ECC REPORT 97

Electronic Communications Committee (ECC)
within the European Conference of Postal and Telecommunications Administrations (CEPT)

CROSS BORDER INTERFERENCE FOR LAND MOBILE TECHNOLOGIES

Bern, February 2007

0 EXECUTIVE SUMMARY

This report has been completed by WGSE in response to a request from WGFM concerning studying the methods of setting a threshold level for coordination. It was required that the study should cover new technologies and examine ways of improving the frequency utilisation in border areas.

The report is based on studies which include a large number of simulations of interference in cross border scenarios. The well known analogue narrow band technology has been simulated to provide a benchmark against which the new technologies may be measured. A number of basic principles have been established to enable a consistent result that also allows for an increase in the spectrum utilisation in border areas as well as allowing new technologies to be introduced on a non discriminatory basis. These principles are listed below:

- A network should not be protected to a greater extent than it would be from its own continuously rolled out network.
- The permissible interference for duplex technologies is measured in a bandwidth of 25 kHz at a height of 3 metres. For simplex, the measurement height proposed remains 10 metres.
- Whilst both aligned networks and networks which are misaligned to yield the worst case were studied the threshold power level at the border is based on the worst case i.e. uncoordinated networks.
- The studies were undertaken using Monte Carlo modelling. At the modelled separation distances the difference between propagation for 10% and 50% of the time probability is negligible (approximately 2 dB).

The use of deterministic methods for cross border co-ordination was studied, it was concluded that the statistical methods offered accuracy over a broader range of parameters.

The interference from and into the following technologies has been studied

Narrowband FM
TETRA
CDMA-PAMR
Flash OFDM

The methods developed should be easily adaptable for any new technology and, because it uses SEAMCAT, which is expected to continue to be updated, the methods described should remain future proof.

The study involved the development of scenarios which permitted self-interference to be calculated. From these scenarios part of the model which represented that section of the network which was considered to be across the border was removed and replaced by an interfering network. The separation distance between the two networks could be varied.

The studies also covered technologies that are more sensitive to interference and which require a higher frequency reuse than would be available with the threshold recommended. For these technologies it was found that it is common to roll out with a lower frequency reuse pattern than is ideal for the technology, because of this a higher self interference is already accepted and this should also be reflected across a border. Therefore a single threshold value is recommended for all technologies. In very special cases where this may not be acceptable, a greater separation distance (in-country) to the border should be used or a co-ordination procedure based on the actual frequency reuse should be commenced. The approach is in line with a philosophy of sharing on equal terms and it was felt this should also be reflected in cross border situations.

The methods used in this report could form the basis of future cross border studies. Reference to this report should be included in a revised version of CEPT Rec. T/R 25-08.

Based on the studies, the results and observation from these a single level of -111 dBm is proposed as the threshold above which co-ordination is required. The value is measured in a 25 kHz bandwidth and referring to a measuring height of 3 metre for duplex bands. For simplex bands the same threshold should be measured at 10 metres. By expressing the threshold in dBm it is frequency independent.

For the work undertaken for this study the frequency, time, code and grade of service parameters were defined and fixed. During co-ordination between two countries a reduced grade of service may accepted close to the border in order to achieve coverage at the border.

Table of contents

Cross Border Interference for Land Mobile Technologies

1 INTRODUCTION

This report contains a study of methods required to carry out the calculations of interference across a border for a number of technologies.
The report also bench marks existing technologies to determine the percentage loss of service using the existing threshold levels for cross border co-ordination as set out in CEPT Rec. T/R 25-08.
The report determines the percentage loss of service between well known analogue narrow band technologies across a border. This parameter is then used as the basis for comparison with the other technologies which are being studied.

The basic philosophy used in this report is that the frequency resource at a border is always shared – this means that a maximum of half of the resource can be available to either country on the border line. The split of the frequency resource may be in the frequency, time, code, grade of service or any combination of these elements. The secondary philosophy applied in this report is that any system on a border line should not receive more protection against interference than it would in a continuously rolled out wide area coverage system within a country.

For the work undertaken for this study the frequency, time, code and grade of service parameters were defined and fixed.

During co-ordination between two countries a reduced grade of service may accepted close to the border in order to achieve coverage at the border.

The report uses the probabilistic approach (SEAMCAT) in order to simulate the different scenarios at a border line between the different technologies. The procedures developed to carry out the studies in support of this report are described in the annexes to the report. The report has additionally evaluated the feasibility of the deterministic method with the aim of easing cross border coordination.

2 METHODOLOGY

2.1 Monte Carlo

Monte Carlo (MC) modelling using SEAMCAT® (Spectrum Engineering Advanced Monte Carlo Analysis Tool) was undertaken for the following scenarios with the aim of developing a benchmark for analogue narrow band to analogue narrow band interference. The analogue studies provided a basis for comparison with other technologies:

- Annex 1, Evaluates the different scenarios and their viability for the study.
- Annex 2, Analogue into analogue narrow band (bench mark and substitution)
- Annex 3, CDMA into analogue narrow band (substitution)
- Annex 4, CDMA into CDMA (bench mark and substitution)
- Annex 5, Analogue into CDMA (substitution).
- Annex 6, Variation of cell repeat pattern
- Annex 7, TETRA
- Annex 8, Flash OFDM
- Annex 9, Parameters used for Seamcat Modelling

The procedure involved the development of scenarios which permitted self-interference to be calculated. From these scenarios part of the model which represented that section of the network which was considered to be across the border was removed and replaced by an interfering network. The separation distance between the two networks could be varied and the power of the wanted and unwanted signal could be determined on the borderline.

3 INTERFERENCE MODELLING

This section presents results from the interference modelling, using SEAMCAT.

The study initially investigates the interference that occurs within an analogue system into a reference cell located within a wide area continuously rolled out network.

This network is then cut in half with a line parallel to the border. The cut is made so the reference cell is located adjacent to the border. A similar system is established on the other side of the border and the interference produced is simulated for the situations where the networks are coordinated and uncoordinated. The separation distance is then adjusted such that the percentage loss of service is that same as that experienced within the continuously rolled out network. The separation distance at which this occurs provides the basis for the determination of the interference at the border.

The interfering analogue network was then replaced by a CDMA network and the distance adjusted to produce the same interference level as the analogue network.

In a similar way a CDMA network was rolled out and halved and another CDMA network is set up as the interfering network on the other side of border and adjusted in distance to produce the same interference as before the CDMA network was halved. This is performed both for a coordinated and an uncoordinated situation.

Finally the interfering CDMA network was replaced by an analogue network and the distance adjusted to produce the same interference as before the victim CDMA network was halved.

3.1 Propagation models

The propagation model selected for the studies was the Extended Hata propagation model as defined by WGPT SE21.

4 MONTE CARLO MODELLING RESULTS

Monte Carlo simulations were performed using the SEAMCAT Monte Carlo modelling tool in order to establish the percentage interference from the range of technologies to be studied. The simulations considered six scenarios, namely:

- Scenario 1, Annex 2 Interference within Narrowband Systems
- Scenario 2, Annex 3 CDMA PAMR to Narrowband Systems
- Scenario 3, Annex 4 CDMA PAMR to CDMA PAMR
- Scenario 4, Annex 5 Narrowband Systems to CDMA PAMR
- Scenario 5, Annex 6 Variation of Cell Repeat Patterns
- Scenario 6, Annex 7 TETRA Systems
- Scenario 7, Annex 8 Flash OFDM

Modelling was undertaken at 450 MHz but the results are applicable over the range of frequencies used by Land Mobile systems below 1000 MHz. Whilst the studies show separation distances at 450 MHz, at lower frequencies both the distances and the cell radii will be greater, whilst at higher frequencies the separation distances and the cell radii will be less. The power measured at the border will not vary with frequency although the field strength will. The ratio between the cell radius and the separation distance will also remain constant. The distances shown in the annexes to this report are to illustrate the coverage gap for a selected band.

The following was determined from the studies undertaken:-

1. Duplex narrowband systems which are un-coordinated and are planned to yield minimal levels of self-interference will deliver a power at the border of -110.9 dBm (field strength at 450 MHz 19.4 dBuV/m).

2. A CDMA system providing an interfering signal to a narrowband system will deliver a power at the border of -104.1 dBm per 25 kHz (26.2 dBuV/m measured in 25 kHz at 450 MHz).

3. CDMA to CDMA interference may deliver a power at the border of -104.1 dBm. (26.2 dBuV/m per 25 kHz at 450 MHz).

4. A fully rolled out narrowband network interfering to a CDMA network could safely deliver a power at the border of-105.9 dBm per base station (24.4 dBuV/m per 25 kHz at 450 MHz). This figure is based on -104.1 dBm less the frequency repeat factor of 1.8 dB. The frequency repeat factor shows the effect of more than one base station falling within the bandwidth of the CDMA carrier.

5. TETRA was taken as an example of a system for which a higher cell repeat patterns is required as a result of the higher required C/I ratio (19 dB for TETRA v. 12 dB for NB.) For a comparable grade of service a re-use pattern of 49 was required and the power delivered at the border was -114.7 dBm. When repeat patterns of 36

were studied then the required power delivered at the border returned to -111 dBm but the outage was higher. A re-use of 36 was employed in Report 42.

6. If the networks on the two sides of the border are prepared to operate with lower grade of service then smaller cell repeat patterns, with more power at the border and reduced separation distances are achievable. This would normally be agreed during the process of co-ordination.

7. Simplex systems were not studied in detail due to the unavailability of parameters covering maximum transmitted power, base station antenna height and activity factor from most European countries. Figures were available for base station power and antenna height from Germany, based on these figures it was proposed that -111 dBm in 25 kHz measured at the border as for narrowband duplex systems is allowed. The measurement height for simplex technologies shall be, 10 metres to reflect the interference which would be experienced from base station to base station transmissions..

The results from the studies are summarised as follows:

		Interfering Technology			
		FM	**CDMA**	**TETRA**	**Flash OFDM**
Victim Technology	**FM**	40 km	25 km	40 km	60 km
		-110.9 dBm	**-104.1 dBm**	**-111.4 dBm**	**-115.7 dBm**
	CDMA	20 km	30 km		
		-105.9 dBm	**-104.1 dBm**		
	TETRA		60 km	50 km	
			-113.1 dBm	**-114.7 dBm**	
	Flash OFDM				12 km
					-103.5 dBm

Table 1

In Table 1 the distances are for information only and give the separations between the base stations of the two networks. The powers are received powers in a 0 dB antenna measured at 3 metres above the ground.

For technologies which have lower bandwidths than 25 kHz, the power threshold may be adjusted using a bandwidth conversion factor. 12.5 kHz technologies may deliver a power at the border of -110.9 dBm - 3 dB = -113.9 dBm within the bandwidth of 12.5 kHz. A CDMA system should be assumed to be capable of accepting an interfering power of -104.1 dBm - 3 dB = -107.1 dBm per 12.5 kHz from 12.5 technologies, both measured at the border line at a measurement height of 3 m.

To summarise, the use of statistical methods is preferred because the results remain valid over a greater range of parameters. The current thresholds, whilst appropriate for simplex technologies, are no longer valid where duplex and half duplex technologies dominate the frequency spectrum.

Thresholds for duplex systems should be based on the power measured in a 0 dBi antenna, these may be converted to field strengths (as dBuV/m) at the appropriate frequency. The use of a 0 dBi antenna, as a standard for comparison, represents a worst case, particularly at lower frequencies, where 0 dBi antennas are less common. The formula for the conversion of dBm to dBuV/m is:-

$$F_{dBuV/m} = P_{dBm} + 77.21 + 20\log(f_{MHz})$$

Where P_{dBm} is the power in dB milliwatts.

It was found that:-

- For a narrowband system a power of -111 dBm measured at 3 metres, at the border, with a time probability of 50%, would provide adequate protection.
- For CDMA PAMR systems the permissible interfering power into the CDMA system, measured at the border in 25 kHz at 3 metres, rises to -104 dBm for 50% of time.
- TETRA systems, and other systems, which have a higher required C/I will require more protection. The required protection for TETRA is 4 dB greater than that for a 25 kHz narrowband system.

It has during the studies been established that for the separation distances under consideration, the percentage time probability makes very little difference (ca. 2 dB worst case).

5 MITIGATION FACTORS

In the following the different mitigation factors available are mentioned. To facilitate a high utilisation of the frequency spectrum in border areas it is imperative that no network is given better conditions in the border area than in the rest of the country it is deployed in. There has been a traditional tendency to use very different methods when planning networks in-country and for cross-border co-ordination, unfortunately this leads to a low frequency utilisation in border areas.

5.1 Frequency planning and network co-ordination

This report proposes a power threshold at the border for duplex technologies that should be permitted before co-ordination is required. Where there is a need to have a very good coverage at the border or even over the border network co-ordination or frequency planning may be required.

5.2 Separation distance

The use of physical separation is the general way of providing protection to the system on the other side of the border and also to own system. This report outlines a threshold power at the border that is established to allow for deployment without co-ordination measures. The report also provides the methods used where a co-ordination is required. This is based on the philosophy that no network should require better protection at the border than it received in its own territory. Networks deploying a technology that requires a high C/I may decide to allow a greater distance to the border in order not to receive undue interference from the other side of the border. However these systems are often required by limitations in the available spectrum to use a more dense frequency reuse than is ideal for the technology and as such is operating with a much higher self interference. This would permit the use of a normal distance to the border.

5.3 Frequency separation

Frequency separation or preferred channels has been the by far most common way of sharing the frequency resource at the border – mainly because it has been a simple exercise to use when the technologies are the same and occupy a fairly narrow band. It is becoming increasing difficult to use this method as the technologies on the market and in the near future use greater channel bandwidths. If the preferred channel method is to be maintained this can only be done by relaxing the interference criteria for the wideband technologies.

5.4 Code Co-ordination

Code co-ordination is a method that can reduce interference between two CDMA networks.

5.5 Time separation

Time separation is a very traditional method of sharing a resource it works where the traffic requirement is low because of the random access to the same frequency. The method is generally only used in PMR systems. The method can be improved using sub audio carrier squelch or digital squelch such that the network on one side of the border cannot hear the speech from the network on the other side.

It would also be possible to time coordinate TDMA technologies if the same technology is used on both sides of the border such that a single frequency resource can be shared across a border. During the preparation of this report there were no known cases where this procedure had been applied.

5.6 Grade of Service

Involved countries may decide to accept a higher interference level and thus a lower grade of service in order to obtain better coverage in the border areas.

6 CONCLUSIONS

The conclusions of the study are based on the following principles:

- A network should not be protected to a greater extent than it would be from its own continuously rolled out network.

- The permissible interference is measured in a bandwidth of 25 kHz at a height of 3 metres. The height of 3 metres was adopted being easier to measure and more realistic than the existing height of 10 metres.
- Whilst both aligned networks and networks which are misaligned to yield the worst case were studied the threshold power level at the border shall be based on the worst case i.e. uncoordinated networks.
- The studies were undertaken using Monte Carlo modelling. At the modelled separation distances the difference between propagation for 10% and 50% of the time probability is negligible (approximately 2 dB).

Considerable work was carried out on the basis that it would be possible to employ a deterministic solution but it was found that whilst the deterministic solution worked well within a very limited range of variables the functions were non-linear over the greater range of values and it raised the concern that deterministic methods might lead to incorrect conclusions

The interference from and into the following technologies has been studied:

Narrowband FM
TETRA
CDMA-PAMR
Flash OFDM

If the networks on the two sides of the border are prepared to operate with higher levels of interference then smaller cell repeat patterns and reduced separation distances are achievable. It also means that if the networks are operating with smaller cell repeat patterns than the usual network conditions then reduced separation distances are acceptable.

If a denser cell reuse pattern is employed, the interference will be derived from more than one transmitter. This is because the separation distances required exceed the distances used within a network for reuse of the same frequency or a frequency that may interfere to the other side of the border.

Based on the studies, the results and observation from these a single level of -111 dBm is proposed as the threshold above which co-ordination is required. The value is measured in a 25 kHz bandwidth and referring to a measuring height of 3 metre for duplex bands. For simplex bands the same threshold should be measured at 10 metres. By expressing the threshold in dBm it is frequency independent.

For the work undertaken for this study the frequency, time, code and grade of service parameters were defined and fixed. During co-ordination between two countries a reduced grade of service may accepted close to the border in order to achieve coverage at the border.

It also covers technologies which have a higher required C/I and therefore require a greater frequency reuse than would be available with the threshold recommended. For these technologies it was found that it is common to roll out with a lower frequency reuse pattern than is ideal for the technology. A higher self interference is already accepted and this should also be reflected across a border. Therefore a single threshold value is recommended for all technologies. In very special cases, where this may not be acceptable, a greater separation distance (in-country) to the border should be used or a co-ordination procedure based on the actual frequency reuse should be commenced. This approach complies with a philosophy of sharing on equal terms and should therefore be reflected in cross border situations.

It is recommended that the statistical procedures which have been developed for co-ordination in this report should be referenced in CEPT Rec. T/R 25-08. This will permit administrations to undertake equivalent studies for new technologies without the uncertainty which was found using the existing deterministic methods. It is anticipated that SEAMCAT will continue to be expanded in the future making the simulation tool an ideal basis for the development of figures for cross-border coordination. This should have the effect of ensuring that CEPT Rec. T/R 25-08 will remain relatively immune to future changes.

7 BIBLIOGRAPHY

[1] CDMA-PAMR SRDoc V0.1.1 (2002-8), “System Reference Document, CDMA-PAMR”, SE(02)114.
[2] ETSI TR 102 260 v1.1.1: CDMA-PAMR System Reference Document.
[3] EN 300 113-2, Electromagnetic compatibility and Radio spectrum Matters (ERM); Land MS service; Radio equipment intended for the transmission of data (and/or speech) using constant or non-constant envelope modulation and having an antenna connector; Part 2: Harmonized EN covering essential requirements under article 3.2 of the R&TTE Directive
[4] EN 300 392-2, Terrestrial Trunked Radio (TETRA); Voice plus Data (V+D).

ANNEX 1 – SCENARIOS

This annex summarises the scenarios studied and the options considered. For these scenarios the interference at the border is calculated for a range of separations from the border.

Objectives

The scenarios define the configurations of base stations which may be used for the study of cross border scenarios. For this annex a range of scenarios were considered and from these the scenarios for the majority of the studies were selected.

Each scenario creates a certain interference at the border for each one the cumulative interference at the border must be evaluated. This annex also includes the results of these studies.

Methodology

The scenarios were selected by envisaging a continuously rolled out network which crossed a border, the location of the border relative to the network was capable of being varied relative to the alignment of the base stations within the network.

If the two networks on either side of the border are perfectly compatible and perfectly co-ordinated then the network at the border will have the appearance of a continuously rolled out network across the border. In practice the differences are likely to include:-

Different allocations of channels on either side of the border
Different base station densities to reflect different user densities
Different technologies on either side of the border
Networks rolled out according to different rules on the two sides of the border

It may be seen that the probability of perfect co-ordination is extremely low. The other extreme is the worst case in which the same channels are used on opposite sides of the border at the closest possible interval. It is necessary that cross border agreements are planned to cope with this worst case and that any gains which may be achieved by co-ordination should be available to those administrations and network operators as a benefit resulting from the additional work that they have undertaken.

For each case it was necessary to determine the appropriate interference at the border, this was achieved by modelling the proposed configuration using SEAMCAT. The power was modelled using both one and two rings of supplementary interferers in order to determine whether the number of rings made a significant difference, it was found that, at the repeat patterns used, only one ring was necessary. For these models within SEAMCAT the victim receiver was located at the agreed measurement height of 3 metres at the distance agreed. The received bandwidth of the victim receiver was 25 kHz so that the mean received signal shown using SEAMCAT and the standard deviation would be available from the SEAMCAT modelling tool.

Conclusions

The scenarios were evaluated and it was decided that for the majority of the interference modelling it would be appropriate to use the scenario for narrowband base stations in which the row of base stations is not aligned with the border because this would have a higher probability of conforming to the environment found in practice.

Scenarios

It was determined that networks may be either co-ordinated at a border or unco-ordinated. Co-ordination is commonly used for GSM networks at borders when the adjacent operators co-operate to ensure that there is neither excessive interference nor loss of service at the border. In this case the resulting services appear to offer a seamless service across the border.

There are also networks which do not co-operate at borders. In this circumstance the worst case of interference of the border would occur when the same frequency is used on opposite sides of the border and the best case would occur when the two sides have been accidentally aligned as though they had co-operated. The two limiting circumstances are improbable but the most common case must lie between the two extremes so these have formed the basis for the models. In the following examples the two sides the border have been labelled:-

L left
R right

Co-Operation

In the following example the network operators have used the same repeat pattern in order to minimise the area which suffers poor coverage. The interference is the same as would be the case for their network within the countries.

In this model only a single frequency has been shown and the spaces between the cells would be occupied by other frequencies as dictated by the repeat pattern.

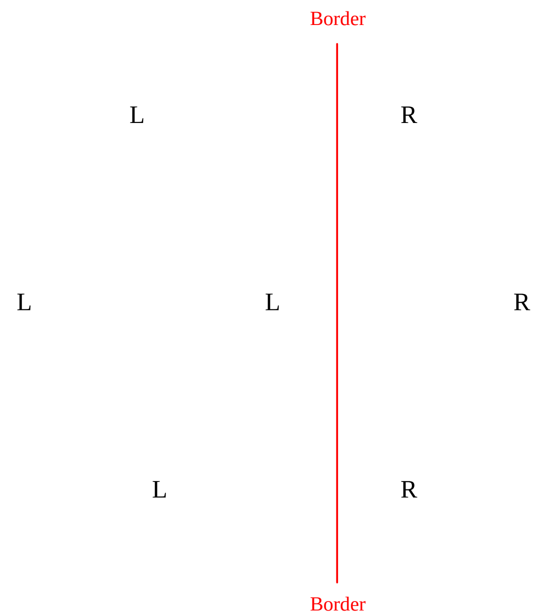
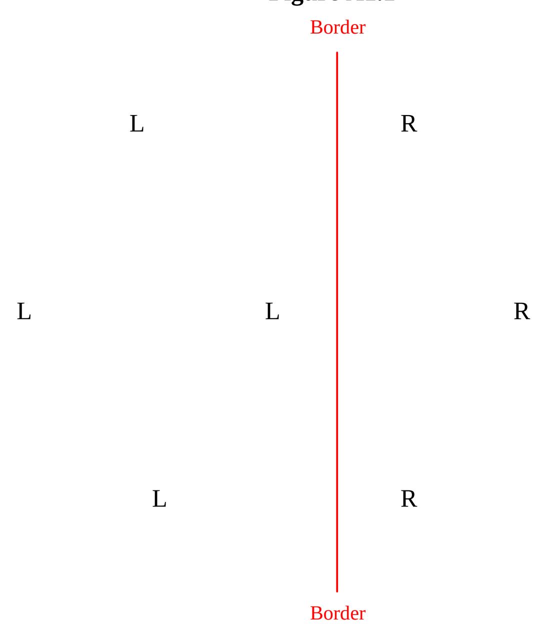


Figure A1.1



If these operators were also limited by a maximum field strength at the border then the effect would be to split arrangement shown above as follows:-

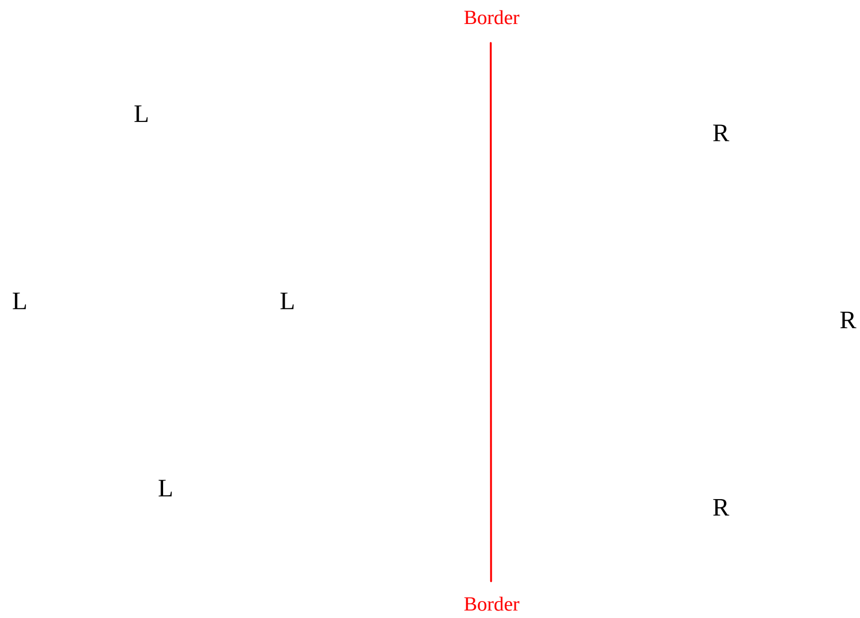
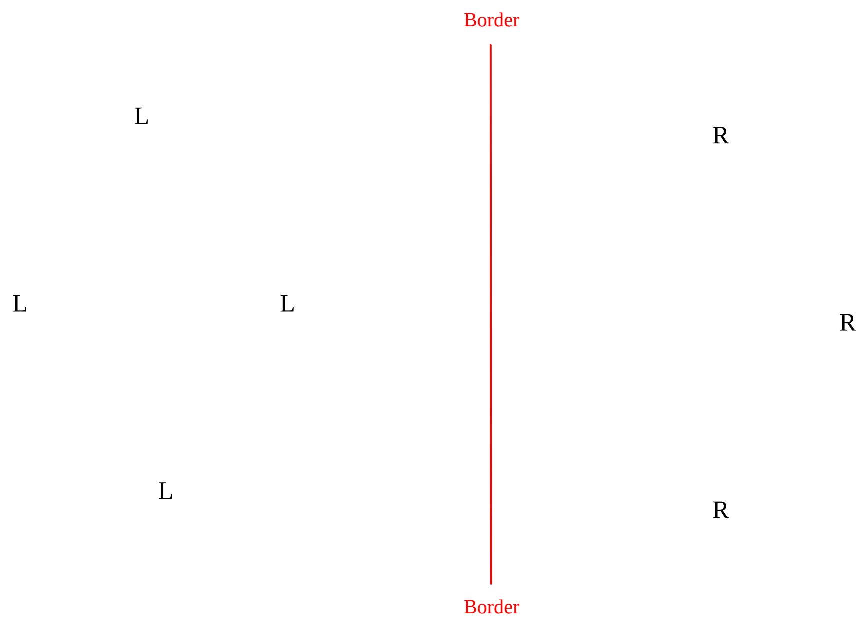


Figure A1.2



It was decided to calculate the field strength at a border for both sides of the border shown above although only the left side is likely to be used in the majority of interference cases.

A worst case of interference for the arrangement shown above would appear as follows:-

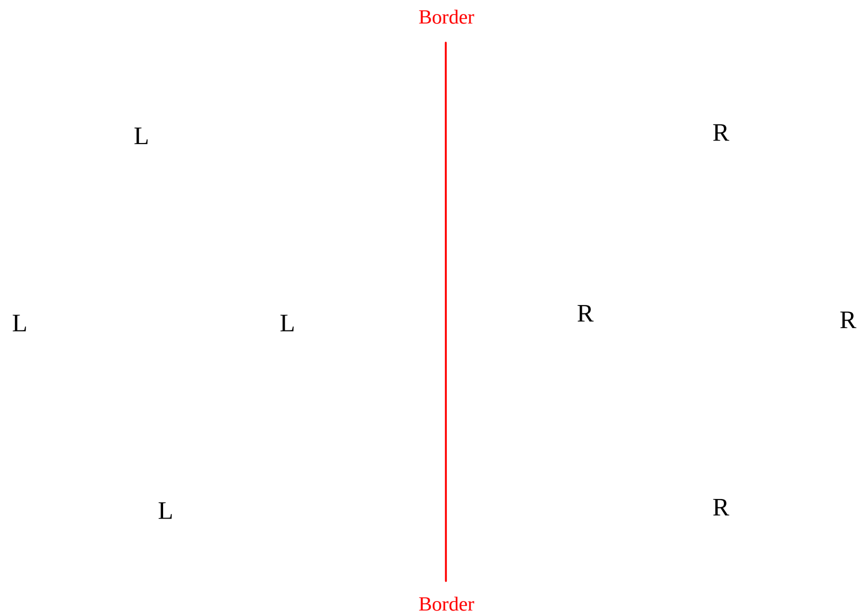
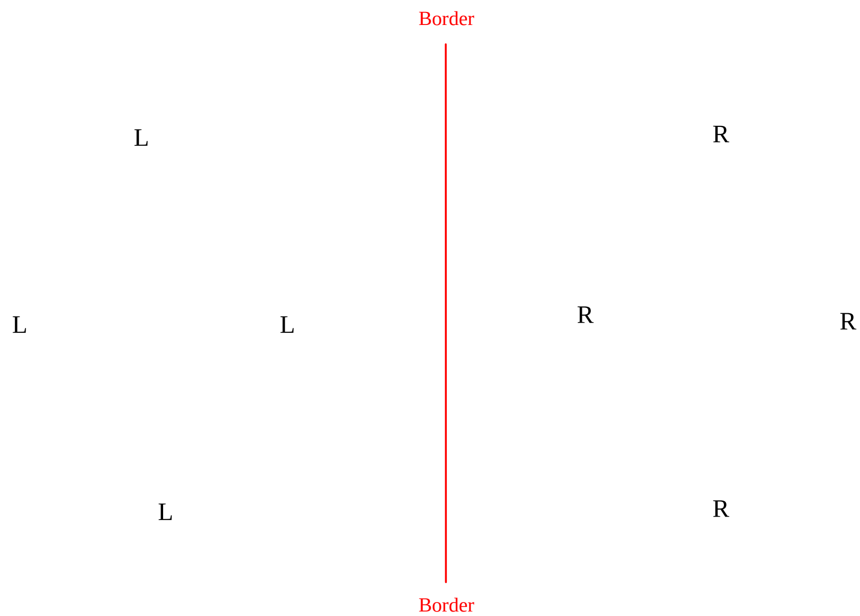


Figure A1.3



The other arrangement which may take place at a border would be one in which an attempt is made to align the base stations with the direction of the border. This co-ordinated case is shown below:-

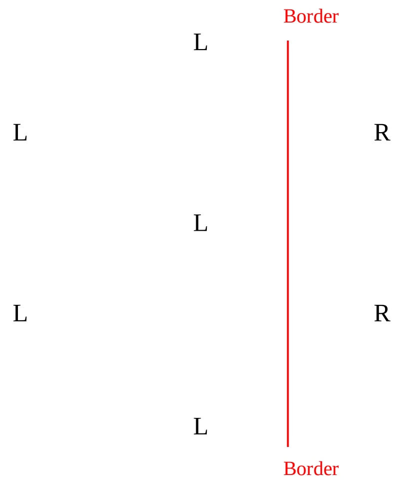
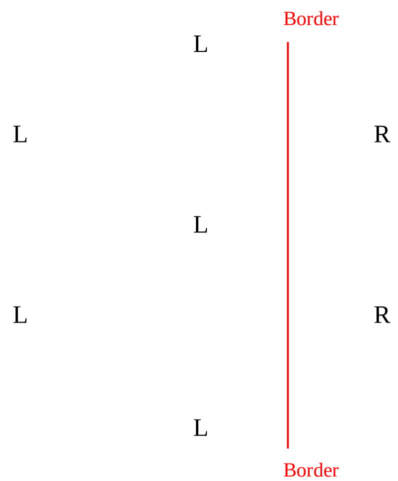


Figure A1.4



When this arrangement is separated by a restriction of the maximum power at the border there will be only two base stations on the right side of the border. To improve the accuracy of the calculation these two base stations may be supplemented by the closest ones from the next ring, as shown:-

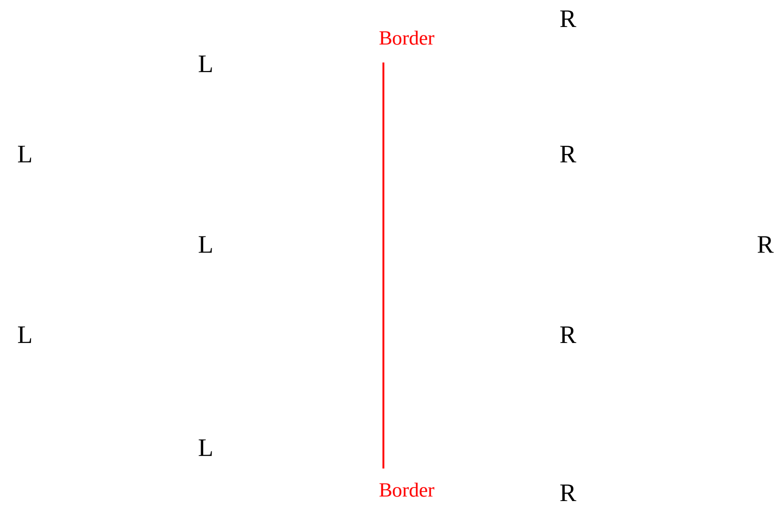
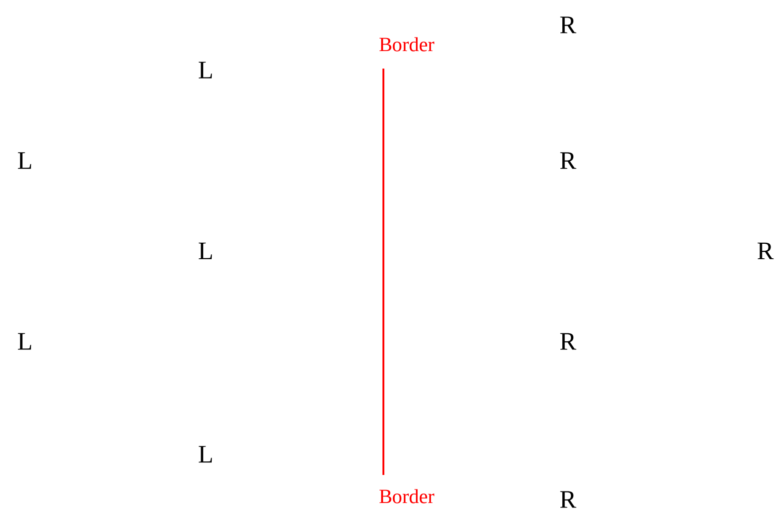


Figure A1.5



For each of these arrangements the distance of the measurement point from the network is taken as the distance of the closest base station to the border. The measurement height is 3 metres, the work has revealed that, for the Hata path loss used, the difference between 3 metres and 10 metres is 15.3 dB.

Field Strengths at Border

For each scenario and each technology it is necessary to determine a field strength at the border which is comparable for all of the technologies. The power was measured in a bandwidth of 25 kHz.

A bandwidth of 25 kHz is not directly comparable between the technologies being studied because the receive bandwidth of the 25 kHz technologies varies. For narrowband FM systems using a 25 kHz raster the bandwidth is typically 16 kHz which results in it receiving -1.8 dB relative to the bandwidth of 25 kHz. For TETRA systems having a 25 kHz raster the bandwidth is 18 kHz which will result in TETRA receiving -1.4 dB relative to the bandwidth of 25 kHz.

In order to determine these field strengths and their variability at the agreed measurement height of 3 metres a terminal was modelled at that height and with those characteristics and for each configuration the received power was modelled using SEAMCAT and the agreed path loss model.

Results

In all of these studies:-

The distance is the closest base station to the border in kilometres

The RSS is the received signal strength through a 0 dB antenna, expressed as dBm

The SD is the standard deviation derived from SEAMCAT expressed as dB

For the first set of studies the repeat pattern for narrowband FM systems was assumed to be 36 and the path loss model was assumed to be the SE21 version of Okamura Hata with the environment parameter set to Suburban.

Base stations not parallel to the border

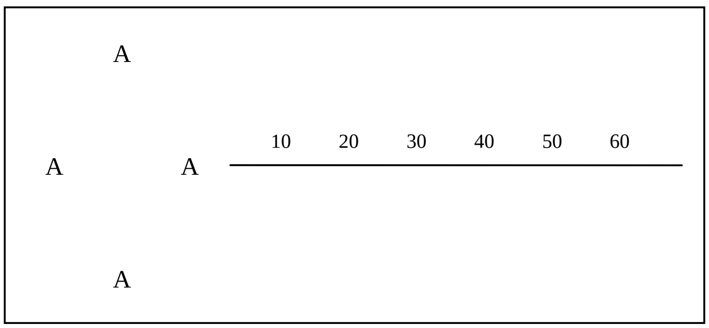
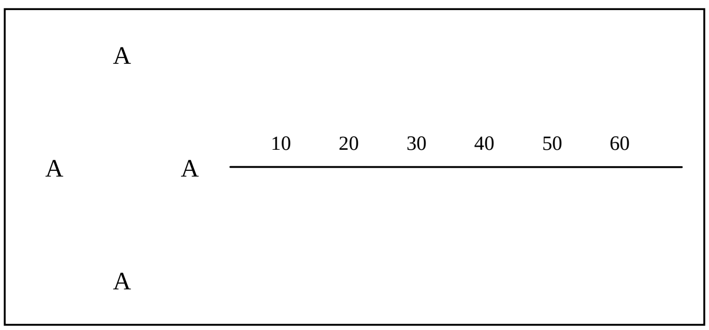


Figure A1.6



Distance	10	20	30	40	50	60
RSS	-100.9	-110.9	-117.6	-122.6	-126.7	-130.1
SD	8.7	8.0	7.5	7.1	6.7	6.5

Table A1.1

The same process was undertaken for this scenario with a range of repeat patterns:-

Repeat Pattern 25

Distance	5	10	15	20	25	30	40	50
RSS	-90.1	-100.0	-105.6	-109.6	-113.0	-115.9	-120.7	-124.7
SD	8.73	8.23	7.69	7.36	7.11	6.83	6.51	6.29

Table A1.2

Repeat Pattern 16

Distance	5	10	15	20	25	30	40	50
RSS	-89.8	-99.5	-104.9	-108.7	-112.0	-114.9	-119.7	-123.8
SD	8.55	7.86	7.28	6.95	6.67	6.47	6.25	6.11

Table A1.3

Repeat Pattern 9

Distance	5	10	15	20	25	30	40	50
RSS	-89.3	-98.7	-103.7	-107.4	-110.7	-113.6	-118.5	-122.6
SD	8.21	7.21	6.75	6.5	6.31	6.14	6.0	5.95

Table A1.4

Right Hand Side of Base Stations Not Parallel to the Border

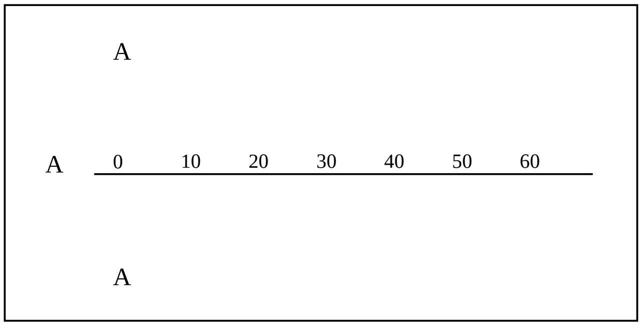
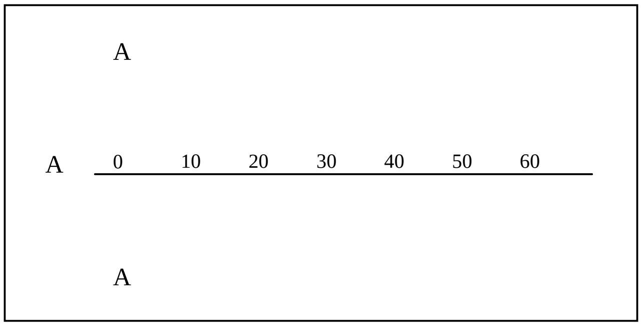


Figure A1.7



Distance	0	10	20	30	40	50	60
RSS	-112.7	-116.5	-119.6	-122.5	-125.4	-128.2	-131.0
SD	6.9	6.4	6.2	6.3	6.2	6.2	6.3

Table A1.5

Base Stations Parallel to the Border

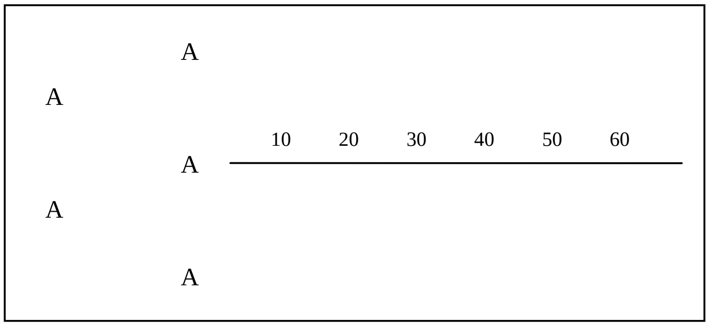
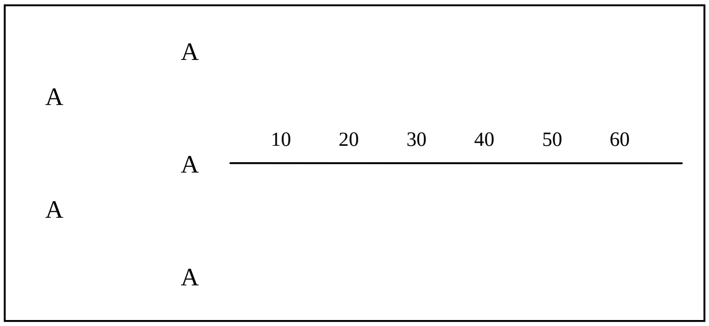


Figure A1.8



Distance	10	20	30	40	50	60
RSS	-100.9	-110.3	-116.5	-120.9	-124.6	-128.4
SD	8.5	7.6	6.9	6.4	6.1	5.9

Table A1.6

Right Hand Side of Base Stations Parallel to Border

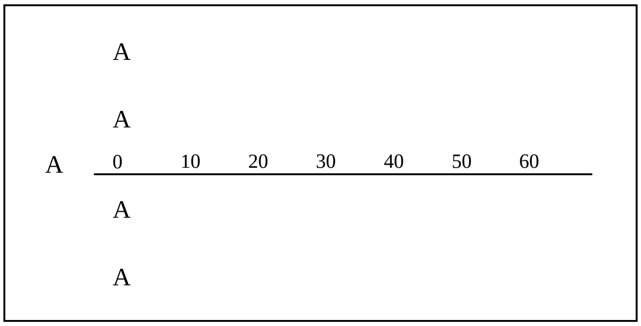
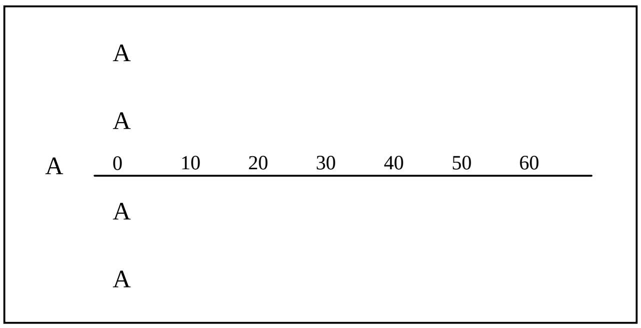


Figure A1.9



Distance	0	10	20	30	40	50	60
RSS	-109.3	-110.8	.-114.1	-117.8	-121.4	-124.7	-127.8
SD	6.4	6.5	6.5	6.4	6.2	6.0	5.8

Table A1.7

CDMA System

The interference created by a CDMA system in a 25 kHz band width was modelled using the same methods as are specified above. The parameters for this CDMA network are included in Annex 10.

Tx Power 40 dBm

Distance	5	10	15	20	25	30	35	40
RSS	-96.9	-103.5	-108.0	-111.1	-114.6	-117.6	-119.8	-122.0
SD	5.6	5.2	4.5	4.5	4.2	3.9	4.1	4.0

Table A1.8

Tx Power 44 dBm

Distance	5	10	15	20	25	30	35	40
RSS	-93.0	-99.2	-104.1	-107.1	-110.6	-113.1	-115.9	-118.4
SD	5.8	4.7	4.6	4.5	4.2	4.0	3.7	3.5

Table A1.9

ANNEX 2 – INTERFERENCE WITHIN NARROWBAND SYSTEMS

Objective of Studies

The purpose of the studies of narrowband systems was to study and compare the interference for all of the scenarios under consideration using a widely used technology so that the relative interference for the various configurations would become apparent.

Methodology

A cell repeat pattern was selected which would deliver a low percentage of interference in a fully rolled out network with the path loss model which was selected. It should be understood that the cell repeat pattern is strongly affected by the path loss model which is used and the path loss exponent employed.

The first step was to model the interference from a single ring of interferers in order to obtain the percentage interference for a rolled out network. This scenario was then sectioned in the manner listed in the annex which specifies the scenarios and for each scenario the percentage interference was calculated.

Conclusion

The studies demonstrated that if a lower rate of interference is required resulting from interference across a border than that which is inherent in the cell repeat pattern selected then, even if the frequency re-use in the networks are co-ordinated a significant increase in the separation distance across a border will be necessary. If the networks are not co-ordinated and a low percentage of interference is required across a border is required then the separation distance required will be very great. It may be concluded that it is inappropriate for a protection level to be specified at a border which protects an operator to a greater extent than his own repeat pattern protects his network.

Where the worst of interference may occur then it is necessary that there will be a gap between the networks in which the percentage coverage will be poor and the quality of service will decline in those areas where coverage is available. The separation distances between base stations for the worst case of interference was 40 kilometres if the line of base stations is not aligned with the border and 50 kilometres if both lines of base stations are aligned. The second option is relatively improbable so that in practical terms it should be expected that a separation equivalent to a path loss using Okamura Hata – suburban environment – for 40 kilometres will be required.

This separation does not imply that there will be no service at the border. If the border is 20 kilometres from the nearest base station to it, the first 4.2 kilometres would be within the cell and therefore unaffected and the next 15.8 km to the border would suffer progressively degraded service until, at the border, the probability of obtaining a service would be low.

Results of Studies

The limiting interference which should be endured is that which would occur in a continuously developed narrowband network. In this case the same frequency is repeated at the distance which is calculated from the cell pitch and the cell repeat pattern.

Self Interference from a Network

For this case a single ring of interferers has been studied:-

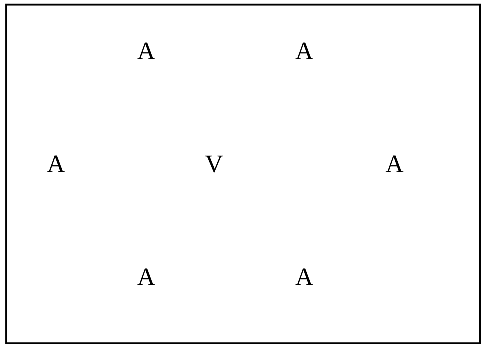
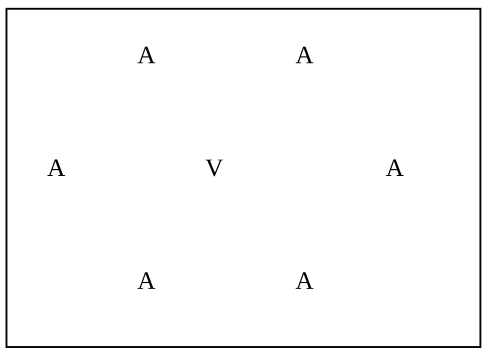


Figure A2.1



The percentage interference found was 2.2%.

With just three interferers:-

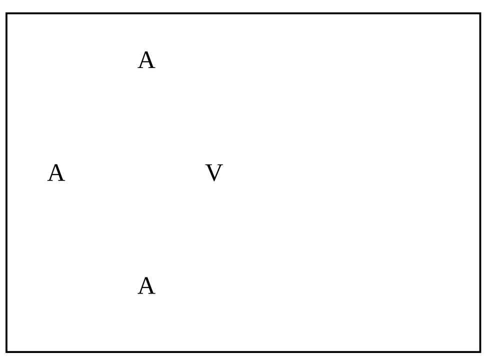
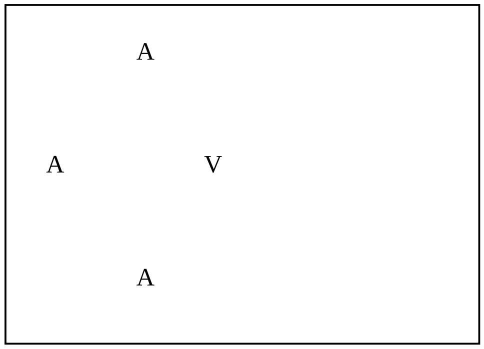


Figure A2.2



The interference percentage was found to be 1 %.

With 4 interferers and a line parallel to the border:-

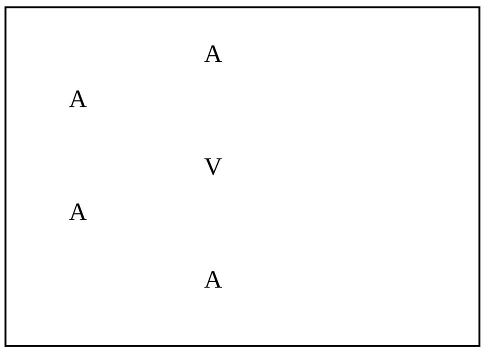
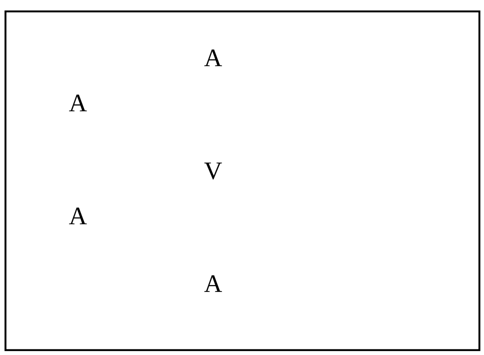


Figure A2.3



The percentage interference was 1.4 %.

We may deduce that the interference across a border for the co-ordinated case should be expected to commence at 2.2 % and decline to either 1.4% or 1%.

Note: Concerning the accuracy of the percentages. In order to achieve accuracy to the second decimal of a percentage point it is necessary to undertake a very great number of iterations of the model. This has not been deemed to be necessary at this stage of the calculations. The last decimal point of the figures above could be in error by up to one tenth of a decimal point.

Separating Co-Ordinated Networks Across Borders

Base Stations not Aligned with Border

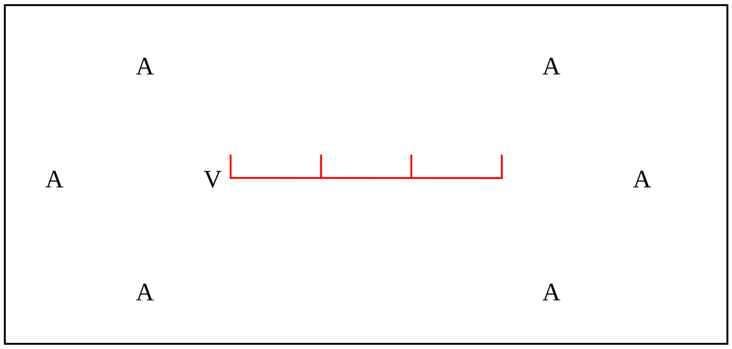
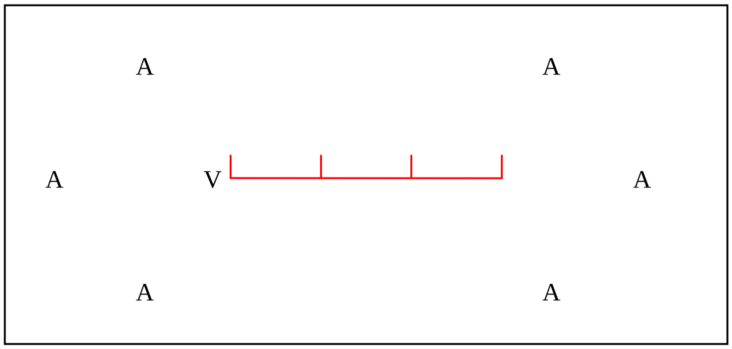


Figure A2.4



Separation (km)	0	2	5	10	20	30	40	50
Distance to border (km)	10.9	11.9	13.4	15.9	20.9	25.9	30.9	35.9
Percentage Interference	2.2	2.1	1.7	1.6	1.4	1.1	1	1

Table A2.1

In table A2.1 the separation is the additional distance which has been applied between the two sides of the continuously developed network. The distance to the border assumes that the border is equidistant from the two closest antennas.

Base Station Aligned with Border

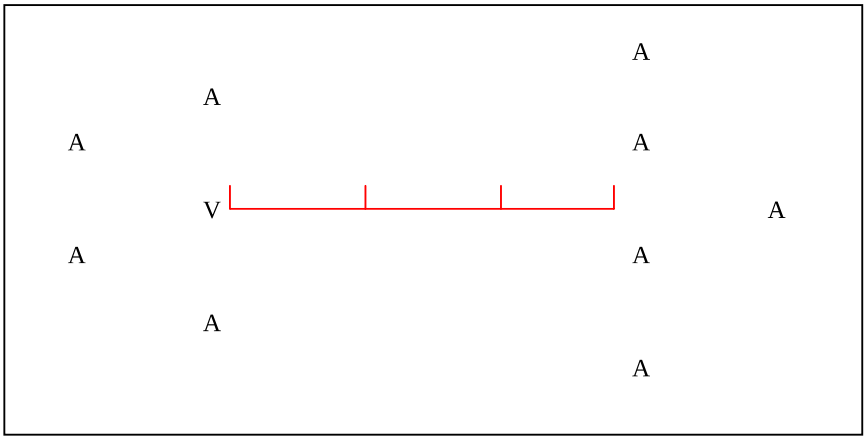
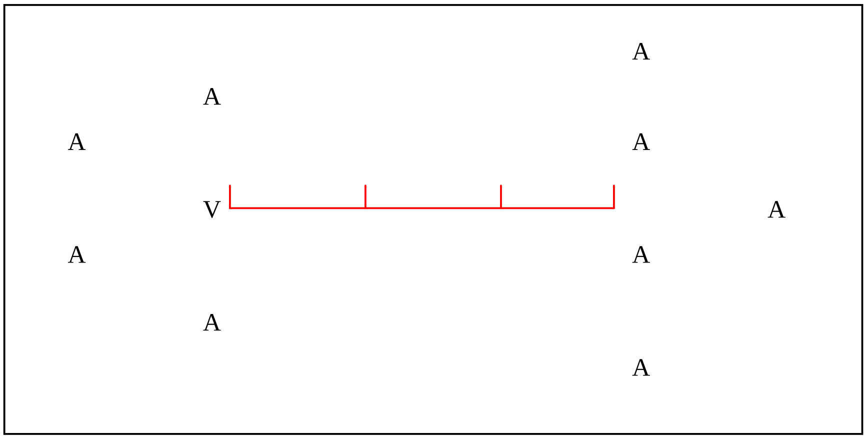


Figure A2.5



Separation (km)	0	5	10	20	30	40
Distance to border (km)	18.9	21.4	23.9	28.9	33.9	38.9
Percentage Interference	2.1	1.8	1.7	1.5	1.5	1.48

Table A2.2

Separating Worst Case Networks Across a Border

Base Stations Not Aligned with Border

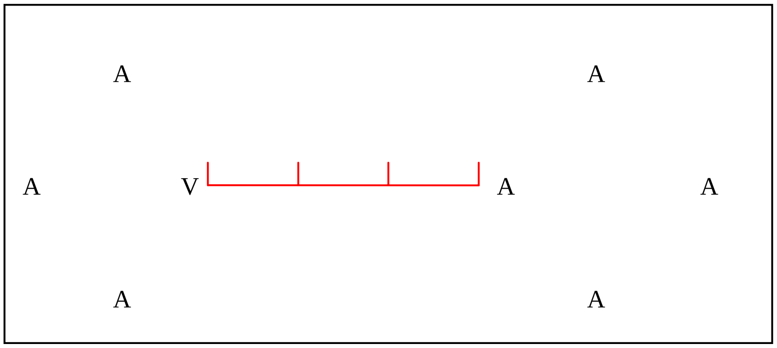
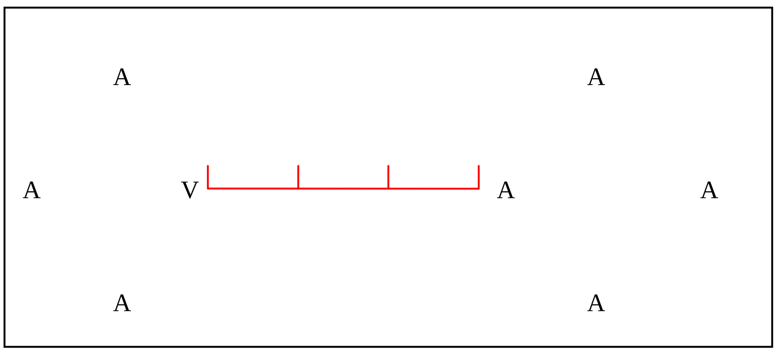


Figure A2.6



Separation (km)	10	20	30	40	50	60	70	80	90	100
Dist to border (km)	5	10	15	20	25	30	35	40	45	50
Percent Interference	28.9	9.8	4.4	2.0	1.5	1.28	1.17	1.16	1.07	1.03

Table A2.3

Base Stations Aligned with Border

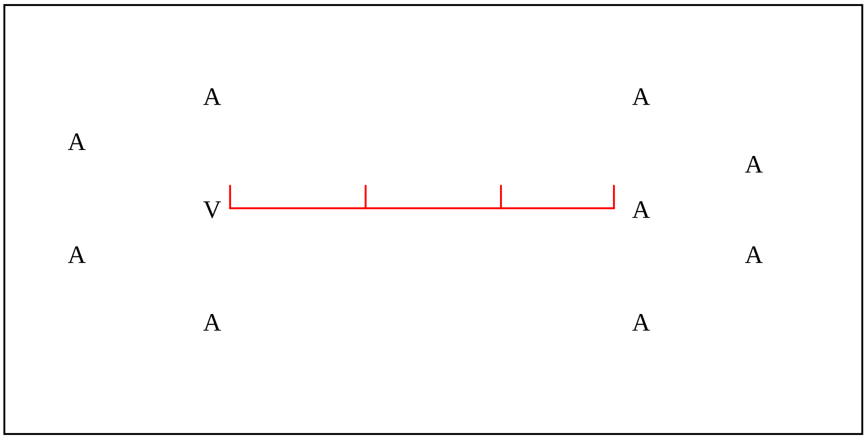
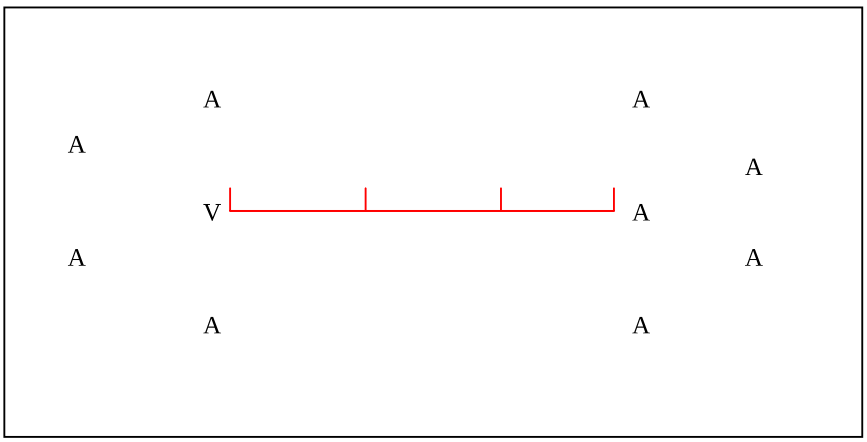


Figure A2.7



Separation (km)	10	20	30	40	50	60	70	80	90	100
Dist to border (km)	5	10	15	20	25	30	35	40	45	50
Percent Interference	28.9	10.4	5.1	3.0	2.0	1.55	1.57	1.48	1.39	1.3

Table A2.4

ANNEX 3 - INTERFERENCE FROM CDMA PAMR TO NARROWBAND SYSTEMS

Objective of Studies

The relative interference between narrowband systems was derived in annex 2. This annex provides comparable figures for the worst case narrowband interference figures when the interferer is a CDMA system.

It should be noted that there is no equivalent to the co-ordinated case if the technologies have greatly different technical parameters, therefore the co-ordinated case could not be studied.

The interference from narrowband into CDMA is studied in annex 5.

Methodology

The methodology followed that used for the studies for narrowband systems. A narrowband system exactly equivalent to that used in the narrowband studies was created on one side of the border and the CDMA network was created on the other. The separation distance between the networks was increased in order to reveal the separation distance at which the percentage interference became the same as that for a narrowband network.

The CDMA system was configured to use two different maximum powers and an attempt was made to ensure that the self-interference in the network was close to the 2% used in the narrowband systems.

Conclusion

It was found that the CDMA-PAMR system yielded a lower percentage interference than the equivalent narrowband system at the same separation distance and that separation distances across the border are reduced for CDMA-PAMR technologies to between 20 and 30 kilometres.

Results of Studies

Two traffic channel powers were used 40 dBm and 44 dBm.

Narrowband Network Not Aligned with a Border.

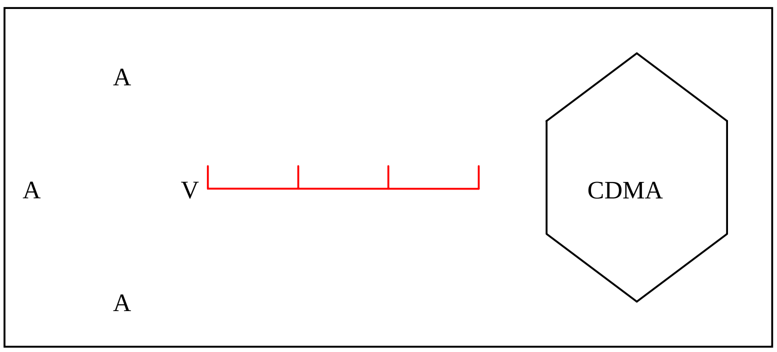
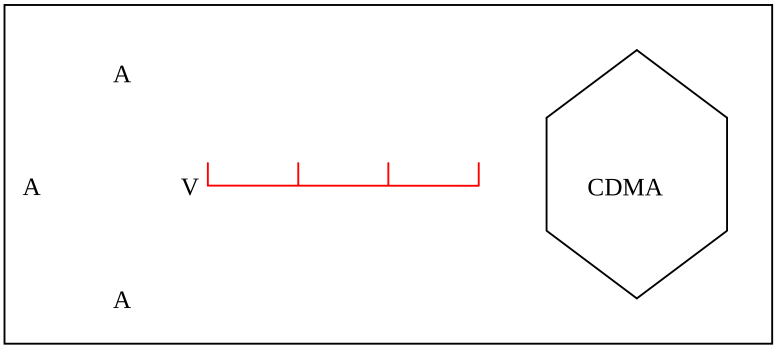


Figure A3.1



The results obtained from modelling this form of interference included:-

Tx Power - 40 dBm

Separation (km)	5	10	15	20	25	30
Percent Interfered	22.5	7.9	3.1	1.2	0.9	0.8

Table A3.1

Tx Power - 44 dBm

Separation (km)	5	10	15	20	25	30
Percent Interfered	32.6	14.3	8.9	3.9	1.8	0.51

Table A3.2

ANNEX 4 - INTERFERENCE FROM CDMA PAMR TO CDMA PAMR

Objective of Studies

The objective of this study was to extend the studies undertaken to show the impact of CDMA on a narrowband FM system to include the probability of interference from two unco-ordinated CDMA PAMR systems.

Methodology

The two CDMA systems were modelled at separation distances which were progressively increased. It was noted that two transmitter powers are widely quoted in studies of CDMA-PAMR both transmitter powers were modelled, without changing the cell sizes, in order to demonstrate the differences which would result from an increase in the transmitter power.

Conclusion

For the scenarios studied the separation distance at which the natural level of internal interference within the network occurs varies between slightly more than 20 kilometres to less than 30 kilometres.

It is notable that CDMA is a technology which benefits from increased power when suffering interference from neighbouring networks.

Results of Studies

The CDMA to CDMA case considers interference between two un-coordinated CDMA systems across a border.

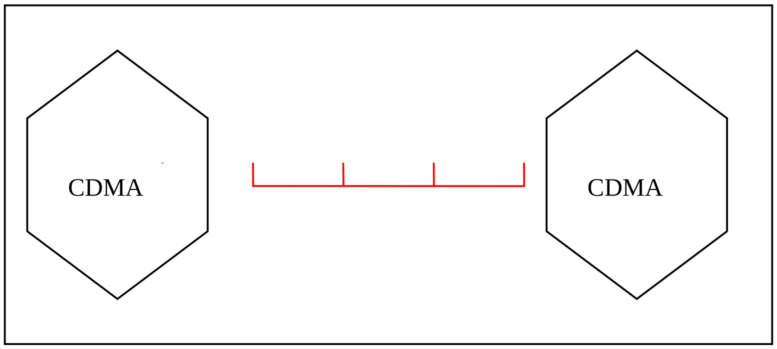
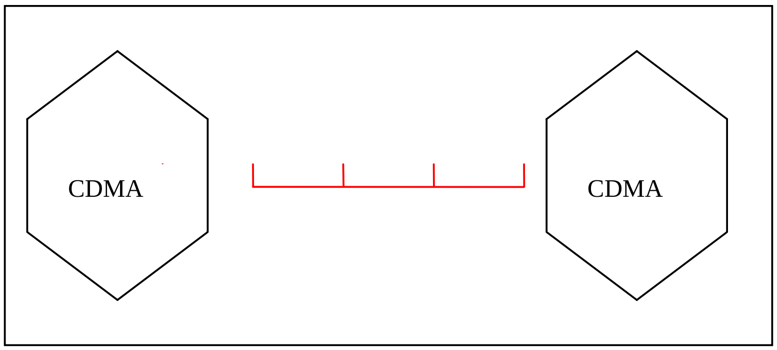


Figure A4.1



The results of the study include:-

For 44 dBm Tx power

Separation (km)	5	10	15	20	25	30
Percent Interfered	40.3	21.7	9.9	3.9	2.6	1.3

Table A4.1

For 40 dBm Max Tx Power

Separation (km)	5	10	15	20	25
Percent Interfered	35.1	18.2	6.6	3.2	1.57

Table A4.2

It should be expected that these two sets of results would be very similar.

For 44 dBm Max Power Interfering to 40 dBm Max Power

Separation (km)	5	10	15	20	25	30
Percent Interfered	47.21	31.46	15.9	7.6	3.9	2.0

Table A4.3

ANNEX 5 - INTERFERENCE FROM NARROWBAND SYSTEMS INTO CDMA PAMR

Objective of Studies

Studies were undertaken to determine the impact of a fully rolled out narrowband network into a CDMA technology. It was forecast that the CDMA-PAMR network would be more resistant to interference than a narrowband network, these studies tested that assumption by using a fully rolled out narrowband network which would occupy the full 1.25 MHz of the CDMA technology at the cell repeat pattern selected.

Methodology

In order to measure the effect of interference from a continuous narrowband network into a CDMA network it was necessary to simulate a narrowband network in SEAMCAT 3. The procedure used to undertake this task included the following steps:-

The distance between cells was calculated for the narrowband network

A single row of interferers was established parallel to the border which extended to either side of the CDMA network. This model was run to determine the percentage interference which it created.

Another two rows of interferers were entered and the model was run again, the increase of the percentage interference was noted.

Another two rows of interferers was added and it was found that the percentage interference had not risen. This was the number of interferers used. The total was 33 BSs arranged as 3 rows of seven base stations and 2 rows of 6 base stations.

Since the bandwidth of the CDMA system is 50 times that of the narrowband system it was necessary to represent a total of 50 base stations this was achieved by increasing the transmitted power by 50/33 = 1.8 dB.

The network therefore models the interference from a fully rolled out narrowband network into a CDMA network.

Conclusion

The percentages of interference between the two networks are lower than or comparable to those found whilst studying interference from a CDMA network into a narrowband network, it is therefore evident that, when the use of a narrowband network on one side of a border is compared with the use of a CDMA network across the border, and the frequencies are shared, the studies should focus on the interference from CDMA into the narrowband network.

Results of Studies

The model was run for CDMA powers of 40 dBm and 44 dBm. The results are shown the following table as percentages:-

Distance (km)	10	15	20	25	30
40 dBm	18.2	8.1	3.6	1.7	0.7
44 dBm	9.8	4.3	1.8	0.9	0.3

Table A5.1

ANNEX 6 – VARIATIONS OF THE CELL REPEAT PATTERN

This annex studies the impact of variations of the cell repeat pattern. The primary studies have been based on a high repeat pattern with low interference. These studies reflect the lower repeat patterns which may be encountered in practice in certain countries.

Objectives of Studies

The studies reflect the lower cell repeat patterns which may be encountered in practice. A continuously developed network of base stations will suffer co-channel interference from all of its neighbouring cells. In practice real networks will gain benefits from terrain shielding, from a distribution of customers which requires that the network is only rolled out in some directions and not in others and also a distribution of the base stations which is focused on those areas in which there is a high concentration of users.

The location of base stations in the areas in which there is a great concentration of users is very common in narrowband FM systems and is typically seen when the population is concentrated in a series of small towns. This alternative is common in border areas and is examined in detail in this annex.

Methodology

The methodology for this annex followed the methodology used in the primary studies for this report:-

> A continuously rolled out network was defined which employs the cell repeat pattern to be studied. The self interference for this arrangement is determined by modelling.
>
> A network of narrowband interferers using the same repeat pattern is studied with a range of separation distances from the victim receiver.
>
> The interfering narrowband network is replaced by an interfering CDMA network.
>
> The interference is studied to reveal the relative interference and the power at the border.

It should be noted that the interference from systems constructed such that they exploit the natural shielding from the terrain or in which the population covered does not require the network to be rolled out in all directions will encounter lower levels of interference.

The scenario in which the services are concentrated within towns have been studied by converting the user distribution from an even spread across the territory to a Gaussian distribution around the base station transmitter which is assumed to be within the town. The Gaussian distribution has been selected such that 68% of the users are within half of the cell radius. This figure should be compared with the even distribution in which only 25% of the users will be within this distance.

Conclusions

In order to provide a comparison, the interference figures for a narrowband system with a 36 cell repeat pattern have been copied from Annex 1. These figures show self-interference at 2.2% and a separation between the narrowband networks of 40 kilometres.

When this network is converted to a 25 cell repeat pattern, the loss of service resulting from co-channel interference increases to 6.5% but the separation across the border is reduced to less than 30 kilometres. In exchange for the networks on both sides of the border being willing to tolerate increased percentages of loss of service the area lost at the border is significantly reduced.

The equivalent separation distance for a CDMA system against the 25 cell repeat pattern for the narrowband network is 20 kilometres.

When the 25 cell repeat pattern is used with a Gaussian distribution of users, as might be found in a network serving a series of small towns, the power at the border and the separation distance remain the same but the loss of service due to co-channel interference falls to 1.4%.

A 16 cell repeat pattern was studied in a similar manner. In this case the separation distance falls to slightly more than 20 kilometres for a narrowband network and to slightly more than 10 kilometres for a CDMA network but the self-interference rises to 14.1%. When the Gaussian distribution of users is applied then the separation across the border and the power at the border remain the same but the self interference falls to 2.8%.

Finally a 9 cell repeat pattern was studied and whilst the loss of service due to co-channel interference for a continuously rolled out network rose to 27.9%, the separation across the border fell to between 10 and 15 kilometres for a narrowband interferer and less than 10 kilometres for a CDMA interfering system. For the Gaussian distribution of users the loss of service due to co-channel interference increased to 6.1%.

Two key conclusions may be derived from these results:-

If the network operators on both sides of the border are prepared to accept higher levels of interference or, if they are able to use low repeat patterns as a result of terrain factors or the distribution of users, then it is possible to work closer to the borders with less impact on the loss of service.

The reduced percentage of interference which is available from the terrain effects or the concentration of users close to the base stations, does not affect the power at the border or the required separation distance. These figures are fixed by the cell repeat pattern employed.

Results of Studies

The high repeat pattern and low interference case which formed the basis of the studies of narrowband systems employed a repeat pattern of 36. A repeat pattern of 36 yields a distance between the locations of the repeated channels of:-

$$6 \times \sqrt{3} \times Rad_{cell} = 10.4 \times Rad_{cell}$$

In this case:-

$Rad_{cell} = 4.2$
Separation of repeated channels = 43.6 km

For this repeat pattern the results included:-

Self interference from 6 surrounding cells = 2.2%

Narrowband Interferer – not aligned with border

Separation (km)	10	20	30	40	50	60	70	80	90	100
Percent Interference	28.9	9.8	4.4	2.0	1.5	1.28	1.17	1.16	1.07	1.03

Table A6.1

These figures have also been derived for cell repeat patterns of 25, 16 and 9.

Cell Repeat Pattern 25

Self Interference from 6 cells = 6.5%

Narrowband Interferer – not aligned with border

Separation (km)	10	20	30	40	50
Percent %	29.3	11.3	5.6	4.0	3.45

Table A6.2

CDMA Interferer (44 dBm)

Separation (km)	10	20	30	40	50
Percent %	18.2	6.5	3.2	1.6	1.8

Table A6.3

The same set of calculations were repeated with the user distribution in the victim network as a Gaussian distribution. The Gaussian distribution was configured such that 68% of the users were within 50% of the cell radius (2.1 kilometres). This compares with equal distribution above in which 75% of the users would be at greater than 50% of the cell radius from the transmitter.

Self Interference from 6 cells = 1.4%

Narrowband Interferer – not aligned with border

Separation (km)	10	20	30	40
Percent %	7.0	2.63	1.28	0.85

Table A6.4

CDMA Interferer (44 dBm)

Separation (km)	10	20	30	40
Percent %	3.9	1.4	0.5	0.7

Table A6.5

Cell Repeat Pattern 16

Self Interference from 6 cells = 14.1%

Narrowband Interferer – not aligned with border

Separation (km)	10	20	30	40	50
Percent %	32.3	15.3	10.1	8.4	7.3

Table A6.6

CDMA Interferer (44 dBm)

Separation (km)	10	20	30	40
Percent %	15.46	8.4	7.1	4.7

Table A6.7

The same set of calculations were repeated with the user distribution in the victim network as a Gaussian distribution. The Gaussian distribution was configured such that 68% of the users were within 50% of the cell radius (2.1 kilometres). This compares with equal distribution above in which 75% of the users would be at greater than 50% of the cell radius from the transmitter.

Self Interference from 6 cells = 2.8%

Narrowband Interferer – not aligned with border

Separation (km)	10	20	30	40
Percent %	7.9	3.4	2.1	1.7

Table A6.8

CDMA Interferer (44 dBm)

Separation (km)	10	20	30	40
Percent %	3.26	1.88	1.75	0.88

Table A6.9

Cell Repeat Pattern 9

Self Interference from 6 cells = 27.7%

Narrowband Interferer – not aligned with border

Separation (km)	5	10	15	20	25	30	35	40
Percent %	59.5	38.6	28.5	23.3	20.8	18.8	18.2	17.2

Table A6.10

CDMA Interferer (44 dBm)

Separation (km)	5	10	15	20	25	30
Percent %	38.2	23.7	16.5	14.2	12.7	11.3

Table A6.11

The same set of calculations were repeated with the user distribution in the victim network as a Gaussian distribution. The Gaussian distribution was configured such that 68% of the users were within 50% of the cell radius (2.1 kilometres). This compares with equal distribution above in which 75% of the users would be at greater than 50% of the cell radius from the transmitter.

Self Interference from 6 cells = 6.1%

Narrowband Interferer – not aligned with border

Separation (km)	5	10	15	20	25	30
Percent %	16.7	9.2	6.7	5.1	4.4	4.4

Table A6.12

CDMA Interferer (44 dBm)

Separation (km)	5	10	15	20	25	30
Percent %	8.9	4.3	3.9	2.8	2.4	2.5

Table A6.13

ANNEX 7 – TETRA SYSTEMS

It was requested that TETRA systems should be studied and also that higher interference percentages should form the basis of the network design.

Objectives of the Study

There are technologies which require a high carrier to interference ratio in order to provide a good service. These technologies have gained capacity within the amount of spectrum used at the cost of vulnerability to interference. It was requested that this alternative should be studied in order to determine the effect on the cross border performance. The study extracts:-

Cell repeat pattern

Cross border separation as a result of interference from a similar technology

Cross border interference from a wide band technology

For this study TETRA has been used as the technology under consideration.

Methodology

The methodology follows that defined for the studies of narrowband technologies:-

Six interferers all at the same distance and evenly spaced around the victim system are used to represent a continuously rolled out network. It has been found that this arrangement offers a model which is close to a continuously rolled out network.

One half of the interferers are removed and replaced by an interfering network. From the original work on scenarios described in Annex 1 it was clear that there were two alternative methods by which this could occur, with the base stations aligned with the border and with them not aligned with the border. The scenario in which the base stations area aligned with the border is relatively improbable so for this study the unaligned scenario was adopted. Thus:-

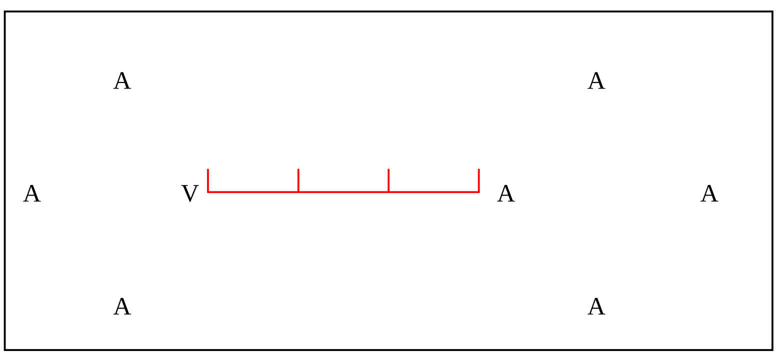
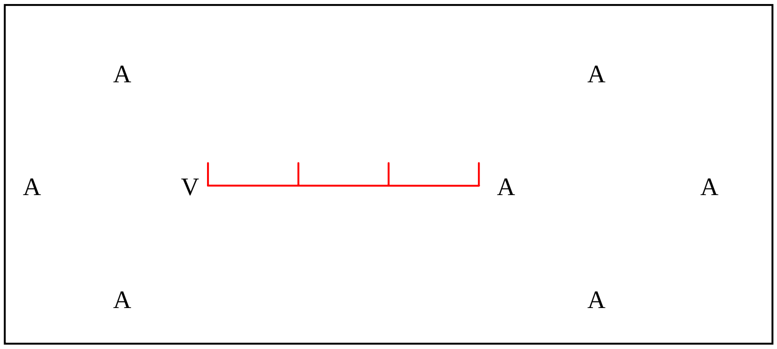


Figure A7.1



The interfering TETRA network was then replaced with a CDMA cluster. Thus:-

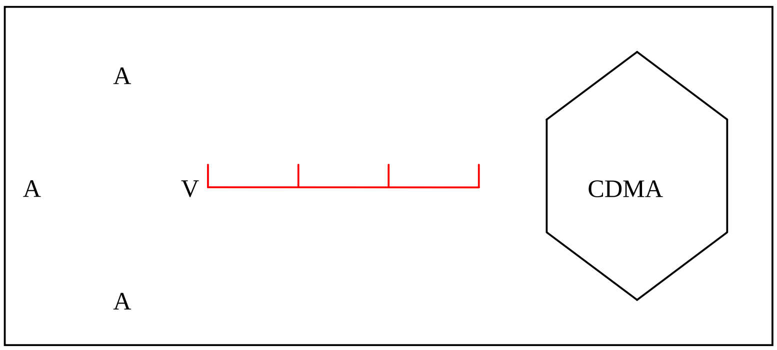
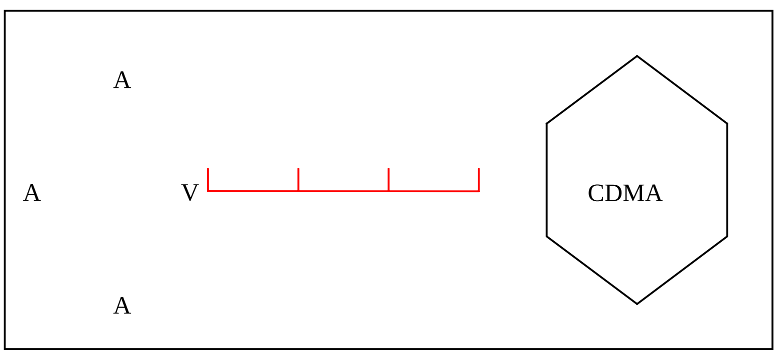


Figure A7.2



In the original studies of narrowband systems the power measured at 3 metres above the ground in 25 kHz was derived in order to provide the equivalent of the measurable power at the border. This process was also applied to the TETRA model. Thus:-

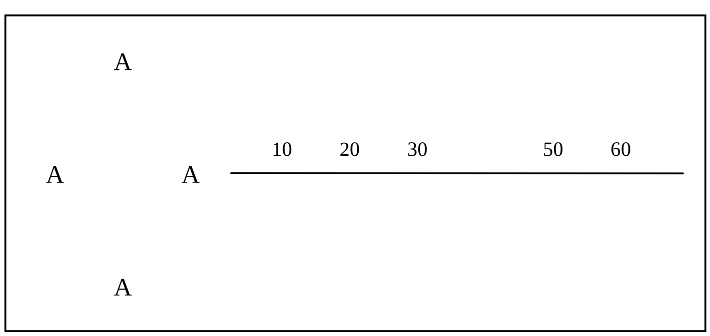
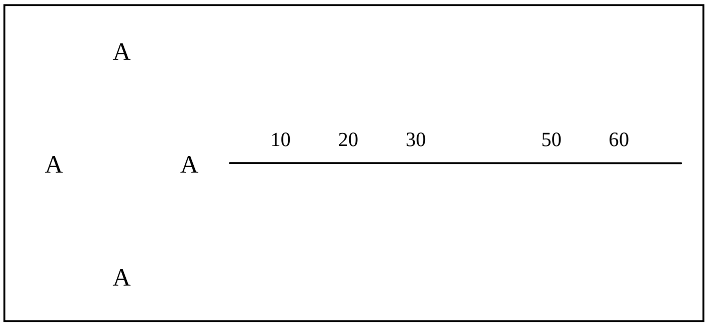


Figure A7.3



Conclusions

The tests demonstrated that:-

> The increase in the required C/I results in a need for a repeat pattern which yields a lower density of re-use. In this case the cell repeat pattern for an analogue system with a required C/I ratio of 12 is 36 whilst that for a TETRA system with a required C/I of 19 the cell repeat pattern increases to 49.
>
> The higher required C/I ratio results in an increase in the separation across a border in this case the 40 kilometres of separation which is required for a narrowband FM system with a C/I of 12 increases to 50 kilometres when the required C/I increases to 19.
>
> The CDMA system required a similar separation across a border to the equivalent narrowband TETRA system.
>
> There was no significant difference in the power measured at the border between the TETRA system and the equivalent narrowband system. The two systems have approximately the same power, antenna height and bandwidth so this should be expected.

Results of the Studies

Cell Repeat Pattern

A victim system surrounded by 6 evenly spaced interferers, as described in the Methodology above, was modelled at varying cell repeat ratios in order to find a cell repeat pattern which offered an acceptably low self interference.

Using the parameters listed in the relevant section below a repeat pattern of 49 was found to yield a self interference of 3.67%. These studies were repeated with a cell repeat pattern of 36 which yielded a self interference of 10.1%.

Interference from TETRA to TETRA Across a Border

Two unaligned networks were established as described under the methodology above and the interference into a victim cell which is closest to the border was found. The figures found for a cell repeat pattern of 49 included:-

Separation (km)	20	30	40	50	60	70
Percent	24.9	12.1	5.9	3.5	2.5	1.9

Table A7.1

With a cell repeat pattern of 36 the figures became:-

Separation (km)	20	30	40	50	60
Percent	27.4	16.1	10.2	7.7	6.75

Table A7.2

It was found that the greater C/I ratio for TETRA required an increased separation at the border relative to the equivalent figures for a conventional FM system having a lower required C/I ratio. The figures may be summarised as:-

	Required C/I	Separation (km)
Narrowband FM	12 dB	40 km
TETRA	19 dB	50 km

Table A7.3

The reduction of the cell repeat pattern to 36 restores the 40 kilometre separation distance which was found for narrowband systems but the percentage interference will then match the higher self interference figure of 10%.

Interference from CDMA PAMR to TETRA Across a Border

The interference from a CDMA system into a TETRA system was studied by replacing the interfering TETRA system in the study of TETRA to TETRA with a 19 cell CDMA cluster. The study was undertaken at two maximum CDMA e.i.r.p. levels, 49 dBm and 53 dBm, equivalent to transmit powers at the antenna input of 40 dBm and 44 dBm. The cell repeat pattern was 49.

CDMA Interference with an output power of 44 dBm (53 dBm e.i.r.p.)

Separation (km)	20	30	40	50	60
Percent	21.0	9.6	6.4	5.0	3.6

Table A7.4

CDMA Interference with an output power of 40 dBm (49 dBm e.i.r.p.)

Separation (km)	20	30	40	50
Percent	12.5	6.3	4.6	3.3

Table A7.5

The study with an output power of 44 dBm (53 dBm e.i.r.p.) was repeated for a cell repeat pattern of 36 in the TETRA system and the following figures were found:-

Separation (km)	20	30	40	50	60
Percent	23.8	12.1	7.3	6.9	5.7

Table A7.6

It is seen that the CDMA system requires a similar or slightly greater separation distance across the border relative to the TETRA system suffering interference from a similar system.

Measurement of RSS at the Border

The received signal strength at the border was measured in a 25 kHz bandwidth at a height of 3 metres. The e.i.r.p. of the base station was 44 dBm.

Distance	10	20	30	40	50	60
RSS	-101.5	-111.4	-117.9	-122.9	-126.8	-130.25
SD	8.67	7.9	7.35	6.53	6.52	6.52

Table A7.7

ANNEX 8 – FLASH OFDM

Background

It was requested that the cross border parameters for Flash OFDM should be studied. This note will describe the methodology used and the results found.

Methodology

It is not currently possible to model Flash OFDM using SEAMCAT. SE7 developed a method which involved the use of a small bespoke Monte Carlo modelling program to determine the interference to Flash OFDM from a narrowband network and SEAMCAT to determine the effect of the interference from Flash OFDM to a narrowband network.

In all of the studies which have been completed for this report a number of steps have been necessary:-

i. Find the percentage loss of service for a fully rolled out network of base stations. It is assumed that this loss of service will result from co-channel interference.

ii. Define a network such that the victim cell is at the edge of the network, find the (reduced) figure for percentage loss of service due to co-channel interference.

iii. Move an interferer closer to the victim cell until the percentage loss of service returns to the figure for a fully rolled out network.

The process for Flash OFDM remained the same. A Monte Carlo model was created in order to represent the arrangement of base stations in a Flash OFDM network. The power transmitted by a Flash OFDM base station is dependent on the number of terminals in use, this model permitted this power profile to be extracted as a histogram. It also extracted the percentage loss of service due to both cell overloading and failure to achieve the minimum required C/I. The mean bit rate for an entire cell was also calculated. In this case cell overloading refers to the capability of the base station to serve the number of mobile terminals in the cell. If a base station can serve 8 mobiles and there are 9 mobiles within the cell then one mobile will be unable to gain a service as a result of the overload.

The interference into Flash OFDM was obtained by including an array of interfering base stations and measuring the effect on the percentage loss of service in the victim cell.

The interference from Flash OFDM was created using SEAMCAT and applying the transmitted power profile which was derived from the small bespoke model.

It should be noted that the primary study has used a cell radius of 12 kilometres, this is significantly larger than that used for the remaining technologies studies. The studies were also undertaken using a cell radius of 6 kilometres (comparable with the cell radius for CDMA-PAMR), this resulted in greater self-interference and a reduced separation distance between the networks, as discussed in section 4.0 of the report.

Results

The received signal strength in a 25 kHz bandwidth was calculated in the same manner as has been used in the other studies, namely the received RSS into a 25kHz measurement bandwidth at a height 3 metres. The results appeared as follows:-

Distance	10	15	20	25	30	40	50
RSS	-103.5	-107.43	-110.6	-113.2	-115.7	-119.9	-123.7
SD	5.74	5.07	4.89	4.59	4.42	4.3	4.11

Table A8.1

A similar set of calculations have been carried out to find the impact of a fully rolled out network on a narrowband system, the results include:-

Distance	20	25	30	40	50	60
Percent	7.48	5.26	3.9	2.78	2.36	2.2

Table A8.2

The percentage outage for a fully rolled out narrowband network with a cell repeat pattern was 2.2%. This figure is achieved with a separation distance of 60 km.

In both of these studies the OFDM network comprised 16 OFDM cells arranged as a parallelogram with 7 cells in the first row. The power output of the Flash OFDM cells complied with the power profile determined from the bespoke model which was constructed to study the performance of a Flash OFDM network.

Interference into Flash OFDM

The process of modelling agreed was that the capacity/outage for a continuously rolled out network would be modelled using the centre cell of an array as the reference cell. The reference cell would then be moved to the edge of the network and the interference would be applied. Then the model would be run with various interferer distances until the interference experienced was the same as that in the fully rolled out network. This method was applied to interference into Flash OFDM.

Continuously Rolled Out Network

Requested Users per Cell	**2**	**3**	**4**	**5**	**6**	**7**
Mean Users Connected	2.03	3.12	4.15	5.1	5.89	6.45
% Lost to Cell OverLoad	0	0.05	0.34	1.3	3.29	6.44
% Failed C/I	0.38	1.07	2.20	3.43	4.47	5.35
Mean Delivered Bit Rate Per Cell	230.6	324.87	408.86	478.75	528.77	571.58
Mean C/I (dB)	12.32	12.33	12.40	12.43	12.37	12.40

Table A8.3

Flash OFDM is a technology which can support a number of different mean user loads per cell but it cannot sustain all base stations being fully loaded if the users are randomly placed. It was necessary to select a user load which would represent a fully loaded network. It was noticed that beyond a mean number of 6 users per cell the performance of the cell started to degrade severely. The percentage of users rejected because the nearest cell was fully loaded started to exceed the number rejected as a result of C/I failure. It was decided that a mean user load of 6 users should be considered to be a high load.

The reference cell was moved to the outside of the network and the following figures were found.

Requested Users per Cell	6
Mean Users Connected	5.69
% Lost to OverLoad	2.78
% Lost to Failed C/I	2.64
Mean Delivered Bit Rate	584.77
Mean C/I (dB)	14.56

Table A8.4

It was evident that the reduced noise from the neighbouring cells had resulted in the reduced interference which would be expected.

Cross Border Interference

Cross border interference was applied using multiple narrowband base stations in exactly the same manner as was used for CDMA. 33 base stations were arranged as five rows of interferers. All of the base stations were assumed to be transmitting. The difference between the assumed number of channels required to fill the spectrum (50) and the number of base stations modelled (33) was corrected by increasing the base station power. The results found included:-

Separation (km)	20	30	40	50	60
Mean Number Connected	5.7	5.69	5.7	5.7	5.69
% Lost to Overload	2.75	2.7	2.79	2.69	2.68
% Lost Failed C/I	29.26	14.78	7.47	4.7	3.53
Delivered Bit Rate	325.99	439.6	512.99	550.23	568.86
Mean C/I	6.86	11.06	13.05	13.9	14.32

Table A8.5

This table reveals that a separation distance of 50 kilometres will return the percentage of users lost as result of failed C/I to the figure found for the continuously rolled out network

Reduced Cell Radius

The calculations were also undertaken using a cell radius of 6 kilometres for comparison with CDMA-PAMR. The self-interference table included:-

Users per Cell	2	3	4	5	6	7
Mean Users Connected	2.11	3.16	4.17	5.13	5.96	6.62
Lost to Cell OverLoad	0	0.06	0.41	1.38	3.56	7.12
Failed C/I	0.18	0.81	1.99	3.38	4.84	5.7
mean Delivered Bit Rate Per Cell	233.3	325.7	403.6	469.4	520.9	560.8
Mean C/I	12.1	12.06	12.15	12.03	12.08	12.12

Table A8.6

The table for interference from across a border included:-

Separation (km)	20	25	30
Mean Number Connected	5.66	5.66	5.69
% Lost to Overload	2.60	2.70	2.75
% Lost Failed C/I	6.18	4.48	3.7
Delivered Bit Rate	517.7	542.2	559.1
Mean C/I	13.25	13.73	14.11

Table A8.7

It can be seen that the separation distance falls to 25 kilometres when comparable cell radii are employed.

ANNEX 9 – PARAMETERS USED FOR SEAMCAT MODELLING

Modelling Parameters for Narrowband FM Technologies

The parameters used for SEAMCAT models of narrowband FM technologies included:-

BS Power	38 dBm
BS antenna gain	3 dBi
BS Antenna height	30 metres
Mobile Sensitivity	-106 dbm
Mobile antenna gain	0 dBi
Mobile antenna height	1.5 metres
Mobile required C/I	12 dB
Cell radius	4.2 km
Path loss model	Hata suburban
Carrier raster	25 kHz
Carrier bandwidth	16 kHz

CDMA Modelling Parameters

The percentages of interference measured are the percentages of the downlink only.

The allowable initial outage has been set to 5%.

The specification of the CDMA network included:-

Cell Radius	5.9 km
BS Antenna Gain	9.0 dBi
BS Antenna Height	30 metres
MS Antenna Height	1.5 metres
MS Antenna Gain	0 dBi
Rx Noise Figure	8 dB
Handover Margin	4 dB
Call Drop Threshold	3 dB
Voice Bit Rate	9.6 kbps
Voice Activity Factor	1.0
Minimum coupling Loss	70 dB
Pilot Channel	15%
Overhead Channel	5%
Max Traffic Channel	15%

Model Parameters for TETRA System

The following parameters were used for the SEAMCAT model of the TETRA network:-

MS ERP	30 dBm
MS Antenna Gain	0 dBi
BS ERP	44 dBm
BS Antenna Gain	11 dBi
BS Antenna Height	30 metres
BS Tx Power	33 dBm
MS Sensitivity	-103 dBm
Carrier Raster	25 kHz
Carrier Bandwidth	18 kHz
Required C/I ratio	19 dB
Cell Radius	5 km
Path Loss Model	Hata Suburban
Cell Repeat (default)	49

Downlink power control was not applied.

Model Parameters for Flash OFDM

The Flash OFDM network was a continuously rolled out network with a cell repeat pattern of 1. It was modelled with a mean of up to 7 users each taking one eighth of the downlink capacity. This method ensured that some cells would have more users than they can serve and others would have fewer than the average. This process reflects the practical implementation.

The studies identified that the Flash OFDM network approached the maximum practical load when the mean number of users per cell reached 6 users. This figure was used to generate a downlink power profile.

The interfering network on the down link was assumed to comprise 16 cells arranged as a parallelogram with 7 cells in the row which was adjacent to the border. This profile maximised the number of cells which would be within the range at which the interference to the victim cell would be significant. The cell radius was assumed to be 12 kilometres.

Max Tx Power BS	41 dBm
Antenna Gain BS	11 dBi
Antenna Height BS	30 metres
Antenna Height Mobile	1.5 metres

Path Loss Model

The path loss model used throughout these studies was the SE21 version of Hata with the Suburban environment which is specified in ERC Report 068. The suburban environment was selected as being representative of the environment in which the majority of mobile radios are used, it also provides a good representation of a border area with tree cover.

For those borders which are both flat and lacking in trees the separation distances shown will not adequately represent reality.

The path loss exponent for Hata with the model parameters used is 3.52, it will be found that at certain border areas and at greater distances the path loss exponent will be higher and it should be expected that both cell re-use patterns will be lower and the required separation distance will be reduced.