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

ADJACENT BAND COMPATIBILITY OF TETRA AND TETRAPOL IN THE 380 - 400 MHZ FREQUENCY RANGE, AN ANALYSIS COMPLETED USING A MONTE CARLO BASED SIMULATION TOOL

Naples, February 2000

EXECUTIVE SUMMARY

TETRA and TETRAPOL are two technologies for digital trunked PMR. The TETRA standard (ETS 300 392) has been developed by ETSI. The TETRAPOL Public Available Specification (PAS) has been developed by the TETRAPOL Forum Technical Working Group, based on the generic ETSI EN 300 113 standard. These two technologies are used, in particular, for digital land mobile radio-communications for the emergency services. The ERC Decision ERC/DEC/(96)01 designates the bands 380-385 MHz and 390-395 MHz as frequency bands for use by such systems.

This study, based on Monte-Carlo simulations, has analysed a large range of interference scenarios related to the coexistence between TETRA and TETRAPOL in adjacent channels for the emergency services. It includes consideration of compatibility issues within a single country, at a border area and 'direct mode' (terminal to terminal communication without, necessarily, connection through the network). Within this range of scenarios the influence of a number of factors has been tested, such as: density of interferers, distance from the victim to the border, power control, BS antenna elevation discrimination, frequency plan and co-ordination, type of interference mechanisms. Further work would be required to model more specific scenarios within CEPT administrations. The following conclusions can be drawn.

- **Typical operating conditions :**
  Under typical operating conditions, TETRA and TETRAPOL are able to coexist within a single country or neighbouring border areas, without guard bands and in accordance with accepted frequency plans, (see Figure 1, within Section 2). Under typical working conditions (in terms of density of interferers and distance to the border) the estimated values of the probability of interference appear operationally acceptable - even when some features such as power control or discrimination of the BS antennas are not taken into account. The effect of such features being to reduce the risk of interference.

- **Special circumstances :**
  - High density of active interferers : it has been found that, when the density of interferers is very high, the estimated probability of interference to the victim BS can be large. However, for these scenarios, the elevation discrimination of the BS antennas has generally not been taken into account. Additional simulations have been made to assess the influence of this factor. It results in a significant reduction in the probabilities of interference, especially when there is a large number of interferers in the close vicinity of the victim BS, leading to more acceptable levels of interference.
    For the most critical scenarios, local frequency coordination arrangements could help reduce compatibility problems.

  - Direct mode : TETRA or TETRAPOL direct mode may cause higher levels of interference to a user of the other system when compared to network mode, especially when the victim is in the close vicinity of a direct mode user group. This is mainly due to the fact that power control is not implemented for direct mode and the density of interferers is higher for the special cases studied when direct mode operation is involved.
    For the most specific scenarios where a very high density of interferers operating in direct mode is expected, frequency coordination may be required to maintain compatibility between TETRA and TETRAPOL on a case by case basis.

  - Compatibility at border areas : at border areas, the levels of interference depend largely on the distance between the victim and the border. These levels are in most cases acceptable. The exceptions may occur in extreme conditions (short distance between the victim and the border in addition to a very high density of interferers and eventual use of direct mode).
    Comparison between 2-country case and 4-country case has been studied. The difference in the results is not significant mainly because the results are derived from the average of a large number of trials. Practically, in very specific cases, it is likely that the levels of interference will be higher in a 4-country case than in a 2-country case.

INDEX TABLE

1 INTRODUCTION

1.1 Background

TETRA and TETRAPOL are two technologies for digital trunked PMR. The TETRA standard, (ETS 300 392), has been developed by ETSI. The TETRAPOL Public Available Specification (PAS) has been developed by the TETRAPOL Forum Technical Working Group, based on the generic ETSI EN 300 113 standard. These two technologies are used, in particular, for digital land mobile radio-communications for the emergency services.

The ERC Decision, of 7 March 1996 on the harmonised frequency band to be designated for the introduction of the Digital Land Mobile System for the Emergency Services (ERC/DEC/(96)01), designates the bands 380-385 MHz and 390-395 MHz as frequency bands for such systems. Furthermore, T/R02-02 gives the harmonised radio frequency channel arrangements for the emergency services operating in the band 380-400 MHz. Whilst, CEPT Technical Recommendation T/R 25-08 gives the planning criteria and coordination of frequencies in the land mobile service in the range 29.7-960 MHz.

Some bi-or multilateral agreements, such as the "Memorandum of Understanding between the Administrations of Belgium, Germany, France, Ireland, Luxembourg, the Netherlands, Switzerland and the United Kingdom concerning coordination of frequencies in the frequency bands 380-385 MHz and 390-395 MHz ", have already successfully been concluded between some CEPT member countries concerning planning criteria and partitioning of the frequency bands in border areas.

1.2 Objectives

The main objectives of this study are :

- Identification of all interference scenarios between TETRA and TETRAPOL in frequency bands used for the emergency services. Scenarios related to the coordination between neighbouring countries are considered.
- Determination of the most critical interference scenarios from a large set of simulations.
- Analysis of the effect on the probabilities of interference provided by different factors such as power control, minimum frequency separation, directivity of the BS antennas. This is done in order to propose some means to ease the coexistence between both systems when interference problems are likely to occur.

2 OVERVIEW OF THE STUDY

The results of this study are taken from simulations based on a Monte-Carlo analysis. Details on this kind of analysis and on some specifics of the simulation tool used for this report are given in Appendix 1. Furthermore, some elements valid for the whole report are presented in this section.

2.1 Identification of the interference scenarios

The interference scenarios studied are grouped into 4 main types, each of which being addressed separately in a section of this analysis.

- MS interfering with MS — Section 3.
- MS interfering with BS — Section 4.
- BS interfering with MS — Section 5.
- BS interfering with BS — Section 6.

MS refers to Mobile Station and BS refers to Base Station of either TETRA or TETRAPOL systems.

2.2 Frequency plan

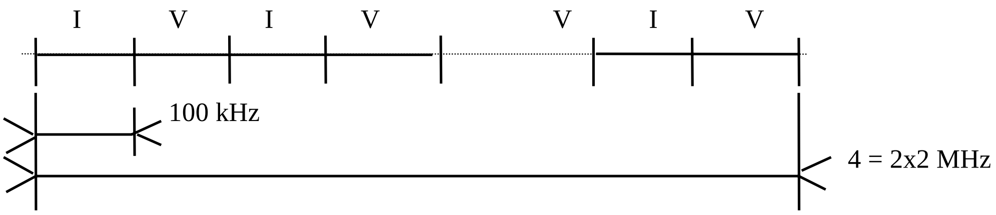
In this study, TETRA and TETRAPOL are assumed to work in the frequency ranges 380 - 384 MHz and 390 - 394 MHz. In all cases, the following allocations are assumed :

- transmission BS = 390 – 394 MHz
- reception BS = 380 – 384 MHz
- transmission MS = 380 – 384 MHz in network mode, both ranges for direct mode
- reception MS = 390 – 394 MHz in network mode, both ranges for direct mode.

Within these ranges, a frequency plan in accordance accepted practice such as the « Memorandum of Understanding between the Administrations of Belgium, Germany, France, Ireland, Luxembourg, the Netherlands, Switzerland and the United Kingdom concerning coordination of frequencies in the frequency bands 380-385 MHz and 390-395 MHz » or other bi or milti-lateral agreements (see Figure 1 below, as an example) has been assumed for the analysis presented in sections 3 to 6:

- 2 MHz is allocated to the interfering system
- 2 MHz is allocated to the victim system.

These 2 MHz are made up of 20 blocks of 100 kHz which are overlapping for the considered systems.



I=Interfering system, V=Victim system.

This frequency separation enables to deal with the case of adjacent band compatibility of the two systems at a border area. Such a separation is typical of the case of a 2-country issue where one system is deployed in a country and the other system in an other country. This case will be used in the major part of this report. In addition, other separation schemes will be analysed in a specific section.

The carrier frequencies are randomly distributed. Considering the values of channel spacing (25 kHz for TETRA, 10 kHz for TETRAPOL), there are 4 TETRA and 10 TETRAPOL carriers per block of 100 kHz.

The minimum spacing between a TETRA carrier and a TETRAPOL carrier is 17.5 kHz. It has been calculated that the proportion of the cases of spacing smaller than 50 kHz is 1.2% and that of the cases smaller than 100 kHz is 4.9%.

In consideration of geographical coexistence, the influence of frequency separation will be analysed by putting some additional local constraints on the frequency distribution in the following way: spacing between the carriers of the interferer and the victim greater than Δf_{min}. The values of Δf_{min}=0, 50 and 100 kHz will be considered. The case which is referred as Δf_{min}=0 does not mean that the same frequency is used by both TETRA and TETRAPOL, but that no additional constraint are considered. In this case, the minimal spacing between the interferer and victim carriers is still 17.5 kHz.

Another frequency plan corresponding to the case of compatibility issues at a border area between 4 countries will be considered and presented in details in section 7.

2.3 General assumptions

Propagation model: In all the analysed scenarios, it is assumed that the deployments of TETRA and TETRAPOL are in urban area. The path loss model is the modified Hata model for urban case specified by WGSE in the Monte-Carlo specification.

Modelling of the distance between the victim and the interferer – Application to the analysis at a border area: In the whole report, it is assumed that the influence of the closest interferer to the victim is the dominant one (see Appendix 1 for justification and details). The distance from the closest interferer to the victim is modelled as follows:

$$d(I \rightarrow V)=d_0+d_R(di) \quad \text{where}$$

d_0 is a fixed distance used in compatibility issues in a border area. In this case, d_0 can be considered as the distance between the victim and the border. $d_0=0$ correspond to the general case without any border consideration. The relevant values for d_0 depend on the considered scenario. They are given in the corresponding sections.

$d_R(di)$ is a random drawing according to a Rayleigh distribution with di=density of instantaneous interferers, the interferers being assumed to be uniformly distributed on the other side of the border.

Use of power control : In this study, power control has been used only for TETRA and TETRAPOL mobiles and not for base stations. Power control for mobiles for both systems is used only when the considered mobile station is being considered as the transmitting part of the interfering system. Considering the victim system, when the mobile is transmitting to its base station, then power control is not considered. Furthermore, power control is assumed not to be used for communications in direct mode.

Interference mechanisms : The results of the simulation are under the form of interference conditional probabilities p in %.

$$P = \text{Prob}\ (i > s - C/I \text{ when } s > so)$$

when s is the useful signal at the victim receiver, C/I is the protection ratio of the victim, s_0 is the sensitivity of the victim and i, the level of interference.

To assess the level of interference, it is assumed that receiver blocking and the unwanted emissions are the dominant interference mechanisms. If there are no specifications, i=iue+ibl, where iue is the interference level due to unwanted emissions and ibl is the interference level due to receiver blocking.

2.4 Estimation of the interferer density

The values of interferer densities have been derived from the values of the sizes of the cells assuming a coverage of 95% for the uplink. The values for the radius are 6.20 km for TETRAPOL and 3.25 km for TETRA. These values of radius cells have been obtained from simulations in order to have a quality of coverage of 95% for the most critical link, i.e. the uplink (MS $\rightarrow$ BS). For each simulation presented in the report, the quality of coverage is given for the victim link. Hence, it is very close to 95% when the victim receiver is a BS and higher when the victim receiver is a MS.

From these values, averaged values of density for Base Stations have been estimated by comparing the characteristics of two possible distributions (average, median and most probable values).

- one corresponding to the case of the simulations made in this report where the BS are randomly distributed with a density d and where the distance from a given point (corresponding to the victim receiver) to the closest BS of the distribution is considered;
- one corresponding to a regular distribution of the BS (according to a hexagonal pattern for example) where the victim receiver is randomly placed into the cell of radius R related to its closest interferer BS and where its distance to the centre of the cell (BS position) is considered.

These comparisons give relations between the cell radius R and the density d of base stations.

Thus, the estimated averaged values of density for the BS are :
d(BS) = 0.010 /km^2 for TETRAPOL;
d(BS) = 0.038 /km^2 for TETRA.

Thus, for base stations, the density values of 0.01, 0.03 and 0.1 /km^2 are considered for this study.

Concerning the mobile stations, if we assume that 20 traffic channels are available per cell and that the loading is estimated at 75%, an average of 15 mobiles per cell is active. From the BS density values, it gives the following averaged densities for the MS :
d(MS) = 0.16 /km^2 for TETRAPOL;
d(MS) = 0.57 /km^2 for TETRA.

In the simulations, it has been decided to consider for the MS as interferers the density values of 0.3, 1.0, 3.0, 10.0 and 30.0. The three last values are worst case values corresponding to very specific cases where there is a high concentration of interferer mobiles in a close vicinity to the victim receiver.

For example, if we consider a density of 30 TETRA mobile interferers, the concentration factor X is

$$X = 30/0.57 = 53,$$

which means that the interferers are distributed in 2% of the whole size of the cell, which is not a very realistic case.

However, these densities are also used for direct mode scenarios for which the density of mobiles can be in very specific cases larger than in network communication. But, even in direct mode scenarios, a density of 30 mobile interferers constitutes a special case.

2.5 Case of communications in direct mode

Both systems TETRA and TETRAPOL have the capability of doing direct mode communications, that is, direct communication between mobile stations without using base station.

Considering the direct mode, there are two possible cases:

Non reversed direct mode
- transmission MS = 380 – 384 MHz
- reception MS = 380 – 384 MHz.

Reversed direct mode
- transmission MS = 390 – 394 MHz
- reception MS = 390 – 394 MHz.

The number of possible scenarios with direct mode will depend on the choice of the basis scenario (i.e. MS→MS, MS→BS or BS→MS), taking into account that the case BS → BS does not include direct mode. It will be detailed in the relevant paragraphs.

It is assumed that for both TETRA and TETRAPOL, power control is not implemented for direct mode.

When the interfering system operates in direct mode, the difference compared to the corresponding network mode scenarios is due to the fact that power control is not considered for mobile stations communicating in direct mode. When the victim system operates in direct mode, the major change is due to the fact that the transmitter of the wanted signal is then a mobile station and not a base station. It implies some modifications in the size of the cell of the victim system, if we want to have in every case similar percentages of coverage.

3 THE EFFECT OF MOBILE STATIONS FROM THE SYSTEM X TO A MOBILE STATION FROM THE SYSTEM Y (MS → MS)

3.1 Specific conditions for the simulations relative to this scenario

In an urban area, the size of the cells for TETRA and TETRAPOL are given below :

R cell TETRA = 3,25 km
R cell TETRAPOL = 6,20 km

Those values correspond to a 95% coverage for the most critical link (MS→BS for both TETRA and TETRAPOL).

The density of active transmitting interferers is d (in km²).

Until now, it has not been possible to agree on the effect of the TDMA structure on the jamming mechanism . For this reason, in the case of TETRA being the interferer, two options for the values of the instantaneous interferers density are considered to reflect the fact that there are 4 users per carrier :
- option a : active interferers density = instantaneous interferers density ; d = di
- option b : active interferers density = 4 x instantaneous interferers density ; d = 4 di .

In the case of TETRAPOL being the interferer, only the first option is considered.

3.2 General results for the case MS → MS

In this paragraph, MS victim is assumed to work in network mode and MS interferers in network mode if PC is on and in direct mode if PC is off. The case of direct mode for MS victim is studied in a following paragraph of this section.

In the case where the interferer and the victim are mobile stations, 4 scenarios have been identified taking into account that it has been decided that the interferer will always transmit in the 380 - 384 MHz range :

- Interferer : TETRA. Victim : TETRAPOL in 380 - 384 MHz
- Interferer : TETRA. Victim : TETRAPOL in 390 - 394 MHz
- Interferer : TETRAPOL. Victim : TETRA in 380 - 384 MHz
- Interferer : TETRAPOL. Victim : TETRA in 390 - 394 MHz.

In each scenario, a big range of values is given corresponding to some possible choices in some parameters (value of the density of active interferers (d), value of the fixed distance necessary to ensure compatibility in a border area (d0) and use or not of the power control for the interfering MS (PC)). The results are given in the tables below.

D	**d0 = 0 with PC** (network	**d0 = 0 without PC** (direct mode)	**d0 = 25 m with PC** (network	**d0 = 25 m without PC** (direct mode)	**d0 = 100 m with PC** (network	**d0 = 100 m without PC** (direct mode)
0.3	0.10/0.03	0.12/0.03	0.02/0.01	0.03/0.01	0.00/0.00	0.00/0.00
1.0	0.33/0.08	0.37/0.10	0.08/0.02	0.09/0.02	0.01/0.00	0.01/0.00
3.0	0.97/0.25	1.10/0.28	0.23/0.06	0.26/0.07	0.02/0.01	0.02/0.01
10.0	3.07/0.82	3.53/0.93	0.70/0.17	0.82/0.22	0.05/0.02	0.06/0.02
30.0	8.43/2.34	9.68/2.69	1.87/0.54	2.21/0.63	0.08/0.04	0.10/0.05

Percentage of coverage for the victim : **97.5%**

Table 1 : Probability of interference of TETRA MS in 380 - 384 MHz to TETRAPOL MS in 380 - 384 MHz

D	**d0 = 0 with PC** (network	**d0 = 0 without PC** (direct mode)	**d0 = 25 m with PC** (network	**d0 = 25 m without PC** (direct mode)	**d0 = 100 m with PC** (network	**d0 = 100 m without PC** (direct mode)
0.3	0.01/0.00	0.01/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00
1.0	0.04/0.01	0.05/0.01	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00
3.0	0.12/0.03	0.13/0.03	0.01/0.00	0.01/0.00	0.00/0.00	0.00/0.00
10.0	0.39/0.10	0.44/0.11	0.02/0.01	0.03/0.01	0.00/0.00	0.00/0.00
30.0	1.13/0.30	1.27/0.33	0.07/0.02	0.08/0.02	0.00/0.00	0.00/0.00

Percentage of coverage for the victim : **97.3%**

Table 2 : Probability of interference of TETRA MS in 380 - 384 MHz to TETRAPOL MS in 390 - 394 MHz

Note : the two values of probability given in Table 1 and Table 2 correspond to the two possible options to describe the effect of the TDMA structure of TETRA (for the first, d=di ; for the second, d=4*di).

D	**d0 = 0 with PC** (network	**d0 = 0 without PC** (direct mode)	**d0 = 25 m with PC** (network	**d0 = 25 m without PC** (direct mode)	**d0 = 100 m with PC** (network	**d0 = 100 m without PC** (direct mode)
0.3	0.03	0.03	0.00	0.01	0.00	0.00
1.0	0.09	0.11	0.02	0.02	0.00	0.00
3.0	0.26	0.33	0.05	0.06	0.00	0.00
10.0	0.84	1.08	0.15	0.19	0.01	0.01
30.0	2.35	3.03	0.40	0.53	0.01	0.02

Percentage of coverage for the victim : **99.1%**

Table 3 : Probability of interference of TETRAPOL MS in 380 - 384 MHz to TETRA MS in 380 - 384 MHz

D	**d0 = 0 with PC** (network	**d0 = 0 without PC** (direct mode)	**d0 = 25 m with PC** (network	**d0 = 25 m without PC** (direct mode)	**d0 = 100 m with PC** (network	**d0 = 100 m without PC** (direct mode)
0.3	0.01	0.01	0.00	0.00	0.00	0.00
1.0	0.02	0.03	0.00	0.00	0.00	0.00
3.0	0.07	0.10	0.00	0.01	0.00	0.00
10.0	0.24	0.33	0.01	0.02	0.00	0.00
30.0	0.69	0.97	0.04	0.06	0.00	0.00

Percentage of coverage for the victim : **99.0%**

Table 4 : Probability of interference of TETRAPOL MS in 380 - 384 MHz to TETRA MS in 390 - 394 MHz

From the 4 tables above, it is possible to make the following observations :

- Effect of active interferers density : the probabilities of interference increase as the density of interferers (d) increases.
- Effect of the value of the fixed distance d0 : d0 ≠ 0 corresponds to an analysis of compatibility at a border area where d0 is the distance between the victim and the border. The probabilities of interference decrease significantly as the distance d0 increases.
- Effect of the use of power control for the interfering mobile stations – Consequences for direct mode : the probabilities of interference decrease with the use of power control. The effect of power control is more significant with high density of active transmitters. Consequently, when the interfering mobile stations operate in direct mode, the probabilities of interference will be slightly higher than in network mode because power control is not used in direct mode.
- Effect of the frequency separation between the victim and the interferers : the case where the two systems are in two different 4 MHz blocks correspond to a constraint on the minimum carrier separation of the order of 10 MHz. The probabilities are lower in this case but the difference is not very important. The fact that this difference is lower than expected can be explained taking into account the dominant interference mechanisms (see section 3.3 below). When the two systems are in different 4 MHz bocks, blocking is the dominant mechanism. Moreover, the blocking characteristics used in the simulations for both TETRA and TETRAPOL are flat for frequency offset greater than 500 kHz. Consequently, in the simulations, the effect of large frequency offset is smaller than it can be expected in practice.
- Comparison between both systems : the results obtained with TETRA as interferer and those with TETRAPOL are of the same order if we consider that, due to the TDMA structure for the TETRA MS, the number of instantaneous interferers to take into account is a quarter of the active interferers (second values of probabilities in the relevant cases). If this assessment is not verified, the probabilities of interference from TETRA MS upon TETRAPOL MS are higher than the probabilities of interference from TETRAPOL MS upon TETRA MS.

3.3 Analysis of the type of interference in the case MS → MS

If we note pue, the probability of interference due to unwanted emissions only, and pbl, the probability of interference due to receiver blocking only, the ratio pue/pbl is an interesting parameter to assess if there is a determinant interference mechanism, and if there is one, which one it is.

D	**d0 = 0 with PC** (network mode)		**d0 = 0 without PC** (direct mode)	
	unwanted emissions	**blocking**	**unwanted emissions**	**blocking**
10.0	3.01/0.80	0.67/0.18	3.46/0.91	0.80/0.21
30.0	8.26/2.29	1.88/0.51	9.51/2.63	2.22/0.60

Table 5 : Influence of the type of interference from TETRA MS in 380 - 384 MHz to TETRAPOL MS in 380 - 384 MHz

In this scenario, pue/pbl=4.4. So, it is possible to conclude that the interference due to unwanted emissions is the dominant mechanism.

D	d0 = 0 with PC (network mode)		d0 = 0 without PC (direct mode)	
	unwanted emissions	**blocking**	**unwanted emissions**	**Blocking**
10.0	0.18/0.05	0.25/0.06	0.18/0.05	0.30/0.08
30.0	0.54/0.14	0.72/0.19	0.53/0.14	0.88/0.23

Table 6 : Influence of the type of interference from TETRA MS in 380 - 384 MHz to TETRAPOL MS in 390 - 394 MHz

Note : the two values of probability given in Table 5 and Table 6 correspond to the two possible options to describe the effect of the TDMA structure of TETRA (for the first, d=di ; for the second, d=4*di).

In this scenario, pue/pbl=0.7. The blocking is dominant but not enough to conclude firmly.

D	d0 = 0 with PC (network mode)		D0 = 0 without PC (direct mode)	
	unwanted emissions	**blocking**	**Unwanted emissions**	**Blocking**
10.0	0.68	0.42	0.87	0.56
30.0	1.89	1.20	2.43	1.61

Table 7 : Influence of the type of interference from TETRAPOL MS in 380 - 384 to TETRA MS in 380 - 384 MHz

In this scenario, pue/pbl=1.6. The effect of unwanted emissions is dominant but not enough to conclude firmly.

D	d0 = 0 with PC (network mode)		d0 = 0 without PC (direct mode)	
	unwanted emissions	**blocking**	**Unwanted emissions**	**Blocking**
10.0	0.01	0.23	0.02	0.332
30.0	0.04	0.66	0.06	0.93

Table 8 : Influence of the type of interference from TETRAPOL MS in 380 - 384 MHz to TETRA MS in 390 - 394 MHz

In this scenario, pue/pbl=0.067. The effect of receiver blocking is largely the dominant interference mechanism.

It can be noted that, pue + pbl is often larger than the global probability of interference given in 3.2 for the corresponding scenarios due to the fact that interference due to unwanted emissions and receiver blocking can occur at the same time.

From the 4 tables above, it appears that in the two scenarios where the victim and the interferer are in the same 4 MHz block, the main interference mechanism is due to the unwanted emissions of the interferer, especially when TETRA is the interferer. When the systems are in different 4 MHz blocks, blocking at the receiver is the main interference mechanism, especially when TETRAPOL is the interferer.

3.4 Analysis of the influence of a minimum frequency separation between the carriers of the interferer and the victim in the case MS $\rightarrow$ MS

The general frequency separation is indicated in paragraph 1.1. As mentioned, the influence of a minimum frequency separation between the carriers of the interferer and the victim can be analysed by putting some restrictions in the following form : spacing between the carriers of the interferer and the victim greater than Δf_{min}. The values of Δf_{min}=0, 50 and 100 kHz will be considered.

In order to assess the influence of a local constraint related to a minimum frequency separation between the interfering system and the victim system, only the two scenarios where the interferer and the victim are in the same 4 MHz block (380-384 MHz) are considered .

D	d0 = 0 without PC		
	Δf_{min}=0 kHz	Δf_{min}=50 kHz	Δf_{min}=100 kHz
3	1.10/0.28	1.05/0.27	1.00/0.26
30	9.68/2.69	9.45/2.59	9.08/2.47

Table 9 : Influence of a minimum frequency separation on the interference from TETRA MS in 380 - 384 MHz to TETRAPOL MS in 380 - 384 MHz

Note : the two values of probability given in Table 9 correspond to the two possible options to describe the effect of the TDMA structure of TETRA (for the first, d=di ; for the second, d=4*di).

D	d0 = 0 without PC		
	Δf_{min}=0 kHz	Δf_{min}=50 kHz	Δf_{min}=100 kHz
3	0.33	0.30	0.25
30	3.03	2.80	2.35

Table 10 : Influence of a minimum frequency separation on the interference from TETRAPOL MS in 380 - 384 MHz to TETRA MS in 380 - 384 MHz

When imposing a local constraint on a minimum frequency separation between the carriers of the interferer and the victim, the probability of interference decreases, but the effect is very slight. This can be explained by the following. In the general cases given in 3.2, the frequency of the interferers is randomly distributed over the allocated channels in the considered 4 MHz bandwidth according to the frequency plan given in 2.2. Due to the fact that this bandwidth is much larger than the value of Δf_{min}, the frequency separation is for most of the trials already greater than Δf_{min}. Thus, the influence of an additional constraint on Δf_{min} is relatively marginal on the estimated probabilities, which are derived from an averaging of a large number of trials. Practically, it can be expected that the effect of the local constraint on a minimum frequency separation will be greater than given by the simulations.

3.5 Analysis of the direct mode in the case MS $\rightarrow$ MS

Presentation of the possible scenarios and connections with the general case :

Taking into account the different possible allocations (see paragraphs 2.2 and 2.5), the use of direct mode leads to nine different scenarios, each of them corresponding to a scenario studied in the general case. As it is explained in 2.5, there are changes in the results only if the system using direct mode is the victim system. It must be noted that in direct mode, the power control is not implemented.

- MS direct mode non reversed → MS direct mode non reversed correspond to the case where the interfering system is in 380 - 384 MHz, the victim system is in 380 - 384 MHz and no power control is used. See tables 11 and 13, columns 3,5 and 7 below.
- MS direct mode non reversed → MS direct mode reversed correspond to the case where the interfering system is in 380 - 384 MHz, the victim system is in 390 - 394 MHz and no power control is used. See tables 12 and 14, columns 3,5 and 7 below.
- MS direct mode non reversed → MS network mode correspond to the case where the interfering system is in 380 - 384 MHz, the victim system is in 390 - 394 MHz and no power control is used. See tables 2 and 4, columns 3,5 and 7 in section 3.2.
- MS direct mode reversed → MS direct mode non reversed correspond to the case (taking into account a 10 MHz inversion of the bands) where the interfering system is in 390 - 394 MHz, the victim system is in 380 - 384 MHz and no power control is used. See tables 12 and 14, columns 3,5 and 7 below.
- MS direct mode reversed → MS direct mode reversed correspond to the case (taking into account a 10 MHz inversion of the bands) where the interfering system is in 390 - 394 MHz, the victim system is in 390 - 394 MHz and no power control is used. See tables 11 and 13, columns 3,5 and 7 below.
- MS direct mode reversed → MS network mode correspond to the case (taking into account a 10 MHz inversion of the bands) where the interfering system is in 390 - 394 MHz, the victim system is in 390 - 394 MHz and no power control is used. See tables 1 and 3, columns 3,5 and 7 in section 3.2.

- <u>MS network mode → MS direct mode non reversed</u> correspond to the case where the interfering system is in 380 -384 MHz, the victim system is in 380 - 384 MHz and power control is used. See tables 11 and 13, columns 2,4 and 6 below.
- <u>MS network mode → MS direct mode reversed</u> c orrespond to the case where the interfering system is in 380 - 384 MHz, the victim system is in 390 - 394 MHz and power control is used. See tables 12 and 14, columns 2,4 and 6 below.
- <u>MS network mode → MS network mode</u> correspond to the case where the interfering system is in 380 - 384 MHz, the victim system is in 390 - 394 MHz and power control is used. See tables 2 and 4, columns 2,4 and 6 in section 3.2.

Modifications due to the communication in direct mode :

When the interfering mobile station is operating in direct mode, the change compared to the case of network mode is due to the fact that power control is not implemented for mobile stations in direct mode. **Thus, the results for the scenarios when the interfering system operates in direct mode are given in 3.2 when power control is not used.**

When the victim mobile station is operating in direct mode, the major change is due to the fact that the transmitter of the wanted signal is now a mobile station and not a base station. It causes some modifications in the size of the cell of the victim system. The values of the radius of the victim cell related to the use of direct mode are :

- 0.125 km for TETRA which gives a percentage of coverage of 99%
- 0.340 km for TETRAPOL which gives a percentage of coverage of 97.5%.

These values of the radius have been calculated in order to have similar percentage of coverage than in the previous simulations.

Results of the simulations for the victim system operating in direct mode in the case MS → MS :

For both TETRA and TETRAPOL, power control is not used for transmission in direct mode. In the corresponding simulations, the receiver of the interfering system is not taken into consideration. So, in this case, there are no changes in comparison with the scenarios analysed before when the receiver of the interfering system is a base station. Therefore, the relevant simulations relative to the study of the direct mode refer only to the victim system working in direct mode, the interfering system communicating either in the network mode (with power control) or in the direct mode (without power control). The results are given in the tables below :

D	**d0 = 0 with PC** (network	**d0 = 0 without PC** (direct mode)	**D0 = 25 m with PC** (network	**d0 = 25 m without PC** (direct mode)	**d0 = 100 m with PC** (network	**d0 = 100 m without PC** (direct mode)
0.3	0.07/0.02	0.09/0.02	0.02/0.00	0.02/0.01	0.00/0.00	0.00/0.00
3.0	0.73/0.19	0.83/0.21	0.16/0.04	0.20/0.05	0.01/0.00	0.02/0.00
30.0	6.29/1.75	7.25/2.01	1.35/0.39	1.61/0.46	0.06/0.03	0.07/0.03

Percentage of coverage for the victim : **97.5%**

Table 11 : Probability of interference of TETRA MS in 380 - 384 MHz to TETRAPOL MS in 380 - 384 MHz in direct mode

d	**d0 = 0 with PC** (network	**d0 = 0 without PC** (direct mode)	**D0 = 25 m with PC** (network	**d0 = 25 m without PC** (direct mode)	**d0 = 100 m with PC** (network	**d0 = 100 m without PC** (direct mode)
0.3	0.01/0.00	0.01/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00
3.0	0.09/0.02	0.10/0.02	0.01/0.00	0.01/0.00	0.00/0.00	0.00/0.00
30.0	0.82/0.21	0.92/0.24	0.05/0.01	0.06/0.02	0.00/0.00	0.00/0.00

Percentage of coverage for the victim : **97.4%**

Table 12 : Probability of interference of TETRA MS in 380 - 384 MHz to TETRAPOL MS in 390 - 394 MHz in direct mode

Note : the two values of probability given in Table 11 and Table 12 correspond to the two possible options to describe the effect of the TDMA structure of TETRA (for the first, d=di ; for the second, d=4*di).

D	d0 = 0 **with PC** (network	d0 = 0 **without PC** (direct mode)	d0 = 25 m **with PC** (network	d0 = 25 m **without PC** (direct mode)	d0 = 100 m **with PC** (network	d0 = 100 m **without PC** (direct mode)
0.3	0.01	0.02	0.00	0.00	0.00	0.00
3.0	0.14	0.17	0.03	0.03	0.00	0.00
30.0	1.23	1.58	0.21	0.28	0.01	0.01

Percentage of coverage for the victim : **99.0%**

Table 13 : Probability of interference of TETRAPOL MS in 380 - 384 MHz to TETRA MS in 380 - 384 MHz in direct mode

D	d0 = 0 **with PC** (network	d0 = 0 **without PC** (direct mode)	d0 = 25 m **with PC** (network	d0 = 25 m **without PC** (direct mode)	d0 = 100 m **with PC** (network	d0 = 100 m **without PC** (direct mode)
0.3	0.00	0.01	0.00	0.00	0.00	0.00
3.0	0.04	0.05	0.00	0.00	0.00	0.00
30.0	0.37	0.51	0.02	0.04	0.00	0.00

Percentage of coverage for the victim : **98.9%**

Table 14 : Probability of interference of TETRAPOL MS in 380 - 384 MHz to TETRA MS in 390 - 394 MHz in direct mode

According to these results, it must be noted that, in the case where the interferer and the victim are mobile stations, the probabilities of interference are lower when the victim is in direct mode than in network mode, considering equivalent conditions of coverage.

As it is explained above, when direct mode is used between interfering mobile stations, the probabilities of interference are higher to those obtained when the interfering mobile stations communicate in network mode because PC is not activated in the first case.

Furthermore, it must be noted that the density of interfering mobile stations using direct mode may, in specific cases, be larger than the density of interferers in network mode.

4 THE EFFECT OF MOBILE STATIONS FROM THE SYSTEM X TO A BASE STATION FROM THE SYSTEM Y (MS → BS)

4.1 Specific conditions for the simulations relative to this scenario

In general, the simulation conditions are the same as in section 3, the interfering system being similar.

As explained in paragraph 2.2, power control is not used in the link MS → BS for the victim. The probabilities presented in the tables below correspond to the probability of interfering with one carrier of the receiving base station from the victim system.

In addition, an analysis has been made to assess the influence of the directivity of the antennas of the base stations.

4.2 General results for the case MS → BS

In this paragraph, MS interferers are assumed to work in network mode if power control is on and in direct mode if power control is off.

As in the case MS → MS developed before, 4 scenarios have been identified taking into account that the victim Base Station is always assumed to receive in the 380 - 384 MHz range:

- Interferer : TETRA in 380 - 384 MHz. Victim : TETRAPOL.
- Interferer : TETRA in 390 - 394 MHz. Victim : TETRAPOL.
- Interferer : TETRAPOL in 380 - 384 MHz. Victim : TETRA.
- Interferer : TETRAPOL in 390 - 394 MHz. Victim : TETRA.

In each scenario, a big range of values is given corresponding to some possible choices in some parameters (value of the density of active interferers (d), value of the fixed distance enabling to deal with the compatibility issue at a border area (d0) and use or not of the power control for the interfering MS (PC)).

Compared to the MS → MS case, a larger range of the fixed distance d0 is proposed, from 0 to (Rcell/8) where Rcell is the radius of the victim cell (Rcell=6.2 km for TETRAPOL gives Rcell/8=775m and Rcell=3.25 km for TETRA gives Rcell/8=406m).

The results are given in the tables below.

d	**d0 = 0 with PC** (network mode)	**d0 = 0 without PC** (direct mode)	**d0 = 100 m with PC** (network mode)	**d0 = 100 m without PC** (direct mode)	**d0 = 300 m with PC** (network mode)	**d0 = 300 m without PC** (direct mode)	**d0 = 775 m with PC** (network mode)	**d0 = 775 m without PC** (direct mode)
0.3	0.79/0.23	0.91/0.26	0.25/0.08	0.29/0.10	0.08/0.03	0.09/0.04	0.03/0.02	0.04/0.02
1.0	2.31/0.68	2.68/0.78	0.64/0.22	0.75/0.26	0.15/0.07	0.18/0.08	0.05/0.03	0.06/0.04
3.0	5.84/1.81	6.74/2.08	1.44/0.52	1.71/0.61	0.25/0.13	0.29/0.15	0.06/0.05	0.08/0.05
10.0	14.42/5.05	16.43/5.82	3.06/1.27	3.64/1.51	0.44/0.24	0.51/0.27	0.08/0.06	0.09/0.07
30.0	28.84/11.78	32.61/13.46	5.13/2.61	6.07/3.09	0.65/0.39	0.76/0.45	0.09/0.08	0.10/0. 09

Percentage of coverage for the victim : **95.1%**

Table 15 : Probability of interference of TETRA MS in 380 - 384 MHz to TETRAPOL BS in 380 - 384 MHz

D	**d0 = 0 without PC** (direct mode)	**d0 = 100 m without PC** (direct mode)	**d0 = 300 m without PC** (direct mode)	**d0 = 775 m without PC** (direct mode)
0.3	0.08/0.02	0.00/0.00	0.00/0.00	0.00/0.00
1.0	0.25/0.06	0.01/0.00	0.00/0.00	0.00/0.00
3.0	0.71/0.19	0.04/0.01	0.00/0.00	0.00/0.00
10.0	2.16/0.60	0.11/0.03	0.00/0.00	0.00/0.00
30.0	5.42/1.67	0.23/0.08	0.00/0.00	0.00/0.00

Percentage of coverage for the victim : **95.1%**

Table 16 : Probability of interference of TETRA MS in 390 - 394 MHz to TETRAPOL BS in 380 - 384 MHz

Note : the two values of probability given in Table 15 and Table 16 correspond to the two possible options to describe the effect of the TDMA structure of TETRA (for the first, d=di ; for the second, d=4*di).

d	**d0 = 0 with PC** (network mode)	**d0 = 0 without PC** (direct mode)	**d0 = 100 m with PC** (network mode)	**d0 = 100 m without PC** (direct mode)	**d0 = 300 m with PC** (network mode)	**d0 = 300 m without PC** (direct mode)	**d0 = 406 m with PC** (network mode)	**d0 = 406 m without PC** (direct mode)
0.3	0.32	0.41	0.08	0.11	0.02	0.02	0.01	0.01
1.0	0.96	1.24	0.23	0.30	0.04	0.06	0.02	0.03
3.0	2.48	3.18	0.54	0.71	0.09	0.12	0.04	0.05
10.0	6.36	8.06	1.13	1.50	0.17	0.23	0.07	0.10
30.0	13.58	17.00	1.89	2.48	0.26	0.35	0.11	0.14

Percentage of coverage for the victim : **95.0%**

Table 17 : Probability of interference of TETRAPOL MS in 380 - 384 MHz to TETRA BS in 380 - 384 MHz

D	d0 = 0 without PC (direct mode)	d0 = 100 m without PC (direct mode)	d0 = 300 m without PC (direct mode)	D0 = 406 m without PC (direct mode)
0.3	0.09	0.00	0.00	0.00
1.0	0.28	0.02	0.00	0.00
3.0	0.81	0.05	0.00	0.00
10.0	2.45	0.13	0.00	0.00
30.0	6.11	0.27	0.00	0.00

Percentage of coverage for the victim : **95.1%**

Table 18 : Probability of interference of TETRAPOL MS in 390 - 394 MHz to TETRA BS in 380 - 384 MHz

It must be noted that power control is not considered in tables 16 and 18 because mobiles transmitting in 390 - 394 MHz are necessarily communicating in direct mode and power control is not assumed for direct mode.

From the 4 tables above, it is possible to make the following observations :

- In the scenario MS -> BS, the probabilities of interference obtained for high densities of interferers are very large especially when d0=0. However, it must be noted that the density values of 10 and 30 active interferers/km^2 are very extreme, almost unrealistic.
- Effect of active interferers density : the probabilities of interference increase as the density of interferers (d) increases.
- Effect of the value of the fixed distance d0 : d0 ≠ 0 corresponds to an analysis of compatibility at a border area where d0 is the distance between the victim and the border. The probabilities of interference decrease significantly as the distance d0 increases.
- Effect of the use of power control for the interfering mobile stations – Consequences for direct mode: the probabilities of interference decrease with the use of power control. The effect of power control is more significant with high density of active transmitters. Consequently, when the interfering mobile stations operate in direct mode, the probabilities of interference will be slightly higher than in network mode because power control is not used in direct mode.
- Effect of the frequency separation between the victim and the interferers : the case where the two systems are in two different 4 MHz blocks correspond to a constraint on the minimum carrier separation of the order of 10 MHz. The probabilities are lower in this case but the difference is not very important. The fact that this difference is lower than expected can be explained taking into account the dominant interference mechanisms (see section 4.3 below). When the two systems are in different 4 MHz bocks, blocking is the dominant mechanism. Moreover, the blocking characteristics used in the simulations for both TETRA and TETRAPOL are flat for frequency offset greater than 500 kHz. Consequently, in the simulations, the effect of large frequency offset is smaller than it can be expected in practice.
- Comparison between both systems : the results obtained with TETRA as interferer and those with TETRAPOL are of the same order if we consider that, due to the TDMA structure for the TETRA MS, the number of instantaneous interferers to take into account is a quarter of the active interferers (second values of probabilities in the relevant cases). If this assessment is not verified, the probabilities of interference from TETRA MS upon TETRAPOL BS are slightly higher than the probabilities of interference from TETRAPOL MS upon TETRA BS.

4.3 Influence of the elevation discrimination of the BS antennas in the case MS → BS

Until now, the gain of the base station antennas has been assumed to be constant, without taking account of the elevation discrimination angle, under which the mobile stations are located from the base station main lobe (bore site).

In order to consider more realistic conditions, the following discrimination mask depending on the elevation angle has been introduced.

ea < 5°	$g = g_0$
5° < ea <10°	$g = g_0$ - 10 dB
10° < ea	$g = g_0$ - 20 dB

with :
ea = elevation angle,
g_0 = antenna gain of the base station for ea = 0° corresponding to the maximum of the antenna gain.

This mask is valid for both the wanted link and the interfering link.

The results are shown in the tables below. For a matter of comparison, the results without antenna directivity considerations are also presented in the tables. Furthermore, only the values for the interfering mobile stations without power control have been calculated.

d	d_0 = 0 without PC		d_0 = 100 m without PC		d_0 = 300 m without PC	
	without discrimination	with discrimination	without discrimination	with discrimination	Without discrimination	with discrimination
0.3	0.91 / 0.26	0.26 / 0.09	0.29 / 0.10	0.16 / 0.07	0.09 / 0.04	0.09 / 0.04
3.0	6.74 / 2.08	1.11 / 0.48	1.71 / 0.61	0.57 / 0.29	0.29 / 0.15	0.19 / 0.15
30.0	32.61 / 13.46	4.49 / 1.83	6.07 /3.09	0.90 / 0.73	0.76 / 0.45	0.70 / 0.44

Percentage of coverage for the victim : **95.1%**

Table 19 : Influence of the elevation discrimination of the BS antennas on the probability of interference from TETRA MS in 380 - 384 MHz to TETRAPOL BS in 380 - 384 MHz

d	d_0 = 0 without PC		d_0 = 100 m without PC		d_0 = 300 m without PC	
	Without discrimination	with discrimination	without discrimination	With discrimination	Without discrimination	with discrimination
0.3	0.08 / 0.02	0.00 / 0.00	0.00 / 0.00	0.00 / 0.00	0.00 / 0.00	0.00 / 0.00
3.0	0.71 / 0.19	0.00 / 0.00	0.04 / 0.01	0.00 / 0.00	0.00 / 0.00	0.00 / 0.00
30.0	5.42 / 1.67	0.01 / 0.01	0.23 / 0.08	0.01 / 0.0	0.00 / 0.00	0.00 / 0.00

Percentage of coverage for the victim : **95.1%**

Table 20 : Influence of the elevation discrimination of the BS antennas on the probability of interference from TETRA MS in 390 - 394 MHz to TETRAPOL BS in 380 - 384 MHz

Note : the two values of probability given in Table 19 and Table 20 correspond to the two possible options to describe the effect of the TDMA structure of TETRA (for the first, d=di ; for the second, d=4*di).

d	d_0 = 0 without PC		d_0 = 100 m without PC		d_0 = 300 m without PC	
	without discrimination	with discrimination	without discrimination	With discrimination	without discrimination	with discrimination
0.3	0.41	0.10	0.11	0.06	0.02	0.02
3.0	3.18	0.45	0.71	0.25	0.12	0.12
30.0	17.00	1.58	2.48	0.39	0.35	0.32

Percentage of coverage for the victim : **95.0%**

Table 21 : Influence of the elevation discrimination of the BS antennas on the probability of interference from TETRAPOL MS in 380 - 384 MHz to TETRA BS in 380 - 384 MHz

d	d_0 = 0 without PC		d_0 = 100 m without PC		d_0 = 300 m without PC	
	without discrimination	with discrimination	without discrimination	with discrimination	without discrimination	with discrimination
0.3	0.09	0.00	0.00	0.00	0.00	0.00
3.0	0.81	0.00	0.05	0.00	0.00	0.00
30.0	6.11	0.01	0.27	0.01	0.00	0.00

Percentage of coverage for the victim : **95.0%**

Table 22 : Influence of the elevation discrimination of the BS antennas on the probability of interference from TETRAPOL MS in 390 - 394 MHz to TETRA BS in 380 - 384 MHz

It can be seen from the tables above that the influence of the elevation discrimination of the base station antennas is very sensitive especially when a large amount of interferers is concentrated close to the victim receiver, which corresponds to d_0=0 and to a high density of interferers. This influence is much less significant when the interferers are far from the victim (d0 ≥ 300m).

4.4 Analysis of the type of interference in the case MS → BS

In this paragraph and all the following ones of this section, the antenna gain of the base station is assumed to be constant and equal to g_0. We note pue, the probability of interference due to unwanted emissions only, and pbl, the probability of interference due to receiver blocking only.

d	d0 = 0 without PC		d0 = 100 m without PC	
	unwanted emissions	blocking	Unwanted emissions	blocking
10	16.22/5.71	3.42/1.09	3.54/1.46	0.49/0.19
30	32.31/13.27	7.61/2.73	5.92/3.00	0.86/0.41

Table 23 : Influence of the type of interference from TETRA MS in 380-384 MHz to TETRAPOL BS in 380-384 MHz

In this case, pue/pbl=4.8 for d0=0 and 7.3 for d0=100 m. So, it is possible to conclude that the interference due to unwanted emissions is the dominant mechanism.

d	d0 = 0 without PC		d0 = 100 m without PC	
	unwanted emissions	blocking	Unwanted emissions	Blocking
10	1.18/0.33	1.31/0.36	0.05/0.01	0.06/0.02
30	3.06/0.91	3.37/1.01	0.11/0.04	0.12/0.04

Table 24 : Influence of the type of interference from TETRA MS in 390 - 394 MHz to TETRAPOL BS in 380 - 384 MHz

In this case, pue/pbl=0.9 for d0=0 and for d0=100 m. The blocking is dominant but not enough to conclude firmly.

Note : the two values of probability given in Table 23 and Table 24 correspond to the two possible options to describe the effect of the TDMA structure of TETRA (for the first, d=di ; for the second, d=4*di).

d	d0 = 0 without PC		d0 = 100 m without PC	
	unwanted	blocking	unwanted	Blocking
10	7.21	3.76	1.35	0.42
30	15.23	8.68	2.22	0.77

Table 25 : Influence of the type of interference from TETRAPOL MS in 380 - 384 MHz to TETRA BS in 380 - 384 MHz

In this case, pue/pbl=1.8 for d0=0 and 3.0 for d0=100 m. The effect of unwanted emissions is dominant but not enough to conclude firmly.

D	d0 = 0 without PC		d0 = 100 m without PC	
	Unwanted	**blocking**	**unwanted**	**Blocking**
10	0.27	2.28	0.01	0.11
30	0.69	5.69	0.03	0.24

Table 26 : Influence of the type of interference from TETRAPOL MS in 390 - 394 MHz to TETRA BS in 380 - 384 MHz

In this case, pue/pbl=0.12 for d0=0 and pue/pbl=0.11 for d0=100 m. Therefore, it is possible to conclude that the interference due to blocking is the dominant mechanism.

It can be noted that, pue + pbl is often larger than the global probability of interference given in 4.2 for the corresponding scenarios due to the fact that interference due to unwanted emissions and receiver blocking can occur at the same time.

From the 4 tables above, it appears that in the two scenarios where the victim and the interferer are in the same 4 MHz block, the main interference mechanism is due to the unwanted emissions of the interferer, especially when TETRA is the interferer. When the systems are in different 4 MHz blocks, blocking at the receiver is the main interference mechanism, especially when TETRAPOL is the interferer.

4.5 Analysis of the influence of a minimum frequency separation between the carriers of the interferer and the victim in the case MS $\rightarrow$ BS

This paragraph analyses the influence of a local condition on a frequency separation between the carriers of the victim and the interferer when the allocated bands are overlapping, that means when both systems use the same 4 MHz range, 380 - 384 MHz for example.

In the case MS $\rightarrow$ BS, it is considered that the scenario with d0=100 m is more realistic. That is why this assumption has been taken, the different values of Δf_{min}=0, 50 and 100 kHz being considered.

d	d0 = 100 m without PC		
	d.f. min =0	**d.f. min = 50**	**d.f. min = 100**
3	1.71/0.61	1.45/0.45	1.25/0.37
30	6.07/3.09	5.66/2.76	5.12/2.42

Table 27 : Influence of a minimum frequency separation on the interference from TETRA MS in 380 - 384 MHz to TETRAPOL BS in 380 - 384 MHz

Note : the two values of probability given in Table 27 correspond to the two possible options to describe the effect of the TDMA structure of TETRA (for the first, d=di ; for the second, d=4*di).

d	d0 = 100 m without PC		
	d.f. min =0	**d.f. min = 50**	**d.f. min = 100**
3	0.71	0.54	0.32
30	2.48	2.09	1.45

Table 28 : Influence of a minimum frequency separation on the interference from TETRAPOL MS in 380 - 384 MHz to TETRA BS in 380 - 384 MHz

When imposing a local constraint on a minimum frequency separation between the carriers of the interferer and the victim, the probability of interference decreases, but the effect is very slight. This can be explained by the following. In the general cases given in 4.2, the frequency of the interferers is randomly distributed over the allocated channels in the considered 4 MHz bandwidth according to the frequency plan given in 2.2. Due to the fact that this bandwidth is much larger than the value of Δf_{min}, the frequency separation is for most of the trials already greater than Δf_{min}. Thus, the influence of an additional constraint on Δf_{min} is relatively marginal on the estimated probabilities, which are derived from an averaging of a large number of trials. Practically, it can be expected that the effect of the local constraint on a minimum frequency separation will be greater than given by the simulations.

4.6 Analysis of the direct mode in the case MS → BS

In the case MS → BS, three different scenarios may be identified to reflect the influence of the direct mode.

- MS direct mode non-reversed → BS corresponding to the case where the interfering system is in 380 - 384 MHz, the victim system is in 380 - 384 MHz and no power control is used. See Tables 15 and 17, columns 3, 5, 7 and 9 in section 4.2.
- MS direct mode reversed → BS corresponding to the case where the interfering system is in 390 - 394 MHz, the victim system is in 380 - 384 MHz and no power control is used. See Tables 16 and 18, in section 4.2.
- MS network mode → BS corresponding to the case where the interfering system is in 380 - 384 MHz, the victim system is in 380 - 384 MHz and power control is used. See Tables 15 and 17, columns 2, 4, 6, and 8 in section 4.2.

According to what is explained in paragraph 2.5, when an interfering mobile station is operating in direct mode, the results are different from the corresponding network mode scenarios only because power control is not implemented in direct mode. **Thus, the results for the scenarios when the interfering system operates in direct mode are given in 4.2 when power control is not used.** The obtained probabilities of interference are slightly higher than in network mode. Furthermore, it must be noted that the density of interfering mobile stations using direct mode may, in specific cases, be larger than the density of interferers in network mode.

In this section, as the victim is a base section, communications in direct mode for the victim system are not possible.

5 THE EFFECT OF BASE STATIONS FROM THE SYSTEM X TO A MOBILE STATION FROM THE SYSTEM Y (BS → MS)

5.1 Specific conditions for the simulations relative to this scenario

The general assumptions are similar to those considered in the previous sections. The major change concerns the value of the density of active interferers. As the transmitter of the interfering system is now a base station, the densities are much lower than when the interferers are mobile stations. The chosen values for the interfering base stations vary from 0.01 and $0.1/km^2$.

When the interfering base station is a TETRA base station, it has been considered that the density of active interferers is equal to the density of instantaneous interferers, which means that the transmission from the base station is ‘continuous’.

The calculated probabilities of interference are assumed to be caused by one single carrier.

Furthermore, no power control is taken into account because the interferer is a base station.

5.2 General results for the case BS →MS

In this paragraph, MS victim is assumed to work in network mode. The case of direct mode for MS victim is studied in paragraph 5.5 of this section.

As in the previous cases, 4 scenarios have been considered, taking into account that the interfering base station is assumed to transmit in the 390 - 394 MHz range :

- Interferer : TETRA. Victim : TETRAPOL in 390 - 394 MHz.
- Interferer : TETRA. Victim : TETRAPOL in 380 - 384 MHz.
- Interferer : TETRAPOL. Victim : TETRA in 390 - 394 MHz.
- Interferer : TETRAPOL. Victim : TETRA in 380 - 384 MHz.

The values of the fixed distance *d0* enabling to deal with the issue of compatibility at a border area are assumed to vary from 0 to Rcell/4 where Rcell is the radius of the cell of the interfering system. According to the assumed values for Rcell, Rcell/4 is equal to 813m for TETRA and 1550m for TETRAPOL.

The results are given in the tables below.

d	d0 = 0 without PC	d0 = 100 m without PC	d0 = 300 m without PC	d0 = 406 m without PC	d0 = 813 m without PC
0.01	0.05	0.03	0.02	0.01	0.01
0.03	0.13	0.07	0.04	0.03	0.02
0.10	0.35	0.16	0.08	0.07	0.04

Percentage of coverage for the victim : **97.3%**

Table 29 : Probability of interference of TETRA BS in 390 - 394 MHz to TETRAPOL MS in 390 - 394 MHz

d	d0 = 0 without PC	d0 = 100 m without PC	d0 = 300 m without PC	d0 = 406 m without PC	d0 = 813 m without PC
0.01	0.01	0.00	0.00	0.00	0.00
0.03	0.02	0.00	0.00	0.00	0.00
0.10	0.07	0.01	0.00	0.00	0.00

Percentage of coverage for the victim : **97.5%**

Table 30 : Probability of interference of TETRA BS in 390 - 394 MHz to TETRAPOL MS in 380 - 384 MHz

D	d0 = 0 without PC	d0 = 100 m without PC	d0 = 300 m without PC	d0 = 775 m without PC	d0 = 1550 m without PC
0.01	0.01	0.00	0.00	0.00	0.00
0.03	0.03	0.01	0.00	0.00	0.00
0.10	0.09	0.02	0.01	0.00	0.00

Percentage of coverage for the victim : **99.0%**

Table 31 : Probability of interference of TETRAPOL BS in 390 - 394 MHz to TETRA MS in 390 - 394 MHz

D	d0 = 0 without PC	d0 = 100 m without PC	d0 = 300 m without PC	d0 = 775 m without PC	d0 = 1550 m without PC
0.01	0.00	0.00	0.00	0.00	0.00
0.03	0.01	0.00	0.00	0.00	0.00
0.10	0.03	0.00	0.00	0.00	0.00

Percentage of coverage for the victim : **99.1%**

Table 32 : Probability of interference of TETRAPOL BS in 390 - 394 MHz to TETRA MS in 380 - 384 MHz

As in this section, the victim mobile station is assumed to operate in network mode, tables 30 and 32 in which the victim received in the 380 - 384 MHz range, are not practically relevant. They are provided for information on the effect of a large frequency offset between the interferer and the victim.

From the 4 tables above, it is possible to make the following observations :

- Effect of active interferers density : the probabilities of interference increase as the density of interferers (d) increases.
- Effect of the value of the fixed distance d0 : d0 ≠ 0 corresponds to an analysis of compatibility at a border area where d0 is the distance between the victim and the border. The probabilities of interference decrease significantly as the distance d0 increases.
- Effect of the frequency separation between the victim and the interferers : the case where the two systems are in two different 4 MHz blocks correspond to a constraint on the minimum carrier separation of the order of 10 MHz. The probabilities are lower in this case but the difference is difficult to assess because of the low level of the obtained values.
- Comparison between both systems : according to the tables above, the probabilities of interference in the scenario TETRA BS -> TETRAPOL MS are higher than those in the scenario TETRAPOL BS -> TETRA MS.

It can also be noticed that there is a large difference in the results between these results and the results in the case MS → BS. This is due to the fact that the calculated probabilities refer to only one victim and that the density of active interferers is much greater in the MS → BS case. This implies that a mobile station victim is less likely to be close to a base station interferer than a base station victim close to a mobile station interferer. More details on this comparison are given in paragraph 5.6.

5.3 Analysis of the type of interference in the case BS → MS

As in the previous sections, pue is the probability of interference due to unwanted emissions only and pbl is the probability of interference due to receiver blocking only.

In this paragraph, only the results for d0 =0 are presented.

d	d0 = 0	
	Unwanted emissions	**Blocking**
0.01	0.04	0.01
0.03	0.11	0.04
0.10	0.32	0.14

Table 33 : Influence of the type of interference from TETRA BS in 390 - 394 MHz to TETRAPOL MS in 390 - 394 MHz

In this case, pue/pbl=2.5. As in the corresponding scenarios in the MS → MS case and in the MS → BS case, the interference due to unwanted emissions is the dominant mechanism.

d	d0 = 0	
	Unwanted emissions	**Blocking**
0.01	0.00	0.01
0.03	0.01	0.02
0.10	0.04	0.06

Table 34 : Influence of the type of interference from TETRA BS in 390 - 394 MHz to TETRAPOL MS in 380 - 384 MHz

In this case, pue/pbl=0.6. As in the corresponding scenarios in the MS → MS case and in the MS → BS case, the interference due to blocking is larger but the difference is not so great.

d	d0 = 0	
	Unwanted emissions	**Blocking**
0.01	0.01	0.01
0.03	0.02	0.02
0.10	0.06	0.05

Table 35 : Influence of the type of interference from TETRAPOL BS in 390 - 394 MHz to TETRA MS in 390 - 394 MHz

In this case, pue/pbl=1.1. As in the corresponding scenarios in the MS → MS case and in the MS → BS case, the interference due to unwanted emissions is larger but the difference is not so great.

d	d0 = 0	
	Unwanted emissions	**Blocking**
0.01	0.00	0.00
0.03	0.00	0.01
0.10	0.00	0.03

Table 36 : Influence of the type of interference from TETRAPOL BS in 390 - 394 MHz to TETRA MS in 380 - 384 MHz

In this case, pue/pbl<0.13. As in the corresponding scenarios in the MS $\rightarrow$ MS case and in the MS $\rightarrow$ BS case, the interference due to blocking is the dominant mechanism.

It can be noted that, pue + pbl is often larger than the global probability of interference given in 5.2 for the corresponding scenarios due to the fact that interference due to unwanted emissions and receiver blocking can occur at the same time.

From the 4 tables above, it appears that in the two scenarios where the victim and the interferer are in the same 4 MHz block, the main interference mechanism is due to the unwanted emissions of the interferer, especially when TETRA is the interferer. When the systems are in different 4 MHz blocks, blocking at the receiver is the main interference mechanism, especially when TETRAPOL is the interferer.

5.4 Analysis of the influence of a minimum frequency separation between the carriers of the interferer and the victim in the case BS $\rightarrow$ MS

The influence of a minimum local frequency separation between the carriers of the interferer and the victim is analysed in putting some restrictions under the following form : spacing between the carriers of the interferer and the victim greater than Δf_{min}. The values of Δf_{min}=0, 50 and 100 kHz are considered.

In this analysis, only the two scenarios where the interferer and the victim are in the same 4 MHz blocks (390 - 394 MHz) are studied. Furthermore, although it is not quite realistic, the fixed distance d0 is assumed to be equal to 0 in order to have values of interference probabilities not too low.

d	d0 = 0		
	d.f. min = 0	**d.f. min = 50**	**d.f. min = 100**
0.01	0.05	0.02	0.02
0.03	0.13	0.08	0.06
0.10	0.35	0.24	0.20

Table 37 : Influence of a minimum frequency separation on the interference from TETRA BS in 390 - 394 MHz to TETRAPOL MS in 390 - 394 MHz

d	d0 = 0		
	d.f. min = 0	**d.f. min = 50**	**d.f. min = 100**
0.01	0.01	0.01	0.01
0.03	0.03	0.02	0.02
0.10	0.09	0.07	0.05

Table 38 : Influence of a minimum frequency separation on the interference from TETRAPOL BS in 390 - 394 MHz to TETRA MS in 390 - 394 MHz

When imposing a local constraint on a minimum frequency separation between the carriers of the interferer and the victim, the probability of interference decreases, but the effect is very slight. This can be explained by the following. In the general cases given in 5.2, the frequency of the interferers is randomly distributed over the allocated channels in the considered 4 MHz bandwidth according to the frequency plan given in 2.2. Due to the fact that this bandwidth is much larger than the value of Δf_{min}, the frequency separation is for most of the trials already greater than Δf_{min}. Thus, the influence of an additional constraint on Δf_{min} is relatively marginal on the estimated probabilities, which are derived from an averaging of a large number of trials. Practically, it can be expected that the effect of the local constraint on a minimum frequency separation will be greater than given by the simulations.

5.5 Analysis of the direct mode for the victim in the case BS → MS

In the case BS → MS, three different scenarios may be identified to reflect the influence of the direct mode.

- BS → MS direct mode non-reversed corresponding to the case where the interfering system is in 390 - 394 MHz, the victim system is in 380 - 384 MHz and no power control is used. See tables 40 and 42 below.
- BS → MS direct mode reversed corresponding to the case where the interfering system is in 390 - 394 MHz, the victim system is in 390 - 394 MHz and no power control is used. See tables 39 and 41 below.
- BS → MS network mode corresponding to the case where the interfering system is in 390 - 394 MHz, the victim system is in 390 - 394 MHz and no power control is used. See tables 29 and 31 in section 5.2.

As in the case MS → MS, there are some changes in the probability of interference when the system operating in direct mode is the victim system due to the difference in the size of the cells. The values of the radius of the victim cell related to the use of direct mode are :

- 0.125 km for TETRA which gives a percentage of coverage of 99%.
- 0.340 km for TETRAPOL which gives a percentage of coverage of 97.5%.

d	d0 = 0	d0 = 300 m
0.01	0.03	0.01
0.03	0.09	0.03
0.10	0.26	0.06

Percentage of coverage for the victim : **97.4%**

Table 39 : Probability of interference of TETRA BS in 390-394 MHz to TETRAPOL MS in 390-394 MHz in direct mode

D	d0 = 0	d0 = 300 m
0.01	0.01	0.00
0.03	0.02	0.00
0.10	0.05	0.00

Percentage of coverage for the victim : **97.5%**

Table 40 : Probability of interference of TETRA BS in 390 - 394 MHz to TETRAPOL MS in 380 - 384 MHz in direct mode

d	d0 = 0	d0 = 300 m
0.01	0.01	0.00
0.03	0.01	0.00
0.10	0.05	0.00

Percentage of coverage for the victim : **98.9%**

Table 41 : Probability of interference of TETRAPOL BS in 390 - 394 MHz to TETRA MS in 390 - 394 MHz in direct mode

d	d0 = 0	d0 = 300 m
0.01	0.00	0.00
0.03	0.00	0.00
0.10	0.01	0.00

Percentage of coverage for the victim : **99.0%**

Table 42 : Probability of interference of TETRAPOL BS in 390 - 394 MHz to TETRA MS in 380 - 384 MHz in direct mode

It is noticed, that, considering equivalent percentages of coverage, the probabilities of interference are lower when the victim mobile station is working in direct mode than in network mode.

5.6 Comparison between the cases MS → BS and BS → MS – Correspondence between interference probabilities and separation distances

As it is stated in section 5.2, the values of interference probability for the scenario BS → MS are much lower than for the scenario MS → BS. This can be explained by the fact that the probability of having a victim base station close to an interferer mobile station is greater than the probability of having a victim mobile station close to an interferer base station.

However, the large difference between the results can be amazing. This will be justified by the following considerations based on a correspondence between interference probabilities and separation distances.

In the ERC Report « Evaluation of minimum frequency separation – Comparison of the MCL, E-MCL and MC simulation », paragraph 2.4.1.4 provides a method of comparing the Monte-Carlo and E-MCL results using the following formula which converts interference probabilities into separation distances :

$$dD = \sqrt{P / \pi di},$$

where dD is defined as the radius of the mean individual disturbing area, P is the probability of interference and di the density of instantaneous interferers.

The following tables give values of dD for the scenarios MS → BS and BS → MS assuming that the fixed distance d0 is equal to 0, power control is not used and the interferer and the victim are in the same 4 MHz frequency range.

d	P%	dD (m)
0.3	0.91/0.26	98/105
1.0	2.68/0.78	92/100
3.0	6.74/2.08	85/94
10.0	16.43/5.82	72/86
30.0	32.61/13.46	59/76

Table 43 : Values of the radius of the mean disturbing individual area for the interference of TETRA MS in 380 - 384 MHz to TETRAPOL BS in 380 - 384 MHz.

Note : the two values given in Table 43 correspond to the two possible options to describe the effect of the TDMA structure of TETRA (for the first, d=di ; for the second, d=4*di).

It can be noted that, considering the two different options to describe the TDMA effect of the TETRA MS, the separation distances are very close. These separation distances do not strictly depend on the assumption made for the density of instantaneous interferers.

d	P%	dD (m)
0.3	0.41	66
1.0	1.24	63
3.0	3.18	58
10.0	8.06	51
30.0	17.00	42

Table 44 : Values of the radius of the mean disturbing individual area for the interference of TETRAPOL MS in 380 - 384 MHz to TETRA BS in 380 - 384 MHz.

d	P%	dD (m)
0.01	0.05	126
0.03	0.13	117
0.10	0.35	106

Table 45 : Values of the radius of the mean disturbing individual area for the interference of TETRA BS in 390 - 394 MHz to TETRAPOL MS in 390 - 394 MHz.

d	P%	dD (m)
0.01	0.01	56
0.03	0.03	56
0.10	0.09	54

Table 46 : Values of the radius of the mean disturbing individual area for the interference of TETRAPOL BS in 390 - 394 MHz to TETRA MS in 390 - 394 MHz

From the tables above, it appears that, even if the probabilities of interference are quite different between the two scenarios, the values the radius of the mean disturbing individual area are of the same order ,which was expected.

Furthermore, the separation distances are larger when TETRA is the interferer than when TETRAPOL is the interferer.

6 THE EFFECT OF BASE STATIONS FROM THE SYSTEM X TO A BASE STATION FROM THE SYSTEM Y (BS → BS)

6.1 Specific conditions for the simulations relative to this scenario

In all this section, power control is not implemented because the interfering station is a base station.

As it is stated in section 2, in the whole study, the base stations are assumed to transmit in the 390 - 394 MHz range and to receive in the 380 - 384 MHz range. Therefore, in the case BS → BS, there is always a minimum frequency separation greater than 6 MHz between the carriers of the victim and the interferer. Consequently, the analysis of the influence of a minimum frequency separation between the carriers of the interferer and the victim (50kHz or 100 kHz) is not relevant in this case.

Furthermore, the direct mode concerning only mobile stations, the analysis of the influence of the direct mode is not relevant in the case BS → BS.

6.2 General results for the case BS → BS

In this case, the direct mode can not apply. Therefore, there are only two scenarios depending on the system considered as the interferer.

- Interferer : TETRA in 390 - 394 MHz. Victim : TETRAPOL in 380 - 384 MHz.
- Interferer : TETRAPOL in 390 - 394 MHz. Victim : TETRA in 380 - 384 MHz.

The calculated interference probabilities are the probabilities that a base station carrier from the interfering system interferes with a base station carrier from the victim system.

The values of the fixed distance *d0* enabling to deal with the issue of compatibility at a border area are assumed to be included in the following range : 0, Rcell/8 and Rcell/4 where Rcell is the radius of the cell of the interfering system (Rcell = 6.20 km for TETRAPOL and Rcell = 3.25 km for TETRA).

d	d0 = 0	d0 = 775 m	d0 = 1550 m
0.01	0.63	0.08	0.02
0.03	1.78	0.23	0.05
0.10	5.16	0.63	0.12

Percentage of coverage for the victim : **95.0%**

Table 47 : Probability of interference of TETRA BS in 390 - 394 MHz to TETRAPOL BS in 380 - 384 MHz

d	d0 = 0	d0 = 406 m	d0 = 813 m
0.01	0.33	0.08	0.02
0.03	0.96	0.23	0.05
0.10	2.91	0.68	0.18

Percentage of coverage for the victim : **95.1%**

Table 48 : Probability of interference of TETRAPOL BS in 390 - 394 MHz to TETRA BS in 380 - 384 MHz

From the 2 tables above, it is possible to make the following observations :

- Effect of active interferers density : the probabilities of interference increase as the density of interferers (d) increases.
- Effect of the value of the fixed distance d0 : d0 ≠ 0 corresponds to an analysis of compatibility at a border area where d0 is the distance between the victim and the border. The probabilities of interference decrease significantly as the distance d0 increases.
- Comparison between both systems : according to the tables above, the probabilities of interference in the scenario TETRA BS -> TETRAPOL MS are of the same order than those in the scenario TETRAPOL BS -> TETRA MS. However, it must be noted that the fixed distances d0 considered are larger in the first case. This means that the level of interference is slightly higher in the case TETRA BS -> TETRAPOL MS than in the case TETRAPOL BS -> TETRA MS.

6.3 Analysis of the type of interference in the case BS → BS

As in the previous sections, pue is the probability of interference due to unwanted emissions only and pbl is the probability of interference due to receiver blocking only.

d	d0 = 0		d0 = 775 m	
	Unwanted emissions	**Blocking**	**Unwanted**	**Blocking**
0.01	0.40	0.43	0.04	0.04
0.03	1.16	1.24	0.10	0.12
0.10	3.47	3.70	0.29	0.33

Table 49 : Influence of the type of interference from TETRA BS in 390 - 394 MHz to TETRAPOL BS in 380 - 384 MHz

In this case, pue/pbl=0.9. There is no major determinant interference mechanism.

d	d0 = 0		d0 = 406 m	
	Unwanted	**Blocking**	**Unwanted**	**Blocking**
0.01	0.00	0.33	0.00	0.08
0.03	0.00	0.96	0.00	0.23
0.10	0.01	2.91	0.00	0.33

Table 50 : Influence of the type of interference from TETRAPOL BS in 390 - 394 MHz to TETRA BS in 380 - 384 MHz

In this case, pue/pbl ≤ 0.03. The receiver blocking is the dominant interference mechanism.

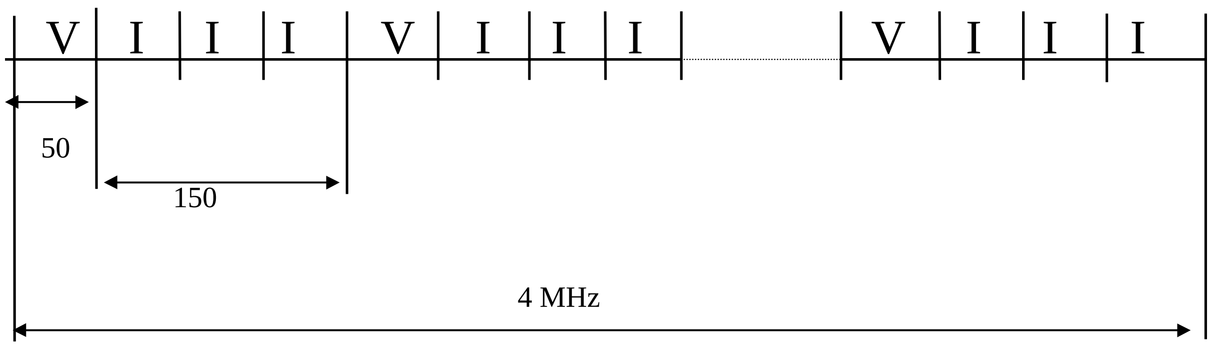
It can be noted that, pue + pbl is often larger than the global probability of interference given in 6.2 for the corresponding scenarios due to the fact that interference due to unwanted emissions and receiver blocking can occur at the same time.

7 ANALYSIS OF THE INFLUENCE OF THE FREQUENCY PLAN

7.1 Presentation of an alternative frequency plan

In all the studies presented from section 2 to 6, a specific frequency plan has been assumed. It is described in paragraph 2.1. In particular, this plan enables to deal with the issue of adjacent band compatibility of the two systems at a border area between two countries where each system is used in one of the two countries.

In this section 7, an other frequency plan has been tested referring to the case of a border area between 4 countries. The following arrangement for both 380 - 384 MHz and 390 - 394 MHz is assumed :
- 1 MHz is allocated to the victim system with 50 kHz blocks.
- 3 MHz is allocated to the interfering system with 150 kHz blocks.



V=victim system, I=interfering system.

It is assumed that the three interfering systems are identical (whether TETRA or TETRAPOL).

The modification of the frequency plan has an effect only when the interferer and the victim are in the same 4 MHz frequency range. For this reason, the scenario BS → BS is not considered in this section, the transmitting frequency of the interferer and the receiving frequency of the victim being in two different frequency ranges.

The effect of having a local constraint on a minimum frequency separation between the interferer and the victim (Δf_{min} = 50 or 100 kHz) will also be analysed. With this frequency plan, it has been calculated that the proportion of the cases of spacing smaller than 50 kHz is 1.6% (1.2% with the previous plan) and that of the cases smaller than 100 kHz is 4.9% (as with the previous plan).

The specific assumptions made for this analysis are no power control for the interferers, no elevation discrimination for the antennas, network mode for the victim, the general assumptions being the same as in sections 2 to 6.

7.2 Results of the simulation with this alternative frequency plan in the case MS → MS

The results are given in the tables below.

d	d0 = 0 without PC			d0 = 100 m without PC		
	Δf_{min}= 0	Δf_{min}= 50	Δf_{min}= 100	Δf_{min}= 0	Δf_{min}= 50	Δf_{min}= 100
3	1.13 / 0.29	1.06 / 0.27	1.01 / 0.26	0.03 / 0.01	0.01 / 0.00	0.01 / 0.00
30	9.75 / 2.72	9.43 / 2.58	9.08 / 2.47	0.11 / 0.05	0.06 / 0.02	0.05 / 0.02

Percentage of coverage for the victim : **97.5%**

Table 51 : Probability of interference of TETRA MS in 380-384 MHz (150 kHz) to TETRAPOL MS in 380-384 MHz (50 kHz) – Influence of a minimum frequency separation (to be compared with tables 1 and 9 section 3)

Note : the two values of probability given in Table 51 correspond to the two possible options to describe the effect of the TDMA structure of TETRA (for the first, d=di ; for the second, d=4*di).

d	d0 = 0 without PC			d0 = 100 m without PC		
	Δf_{min}= 0	Δf_{min}= 50	Δf_{min}= 100	Δf_{min}= 0	Δf_{min}= 50	Δf_{min}= 100
3	0.34	0.30	0.24	0.00	0.00	0.00
30	3.04	2.73	2.32	0.02	0.01	0.01

Percentage of coverage for the victim : **99.1%**

Table 52 : Probability of interference of TETRAPOL MS in 380-384 MHz (150 kHz) to TETRA MS in 380-384 MHz (50 kHz) – Influence of a minimum frequency separation (to be compared with tables 3 and 10 section 3).

The results obtained with this frequency plan are, in the case MS→ MS, very close to those obtained with the previous frequency plan.

7.3 Results of the simulation with this alternative frequency plan in the case MS → BS

d	d0 = 0 without PC			d0 = 300 m without PC		
	Δf_{min}= 0	Δf_{min}= 50	Δf_{min}= 100	Δf_{min}= 0	Δf_{min}= 50	Δf_{min}= 100
3	6.84 / 2.14	6.39 / 1.88	6.03 / 1.73	0.35 / 0.19	0.14 / 0.04	0.09 / 0.03
30	32.7 / 13.59	32.08 / 13.03	31.24 / 12.45	0.85 / 0.52	0.53 / 0.26	0.39 / 0.18

Percentage of coverage for the victim : **95.1%**

Table 53 : Probability of interference of TETRA MS in 380-384 MHz (150 kHz) to TETRAPOL BS in 380-384 MHz (50 kHz) – Influence of a minimum frequency separation (to be compared with tables 15 and 27 section 4)

Note : the two values of probability given in Table 53 correspond to the two possible options to describe the effect of the TDMA structure of TETRA (for the first, d=di ; for the second, d=4*di).

d	d0 = 0 without PC			d0 = 300 m without PC		
	Δf_{min}= 0	Δf_{min}= 50	Δf_{min}= 100	Δf_{min}= 0	Δf_{min}= 50	Δf_{min}= 100
3	3.20	2.81	2.35	0.14	0.06	0.02
30	17.00	16.15	14.81	0.38	0.20	0.07

Percentage of coverage for the victim : **95.0%**

Table 54 : Probability of interference of TETRAPOL MS in 380-384 MHz (150 kHz) to TETRA BS in 380-384 MHz (50 kHz) – Influence of a minimum frequency separation (to be compared with tables 17 and 28 section 4)

The results obtained with this frequency plan are, in the case MS->BS, very close to those obtained with the previous frequency plan.

7.4 Results of the simulation with this alternative frequency plan in the case BS $\rightarrow$ MS

d	d0 = 0 without PC			d0 = 300 m without PC		
	Δf_{min}= 0	Δf_{min}= 50	Δf_{min}= 100	Δf_{min}= 0	Δf_{min}= 50	Δf_{min}= 100
0.03	0.14	0.07	0.06	0.05	0.00	0.00
0.10	0.38	0.24	0.20	0.11	0.01	0.00

Percentage of coverage for the victim : **97.3%**

Table 55 : Probability of interference of TETRA BS in 390-394 MHz (150 kHz) to TETRAPOL MS in 390-394 MHz (50 kHz) – Influence of a minimum frequency separation (to be compared with tables 29 and 37 section 5)

d	d0 = 0 without PC			d0 = 300 m without PC		
	Δf_{min}= 0	Δf_{min}= 50	Δf_{min}= 100	Δf_{min}= 0	Δf_{min}= 50	Δf_{min}= 100
0.03	0.03	0.02	0.01	0.00	0.00	0.00
0.10	0.09	0.07	0.05	0.01	0.00	0.00

Percentage of coverage for the victim : **99.0%**

Table 56 : Probability of interference of TETRAPOL BS in 390-394 MHz (150 kHz) to TETRA MS in 390-394 MHz (50 kHz) – Influence of a minimum frequency separation (to be compared with tables 31 and 38 section 5)

The results obtained with this frequency plan are, in the case BS->MS, very close to those obtained with the previous frequency plan.

7.5 Conclusion on the choice of frequency plan

From the tables above, it can be seen that the values of interference probability obtained considering this frequency plan are very similar to the ones obtained with the previous frequency plan (slightly higher in general).

However, the probabilities obtained from a Monte Carlo simulation analysis are derived from an averaging of a large number of trials. In very specific cases, it is probable that, practically, in a 4-country case, the level of interference at the victim will be higher than in a 2-country case.

The effect of having a local constraint on the minimum frequency separation between the carriers of the interferer and the victim is the same as in the case of the other frequency plan ; the higher the frequency separation is, the lower the interference probabilities are. But this decrease is not so important.

8 DISCUSSION OF THE RESULTS

The results found in the sections 3 to 7 are summarised and critical scenarios are identified. Two different ranges of scenarios are considered, the first one dealing with compatibility issues inside a single country and the second one dealing with compatibility issues at a border area. In both cases, communications in network mode and also direct mode are considered.

This discussion is based on some results given in the previous sections. These results are considered as meaningful being related to either typical scenarios or very specific scenarios. The choice of these scenarios has been made according to the density of active interferers.

It is considered that

- for typical scenarios, the density of TETRA and TETRAPOL mobile interferers are 1 /km^2, the density of TETRA BS interferer is 0.03 /km^2 and the density of TETRAPOL BS interferer is 0.01 /km^2 ;
- for special scenarios, the density of TETRA and TETRAPOL mobile interferers are 10 /km^2 in network mode and 30 /km^2 in direct mode, the density of TETRA and TETRAPOL BS interferer is 0.1 /km^2 .

8.1 Compatibility between TETRA and TETRAPOL inside a single country (simulation results corresponding to d0=0)

8.1.1 Scenarios related to network mode

For these scenarios, the following frequency ranges are assumed for the operation of TETRA and TETRAPOL equipment.

- transmission BS = 390 – 394 MHz
- reception BS = 380 – 384 MHz
- transmission MS = 380 – 384 MHz in network mode
- reception MS = 390 – 394 MHz in network mode.

Scenario	Typical Probability of Interference	Special Case Probability of Interference	Comments
TETRA MS to TETRAPOL MS	0.04 / 0.01 % *	0.39/0.10 % *	high density of interferers; wanted signal from base; low antenna gains on victim / interferer link ; high frequency separation ; power control
TETRA MS to TETRAPOL BS	2.31 / 0.68 % *	14.42/5.05 % *	high density of interferers; wanted signal from mobile; one high antenna gain on victim / interferer link ; power control
TETRA BS to TETRAPOL MS	0.13 %	0.35 %	low density of interferers; wanted signal from base; one high antenna gain on victim / interferer link
TETRA BS to TETRAPOL BS	1.78 %	5.16 %	low density of interferers; wanted signal from mobile; two high antenna gains on victim / interferer link ; high frequency separation .
TETRAPOL MS to TETRA MS	0.02 %	0.24 %	high density of interferers; wanted signal from base; low antenna gains on victim / interferer link ; high frequency separation ; power control
TETRAPOL MS to TETRA BS	0.96 %	6.36 %	high density of interferers; wanted signal from mobile; one high antenna gain on victim / interferer link ; power control
TETRAPOL BS to TETRA MS	0.01 %	0.09 %	low density of interferers; wanted signal from base; one high antenna gain on victim / interferer link
TETRAPOL BS to TETRA BS	0.33 %	2.91 %	low density of interferers; wanted signal from mobile; two high antenna gains on victim / interferer link ; high frequency separation .

Table 57 : Summary of the results for TETRA and TETRAPOL systems in network mode in a single country

*The two values of probability correspond to the two possible options to describe the effect of the TDMA structure of TETRA (for the first, d=di ; for the second, d=4*di).

For all scenarios,

- increasing the minimum carrier separation has marginal effect upon the estimated probabilities of interference to the victim system. This can be explained by the following. In the simulations relative to the general cases, the frequency of the interferers is randomly distributed over the allocated channels in the considered 4 MHz bandwidth according to the frequency plan given in 2.2. Due to the fact that this bandwidth is much larger than the values of Δf_{min}, the frequency separation is for most of the trials already greater than Δf_{min}. Thus, the influence of an additional constraint on Δf_{min} is relatively marginal on the estimated probabilities, which are derived from an averaging of a large number of trials. Practically, it can be expected that the effect of the local constraint on a minimum frequency separation will be greater than given by the simulations.
- power control for mobile stations has a significant effect upon the level of interference typically reducing the probability of interference from between 10 % and 40 % depending upon the density of interferers.

The most critical scenarios are those which involve mobile station to base station and base station to base station interference. In the simulations leading to the results above, the elevation discrimination of the BS antennas has not been taken into account. In the case MS → BS, an additional set of simulations has been made to reflect the influence of a directivity mask depending on the elevation angle for the BS antennas.

This effect is very high, leading to a decrease by a factor from 5 to 10 for the probability of interference (see tables 19 to 22 in section 4.3). These results are summarised in the table below where it is assumed that d0=0, power control is off and that the transmitting frequency range of the interfering mobile station and the receiving frequency range of the victim base station are both 380 - 384 MHz.

Scenario	**Density of interferers**	**Probability of Interference without elevation discrimination in the BS antennas**	**Probability of Interference with elevation discrimination in the BS antennas**
TETRA MS to TETRAPOL BS	0.3 /km^2	0.91/0.26 % *	0.26/0.09 % *
TETRA MS to TETRAPOL BS	30.0 /km^2	32.61/13.46 % *	4.49/1.83 % *
TETRAPOL MS to TETRA BS	0.3 /km^2	0.41 %	0.10 %
TETRAPOL MS to TETRA BS	30 /km^2	17 %	1.58 %

Table 58 : Summary of results on the influence of the elevation discrimination of BS antennas in the case MS→BS

*The two values of probability correspond to the two possible options to describe the effect of the TDMA structure of TETRA (for the first, d=di ; for the second, d=4*di).

Furthermore, in special case environments where the active user density is very high then additional measures may be required to maintain compatibility between TETRA and TETRAPOL. This could be additional filtering in the base transmitter and receiver or frequency coordination between TETRA and TETRAPOL operators.

8.1.2 Scenarios related to direct mode

Both TETRA and TETRAPOL have the capability of operating in direct mode. For the cases when the interfering system operates in direct mode and the victim system operates in network mode, the results are taken from the tables relative to the general cases with relevant parameters : no power control, density of interferers of 1/ km^2 in typical cases and 30 /km^2 in special cases, transmission from the mobiles in both ranges 380 - 384 and 390 - 394 MHz.

In the summary table below, the following scenarios are considered:

- MS direct mode reversed → MS network mode (interferer and victim operate both in 390 - 394 MHz).
- MS direct mode non-reversed → MS network mode (interferer in 380 - 384 MHz, victim in 390 - 394 MHz).
- MS direct mode reversed → BS (interferer in 390 - 394 MHz, victim in 380 - 384 MHz).
- MS direct mode non-reversed → BS (interferer and victim operate both in 380 - 384 MHz).

Scenario	**Typical Probability of Interference**	**Special Case Probability of Interference**	**Comments**
TETRA MS DMO reversed to TETRAPOL MS	0.37 / 0.10 % *	9.68/2.69 % *	higher density of interferers; wanted signal from base; low antenna gains on victim / interferer link ; no power control
TETRA MS DMO non reversed to TETRAPOL MS	0.05 / 0.01 % *	1.27/0.33 %*	higher density of interferers; wanted signal from base; low antenna gains on victim / interferer link ; no power control ; large frequency offset
TETRA MS DMO reversed to TETRAPOL BS	0.25 / 0.06 % *	5.42 / 1.67 %*	higher density of interferers; wanted signal from mobile; one high antenna gain on victim / interferer link ; no power control ; large frequency offset
TETRA MS DMO non reversed to TETRAPOL BS	2.68 / 0.78 % *	32.61/13.46 % *	higher density of interferers; wanted signal from mobile; one high antenna gain on victim / interferer link ; no power control
TETRAPOL MS DMO reversed to TETRA MS	0.11 %	3.03 %	higher density of interferers; wanted signal from base; low antenna gains on victim / interferer link ; no power control
TETRAPOL MS DMO non reversed to TETRA MS	0.03 %	0.97 %	higher density of interferers; wanted signal from base; low antenna gains on victim / interferer link ; no power control ; large frequency offset
TETRAPOL MS DMO reversed to TETRA BS	0.28 %	6.11 %	higher density of interferers; wanted signal from mobile; one high antenna gain on victim / interferer link ; no power control ; large frequency offset
TETRAPOL MS DMO non reversed to TETRA BS	1.24 %	17.00 %	higher density of interferers; wanted signal from mobile; one high antenna gain on victim / interferer link ; no power control

Table 59 : Summary of the results for TETRA and TETRAPOL systems with direct mode for the interferer in a single country

*The two values of probability correspond to the two possible options to describe the effect of the TDMA structure of TETRA (for the first, d=di ; for the second, d=4*di).

As in the network mode case, the probabilities of interference for the case MS DMO $\rightarrow$ BS do not take into account the elevation discrimination of the Base Station antenna. The effect of the directivity will reduce significantly the level of interference (see table 58).

From the table 59, it can be seen that the probability of interference is higher when the interfering system communicates in direct mode mainly due to the higher densities of interferer considered for the special case and to the fact that power control is not assumed to be implemented for direct mode. This applies especially in the worst case scenarios, reversed direct mode when the victim is a mobile and non-reversed direct mode when the victim is a base. In the other scenarios, the victim will be much less affected by direct mode operation of the interferer.

When the victim system operates in direct mode, simulations have shown that the level of interference is lower than for a system operating in network mode with the same quality of coverage for the victim.

8.2 Compatibility between TETRA and TETRAPOL at a border area (simulation results corresponding to d0≠0)

For each scenario, two different possible values of the fixed bias d0 are considered, d0 being introduced to simulate the distance between the border and the victim. The relevant values of d0 are depending upon the scenario:

- MS → MS : the values of 25 m and 100 m are chosen
- MS → BS : the values of 100 m and Rvict/8 are chosen with Rvict, the radius of the victim cell (Rvict=3.25 km for TETRA and Rvict=6.20 km for TETRAPOL)
- BS → MS : the values of 100 m and Rint/8 are chosen with Rint, the radius of the interferer cell
- BS → BS : the values of Rvict/8 and Rvict/4 are chosen with Rvict, the radius of the victim cell

These distance values are worst case. When BS are involved, a value of the order of Rcell/2 can be seen as more usual.

8.2.1 Scenarios related to network mode

For these scenarios, the following frequency ranges are assumed for the operation of TETRA and TETRAPOL equipment:

- transmission BS = 390 – 394 MHz
- reception BS = 380 – 384 MHz
- transmission MS = 380 – 384 MHz in network mode
- reception MS = 390 – 394 MHz in network mode.

The results given in the table 60 below are related to a frequency plan reflecting scenarios with a border between two countries.

Scenario	Distance victim → border : d0	Typical Probability of Interference	Special Case Probability of Interference	Comments
TETRA MS to TETRAPOL MS	25 m 100 m	0.00/0.00 % * 0.00/0.00 % *	0.02/0.01 % * 0.00/0.00 % *	high density of interferers; wanted signal from base; low antenna gains on victim / interferer link ; high frequency separation ; power control
TETRA MS to TETRAPOL BS	100 m 775 m	0.64/0.22 % * 0.05/0.03 % *	3.06/1.27 % * 0.08/0.06 % *	high density of interferers; wanted signal from mobile; one high antenna gain on victim / interferer link ; power control
TETRA BS to TETRAPOL MS	100 m 406 m	0.07 % 0.03 %	0.16 % 0.07 %	low density of interferers; wanted signal from base; one high antenna gain on victim / interferer link
TETRA BS to TETRAPOL BS	775 m 1550 m	0.23 % 0.05 %	0.63 % 0.12 %	low density of interferers; wanted signal from mobile; two high antenna gains on victim / interferer link ; high frequency separation .
TETRAPOL MS to TETRA MS	25 m 100 m	0.00 % 0.00 %	0.01 % 0.00 %	high density of interferers; wanted signal from base; low antenna gains on victim / interferer link ; high frequency separation ; power control
TETRAPOL MS to TETRA BS	100 m 406 m	0.23 % 0.02 %	1.13 % 0.07 %	high density of interferers; wanted signal from mobile; one high antenna gain on victim / interferer link ; power control
TETRAPOL BS to TETRA MS	100 m 775 m	0.00 % 0.00 %	0.02 % 0.00 %	low density of interferers; wanted signal from base; one high antenna gain on victim / interferer link
TETRAPOL BS to TETRA BS	406 m 813 m	0.08 % 0.02 %	0.68 % 0.18 %	low density of interferers; wanted signal from mobile; two high antenna gains on victim / interferer link ; high frequency separation .

Table 60 : Summary of the results for TETRA and TETRAPOL systems in network mode at a border area

For these scenarios, the probabilities of interference are much lower than in the scenarios related to one single country.

As in the case summarised in 8.1 and when d_0 is not too large, the probabilities of interference will decrease significantly in the cases MS $\rightarrow$ BS and BS $\rightarrow$ BS if the elevation discrimination of the BS antennas are taken into account (see table 58).

Additional simulations have been provided with an other frequency plan reflecting the case of a border between 4 countries. The results obtained with this plan are very similar to the ones obtained with the previous frequency plan (slightly higher in general). However, the probabilities obtained from a Monte Carlo simulation analysis are derived from an averaging of a large number of trials. In very specific cases, it is probable that, practically, in a 4-country case, the level of interference at the victim will be higher than in a 2-country case.

8.2.2 Scenarios related to direct mode

Both TETRA and TETRAPOL have the capability of operating in direct mode. For the cases when the interfering system operates in direct mode and the victim operates in network mode, the results are taken as in 8.1.2 from the tables relative to the general cases with relevant parameters : no power control, density of interferers of 30 /km^2 in special cases, transmission from the mobiles in both ranges 380 - 384 and 390 - 394 MHz.

In the summary table below, the following scenarios are considered:
- MS direct mode reversed → MS network mode (interferer and victim operate both in 390 - 394 MHz).
- MS direct mode non-reversed → MS network mode (interferer in 380 - 384 MHz, victim in 390 - 394 MHz).
- MS direct mode reversed → BS (interferer in 390 - 394 MHz, victim in 380 - 384 MHz).
- MS direct mode non-reversed → BS (interferer and victim operate both in 380 - 384 MHz).

The results given in the table 60 below are related to a frequency plan reflecting scenarios with a border between two countries.

Scenario	Distance victim $\rightarrow$ border : d0	Typical Probability of Interference	Special Case Probability of Interference	Comments
TETRA MS DMO reversed to TETRAPOL MS	25 m 100 m	0.09 / 0.02 % * 0.01 / 0.00 % *	2.21/0.63 % * 0.10/0.05 % *	higher density of interferers; wanted signal from base; low antenna gains on victim / interferer link ; no power control
TETRA MS DMO non reversed to TETRAPOL MS	25 m 100 m	0.00/0.00 % * 0.00/0.00 % *	0.08/0.02 % * 0.00/0.00 % *	higher density of interferers; wanted signal from base; low antenna gains on victim / interferer link ; no power control ; large frequency offset
TETRA MS DMO reversed to TETRAPOL BS	100 m 775 m	0.01/0.00 % * 0.00/0.00 % *	0.23/0.08 % * 0.00/0.00 % *	higher density of interferers; wanted signal from mobile; one high antenna gain on victim / interferer link ; no power control ; large frequency offset
TETRA MS DMO non reversed to TETRAPOL BS	100 m 775 m	0.75 / 0.26 % * 0.06/0.04 % *	6.07/3.09 % * 0.10/0.09 % *	higher density of interferers; wanted signal from mobile; one high antenna gain on victim / interferer link ;no power control
TETRAPOL MS DMO reversed to TETRA MS	25 m 100 m	0.02 % 0.00 %	0.53 % 0.02 %	higher density of interferers; wanted signal from base; low antenna gains on victim / interferer link ; no power control
TETRAPOL MS DMO non reversed to TETRA MS	25 m 100 m	0.00 % 0.00 %	0.06 % 0.00 %	higher density of interferers; wanted signal from base; low antenna gains on victim / interferer link ; no power control ; large frequency offset
TETRAPOL MS DMO reversed to TETRA BS	100 m 406 m	0.02 % 0.00 %	0.27 % 0.00 %	higher density of interferers; wanted signal from mobile; one high antenna gain on victim / interferer link ; no power control ; large frequency offset
TETRAPOL MS DMO non reversed to TETRA BS	100 m 406 m	0.30 % 0.03 %	2.48 % 0.14 %	higher density of interferers; wanted signal from mobile; one high antenna gain on victim / interferer link ; no power control

Table 61 : Summary of the results for TETRA and TETRAPOL systems with direct mode for the interferer at a border area

*The two values of probability correspond to the two possible options to describe the effect of the TDMA structure of TETRA (for the first, d=di ; for the second, d=4*di).

As in the general case, the probabilities of interference for the case MS DMO $\rightarrow$ BS do not take into account the elevation discrimination of the Base Station antenna. The effect of the directivity will reduce significantly the level of interference mainly when d_0 is not too large.

From the table 61, it can be seen that the probability of interference is higher when the interfering system communicates in direct mode mainly due to the higher densities of interferer considered to reflect the special cases and the fact that power control is not assumed to be implemented for direct mode. This applies especially in the worst case scenarios, reversed direct mode when the victim is a mobile and non-reversed direct mode when the victim is a base. In the other scenarios, the victim will be much less affected by direct mode operation of the interferer.

When the victim system operates in direct mode, simulations have shown that the level of interference is lower than for a system operating in network mode with the same quality of coverage for the victim.

Additional simulations have been provided with an other frequency plan reflecting the case of a border between 4 countries. The results obtained with this plan are very similar to the ones obtained with the previous frequency plan (slightly higher in general). However, the probabilities obtained from a Monte Carlo simulation analysis are derived from an averaging of a large number of trials. In very specific cases, it is probable that, practically, in a 4-country case, the level of interference at the victim will be higher than in a 2-country case.

9 CONCLUSIONS

The study based on Monte-Carlo simulations has analysed a large range of interference scenarios related to the coexistence between TETRA and TETRAPOL in adjacent channels for emergency services. It includes consideration of compatibility issues within a single country, at a border area and ‘direct mode’ (terminal to terminal communication without, necessarily, connection through the network). Within this range of scenarios the influence of a number of factors has been tested, such as: density of interferers, distance from the victim to the border, power control, BS antennas elevation discrimination, frequency plan and co-ordination, type of interference mechanisms. Further work would be required to model more specific scenarios within CEPT member states. The following conclusions can be drawn.

- **Typical operating conditions :**
  Under typical operating conditions, TETRA and TETRAPOL are able to coexist within a single country or neighbouring border areas, without guard bands - in accordance with frequency plans, such as those proposed for these uses in the CEPT Technical Recommendation T/R02-02 and ERC Report 25. Under typical working conditions (in terms of density of interferers and distance to the border) the estimated values of the probability of interference appear operationally acceptable - even when some features such as power control or discrimination of the BS antennas are not taken into account. The effect of such features being to reduce the risk of interference.

- **Special circumstances :**
  - <u>High density of active interferers :</u> it has been found that, when the density of interferers is very high, the estimated probability of interference to the victim BS can be large. However, for these scenarios, the elevation discrimination of the BS antennas has generally not been taken into account. Additional simulations have been made to assess the influence of this factor. It results in a significant reduction in the probabilities of interference, especially when there is a large number of interferers in the close vicinity of the victim BS, leading to more acceptable levels of interference.
    For the most critical scenarios, local frequency coordination arrangements could help reduce compatibility problems.

  - <u>Direct mode :</u> TETRA or TETRAPOL direct mode may cause higher levels of interference to a user of the other system when compared to network mode, especially when the victim is in the close vicinity of a direct mode users group. This is mainly due to the fact that power control is not implemented for direct mode and the density of interferers is higher for the special cases studied when direct mode operation is involved.
    For the most specific scenarios where a very high density of interferers operating in direct mode is expected, frequency coordination may be required to maintain compatibility between TETRA and TETRAPOL on a case by case basis.

- Compatibility at border areas : at border areas, the levels of interference depend largely on the distance between the victim and the border. These levels are in most cases acceptable. The exceptions may occur in extreme conditions (short distance between the victim and the border in addition to a very high density of interferers and eventual use of direct mode).

Comparison between 2-country case and 4-country case has been realised. The difference in the results is not significant mainly because the results are derived from the average of a large number of trials. Practically, in very specific cases, it is likely that the levels of interference will be higher in a 4-country case than in a 2-country case.

APPENDIX A

THE MONTE CARLO SIMULATION TOOL

The Monte Carlo simulation tool used for this study is based upon that specified by WG SE[1]. A general description is provided below followed by an explanation of some assumptions which are not explicitly stated in the WG SE specification.

1 GENERAL DESCRIPTION

A Monte Carlo simulation is a statistical technique that functions by considering many trials, that means many independent instants in time and many locations in space. For each 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 trials are considered then the probability of a certain event occurring can be calculated with a high level of accuracy.

The Monte Carlo simulation used for this study models a victim receiver operating amongst a population of interferers. The interferers are distributed around the victim using a random distribution. Only a proportion of the interferers are active at any one time. Figure A1 illustrates how the interferers and victim may appear for one simulation trial.

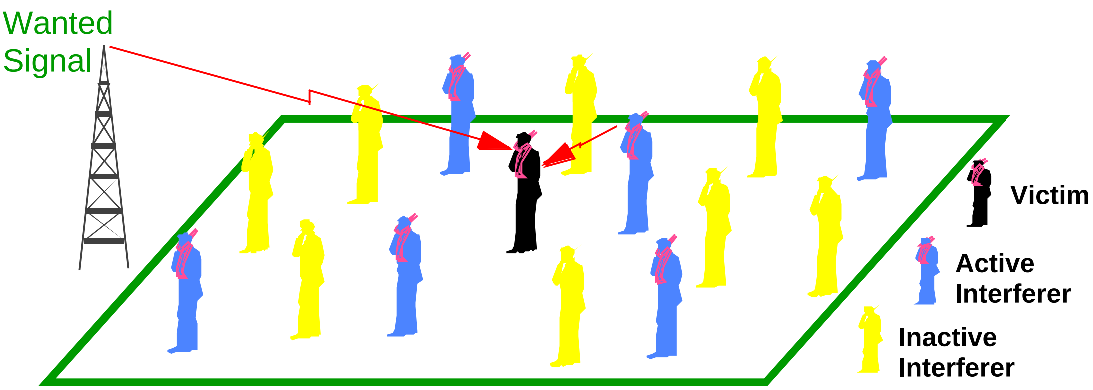


Figure A1 : An Illustration of the Monte Carlo Simulation Model

In general the effect of each interferer upon the victim is determined using mean path loss, slow fading, transmit power, antenna gains, transmitter wideband noise characteristic, receiver blocking and frequency separation. It can be found that for relatively low densities of interferers, for each trial one interferer dominates. This means that once the dominant interferer has been found then the remainder can be ignored without deeply affecting the final result. This means also that only one RF carrier is assumed to be active per interferer, so in the case that the BS are the interferers, the density of BS is equal to the density of sites and also to the density of active RF downlink carriers.

The victim’s wanted signal strength is calculated based upon the transmit power, antenna gains, mean path loss and slow fading.

Figure A1 illustrates a population of mobile stations interfering with a victim mobile. This is an example used for illustration purposes and in fact either or both the victim and interferers can be base stations.

The interfering power from the dominant interferer and wanted signal strength from the wanted signal transmitter are used to determine whether or not interference is occurring. Interference is said to occur when the resultant C/I is less than the protection ratio. Figure A2 illustrates the various signal levels.

---

[1] CEPT ERC Report 68, Monte Carlo Radio Simulation Methodology,
http://www.ero.dk/eroweb/seamcat/seamcat.html

Interference is defined as occuring when the Resultant C/I is less than the C/I used to define Sensitivity

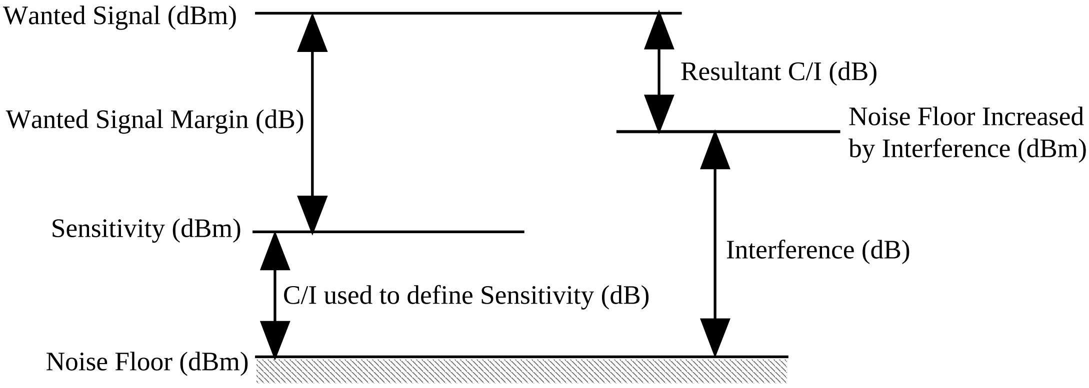


Figure A2 : The Signal Levels used to Determine Whether or Not Interference is Occurring

The left hand side of the diagram represents the situation when there is no interference. In this case the resultant C/I ratio is equal to the sum of the protection ratio and the margin. The right hand side of the diagram illustrates what happens when interference is introduced. The interference may be caused by transmitted unwanted emissions and/or receiver blocking. The interference adds to the noise floor and the resultant C/I is the difference between the increased noise floor and the wanted signal strength. To avoid interference the resultant C/I must be greater than the protection ratio.

2 SPECIFIC ASSUMPTIONS

The following sections provide and explanation to the aspects of the simulation methodology used in this study which may be different to that specified by Doc. SE(97)30.

2.1 Calculating the Victim's Receive Frequency

For this study, the victim radio system is allocated several blocks of channels and for each simulation trial the victim is assigned one channel using a uniform random distribution. The probability result is in fact an average over the frequency set.

When the victim is a base station, the level of interference calculated is for only one among the set of receivers at the base station site i.e. if a victim base station receives on four frequencies and has a probability of interference of 1%, each of the four frequencies has a probability of interference of 1 %.

2.2 Calculating the Interferer’s Transmit Frequency

The interfering radio system is allocated several blocks of channels and for each simulation trial the closest interferer is assigned one channel using a uniform random distribution. When the interferer is a base station, only one transmitter (i.e. one frequency) is assumed to be active, although this transmitter is assumed to transmit all the power of the base station.

2.3 Placing the Closest Interferer

A Rayleigh distribution added to a fixed bias is used to randomly place the closest interferer with respect to the victim. The density of active interferers is used to calculate the standard deviation of the Rayleigh distribution. This optional fixed bias is introduced to take into account the situation where the victim receiver stays at a given distance from a border, the interferers being randomly distributed on the other side of that border. When the victim and interferer are both base stations, this distribution is still used to place the closest interferer. This means that from one trial to the next, the distance between base stations is not fixed modelling a range of possible separations. In this report, the closest interferer has been considered in place of the dominant one. The closest interferer is not necessary the dominant one, but the closest has been considered for simplification reasons, the algorithm to determine the dominant being much more complicated because it has to take into account not only the distance, but also the frequency separation, the shadowing, the transmit power etc... all these parameters being frequently random and to determine what is the dominant combination of them. Due to this simplification, the results of the report could be considered as a little optimistic.

Moreover only the closest interferer is included in the interference calculation. The inclusion of other interferers increases simulation run time without significantly affecting the result. This has been found to be true for relatively low densities of interferers – as experienced in PMR scenarios. For simulations where high densities of interferers are modelled i.e. public cellular systems in hotspots, then all interferers must be considered due to the much higher possibility of a more distant interferer having greater influence due to the effects of fading.

2.4 Power Control

Power control may be used to reduce transmit power when there is a low path loss between transmitter and receiver. In this study, power control has been used only for mobiles (for both TETRA and TETRAPOL) in network mode. Power control has not been used for base stations or mobiles in direct mode – this is believed to reflect reality. Power control for mobiles is used only they are being considered as the transmitting part of the interfering system. When they are part of the victim system, then power control is not considered. By doing so, simulation complexity and run time can be reduced without affecting the results. The results are not changed because an at least 18 dB margin above sensitivity has been assumed before power control is activated. Thus when power control is used then there is always at least 18 dB of wanted signal strength margin. In these cases there is a very low chance of interference occurring. Interference is more likely to occur when the wanted signal strength is relatively low and the margin is below 18 dB.

When power control is activated in the interfering system, the corresponding cell radius has to be known to determine for each trial the position of the wanted receiver in the interfering system. When it is not activated the knowledge of the cell size is not required only the interferers density is needed.

2.5 Path Loss

The path loss model for an outdoor urban area specified by WG SE in the Monte Carlo specification[2] has been used for this study. This path loss model is a combination of free space and Hata models. For distances below 40 m, then free space propagation is assumed. For distances above 100 m, then modified Hata propagation is assumed. Between these two limits, the propagation loss is given by the interpolation between the free space loss at 40 m and the modified Hata loss at 100 m. The effect of shadowing is included using a log normal distribution with standard deviation dependent upon distance.

2.6 Interference Mechanisms

This study has considered the effects of unwanted emissions and receiver blocking. These are believed to be the dominant interference mechanisms for compatibility between TETRA and TETRAPOL. In each studied cases, an analysis has been made to show which of these two types is the dominant one.

2.7 Calculating the Wanted Signal Strength

The wanted signal strength is calculated based upon transmit power, path loss between transmitter and receiver and antenna gains. So the victim cell radius has to be known. In that report the radius values correspond to an intrinsic (only limited by receiver internal noise) ‘worst link’ area availability of 95 %. The wanted signal strength obtained is compared with the interfering signal strength as illustrated in Figure A.2 to determine whether or not the desired C/I ratio is being obtained.

2.8 Parameters used by the simulation

Channel Spacing - The channel bandwidth defined for the system i.e. the separation in frequency between adjacent carriers.

Transmit Power - The nominal transmit power.

Receiver Bandwidth - The bandwidth of the receiver. It may be less than the channel spacing dependent upon the filtering in the terminal’s receive path.

---

[2] CEPT ERC Report 68, Monte Carlo Radio Simulation Methodology, http://www.ero.dk/eroweb/seamcat/seamcat.html

Antenna Height - The height of the antenna in meters.

Antenna Gain - In general, MS and BS antennas in this study are assumed to have equal gain in all directions i.e. a spherical gain pattern. In addition, for BS, an antenna directivity mask in the vertical plane has been introduced for some scenarios to be more realistic. The values specified include cable and connector losses.

Active Interferer Density Range – A range of interferer densities have been considered in this study to include a range of scenarios from what may be considered a 'hot spot' to what may be considered normal operating conditions.

Receiver Sensitivity - The sensitivity defined for the receiving terminal.

Receiver Protection Ratio - The protection ratio defines the number of dB between the thermal noise floor of the receiver and sensitivity.

TDMA users / carrier - The number of TDMA users that can simultaneously operate in the same geographic area on a single carrier. This parameter could have an effect upon the interfering mechanism. When the interferers are TETRA mobile stations, the probabilities of interference are estimated using 2 hypothesis :

a) active interferers density : instantaneous interferers density
b) active interferers density : 4 * instantaneous interferers density taking into account the four slots per frame implemented in TETRA.

When the interferers are TETRAPOL mobiles, only the hypothesis a) is considered taking into account the FDMA implemented in TETRAPOL.

Power Control Characteristic - Specified by a step size, the number of steps and the threshold at which power control is activated. The threshold indicates the received signal level above which the receiver indicates to the transmitter that its power can be reduced. The amount by which it is reduced is determined by the margin above the threshold, the step size and the number of steps.

Unwanted Emissions Characteristic - The out-of-band and spurious emissions characteristic for a transmitter. Defined by a power measured in a specific bandwidth at a specific frequency offset from the nominal transmit frequency. This power can be or not a function of the transmit power.

Receiver Blocking Characteristic - The receiver blocking performance defined by a power level at a specific frequency offset which the receiver can sustain which receiving its wanted signal 3 dB above sensitivity.

3 INTERPRETATION OF THE RESULTS

The probability of interference evaluated is the probability of a victim receiver not obtaining its desired C/I requirement when the wanted signal level is above the receiver sensitivity. So it can be thought of as a reduction of the system area availability.

A radio system may have an area availability of 90 % meaning that either over 10 % of the area, coverage is not provided or that for 10 % of the time a user will be out of coverage (assuming the user to move around the cell occupying both outer and inner cell positions). Likewise the probability of interference can be interpreted in this way and a 1 % probability of interference would reduce a 90 % area availability to 89.1 %.

The probability of interference is the probability for a single receive channel. In the case of a base station where multiple channels are being used then the probability is that for each channel considered in isolation. In the same way, when the interferers are base stations, it is assumed that only one interfering RF carrier is activated per base station and per trial. This RF carrier is assumed to be active 100 % of the time.

It should be kept in mind that in the case of group calls interference to a single base station channel can affect the reception of multiple mobile stations. Furthermore, in that case, the interferers density values have to take into account the "half duplex" effect : a MS involved in a group call communication does not transmit during 100% of the communication duration. It transmits only when its user wishes to speak ("push to talk").

APPENDIX B

PARAMETERS USED FOR SIMULATION

TETRA PARAMETERS USED FOR SIMULATION

Parameter	Mobile Station	Base Station
Channel Spacing	25 kHz	25 kHz
Transmit Power	30 dBm	40 dBm
Receiver Bandwidth	18 kHz	18 kHz
Antenna Height	1.5 m	30 m
Antenna Gain	0 dBi	9 dBi
Receiver Sensitivity	- 103 dBm	- 106 dBm
Receiver Protection Ratio	19 dB	19 dB
TDMA Users / carrier	4	4
Power Control Characteristic	5 dB steps to a minimum of 15 dBm. Threshold = - 86 dBm (used for interferer only)	not used

Table B1 : System Parameters for TETRA

Frequency offset	Blocking (dBm)
8.5 to 16 kHz	- 90 dBm
16 to 50 kHz	- 55 dBm
50 to 100 kHz	- 40 dBm
100 to 200 kHz	- 35 dBm
200 to 500 kHz	- 30 dBm
> 500 kHz	- 25 dBm

Table B2 : Receiver blocking for the TETRA system (MS and BS)

Frequency offset	30 dBm Mobile Station	40 dBm Base Station
13.5 to 16 kHz	p - 30	p - 30
16 to 34 kHz	Max (p - 60, - 36)	Max (p - 60, - 36)
34 to 41 kHz	Max (p - 65, - 36)	Max (p - 65, - 36)
41 to 84 kHz	Max (p - 70, - 36)	Max (p - 70, - 36)
84 to 100 kHz	Max (p - 72,5 , - 53)	Max (p - 75, - 53)
100 to 250 kHz	Max (p - 75, - 70)	Max (p - 80, - 70)
250 to 500 kHz	Max (p - 80, - 70)	Max (p - 85, - 70)
> 500 kHz	Max (p - 80, - 70)	Max (p - 90, - 70)
In the corresponding receiving band	Max (p - 100, -70)	Max (p - 100, - 70)

with p = transmit power in dBm.

Table B3 : Unwanted emissions for the TETRA system (in 18 kHz bandwidth)

Note :

For the low values of frequency offset, some parameters for blocking and for unwanted emissions have been adapted and extrapolated to take into account the frequency plans used in the simulations.

TETRAPOL PARAMETERS USED FOR SIMULATION

Parameter	Mobile Station	Base Station
Channel Spacing	10 kHz	10 kHz
Transmit Power	33 dBm	38 dBm
Receiver Bandwidth	8 kHz	8 kHz
Antenna Height	1.5 m	30 m
Antenna Gain	0 dBi	9 dBi
Receiver Sensitivity	- 111 dBm	- 113 dBm
Receiver Protection Ratio	15 dB	15 dB
Power Control Characteristic	2 dB steps to a minimum of 21 dBm. Threshold = - 95 dBm (used for interferer only)	not used

Table B4 : System Parameters for TETRAPOL

d.f. (kHz)	Blocking (dBm)
13.5 to 25 kHz	- 65 dBm
25 to 40 kHz	- 55 dBm
40 to 100 kHz	- 50 dBm
100 to 150 kHz	- 40 dBm
150 to 500 kHz	- 35 dBm
> 500 kHz	- 25 dBm

Table B5 : Receiver blocking for the TETRAPOL system (MS and BS)

Frequency offset	Mobile Station	Base station
8.5 to 21 kHz	Max (p - 60, - 36)	Max (p - 60, - 36)
21 to 25 kHz	Max (p - 70, - 36)	Max (p - 70, - 36)
25 to 40 kHz	p - 70	p - 70
40 to 100 kHz	p - 75	p - 75
100 to 150 kHz	p - 85	p - 85
150 to 500 kHz	p - 90	p - 95
> 500 kHz	p - 100	p - 105
In the corresponding receiving band	- 80	-100

with p = transmit power in dBm.

Table B6 : Unwanted emissions for the TETRAPOL system (in 8 kHz bandwidth)

Note :

As in the case of TETRA, the parameters for blocking and unwanted emissions have been derived from the specifications to take into account the frequency plans used in the simulations.