considered :

- all the transmitters, the central frequency of which staying between f_R and ($f_R \pm df_A$) will disturb the victim receiver with a transmit spurious level equal to LA. These transmitters can be characterised by being part of the class A jammers.

- all the transmitters, the central frequency of which staying between (f_R - df_B) and (f_R - df_A) or between (f_R + df_A) and (f_R + df_B), will disturb the victim with a transmit spurious level equal to LB. These transmitters can be characterised by being part of the class B jammers

- and so on.

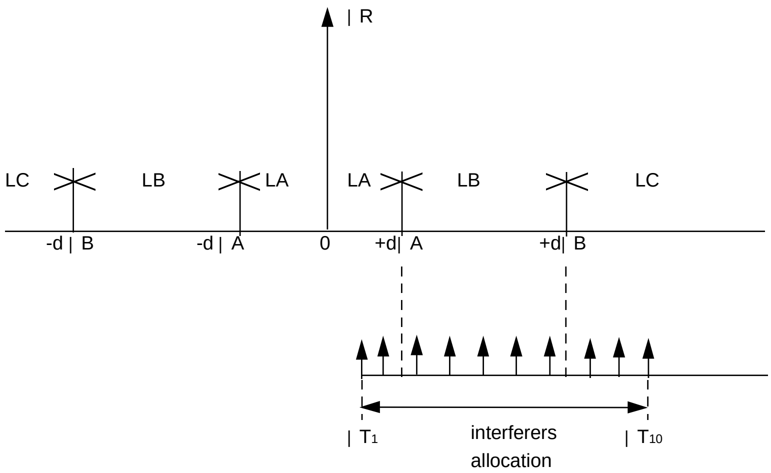
It is clear also that each transmitter is and can be a member of only one class.

So knowing the local frequency plan of the interfering system and the central frequency of the victim the fractions PA, PB and so on ... of the overall set of interferers being part of respectively the class A, B and so on.... can be determined with PA + PB + ... = 1.

At each jammer class corresponds a mean separation dSA, dSB and so on ... each of them being issued from a basic scenario and a function of LA, LB and so on ...

So finally a global mean separation distance can be defined as dS = PA.dSA + PB.dSB +…….

2.2.4.3 Example of the Spurious Limit



As illustrated by the figure in this example :

- the limit mask is symmetrical and defined by 3 limits values LA, LB, LC and 2 frequency boundaries df_A and df_B

- locally, close to the victim, ten frequencies are allocated to the interfering system in the band (f_{T_1} - $f_{T_{10}}$)

- due to the relative position between f_R (victim channel) and interferers allocation, the overall set of interferers is subdivided in 3 classes class A where PA = 2/10 and the spurious transmit level = LA

class B where PB = 5/10 and the spurious transmit level = LB

class C where PC = 3/10 and the spurious transmit level = LC

To the three LA, LB, LC values correspond three dSA, dSB, dSC values.

2.2.4.4 Conclusion of the Spurious Limit

The spurious limit mask being defined by M different steps (in terms of level and frequency separation) and knowing the central frequency of the victim and the frequency plan of the interfering system, M jammers classes can be defined, each class corresponds to a mean separation distance and to a proportion of interferers.

With these two sets of M figures an overall mean separation distance can be calculated.

This part of report shows that with very simple considerations the E-MCL approach can be extended to take into account the global effect of a spurious specification defined by a frequency mask when the local frequency allocation is known.

Obviously, the same method applies when the blocking characteristic of the victim receiver is also defined by a mask.

2.2.5 Interpretation of the Results

The result of an E.MCL analysis is a mean physical separation having chosen an appropriate path loss model. This mean value is issued from a number of specific situations depending on some features like power control or frequency separation and from the fractions of the cell where these situations occur.

Knowing the density of the interferers, this mean physical separation can be converted into a probability of interference. Care must be taken when interpreting this mean physical separation or this probability of interference. The problem is similar to that faced by a system operator when specifying a system availability. A mobile system operator specifies that a system can provide a system availability of 95 %. It is not stated whether this means that 5 % of the users are out of coverage 100 % of the time or that 100 % of the users are out of coverage 5 % of the time. However it is generally understood that the reality is somewhere in between the two extreme limits.

The probability of interference resulting from an E-MCL calculation can be interpreted in two stages. First of all, what precisely the analysis is computing and secondly what this relates to in the real world.

Precisely what the analysis is computing will depend upon the scenario being modelled. For scenarios where the victims are all treated equally and do not have restrictions placed upon their positions then each will experience the same level of interference. In this case the meaning of the result is that 100 % of the users experience a P % probability of being disturbed. For scenarios where the position of some or all of the victims are restricted then it is possible that some victims will experience more interference than others. In this case the meaning of the result will be somewhere between 100 % of the users experiencing a P % probability of being disturbed and P % of users experiencing a 100 % probability of being disturbed.

When interpreting a result in terms of what it means in the real world. A great deal of care needs to be taken. In reality each mobile user is likely to have an individual pattern of mobile terminal usage. This is likely to be related to where that user lives and works. This means that one user may commonly pass through an area of poor signal quality whereas another user may very rarely experience poor signal quality. In this case the P % probability of interference should be interpreted as somewhere between 100 % of the users experiencing a P % probability of being disturbed and P % of users experiencing a 100 % probability of being disturbed.

It should in addition be kept in mind that E-MCL studies should be used to model hotspots or areas of high mobile terminal usage. It is important to recognise that the result produced is specific to that hotspot and does not apply to all areas or to all users.

2.2.6 Enhanced Minimum Coupling Loss Example

It is possible that spectrum allocations for radio systems A and B lead to the uplink band of radio system A meeting the downlink band of radio system B. The following interference scenarios would result:

- System A mobile station transmissions causing interference to a System B mobile station receiver
- System B base station transmissions causing interference to a System A base station receiver.

The occurrence of interference can be limited by imposing a minimum frequency separation between the two systems. Spectrum efficiency requirements dictate that this separation should be as small as possible. The following two sub-sections apply the E-MCL wideband noise and receiver blocking analysis equations to the mobile to mobile interference scenario.

2.2.6.1 Wideband noise E-MCL analysis – Mobile Station to Mobile Station

For the radio system A mobile station interferer the parameter values provided in Table 8 are assumed.

Parameter	Value
Transmit Frequency	915.5125 MHz
Antenna Gain	0 dBi
Antenna Height	1.5 m
Power Class	33 dBm
Power Control Range	5 to 33 dBm
Power Control Step Size	2 dB
interfering system coverage availability	93%

Table 8
Interfering Radio System A Mobile Station Parameters

For the radio system A base station the parameter values provided in Table 9 are assumed.

Parameter	Value
Sensitivity	- 104 dBm (with fading)
Antenna Gain	11 dBi
Antenna Height	30 m

Table 9
Interfering Radio System A Base Station Parameters

Table 10 provides the assumed unwanted emissions performance using a measurement bandwidth of 30 kHz. The figures in dBc are relative to the power on the carrier frequency also measured in 30 kHz.

Frequency Offset	Limit
200 kHz ≤ ΔF < 250 kHz	Max (- 30 dBc, - 36 dBm)
250 KHZ ≤ ΔF < 400 KHZ	Max (- 33 dBc, - 36 dBm)
400 kHz ≤ ΔF < 600 kHz	Max (- 60 dBc, - 36 dBm)
600 kHz ≤ ΔF < 1800 kHz	Max (- 60 dBc, - 51 dBm)
1800 kHz ≤ ΔF < 3000 kHz	Max (- 68 dBc, - 51 dBm)
3000 kHz ≤ ΔF < 6000 kHz	Max (- 70 dBc, - 51 dBm)

Table 10
Interfering Radio System A Mobile Station Unwanted Emissions Performance

For radio system B the victim mobile station is characterised by the parameters shown in Table 11.

Parameter	Value
Receive Frequency	914.8 MHz
Antenna Gain	0 dBi
Antenna Height	1.5 m
Sensitivity	- 103 dBm
C/I Requirement	19 dB
Receiver Bandwidth	18 kHz
Availability Factor, N	3, 10 dB

Table 11
Victim Radio System B Mobile Station Parameters

With α (propagation exponent) = 3.5 σ (shadowing log - normal r.m.s) = 9 dB the above values of N correspond approximately to victim link availability of respectively 82,5 % (N = 3 dB) and 95 % (N = 10 dB) following the W.C. Jakes approach. Table 12 provides the assumed receiver blocking performance.

Frequency Offset	Receiver Blocking Performance
50 kHz to 100 kHz	- 40 dBm
100 kHz to 200 kHz	- 35 dBm
200 kHz to 500 kHz	- 30 dBm
> 500 kHz	- 25 dBm

Table 12
Victim Radio System B Mobile Station Blocking Characteristics

As the density of users for radio system A can change from place to place, several cell sizes have been considered, to each of them corresponds a maximum power, that has been determined considering a minimum interferer link availability of around 93 %.

In Table 13, SC is the cell size in km^2, Pmth (dBm) is the theoretical maximum power issued from J.C. Jakes method (α = 3,5 σ = 9 dB), PM (dBm) is the actual maximum power taking into account the limitations due to the power control characteristics (dynamic range and step size).

CELL SIZE, SC	Cell Radius	Pmth	PM
16 km^2	**2.26 km**	33 dBm	33 dBm
8 km^2	**1.60 km**	27.7 dBm	29 dBm
4 km^2	**1.13 km**	22.4 dBm	23 dBm
3.2 km^2	**1.01 km**	20.7 dBm	21 dBm
1.6 km^2	**0.71 km**	15.4 dBm	17 dBm
0.32 km^2	**0.32 km**	3.1 dBm	5 dBm
0.16 km^2	**0.23 km**	- 2.2 dBm	5 dBm

Table 13
Radio System A Mobile Station E-MCL Transmit Powers for various Cell Sizes

The WG SE propagation model in urban conditions at 900 MHz was used.

The general isolation equation is:

$$\text{Isolation} = P_{INT} + dB_{BW} + MC_{INT} + G_{VICT} + G_{INT} - (S_{VICT} - C/I_{VICT}) + f(dBc_{INT,},P_{INT}) - 10 \log (10^{N/10}-1)$$

As the frequency separation between victim and interferer is around 700 kHz the WBN limit value to be considered is Max (- 60 dBc, - 51 dBm).

The transmit power transition PT is such that, PT + 10 log (30/200) - 60 = - 51
PT = 17.2 dBm (with 200 kHz estimated system A signal bandwidth and 30 kHz measurement bandwidth).

If $P_{INT} \leq$ 17,2 dBm

The - 51 dBm limit applies.

dB_{BW} = 10 log (18/30) = - 2.2 dB considering that 18 kHz is the victim system B receiver bandwidth and 30 kHz being the unwanted emissions measurement bandwidth.

MC_{INT} = 0dB ; only one interferer at a time is considered
$G_{VIC} = G_{INT}$ = 0dBi, victim and interferers are mobiles
S_{VIC} = - 103 dBm and C/I_{VIC} = 19 dB
$P_{INT} + dBc_{INT}$ = - 51 dBm.

So:

$$\text{Isolation} = -51 - 2{,}2 + 0 + 0 + 0 + 103 + 19 - 10 \log (10^{N/10} - 1)$$

P ≤ 17.2 dBm : isolation = 68.8 dB if N = 3 dB
: isolation = 59.3 dB if N = 10 dB

If $P_{INT} \geq$ 17,2 dBm

The - 60 dBc limit applies.

dB_{BW} = 10 log (30/200) + 10 log (18/30) = - 10.5 dB, 18 kHz being the victim receiver bandwidth, 200 kHz the estimation of a system A interferer signal bandwidth and 30 kHz the measurement bandwidth.

MC_{INT}, G_{VIC}, G_{INT}, S_{VIC}, C/I_{VIC} are unchanged
$P_{INT} + dBc_{INT}$ = (P - 60) dBm, P being the actual interferer mobile power.

So :

$$\text{Isolation} = P - 10{,}5 + 0 + 0 + 0 + 103 + 19 - 60 - 10 \log (10^{N/10} - 1)$$

P ≥ 17.2 dBm : isolation = (P + 51,5) dB if N = 3 dB
: isolation = (P + 42) dB if N = 10 dB

As a function of each transmit power (P) the necessary isolation (ISO) and the corresponding separation distance (ds) have been calculated in Tables 14 and 15.

P(dBm)	ISO(dB)	ds(m)
33 dBm	84.5	57
31 dBm	82.5	55
29 dBm	80.5	53
27 dBm	78.5	52
25 dBm	76.5	50
23 dBm	74.5	48
21 dBm	72.5	46
19 dBm	70.5	45
17 dBm	68.8	44
< 17 dBm	68.8	44

Table 14
E-MCL Isolations and Separation Distances for N = 3 dB (‘W.C. Jakes victim link availability of 82.5%’)

P(dBm)	ISO(dB)	ds(m)
33 dBm	75	49
31 dBm	73	47
29 dBm	71	45
27 dBm	69	44
25 dBm	67	42
23 dBm	65	41
21 dBm	63	38
19 dBm	61	30
17 dBm	59.3	25
< 17 dBm	59.3	25

Table 15
E-MCL Isolations and Separation Distances for N = 10 dB (‘W.C. Jakes victim link availability of 95 %’)

Following the procedure previously explained to estimate aver(ds) when power control in the interfering system applies the results in Tables 16 and 17 are obtained (with $\alpha = 3.52$).

SC (km^2)	Cell Radius	PM (dBm)	ds(m) no PC[5]	Aver(ds) (m) with PC
16	**2.26 km**	33	57.0	51.8
8	**1.60 km**	29	53.2	48.8
4	**1.13 km**	23	48.1	45.3
3.2	**1.01 km**	21	46.4	44.5
1.6	**0.71 km**	17	43.6	43.6
0.32	**0.32 km**	5	43.6	43.6
0.16	**0.23 km**	5	43.6	43.6

Table 16
E-MCL Mean Separation Distances for N = 3 dB (‘W.C. Jakes victim link availability of 82.5%’)

SC (km^2)	Cell Radius	PM (dBm)	ds(m) no PC[6]	Aver(ds) (m) with PC
16	**2.26 km**	33	48.5	42.1
8	**1.60 km**	29	45.3	38.2
4	**1.13 km**	23	40.9	31.3
3.2	**1.01 km**	21	37.6	28.5
1.6	**0.71 km**	17	24.5	24.5
0.32	**0.32 km**	5	24.5	24.5
0.16	**0.23 km**	5	24.5	24.5

Table 17
E-MCL Mean Separation Distances for N = 10 dB (‘W.C. Jakes victim link availability of 95 %’)

The interferer’s effect is lower when power control is activated. Also ds and aver(ds) are smaller for N = 10 dB than for N = 3 dB, that means when the intrinsic quality of the victim link is higher.

On the other hand, the influence of the power control is higher when the maximum power within the interfering system is large due to the nature of the WBN limit: max (- 60 dBc, - 51 dBm).

[5] When power control is not activated the interfering transmit power is fixed and equal to PM, PM being a function of cell size.
[6] When power control is not activated the interfering transmit power is fixed and equal to PM, PM being a function of cell size.

To estimate this effect, the results in Table 18 are provided in the case of N = 10 dB considering only (-60 dBc) instead of max (-60 dBc, -51 dBm) as approximated limit for the interfering wideband noise

SC (km^2)	Cell Radius	PM (dBm)	ds(m) no PC[7]	Aver(ds) (m) with PC
16	**2.26 km**	33	49	41
8	**1.60 km**	29	45	36
4	**1.13 km**	23	41	27
3.2	**1.01 km**	21	38	23
1.6	**0.71 km**	17	24	15
0.32	**0.32 km**	5	6	6
0.16	**0.23 km**	5	6	6

Table 18
E-MCL Mean Separation Distances for N = 10 dB ('W.C. Jakes victim link availability of 95 %' with approximated limit = - 60 dBc)

2.2.6.2 Blocking E-MCL analysis – Mobile Station to Mobile Station

The victim and interferer system parameters are the same as for the unwanted emissions analysis. For blocking analysis the general equation for isolation to be considered is:

$$\text{Isolation} = P_{INT} + MC_{INT} + G_{VICT} + G_{INT} - f(B_{VICT},S_{VICT}) - 10 \log (10^{N/10}-1)$$

where:

MC_{INT} = 0 dB (only one interferer at a time)
G_{VICT} = 0 dBi
G_{INT} = 0 dBi
$f(B_{VICT}, S_{VICT})$ = - 25 dBm
N = 3, 10 dB

N = 3 dB and 10 correspond to respectively 82,5% and 95% intrinsic victim link availability (W.C. Jakes margin estimation).

Therefore:

$$\text{Isolation} = P_{INT} + 0 + 0 + 0 + 25 - 10 \log (10^{N/10}-1)$$
$$\text{Isolation} = P_{INT} + 25 - 10 \log (10^{N/10}-1)$$

with N = 3 dB, isolation = P_{INT} + 25
with N = 10 dB, isolation = P_{INT} + 15.5

[7] When power control is not activated the interfering transmit power is fixed and equal to PM, PM being a function of cell size.

As a function of each transmit power (P) the necessary isolation (ISO) and the corresponding separation distance (ds) have been estimated using the mean propagation attenuation of the WG SE model (urban, 900 MHz, MS/MS).

P(dBm)	ISO(dB)	ds(m)
33 dBm	58	21.1
31 dBm	56	16.8
29 dBm	54	13.3
27 dBm	52	10.6
25 dBm	50	8.41
23 dBm	48	6.68
21 dBm	46	5.31
19 dBm	44	4.22
17 dBm	42	3.35
15 dBm	40	2.66
13 dBm	38	2.11
11 dBm	36	1.68
9 dBm	34	1.33
7 dBm	32	1.06
5 dBm	30	0.84

Table 19
E-MCL Isolations and Separation Distances for N = 3 dB

P(dBm)	ISO(dB)	ds(m)
33 dBm	48.5	7.08
31 dBm	46.5	5.62
29 dBm	44.5	4.47
27 dBm	72.5	3.55
25 dBm	40.5	2.82
23 dBm	38.5	2.24
21 dBm	36.5	1.78
19 dBm	34.5	1.41
17 dBm	32.5	1.12
15 dBm	30.5	0.89
13 dBm	28.5	0.71
11 dBm	26.5	0.56
9 dBm	24.5	0.45
7 dBm	22.5	0.35
5 dBm	10.5	0.28

Table 20
E-MCL Isolations and Separation Distances for N = 10 dB

Following the procedure explained previously to estimate aver(ds) when power control applies, the results in Tables 21 and 22 are obtained (with $\alpha = 3.52$)

SC (km^2)	Cell Radius	PM (dBm)	ds(m) no PC[8]	Aver(ds) (m) with PC
16	**2.26 km**	33	21	13
8	**1.60 km**	29	13	7.9
4	**1.13 km**	23	6.7	4.0
3.2	**1.01 km**	21	5.3	3.2
1.6	**0.71 km**	17	3.3	2.1
0.32	**0.32 km**	5	0.84	0.84
0.16	**0.23 km**	5	0.84	0.84

Table 21
E-MCL Mean Separation Distances for N = 3 dB (‘W.C. Jakes victim link availability of 82.5 %’)

SC (km^2)	Cell Radius	PM (dBm)	ds(m) no PC[9]	Aver(ds) (m) with PC
16	**2.26 km**	33	7.1	4.2
8	**1.60 km**	29	4.5	2.7
4	**1.13 km**	23	2.2	1.3
3.2	**1.01 km**	21	1.8	1.1
1.6	**0.71 km**	17	1.1	0.69
0.32	**0.32 km**	5	0.28	0.28
0.16	**0.23 km**	5	0.28	0.28

Table 22
E-MCL Mean Separation Distances for N = 10 dB (‘W.C. Jakes victim link availability of 95 %’)

The separation distance figures less than 1 m are questionable in practice. Comparing these results with those from the unwanted emissions analysis it is clear that wideband noise is the dominant interfering mechanism for this scenario.

It appears also that power control has greater influence for blocking than for unwanted emissions, this behaviour is due to the WG SE propagation model where the attenuation is more sensitive to the distance between transmitter and receiver for distances above 40 m (unwanted emissions separation distances domain) than for distances below 40 m (blocking separation distances domain).

As for unwanted emissions the effect of power control is inhibited for very small cell sizes (0.32 and 0.16 km^2) due to the minimum limitation at 5 dBm for the interfering mobile transmit powers.

[8] When power control is not activated the interfering transmit power is fixed and equal to PM, PM being a function of cell size.
[9] When power control is not activated the interfering transmit power is fixed and equal to PM, PM being a function of cell size.

2.3 Monte Carlo Theory

A Monte Carlo simulation as used in this report is a statistical technique based upon the consideration of many independent instants in time and locations in space. For each instant, or simulation trial, a scenario is built up using a number of different random variables i.e. where the interferers are with respect to the victim, how strong the victim's wanted signal strength is, which channels the victim and interferer are using etc. If a sufficient number of simulation trials are considered then the probability of a certain event occurring can be evaluated with a high level of accuracy.

Examples of the probability distributions that can be evaluated include:

- the probability of a victim receiver attaining its desired C/I ratio
- the probability distribution of mobile station transmit power

In addition, other outputs can be generated such as:

- the effect of system planning techniques e.g. sectorisation, diversity, antenna co-siting
- the effect of transmitter and receiver performance i.e. unwanted emissions and receiver blocking
- capacity evaluation for CDMA systems
- effects of soft handover for CDMA systems

Spectrum engineers can use the results listed above to help optimise frequency planning and in addition make recommendations, for example radio transmitter and receiver performance e.g. levels of unwanted emissions, adjacent channel rejection, receiver blocking etc.

The description of the Monte Carlo methodology provided in this report is relatively simplistic. It is intended to provide a generic outline rather than a simulation specification. A detailed specification can be found in the WG SE SEAMCAT description document [10].

2.3.1 Monte Carlo as Applied to Radio Systems

Consider one active radio terminal operating amongst a population of radio terminals. The population of radio terminals may belong to the same radio system or to different radio systems. The active radio terminal can be thought of as a victim receiver incurring interference from the surrounding population of active radio terminals. For ease of explanation the victim receiver shall be considered as a mobile station but it is equally possible for it to be a base station. In addition the population of interfering transmitters shall be assumed to be mobile stations whereas it is possible for them to be base stations or a mixture of mobile and base stations.

A Monte Carlo simulation uses many simulation trials – instants in time and locations in space. For each simulation trial a snap shot representation of the scenario is built up. This could involve the following steps –

1. the victim mobile station receiver is randomly placed within one of its cells. The victim system cell size having been specified by the user.

2. the link budget for the victim’s desired signal is evaluated using a path loss model, antenna gain patterns, transmit power, power control algorithm and location of the wanted transmitter.

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[10] CEPT ERC Report 68 Monte Carlo Radio Compatibility Tool, http://www.ero.dk/eroweb/seamcat/seamcat.html . The Monte Carlo results in this document have been produced with several different Monte Carlo tools. Those results are proposed only with the purpose of proposing examples for the reader.

3. a population of interferers is distributed around the victim. This is commonly done using a uniform random distribution but may be done using any user defined distribution if it is required to model specific scenarios e.g. interferer's limited to being within a nearby building. The population of interferers can be either of a single type or a mixture. Characteristics such as the multiple access technique of the interferers need to be considered i.e. if the interferer is FDMA then it will transmit continuously when active but if it is TDMA then it will transmit periodically when active.

4. if power control is to be used by the interferers then receiving terminals corresponding to the interfering transmitters are placed and the link budget evaluated.

5. the characteristics of each interferer are identified. This includes properties such as transmit frequency and power. The user defines a range of permitted transmit channels which may consist of multiple channels or simply a single channel. The transmit power is determined using the appropriate power control algorithm and link budget calculation to the appropriate receiving terminal.

6. the effect of each interferer upon the victim can be accumulated to provide a total interference level received by the victim receiver. Under some circumstances it is possible to reduce the complexity of a simulation by considering only a single interferer. One way would be to include only the dominant or strongest interferer. Another way would be to include only the closest interferer. Considering only a single interferer results in approximately the same result as considering all interferers only under certain circumstances i.e. low interferer densities. In the case of CDMA systems all interferers must be considered to obtain a realistic result. Including all interferers is the most realistic, considering only the closest is the simplest to implement. Considering only a single interferer will generate a more optimistic result, considering the closest one being the most optimistic of the two ways. The extent to which it is more optimistic will be dependent upon the scenario. The interference level received by the victim may include the effect of unwanted emissions which will be dependent upon the unwanted emissions performance of the interferers and the frequency offset between interferer and victim; receiver blocking which will be dependent upon the receiver blocking performance of the victim and the frequency offset between the interferer and victim; intermodulation which will be dependant upon transmit powers and frequency offsets.

7. Once the interference level and the desired signal strength are known a check can be made to determine whether or not the target C/I ratio has been achieved.

The precise Monte Carlo algorithm employed is dependent upon the scenario being modelled. CDMA system analysis requires a more complex algorithm due to the greater interaction between users. For a CDMA system many users operate on the same channel. The victim's noise floor is no longer thermal noise limited but interference limited. The power control algorithm belonging to a CDMA system acts to provide each communication link with the desired C/I ratio accounting for both co-channel and adjacent channel interference. CDMA systems also include features such as soft handover which require modelling to gain a true representation of system performance – soft handover provides a gain at the cell edges where interference is most likely to occur.

2.3.2 Interpretation of the Results

The result of a Monte Carlo simulation is a measure of system performance. It is commonly a probability of interference. Care must be taken when interpreting a probability of interference. The problem is similar to that faced by a system operator when specifying a system availability. A mobile system operator specifies that a system can provide a system availability of 95 %. It is not stated whether this means that 5 % of the users are out of coverage 100 % of the time or that 100 % of the users are out of coverage 5 % of the time. However it is generally understood that the reality is somewhere in between the two extreme limits.

The probability of interference resulting from a Monte Carlo simulation can be interpreted in two stages. First of all, what precisely the simulation is computing and secondly what this relates to in the real world.

Precisely what the simulation is computing will depend upon the scenario being modelled. For simulations where the victims are all treated equally and do not have restrictions placed upon their positions then each will experience the same level of interference. In this case the meaning of the result is that 100 % of the users experience a P % probability of being disturbed. For simulations where the position of some or all of the victims are restricted then it is possible that some victims will experience more interference than others. In this case the meaning of the result will be somewhere between 100 % of the users experiencing a P % probability of being disturbed and P % of users experiencing a 100 % probability of being disturbed.

When interpreting a simulation result in terms of what it means in the real world. A great deal of care needs to be taken. In reality each mobile user is likely to have an individual pattern of mobile terminal usage. This is likely to be related to where that user lives and works. This means that one user may commonly pass through an area of poor signal quality whereas another user may very rarely experience poor signal quality. In this case the P % probability of interference should be interpreted as somewhere between 100 % of the users experiencing a P % probability of being disturbed and P % of users experiencing a 100 % probability of being disturbed.

It should in addition be kept in mind that Monte Carlo simulations should be used to model hotspots or areas of high mobile terminal usage. It is important to recognise that the result produced is specific to that hotspot and does not apply to all areas or to all users.

2.3.3 Monte Carlo Simulation Example

It is possible that spectrum allocations for radio systems A and B lead to the uplink band of radio system A meeting the downlink band of radio system B. The following interference scenarios would result -

- System A mobile station transmissions causing interference to a System B mobile station receiver
- System B base station transmissions causing interference to a System A base station receiver.

The occurrence of interference can be limited by imposing a minimum frequency separation between the two systems. Spectrum efficiency requirements dictate that this separation should be as small as possible. The following two sub-sections apply the Monte Carlo simulation tool to the mobile to mobile interference scenario.

2.3.3.1 Wideband Noise Monte Carlo Analysis – Mobile Station to Mobile Station

Tables 23, 24 and 25 provide the parameters used for a Monte Carlo simulation modelling the mobile to mobile interference scenario

Parameter	Value
No. of Channels	**1**
Mobile Transmit Frequency	**914.8 MHz**
Mobile Channel Spacing	**200 kHz**
Mobile Transmit Bandwidth	**200 kHz**
Mobile Antenna Height	**1.5 m**
Mobile Antenna Gain	**0 dBi**
Mobile Power Control Margin	**10 dB**
Mobile Power Control Step Size	**2 dBm**
Mobile Maximum Transmit Power	**33 dBm**
Mobile Minimum Transmit Power	**5 dBm**
Base Antenna Height	**30 m**
Base Antenna Gain	**11 dBi**
Base Sensitivity	**-104 dBm**

Table 23
Interferering Radio System A Parameters

Frequency Offset	Limit
200 kHz ≤ ΔF < 250 kHz	Max (- 30 dBc, - 36 dBm)
250 KHZ ≤ ΔF < 400 KHZ	Max (- 33 dBc, - 36 dBm)
400 kHz ≤ ΔF < 600 kHz	Max (- 60 dBc, - 36 dBm)
600 kHz ≤ ΔF < 1800 kHz	Max (- 60 dBc, - 51 dBm)
1800 kHz ≤ ΔF < 3000 kHz	Max (- 68 dBc, - 51 dBm)
3000 kHz ≤ ΔF < 6000 kHz	Max (- 70 dBc, - 51 dBm)

Table 24
Interfering Radio System A Mobile Station Unwanted Emissions Performance

Parameter	**Value**
No. of Channels	**1**
Mobile Carrier Frequency	**915.5125 MHz**
Mobile Channel Spacing	**25 kHz**
Mobile Receive Bandwidth	**18 kHz**
Mobile Antenna Height	**1.5 m**
Mobile Antenna Gain	**0 dBi**
Mobile Receiver Sensitivity	**- 103 dBm**
Mobile Protection Ratio	**19 dB**
Base Transmit Power	**44 dBm**
Base Antenna Height	**30 m**
Base Antenna Gain	**11 dBi**

Table 25
Victim Radio System B Parameters

For this relatively simplistic example the following assumptions have been made:

- only a single channel is used by each system i.e. the ones with a worst case frequency separation
- antennas are assumed to be omni-directional in both horizontal and vertical planes
- the closest interferer is assumed to dominate and is the only interferer included in each trial
- the cases of power control and no power control have been considered for the interfering system. No power control has been assumed for the victim.

Simulation results modelling a range of active interferer densities are presented in Table 26.

Active Radio System A Interferer Density	**System A - Cell Radius (km)**	**System A – Cell size (km^2)**	**Probability of Interference with Power Control using WG SE Path Loss Model**	**Prob. of Interf. without Power Control using WG SE Path Loss model**
2 / km^2	**2.26**	**16**	0.70 %	1.12 %
4 / km^2	**1.60**	**8**	1.13 %	2.18 %
8 / km^2	**1.13**	**4**	1.78 %	4.24 %
10 / km^2	**1.01**	**3.2**	2.07 %	5.24 %
20 / km^2	**0.71**	**1.6**	3.14 %	10.07 %
100 / km^2	**0.32**	**0.32**	12.18 %	37.72 %
200 / km^2	**0.23**	**0.16**	19.59 %	56.76 %

Table 26
The Probability of Interference due to wideband noise for a Radio System B MS victim to Interference from a Population of Radio System A MSs using a Radio System B Area Availability = 95 %

The cell sizes are then set according to the active user density. The use of power control has a significant effect upon the probability of interference especially in scenarios with a high active user density. The greater the active user density, the smaller the cell size and the more transmit power can be reduced.

It should be noted that the second column of results (when power control is not active and interfering transmit power is fixed independent of the cell size) is included for information only. Such a radio system would suffer from large co-channel interference problems. The small cell sizes required to provide the capacity to support the higher user densities mean that there would be considerable interaction between cells using the same channels – unless a giant frequency reuse pattern was employed.

2.3.3.2 Receiver Blocking Monte Carlo Analysis – Mobile Station to Mobile Station

A similar analysis can be completed using receiver blocking as the interference mechanism. Table 27 provides the receiver blocking characteristic assumed for the victim radio system B.

Frequency Offset	Receiver Blocking Performance
50 kHz to 100 kHz	- 40 dBm
100 kHz to 200 kHz	- 35 dBm
200 kHz to 500 kHz	- 30 dBm
> 500 kHz	- 25 dBm

Table 27
Victim Radio System B Mobile Station Blocking Characteristics

Table 28 provides some example figures for the probability of interference due to receiver blocking. The parameters and assumptions from the previous section have been used.

Active Radio System A Interferer Density	System A Cell size (km^2)	System A Cell Radius	Probability of Interference with Power Control using WG SE Path Loss Model	Prob. of Interf. without Power Control using WG SE Path Loss model
2 / km^2	**16**	**2.26 km**	0.01 %	0.05 %
4 / km^2	**8**	**1.60 km**	0.02 %	0.08 %
8 / km^2	**4**	**1.13 km**	0.02 %	0.16 %
10 / km^2	**3.2**	**1.01 km**	0.03 %	0.19 %
20 / km^2	**1.6**	**0.71 km**	0.03 %	0.38 %
100 / km^2	**0.32**	**0.32 km**	0.11 %	1.85 %
200 / km^2	**0.16**	**0.23 km**	0.17 %	3.48 %

Table 28
The Probability of Interference due to Receiver Blocking for a Radio System B MS victim to Interference from a Population of Radio System A MSs using a Radio System B Area Availability = 95 %

Levels of interference due to receiver blocking are considerably less than those due to unwanted emissions. Thus for this scenario unwanted emissions are the dominant interference mechanism.

2.4 Comparisons

This section compares the Monte Carlo (MC) statistical analysis using a number of randomly placed interferers (on the basis of developments within WG SE) with the Minimum Coupling Loss (MCL) method based on minimum receiver sensitivity and the Enhanced Minimum Coupling Loss (E-MCL) method. Some principle features are discussed and an example is used to compare the results of the three methods. Table 29 provides an initial comparison.

Boundary Conditions	MCL	E-MCL	MC
System Availability	predetermined as specified in the wanted signal box	predetermined as specified in the wanted signal box	predetermined as an input parameter but the instantaneous availability will vary from trial to trial
Wanted Signal Level	receiver noise level + C/I + 3 dB	receiver Noise Level + C/I + N dB (N depending upon the victim link availability)	probability distribution dependent upon path loss model and power control
Distribution of Interferers	one fixed interferer	basically uniform when power control is activated	selectable by the user, variable in time and location
Path Loss	without fading	with slow fading for availability estimation, but without for separation distance calculation	with slow fading
Propagation Model	required and selectable (converts isolation into distance)	required and selectable (converts isolation into distance)	required and selectable (converts distance into isolation)
Interferer EIRP	fixed	depends upon special functions e.g. power control	variable from trial to trial (depends on special functions e.g. power control)
Channel Allocation	single channel used	single or multiple channels can be used	single or multiple channels can be used
Necessary Tools	very easy - simple calculator	semi-analytical – mix of calculator and computer	more complex - computer
Selection of Parameters	simplistic	fixed	fixed or following a probability distribution
Benefits	minimum co-ordination	order of magnitude with confidence of result, physically easy to interpret	more precise (especially in the case of high interferer densities), more flexible, ability to evaluate good spectrum efficiency
Applicability	single highly specific scenarios	statistical scenarios	statistical scenarios with highly complex protocols[11]
Result	isolation, which can be converted into geographical distance or frequency separation – careful interpretation (see Section 2.1.1)	Isolation converted into (mean) separation distance and probability of interference for a given frequency separation – careful interpretation (see Section 2.2.5)	probability of interference with a given frequency separation – careful interpretation (see Section 2.3.2)

Table 29A
Comparison of the Enhanced Minimum Coupling Loss Method, Minimum Coupling Loss Method and Monte Carlo Simulation

[11] particularly applicable to scenarios involving mobiles

2.4.1 Comparing the Results of the MCL, E-MCL and MC Methods

As an example of the results generated by the three techniques, the scenario considered in Section 2.3.2. shall be revisited i.e. a population of radio system A mobiles interfering with a victim radio system B mobile. The MCL method shall be applied first.

2.4.1.1 MCLResults – Mobile Station to Mobile Station

Section 2.1 provided an MCL example for a base station to base station scenario. This section provides a mobile station to mobile station scenario. Table 30 provides the parameters assumed.

Parameter	Value
Interferer Transmit Power	33 dBm
Bandwidth Conversion Factor	10.5 dB
Multiple Carrier Margin	0 dB
Base Antenna Gains	0 dBi
Victim Sensitivity	- 103 dBm
Victim Protection Ratio	19 dB

Table 30
Radio System Parameters for MCL Analysis

Applying the unwanted emissions MCL equation which calculates the isolation required between mobile stations, in this case radio system A and radio system B gives the following result -

$$\text{Isolation (dB)} = P_{INT} + dB_{BW} + MC_{INT} + G_{VICT} + G_{INT} - (S_{VICT} - C/I_{VICT}) + dBc_{INT}$$
$$= 33 - 10.5 + 0 + 0 + 0 - (-103 - 19) + dBc_{INT}$$
$$= 144.5 + dBc_{INT}$$

The path loss and wideband noise characteristics can now be used to determine the necessary geographic and minimum frequency separations required to prevent interference. Table 31 shows the wideband noise characteristic for a 2 Watt radio system A mobile.

Frequency Offset	Wideband Noise Relative to Carrier
200 kHz $\leq f_{offset}$ < 250 kHz	- 30 dBc
250 kHz $\leq f_{offset}$ < 400 kHz	- 33 dBc
400 kHz $\leq f_{offset}$ < 1800 kHz	- 60 dBc
1800 kHz $\leq f_{offset}$ < 3000 kHz	- 68 dBc
3000 kHz $\leq f_{offset}$ < 6000 kHz	- 70 dBc
6000 kHz $\leq f_{offset}$	- 76 dBc

Table 31
The Wideband Noise Characteristic for a 2 Watt Radio System A Mobile

These figures may be applied to the wideband noise MCL analysis result to provide the isolation required as a function of frequency offset. This has been done in Table 32.

Frequency Offset	Isolation	Separation assuming WG SE model
200 kHz ≤ f_{offset} < 250 kHz	114.5 dB	95 m
250 kHz ≤ f_{offset} < 400 kHz	111.5 dB	91 m
400 kHz ≤ f_{offset} < 1800 kHz	84.5 dB	58 m
1800 kHz ≤ f_{offset} < 3000 kHz	76.5 dB	50 m
3000 kHz ≤ f_{offset} < 6000 kHz	74.5 dB	49 m
6000 kHz ≤ f_{offset}	68.5 dB	44 m

Table 32
The Isolation and Physical Separation required for different Radio System A MS to Radio System B MS Frequency Offsets (unwanted emissions analysis)

For this scenario the interferer and victim are both mobiles and may be operating relatively close to one another. If a carrier separation of 712.5 kHz is assumed then 84.5 dB of isolation is required through geographic separation. If the WG SE propagation model is used this equates to approximately 58 m.

Applying the receiver blocking MCL equation to calculate the isolation required between mobiles, gives the following result:

$$\begin{aligned} \text{Isolation (dB)} &= P_{INT} + MC_{INT} + G_{VICT} + G_{INT} - B_{VICT} \\ &= 33 + 0 + 0 + 0 - B_{VICT} \\ &= 33 - B_{VICT} \end{aligned}$$

In this case the multiple carrier margin has been set to zero. This is because the interferer is a mobile and can have only a single carrier at any one time. Table 33 provides the radio system B MS blocking characteristic.

Frequency Offset	MS Receiver Blocking Performance
50 kHz ≤ f_{offset} < 100 kHz	- 40 dBm
100 kHz ≤ f_{offset} < 200 kHz	- 35 dBm
200 kHz ≤ f_{offset} < 500 kHz	- 30 dBm
500 kHz ≤ f_{offset}	- 25 dBm

Table 33
The Radio System B Mobile Station Blocking Characteristic

These blocking levels assume that the radio system B receiver is operating 3 dB above sensitivity and when the blocking signal is present performance is reduced to that which would be obtained if the receiver were operating at sensitivity without an interfering signal.

Applying these figures to the isolation result (33 - B_{VICT}), generates the figures in Table 34.

Frequency Offset	Isolation	Separation assuming WG SE model
50 kHz ≤ f_{offset} < 100 kHz	73 dB	47 m
100 kHz ≤ f_{offset} < 200 kHz	68 dB	44 m
200 kHz ≤ f_{offset} < 500 kHz	63 dB	38 m
500 kHz ≤ f_{offset}	58 dB	21 m

Table 34
The Isolation and Physical Separation required for different Radio System A MS to Radio System B MS Frequency Offsets (receiver blocking analysis)

Comparing these isolation figures with those in Table 32 it is clear that wideband noise is the dominant interference mechanism for a radio system B mobile station using frequencies adjacent to a radio system A mobile station.

2.4.1.2 E-MCL Results – Mobile Station to Mobile Station (unwanted emissions)

This analysis has already been completed in Section 2.2.5.1. The results are repeated here for convenience.
Only the unwanted emissions analysis is provided as this is the dominant case. An interferer/victim carrier separation of 712.5 kHz has been assumed.

As a function of radio system A cell sizes the following E-MCL results (separation distances (without power control) and mean separation distances (with power control) in the interfering system) were obtained for N = 10 dB corresponding to a victim down link availability equal to approximately 95%.

SC (km^2)	Cell Radius (km)	PM (dBm)	ds(m) no PC	Aver(ds) (m) with PC
16	**2.26**	33	48.5	42.1
8	**1.60**	29	45.3	38.2
4	**1.13**	23	40.9	31.3
3.2	**1.01**	21	37.6	28.5
1.6	**0.71**	17	24.5	24.5
0.32	**0.32**	5	24.5	24.5
0.16	**0.23**	5	24.5	24.5

Table 35
E-MCL Mean Separation Distances for N = 10 dB (‘W.C. Jakes victim link availability of 95 %’) – unwanted emissions analysis

where.

- SC = radio system A cell sizes
- PM = maximum radio system A mobiles power within the cell corresponding approximately to an interferer uplink availability of 93% at least when SC > 0.32 km^2
- ds = separation distance without power control but where PM applies
- aver(ds) = mean separation distance with power control in the interfering system.

2.4.1.3 MC Results – Mobile Station to Mobile Station (unwanted emissions)

A similar analysis has already been completed using the Monte Carlo simulation tool in section 2.3.2.1.
The probabilities of interference generated for a number of active interferer densities are shown in Table 36.

Active Radio System A Interferer Density	Cell size (km^2)	System A Cell Radius	Probability of Interference with Power Control using WG SE Path Loss Model	Prob. of Interf. without Power Control using WG SE Path Loss model
2 / km^2	16	**2.26 km**	0.70 %	1.12 %
4 / km^2	8	**1.60 km**	1.13 %	2.18 %
8 / km^2	4	**1.13 km**	1.78 %	4.24 %
10 / km^2	3.2	**1.01 km**	2.07 %	5.24 %
20 / km^2	1.6	**0.71 km**	3.14 %	10.07 %
100 / km^2	0.32	**0.32 km**	12.18 %	37.72 %
200 / km^2	0.16	**0.23 km**	19.59 %	56.76 %

Table 36
The Probability of Interference due to wideband noise for a Radio System B MS victim to Interference from a Population of Radio System A MSs using a Radio System B Cell Radius of 4 km (Area Availability using WG SE Path Loss Model = 95%)

These probabilities of interference are for a minimum carrier separation of 712.5 kHz and there was no restriction upon the physical separation between interferer and victim.

2.4.1.4 A Method of Comparing the Monte Carlo and E-MCL Results

The primary result of the E-MCL methods is a length = the separation distance (ds) or the mean separation distance (aver. (ds)). The primary result of the MC methods is an estimated probability = the probability of interference (P).

The E-MCL approach introduces as an input the cell size in the interfering system to estimate the maximum interferer transmit power PM as a function of the coverage availability of the interfering radio link. The MC approach considers also the cell sizes and the availability of coverage within the interfering system, it introduces also the interferers densities correlated to the cell sizes to maintain constant the transmission capacity (number of channels) of the base station.

To compare the results of the two methods to obtain equivalent output parameters with the same physical and operational meaning is necessary. One very simple way is to consider the probability of interference and the interferers density when a MC approach is used :

The interferers density is d.
S = 1/d is defined as the mean individual area per interferer.
The probability of interference is P.
S.P. = P/d is defined as the mean individual disturbing area per interferer. If a victim receiver is close from one interferer (Ii) that means in one of such individual area per interferer (Si), when it stays very close from it, e.g. in a fraction PiSi of Si it is disturbed when it stays in the complementary fraction (1-Pi)Si of Si it is not disturbed. PiSi is one disturbing individual area. Considering now all the interferers within the system, averaging can be made and all the Pi, Si and PiSi can be globally replaced by P, 1/d and P/d respectively.

dD = $\sqrt{P / \pi d}$ is defined as the radius of the mean individual disturbing area
dD (MC method) and aver.(ds) (E-MCL method) are obviously of the same nature and so will be used to efficiently compare the results of the two approaches

Interferer parameters			**Monte Carlo**		**E-MCL**		**MCL**	
Active Interferer Density	**Cell Radius**	**Cell size (km^2)**	**Probability of Interference**	**Estimated exclusion radius (m)**	**Probability of Interference**	**Average exclusion radius dS (m)**	**MCL Exclusion radius (m)**	**Ratio of MC to E-MCL Results**
2 / km^2	**2.26 km**	16	0.70 %	33.4	1.11 %	42.1		0.63
4 / km^2	**1.60 km**	8	1.13 %	30.0	1.83 %	38.2		0.62
8 / km^2	**1.13 km**	4	1.78 %	26.6	2.46 %	31.3	58	0.72
10 / km^2	**1.01 km**	3.2	2.07 %	25.7	2.55 %	28.5		0.81
20 / km^2	**0.71 km**	1.6	3.14 %	22.4	3.77 %	24.5		0.83
100 / km^2	**0.32 km**	0.32	12.18 %	19.7	18.86 %	24.5		0.65
200 / km^2	**0.23 km**	0.16	19.59 %	17.7	37.71 %	24.5		0.52

Table 37
Comparison of the Results Generated by the Monte Carlo and E-MCL Methodologies assuming interferer / victim carrier separation of 712.5 kHz

Table 37 illustrates the correlation between the results of the Monte Carlo and E-MCL methodologies. For this simple example the results are of the same order of magnitude although at greater interferer densities the figures begin to diverge. This is mainly due to the fact that this method for comparing the MC and EMCL results doesn't take into account the possible overlapping of the exclusion areas around interferers obtained with EMCL. Further details on this point are provided in Annex 2.

2.4.2 Conclusions on MCL, E-MCL and Monte Carlo Comparisons

The main points to be considered are:

- the MCL approach is relatively straight forward, modelling only a single interferer-victim pair. It provides a result which, although spectrally inefficient, guards against the worst case scenario.
- the Monte Carlo approach is a statistical technique which models a victim receiver amongst a population of interferers. It is capable of modelling highly complex systems including CDMA . The result is spectrally efficient but requires careful interpretation (see Section 2.3.2).
- the E-MCL approach provides a useful bridge between the MCL and Monte Carlo methodologies. For relatively simplistic scenarios the results of the E-MCL methodology are of the same order of magnitude as the Monte Carlo. However the methodology is not likely to compare so favourably for all interference scenarios e.g. CDMA scenarios. The result also needs careful interpretation (see Section 2.2.5).

Each methodology has its merits and drawbacks. The choice of which is most appropriate depends upon the criteria being used.

Careful consideration should be given, when determining minimum frequency separation calculations, based upon worst case scenarios, due to current demand for the radio spectrum.

3 CONCLUSIONS

This study has compared three methodologies for the evaluation of minimum frequency separation. These are:

- Minimum Coupling Loss (MCL)
- Enhanced Minimum Coupling Loss (E-MCL)
- Monte Carlo

Each of the methodologies has its merits and drawbacks. The appropriate choice depends upon the criteria used and on the tool available to the user.

The increasing penetration of wireless communications is leading to increased congestion in the radio spectrum. This indicates that one criteria should be the ability of evaluating spectrum efficiency for two radio systems operating adjacent to each other.

Radio systems are becoming more and more complex as the range of services offered is increased. This indicates that another criteria should be the ability to model complex scenarios realistically and with flexibility. Finally, the advent of CDMA systems has led to the concept of soft capacity i.e. capacity is a function of inter and intra system interference. Thus the last criteria is the ability to evaluate capacity, in particular for a CDMA system, for a specific minimum frequency separation and level of interference.

In summary the criteria are:

- the ability of evaluating spectrum efficiency.
- ability to model complex scenarios realistically.
- flexibility.
- ability to evaluate system performance for high density or CDMA systems.

Considering these criteria and the preceding study, the recommended method for evaluating minimum frequency separations is the Monte Carlo simulation. Users of the Monte Carlo simulation should be aware of the following factors :

- the accuracy of the result obtained will rely upon accurate values being assigned to each simulation parameter.
- particular features available in some systems may require dedicated software modules or code.
- simulation parameters may be assigned using values from the relevant radio system standard or using typical equipment values. Care has to be taken in the interpretation of the results, particularly when ~~mixed~~ values of both sources have been used.
- an appropriate path loss model must be used.
- system hot spots may exist where there are unusually high densities of active users potentially generating increased levels of interference
- radio functions such as power control should be included if used in practice. In addition special channel types such as control channels should also be modelled.
- the probability of interference which is acceptable will vary from system to system and user to user and needs to be carefully interpreted for the particular scenario.

WG SE has released a specification for a Monte Carlo based radio system compatibility tool. This tool has been named the Spectrum Engineering Advanced Monte Carlo Analysis Tool (SEAMCAT). It is referred to in document ERC Report 68 'Monte Carlo Radio Compatibility Tool' [12]. SEAMCAT is more sophisticated than the Monte Carlo radio compatibility tool used in this study. It is recommended that once SEAMCAT is available CEPT Administrations use it to evaluate minimum frequency separations between adjacent systems.

SE7 had discussions on which could be the allowable percentage of interference: no specific figure is recommended, because this has to be chosen depending on the systems and services involved and the specific scenario which has been considered for the compatibility study. It is strongly recommended that such figure is carefully identified on a case by case basis, by the relevant Working Groups and Task Groups of the CEPT, based on both technical elements and economical/operational constraints (including safety requirements).

[12] CEPT ERC Report 68 Monte Carlo Radio Compatibility Tool, http://www.ero.dk/eroweb/seamcat/seamcat.html

APPENDIX A

Relevant Documents for Information 1995

SE7(95)62 Compatibility Studies Concerning the Introduction of TETRA in 900 MHz Band.

SE7(95)63 TETRA - GSM Compatibility.

SE7(95)74 Further Results on TETRA - GSM Compatibility.

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SE7(95)106 UIC System Scenarios.

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SE7(98)48 E-MCL Simulation Method Paper from ICP, Portugal

These and other relevant documents are obtainable from :

Chairman of SE7 Roger Williams at ;
Radiocommunications Agency
14R / 3B, Wyndham House
189 Marsh Wall
LONDON E14 9SX
United Kingdom

APPENDIX B

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APPENDIX C

PATH LOSS MODELS

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APPENDIX D

ABBREVIATIONS

BS	Base Station
CDMA	Code Division Multiple Access
CEPT	European Conference of Posts and Telecommunications Administrations
E-MCL	Enhanced Minimum Coupling Loss
MC	Monte Carlo
MCL	Minimum Coupling Loss
MS	Mobile Station
SE	Spectrum Engineering
SEAMCAT	Spectrum Engineering Advanced Monte Carlo Analysis Tool
TDMA	Time Division Multiple Access
WG	Working Group

ANNEX 1

INVERSION OF SEAMCAT PROPAGATION MODEL

In order to produce a compatibility study using the E-MCL approach, it is necessary to choose a propagation model. This is needed for the estimation of a separation distance which corresponds to a certain isolation.

E-MCL method has been developed in order to be able to produce analytical analysis which should give similar results to those obtained with a Monte Carlo approach. In order to make a comparison it is important to use the same propagation model.

The propagation model described in the ERC Report 68 is a modified Hata model, which takes into account the fading, of which the effect is described for a certain distance by a log-normal distribution. The model is given in figure 1, for antenna heights of 1.5 m and a frequency of 915 MHz (the figure shows the mean path loss (Lm) and the curves corresponding to the Lm ±σ and Lm ±3σ.

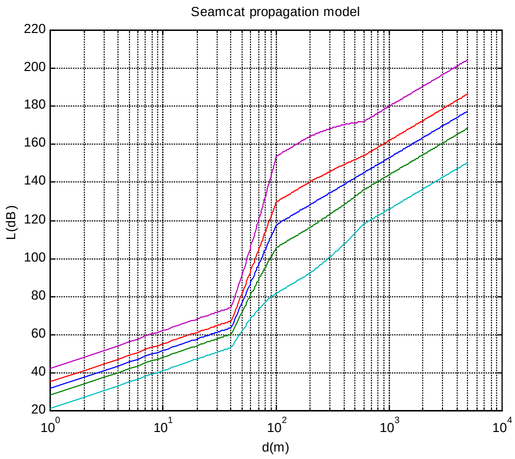


FIGURE A1

Inverting this path loss distribution is not a trivial exercise. For each d the figure shows P(L|d) in terms of mean value and log-normal distribution. We are interested in P(d|L). Using common Bayes transformation, we have:

$$p(d|l) = \frac{p(d,l)}{p(l)} = \frac{p(l|d)p(d)}{p(l)}$$

We need now to estimate P(d) and P(l). For P(d) we make the assumption (justified by the uniform distribution of the mobiles in Monte Carlo approach) that this is a uniform surface distribution, so that:

$$p(d) = \frac{2.d}{R_{simul}^2},$$

where:

R_{simul} is an arbitrarily great analysis radius (i.e. 10 km). We have for P(l):

$$p(l) = \int_0^{R_{simul}} p(l/d)p(d)\partial d = \int_0^{R_{simul}} \frac{1}{\sqrt{2.\pi.\sigma^2}} \exp\left(\frac{-(l-Lm)^2}{2.\sigma^2}\right).\frac{2d}{R_{simul}^2}\partial d$$

But the problem is that we should make this integration for $R_{simul} \rightarrow \infty$. But this would lead to a big mistake, because the propagation model is not valid after a certain distance. So an approximation is required. We decided to limit the calculation of P(d|l) to the range of L included between [min(Lm)+3σ; max(Lm)-3σ]. The rationale for this is that, due to the log-normal distribution, 99% of the probability of

P(l|d) for a certain d is comprised in the range [Lm(d)-3σ(d);Lm(d)+3σ(d)]. The result is showed in figure 2, compared to the inversion of the mean path loss Lm.

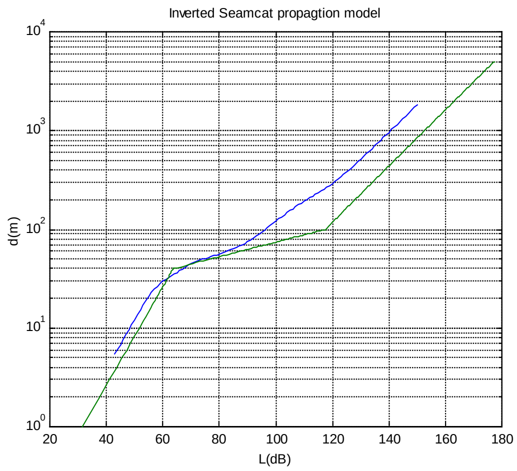


FIGURE A2

The interpretation of the asymptotic trend of the curve is quite easy: when σ is not varying with the distance, given a certain figure for L, as the higher distances are more probable, that figure has more chances to be the result of a higher distance with low attenuation due to fading than of a low distance with strong fading attenuation.

ANNEX 2

IMPACT OF THE INTERSECTION OF INTERFERING ZONES IN THE EMCL ANALYSIS

In section 2.4.1.4 a simplistic approach has been proposed in order to compare the results produced by a Monte Carlo simulation to those obtained with an EMCL calculation. In particular the latter gives as a result an exclusion radius, which defines the area around an interferer where the victim would be interfered with. The issue is that of giving a relationship between this exclusion radius and the probability of interference.

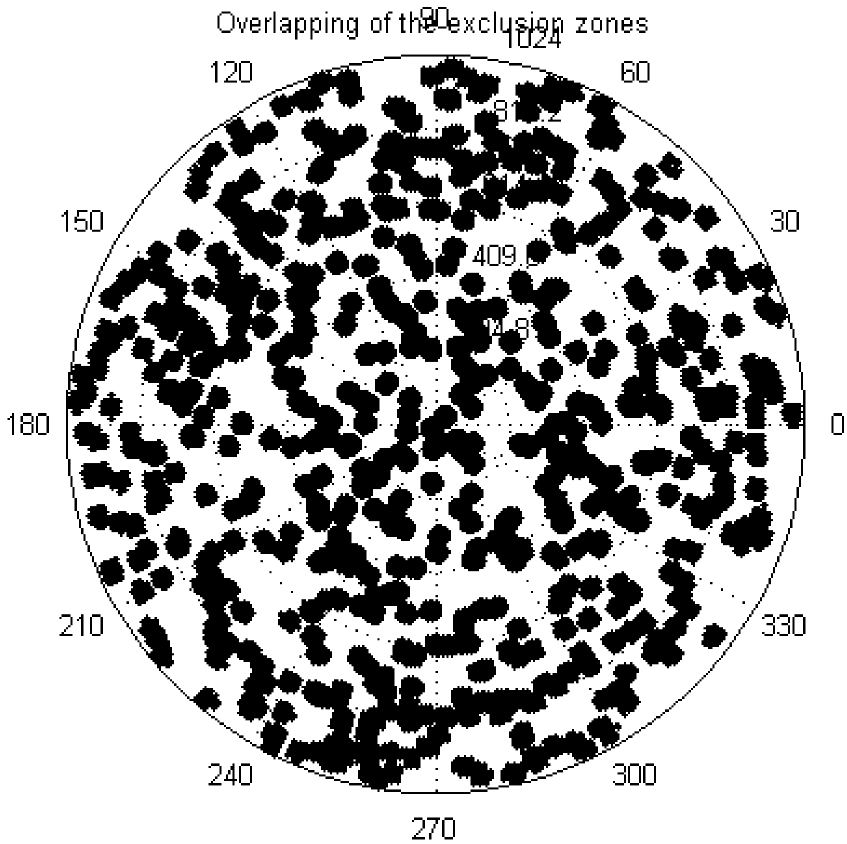
The method is summarised by the simple formula:

$$P = D * \pi * (ds)^2,$$

where D is the density of the interferers, ds is the exclusion radius and P is the resulting probability of interference to be compared to the result of a Monte Carlo simulation.

The equation above doesn't take into account the mitigation factor due to the intersection of exclusion areas. In other words, when more than one exclusion areas are not completely independent (separated), the probabilities of interference associated to each one cannot be simply added to give the total probability of interference.
We produced a simple program in order to estimate case-by-case the probability of interference which could be associated to an EMCL analysis, taking into account the intersections. As it is barely impossible or at least very complicated to estimate the probability of intersection of all the exclusion zones, a Monte Carlo (!!) approach has been used. The advantage of this approach is that the Monte Carlo is used in a very simple way and it does not give the possibility of misleading incorrect interpretation.
The program randomly places the interferers within an analysis surface and calculates the probability of interference as number of interfered points on total number of points. Making it several times and averaging can give an idea of a reduction factor α characteristic of the considered scenario, to be included in the equation above.

The figure below shows the result of one trial and it is possible to see the overlap of several circles (exclusion zones).



Producing the entire calculation it is possible to realise that the figure for α in the case of a density of interferers of 200 users per km² and an exclusion radius of 24.5 m is around 0.8, so that the resulting probability of interference is around 30.7% (to be compared to the previous result of 37.7% obtained with the simple formula of section 2.4.1.4).

ANNEX 3

EXPLANATION OF THE « 10 Log($10^{N/10}$ - 1) » TERM

MCL Background

The isolation equation in the classical Minimum Coupling Loss (MCL) method is such that the necessary isolation obtained from that equation corresponds to a received interference level equal to the internal noise level of the victim receiver and as an implicit assumption with a signal to (noise + interference) ratio equal to the receiver protection ratio.

In other words that isolation figure corresponds also to the situation where the received wanted signal level is 3 dB above the sensitivity of the victim receiver with always the same implicit hypothesis as above.

We have :

s_L : sensitivity (S_L in dB)

b : internal noise level (B in dB)

s : wanted signal level (S in dB)

p : protection ratio (P = (C/I) threshold in dB)

i : interference level (I in dB)

The MCL equation is such that with a linear scale :

i = b (basic MCL assumption)

$s_L/b = p$ (by definition of s_L as a function of p (or of p as a function of s_L)).

$s/(b + i) = p$ (implicit assumption)

so $s/(b + i) = s/2b = p = s_L/b$

consequently $s = 2\ s_L$ or $S = S_L + 3$ dB

The EMCL case

Now one of the Enhanced Minimum Coupling Loss (EMCL) feature is to generalise that « 3dB » figure to a « N dB » figure (« n » in linear scale) N being a function of the considered interfering scenario mainly of the intrinsic victim link quality.

We have now :

$s = n\ s_L$ ($S = N + S_L$ in dB)

and always

$s_L/ b = p$ ($S_L - B = P$ in dB)

and

$s / (b + i) = p$ (implicit assumption)

so

$p(b + i) = s = n\ s_L = npb$

$i = (n - 1)\, b$ instead of $i = b$ using the classical MCL method.

with

$$10 \log i = I \qquad \text{or } i = 10^{I/10}$$

$$10 \log b = B \qquad \text{or } b = 10^{B/10}$$

$$10 \log n = N \qquad \text{or } n = 10^{N/10}$$

$$10 \log (n-1) = 10 \log (10^{N/10}-1)$$

so

$$\mathbf{I = 10 \log (10^{N/10} - 1) + B \qquad (in\ dB)}$$

Conclusion on the explication

The comparison of $I = B$ (MCL) and $I = 10 \log (10^{N/10} -1) + B$ (E.MCL) shows that the necessary isolation using the EMCL method with a N dB figure is $10 \log (10^{N/10} -1)$ dB lower that the one using the MCL method where N = 3 dB systematically.

Remark 1 : obviously when N = 3 dB we have :

$$n = 10^{N/10} = 2$$

$$n -1 = 1$$

and $$10 \log (n-1) = 10 \log (10^{N/10} -1) = 0 \text{ dB}$$

Remark 2 : In the MCL and EMCL methods as well as in the Monte Carlo (MC) simulations, the interfering signal is assumed to look as a thermal noise for the victim receiver. In fact this assumption is in some cases a rough simplification of the reality.