Retuning and Relocating GSM900 Spectrum Assignments in Ireland

ComReg Document 10/71c

Joint Report for ComReg

By

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Executive Summary

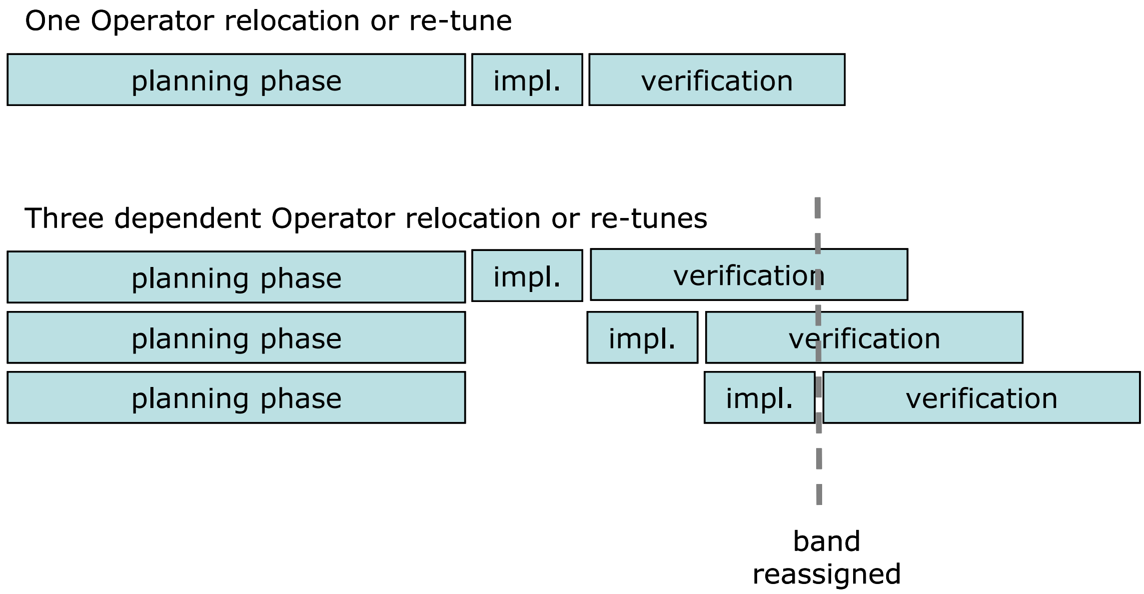
In the context of the liberalisation of 900 MHz mobile spectrum in Ireland, the terms of reference for this study were to examine the implications of three main scenarios:

- Scenario 1 – an existing GSM licensee is assigned 2 x 10 MHz
- Scenario 2 – a GSM licensee is assigned 2 x 5 MHz
- Scenario 3 – Meteor maintains its existing spectrum bandwidth (2 x 7.2MHz), but has to retune 200 kHz lower to ensure 'Block E' is unencumbered for spectrum liberalisation.

Scenarios 1 and 3 are the more benign scenarios for the network operators because neither would necessitate an immediate reduction in the amount of 900 MHz spectrum available for operation of their 2G networks. The timescales and costs of these scenarios can therefore be estimated by examining the required activity and estimating the costs of engineering resources and equipment.

Scenario 1

A project to 'relocate' an operator's spectrum assignment would have a planning, an implementation and a verification phase. In the case of multiple operators moving assignments, the implementation phases are dependent on each other. In the worst practical case, there could be three interdependent implementation phases. The verification phase is undertaken after each operator has relocated to its new spectrum block and does not impact on the other operators.



This study concludes that all of the GSM 900 MHz licensees should be able to modify their networks to take account of revised 900 MHz frequency assignments in a timeframe of approximately 5 months consisting of a planning phase of approximately four months, and an implementation phase of approximately 1 month. The implementation period is relatively short, generally overnight during a weekend. The subsequent verification activity of approximately 2 months occurs after the spectrum has been reassigned, and does not occur on the critical path.

The relocation project will involve some engineering costs which can be split into labour cost and equipment cost categories. These categories of cost will both depend to some extent on the size of the network. Having stated some clear assumptions around the amount of labour required, its costs and relevant equipment costs, the study concludes that the engineering costs for a 'typically' sized Irish network would be of the order of €500,000.

Scenario 3

Scenario 3 is similar to Scenario 1, and the same approach to estimating timescales and costs has been used. In other words, even though the spectrum assignment is only being retuned' by 200 kHz rather than 'relocating' to a different spectrum block, a similar process and activity has been assumed. The analysis is therefore 'worst case' in this regard. The timescale for Scenario 3, when considered in isolation, would be approximately four months consisting of a planning phase of approximately four months, and an implementation phase of approximately 1 week. The subsequent verification activity of approximately 2 months occurs after the spectrum has been reassigned, and does not occur on the critical path.

The cost estimates for Scenario 3 are lower than for Scenario 1, although the same approach has been used. The estimates are lower because the project is a 'retuning' project, and there is no requirement to deal with issues specific to 'relocation' such as replacement of some band selective repeaters. In retuning, co-ordination, both nationally and internationally is simplified, as the coordination activity is with the same third parties before and after the retuning activity.

The resulting cost estimate for Scenario 3 is around €300,000. This is in excess of the figure of around €X[1] estimated by Meteor for the same project. This level of discrepancy is not surprising given the completely independent approaches to estimating costs. The Meteor estimate is more likely to include figures that reflect the actual cost base of Meteor, and the so the figure of €X[2] supplied by Meteor can therefore be accepted as a reasonable estimate of the actual cost of Scenario 3.

Scenario 2

The impact of Scenario 2 on a GSM network operator is much more difficult to estimate as it is very dependent on details of the existing network, its intrinsic capacity and the interaction of the GSM900 layer with the GSM1800 and 3G networks of the operator. This study considers a number of important factors that affect the ability of the GSM operator to respond to a reduction in 900 MHz spectrum. In order to adjust to a reduction in 900 MHz spectrum without significantly affecting network Grade of Service, operators might be expected to take the following mitigating steps in the following order:

[1] Figure supplied is confidential.

[2] Figure supplied is confidential.

- Increase the use of AMR (Adaptive Multi-Rate) coding at 900 MHz and 1800 MHz, especially during the busy hour
- Offload capacity to existing 1800 MHz and 2100 MHz cells where possible
- Add new 1800 MHz & 2100 MHz cells on existing 900 MHz sites where essential
- Add new 1800/2100 MHz sites where absolutely necessary, and add new 900 MHz sites if completely unavoidable

These steps would be implemented in this order because this is the order of increasing marginal cost per unit of additional network capacity.

Analysis of Scenario 2 involves modelling the impact on an operator's network due to a reduction in GSM900 spectrum from 7.2MHz to 5MHz. The study found that key assumptions in establishing an operator's 'baseline' or reference network, and which will depend on an operator's existing network design and traffic management strategy, can have a significant effect on the real impact of Scenario 2. The network design and traffic management strategy will vary from operator to operator and can be influenced by a number of interdependent factors including:

- frequency bands and bandwidths assigned
- the relative timing of the different frequency band assignments to the operator
- customer profiles: use of voice and data services, areas of use, volumes of traffic generated
- Handset types in use
- Mobile broadband usage
- Network hardware types
- Network features and functionalities available and employed

A full appreciation of the impact of Scenario 2 cannot, therefore, be estimated without a good understanding of the current network. As an example, the study identified the increasing use of half rate or Adaptive Multi Rate (AMR) speech coding as the most cost effective traffic management strategy for maintaining network capacity in the face of a reduced spectrum assignment. However, an operator who is already heavily using half rate or AMR will have less to gain from this strategy.

Analysis was carried out using the Forsk Atoll planning tool to model the impact of a reduction in GSM900 bandwidth from 7.2 MHz to 5 MHz. The analysis was conducted for sample networks in rural and urban areas. A number of assumptions were used to generate the model networks, and some standard GSM functionalities were not accounted for due to the modelling complexities. These aspects are detailed in section 4.2. Whereas these assumptions may affect the accuracy of the model results, the analysis is based on comparisons of relative outputs of different scenarios, and not the absolute output of each scenario in isolation. This approach helps to minimises any influence of 'baseline' assumptions that do not match the actual practice of an individual operator.

The analysis was based on the comparison of predicted interference levels on a GSM900 network having 5MHz of spectrum with those levels predicted on a baseline GSM900 network established using 7.2MHz of spectrum. Contiguous GSM900 network coverage is assumed for both networks.

This analysis, whilst establishing a credible reference result for Scenario 2, may not reflect the real situation of an individual operator. For example, a possible strategy for a GSM900 network with a 5MHz frequency assignment is for the operator to move towards a predominantly GSM1800 or UMTS network, with GSM900 used selectively for large area coverage or where the characteristics of better signal propagation are required. In this case, contiguous coverage on GSM900 would not be essential. With such a strategy, GSM900 could be used on rural high sites to provide “umbrella” coverage, with the use of GSM1800 and/or UMTS increased in towns and villages to serve the more concentrated traffic. Similarly, for urban areas, GSM900 might be used selectively where suitable sites cannot be acquired to serve an area with GSM1800 or UMTS cells. Such a strategy would not be adequately represented by the results achieved using the comparison of networks with contiguous GSM900 coverage.

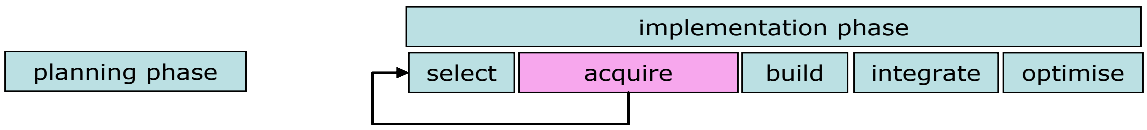
The results showed that the decrease in assignment bandwidth from 7.2 MHz to 5 MHz resulted in a significant impact on the Carrier to Co-Channel Interference (C/Ic) quality of the network which would cause a decrease in the quality of service[3] that a customer would experience. Any reduction in GSM900 bandwidth for an operator would likely result in

[3] The decrease in C/Ic ratio cannot easily be related objectively to the severity of the effects experienced by an individual customer

traffic being offloaded to GSM1800 and UMTS2100 networks respectively as well as an increase in the use of half rate or AMR speech coding. Reducing the GSM900 band traffic improved the C/Ic performance, but even with a 33% reduction in GSM900 band traffic the C/Ic performance was still below that of the initial 7.2 MHz network.

The modelling processes showed that for the assumed reference network, an additional 414 GSM900 sites would be required nationally to counteract the increase in interference caused by the reduction in assigned bandwidth. Building this number of sites would be a major undertaking by an operator, representing an increase of approximately 25% in the total number of GSM900 sites deployed. A significant increase in resources would be required to build such a number of sites in a short timeframe, and these resources would be required both internally within the operator's organisation and externally with subcontracted suppliers. If simultaneous rollout of large numbers of sites was required by more than one operator this would put significant demands on existing industry resources and suppliers adding potential risks of delays to the expansion programmes.

A high level process to build these sites could be split into planning and implementation phases.



In the planning phase, it would be necessary to consider additional recruitment and appointment of subcontractors. The operator might consider how the overall project would be split into regions, and how best to integrate the new activity with 'business as usual activity'. The 'implementation phase' is concerned with building new sites. A generic five stage 'select – acquire – build –integrate – optimise' approach is described in the body of this report. As a rule of thumb, the five stage site build process can be completed in around 9 months if it goes according to plan. This five stage process would be repeated 414 times for each additional site to be built. The overall timescale taken will be subject to a number of constraints such as the time taken to acquire problem sites, resource scheduling constraints and dependency on third parties.

A total CAPEX (capital expenditure) cost of €55m is estimated for an additional 414 sites. The cost estimates assume that there is a mix of typical site types to match urban and rural locations and that all new sites are built as new single operator GSM900 only sites. In this regard this is a ‘worst case’ assumption as multi-technology multi-operator site sharing arrangements reduce per-operator costs. In addition, if existing transceivers are removed from existing GSM900 sites as a result of a reduction in spectrum then they may be re-used elsewhere. The model excludes ongoing OPEX (operational expenditure) associated with the additional sites, such as lease costs, ongoing costs for power and the transmission network and increased maintenance costs arising from the additional sites in the network.

A four year period is estimated for the completion of all 414 sites, but it is estimated that 90% of these sites could be completed by the end of year-2. It is therefore likely that GSM900 spectrum could be relinquished at the end of the 2 year period, although there may be minor additional disruption to network subscribers. This additional disruption would be localised to areas where the remaining sites that are required have not been completed.

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1 Introduction

The Commission for Communications Regulation (ComReg) has responsibility for the management of Ireland's radio spectrum. ComReg previously issued three 15-year licences for operation in the 900 MHz spectrum band. The 900 MHz licences awarded to Vodafone Ireland Ltd (Vodafone) and Telefónica O2 Ireland Ltd (O2) are due to expire in May 2011, whilst the licence awarded to Meteor Mobile Communications Ltd (Meteor) is due to expire in 2015. These licences are used to support a substantial proportion of Ireland's mobile phone traffic. Licence expiry is a therefore a significant event and a plan for what happens after the current licences expire is therefore required.

A ComReg process concerning the methodology for assignment of future spectrum rights of use in the 900 MHz band began prior to the first official consultation in 2008, and is still ongoing. Achieving a consensus on such an important issue for the future of Ireland's mobile market is not straightforward, however it is generally accepted that whatever the outcome of this process, future spectrum in the 900 MHz band in Ireland will be based on blocks of 2 x 5 MHz of spectrum. The last consultation document dealing with this issue (ComReg document 09/99) set a 'per operator cap' of two blocks in the 900 MHz band, giving an operator up to 2 x 10 MHz of spectrum. As the existing 900 MHz licensees currently have 2 x 7.2 MHz of spectrum each, it can be envisaged that all of the operators will have different spectrum assignments following expiry of their current licences.

One of the issues consulted upon is the concept of transitional arrangements over an appropriate period. This period would be necessary to allow orderly transition of spectrum from one licensee to another. ComReg document 09/99 discussed this issue and responses to this consultation were received by the 26th February 2010. As such, ComReg is currently considering next steps in its consultation process.

The purpose of this document is to consider the key issues that relate to engineering of mobile radio networks in the context of the transitional arrangements envisaged by ComReg. In particular it considers the likely timeframes required for existing GSM 900 MHz operators to "retune" and/or "relocate" their respective networks within the 900 MHz spectrum band. In this context, "retuning" means altering the frequencies within an operator's existing spectrum assignment, and "relocation" means moving to a spectrum assignment other than that currently assigned to an operator.

In order to provide continuity of service for all existing 900 MHz operators, retuning and relocation activities may have to take place in several stages. If Operator A acquires spectrum currently occupied by Operator B, then B must vacate the spectrum before it can be occupied by A. This document therefore considers not only the activities and likely timescales of an individual operator, but also the total activity required.

Retuning and relocation activities are most challenging where spectrum is lost. In the limiting case where no 900 MHz spectrum is acquired by an existing operator, continuity of service cannot necessarily be achieved by the radio engineering operations of an individual operator in the short or medium term. This document is not intended to speculate on how this outcome could be managed whether using some or all of the mitigation strategies set out in ComReg document 09/99 or otherwise. The remaining possible outcomes which are considered are therefore those of an existing operator which obtains either one or two blocks of 2 x 5 MHz of spectrum in the band.

2 Background

2.1 Current Spectrum Assignments

In Ireland there are currently three GSM Licensees in the 900 MHz band. These are: Meteor Mobile Communications Limited ("Meteor"), Telefónica O2 Ireland Limited ("O2") and Vodafone Ireland Limited ("Vodafone"). Each of these GSM licensees is currently assigned 2 × 7.2 MHz of 900 MHz spectrum, as outlined in Figure 1 below.

Figure 1 also shows the current arrangement for reassignment of the spectrum in seven blocks of 2 × 5 MHz of spectrum. Blocks A and B (generally known as the 'extended GSM' or E-GSM band) are currently unassigned, and blocks C to G (the P-GSM band) are occupied by the existing operators as illustrated.

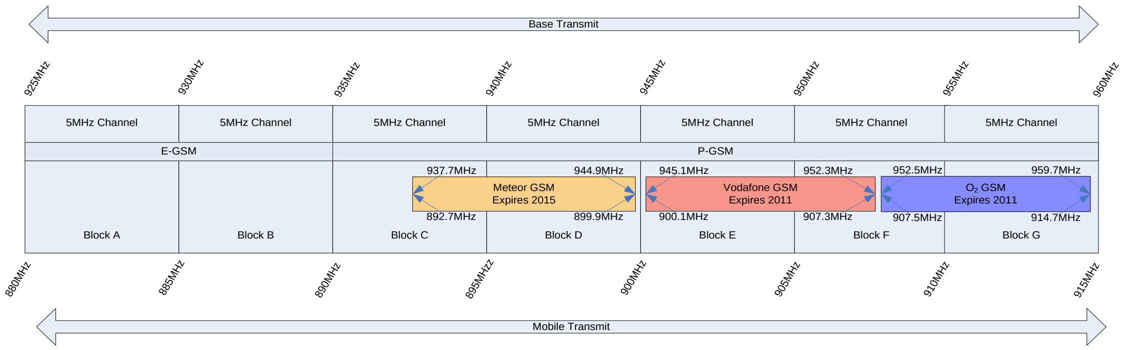


Figure 1: The 900 MHz band and the current GSM licensees' assignments

Each GSM licensee also has 2 x 14.4 MHz of 1800 MHz spectrum, with varying expiry dates, as shown in Figure 2. The 1800 MHz spectrum is of significance since there is a greater amount of spectrum available, and it is currently used less heavily than the spectrum at 900 MHz. Most mobile terminal equipment in use in Ireland is 'dual band' and so is capable of using 1800 MHz instead of 900 MHz when instructed to do so by the network. There are, however, a number of practical limitations which limit the ability of network operators to substitute 1800 MHz for 900 MHz. These limitations are discussed elsewhere in this document.

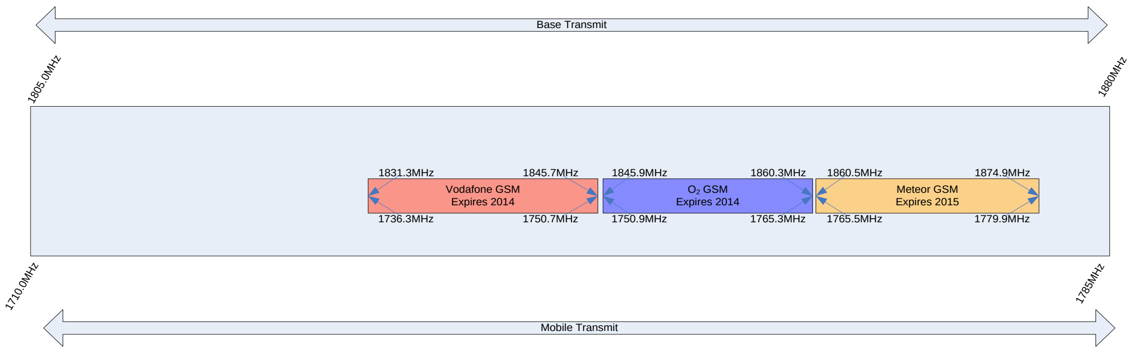


Figure 2: The 1800 MHz band and the current GSM licensees' assignments

In addition, each of the GSM licensees also have 2 x 15 MHz of paired spectrum assigned for use 'on a standard within the IMT-2000 system' in the 2100 MHz band. The spectrum allocated is shown in Figure 3, which also shows the spectrum assignment for Hutchinson 3G Ireland Ltd ("H3GI").

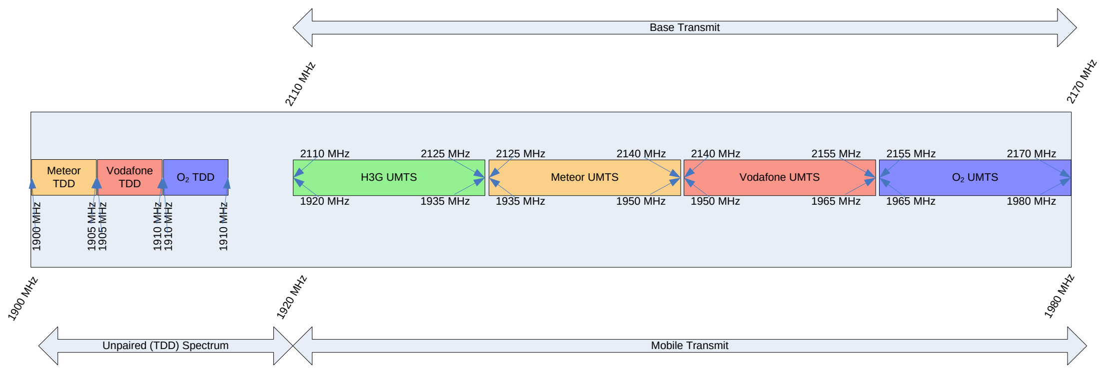


Figure 3: The UMTS 2100 MHz band and the GSM licensees' assignments

The significance of the paired spectrum in these bands is that it is used by the operators to support their mobile voice and broadband networks. The 2100 MHz spectrum can be used to provide significant capacity for voice traffic, but cannot generally be substituted for 900 MHz spectrum. This is because most of the users of networks at 900 MHz do not have handsets compatible with 2100 MHz networks (see section 6.4), and because 2100 MHz cells do not cover as much of the country as the networks at 900 MHz due to the difference in propagation resulting in lower coverage per cell at the higher frequency of operation (2100 MHz).

2.2 Grade of Service

The 'Grade of Service' (GoS) of a mobile network is a general measure of the quality of the communication services provided by the network. Measures of GoS can include a number of inter-related parameters such as:

- Average voice quality, using such objective measures such as 'Mean Opinion Score' (MOS)
- Data throughput speeds
- Percentage of dropped calls (where calls that are established on the network, but terminate abnormally due to poor links or network congestion)
- Percentage of blocked calls (where calls do not get established due to coverage problems or network congestion)

The concept of Grade of Service is important for this study because any given network has a Grade of Service that will degrade slowly as the traffic carried by the network increases. It is therefore important when evaluating network capacity and the effect of actions taken to compensate for loss of spectrum (loss of 2 x 2.2 MHz at 900 MHz for example), that network capacity is measured at a given Grade of Service.

A reduction in assigned bandwidth will result in an increase in interference, which in turn will result in degradation of the Grade of Service. The customer experience will be continuously observed and measured by the operator, and after any increase in interference the impact customer experience can be quantified in terms of increased dropped call rates, etc. However, due to the statistical nature of the network performance and limitations of the planning tools, it is not feasible to model and predict the direct customer impact in terms of dropped call, etc, in advance of a change in interference levels. Therefore, it is standard engineering practice to model the change in interference levels and use this as a basis for performance comparisons.

The Carrier to Interference ratio (C/I) is a measure of the relative magnitude of the wanted signal (C) required to sustain communication and an interfering signal (I) which exists because the same spectrum is being used elsewhere in the network. As network loading increases, the C/I ratio reduces, eventually reaching a level at which communication quality becomes unacceptable. Although it is the C/I ratio that determines the Grade of

Service on the network, there is no practical method to equate a particular C/I with a particular Grade of Service for any network metric. Similarly, it is not possible to quantify change in the Grade of Service due to a predicted change in the C/I ratio.

Within the GSM system, the carrier channel can be negatively affected by interference from another cell. This interference can be from a cell using the same channel (co-channel interference) or interference from a cell using the next adjacent channel in the assignment (adjacent channel interference). The resultant Carrier to Co-Channel Interference is C/Ic, and the Carrier to Adjacent-Channel Interference is C/Ia.

In the simulation study for the scenarios where 900 MHz spectrum is reduced (see section 4), all of the factors that can affect Grade of Service are assumed to be represented by a Carrier to Co-Channel Interference (C/Ic) ratio. As detailed in section 4, the simulation study undertaken to support this study assumes that an acceptable Grade of Service is assumed to be achieved when a C/I ratio of 12dB is maintained.

2.3 Frequency Re-Use

Frequency re-use is the concept of using any radio frequency multiple times within a network. As each GSM 900 MHz operator currently has 7.2 MHz of spectrum, and each GSM carrier occupies a bandwidth of 200 kHz, each operator has 7.2 / 0.2 = 36 channels. As there are of the order of 10,000[4] transceivers [5]in an Irish GSM900 network, each channel is used a large number of times. In this example a channel would be used, on average, 10,000/36 = 278 times in the network.

Clearly, using channels more often is one technique that could help to compensate for loss of spectrum. The degree to which such a technique can be used in response to a reduction of spectrum in the network depends on the starting point. In a mature mobile network, there is almost always a trade-off between greater re-use of channels and reduced Grade of Service. This is because re-using a channel more often gives rise to more areas of the network where interference is an issue, and interference can adversely affect all of the factors that influence Grade of Service.

As the Irish networks are considered 'mature', we consider it unlikely that significantly more aggressive frequency re-use could contribute significantly to more efficient spectrum use without adversely affecting Grade of Service. This conclusion is supported by the results of the simulation study in section 4.

An important concept with a GSM network is the 'Broadcast Common Control Channel' or BCCH. All timeslots on the BCCH carrier are transmitted at constant power whether or not they are in use for communications. This 'pilot' signal is used by mobiles to manage their connection on the network. It is important for successful network operation that mobiles can decode several nearby BCCH channels with low interference at all times whenever they are in network coverage.

[4] This is an order of magnitude estimate as the size of the existing Irish 900 MHz networks varies considerably. Vodafone has the largest network, and Meteor has the smallest.

[5] A transceiver ('transmitter – receiver') is the basic building block of a radio network, supporting simultaneous radio transmission and reception occupying one channel of spectrum. For example, there may be four transceivers on a GSM900 cell and three GSM900 cells on a site.

Normally, the transceiver used for the BCCH is not sufficient to carry all the user traffic generated within the coverage area of that cell. Additional transceivers, typically one to five are added as may be required to meet the traffic capacity demand (within certain engineering constraints and hardware limitations). These additional transceivers are "Traffic Channel" (TCH) transceivers.

Typically, an operator will designate certain channels of its bandwidth assignment for use on BCCH transceivers, and others for use as TCH transceivers. For example, an operator with 36 GSM900 channels might designate a subset of 16 channels for use by BCCH transceivers and the remaining 20 channels for use by the TCH transceivers.

A 16-channel BCCH pattern means that there are 16 frequencies assigned for BCCH use. Consider the 'idealised' scenario shown in Figure 4. Here groups of four or seven hexagons representing regular radio sites are tessellated to cover a surface. In Irish GSM900 networks, nearly all macro cellular sites are tri-sectored, so these patterns correspond to 12- and 21- sectors respectively. Worst case C/I (at the cell edge) for the case of 12-sector re-use are worse than the case of 21-sector re-use. The 16-channel case chosen for the baseline in the simulations in section 4 is not a number that can produce a perfect tessellating shape in a network of tri-sectored sites.

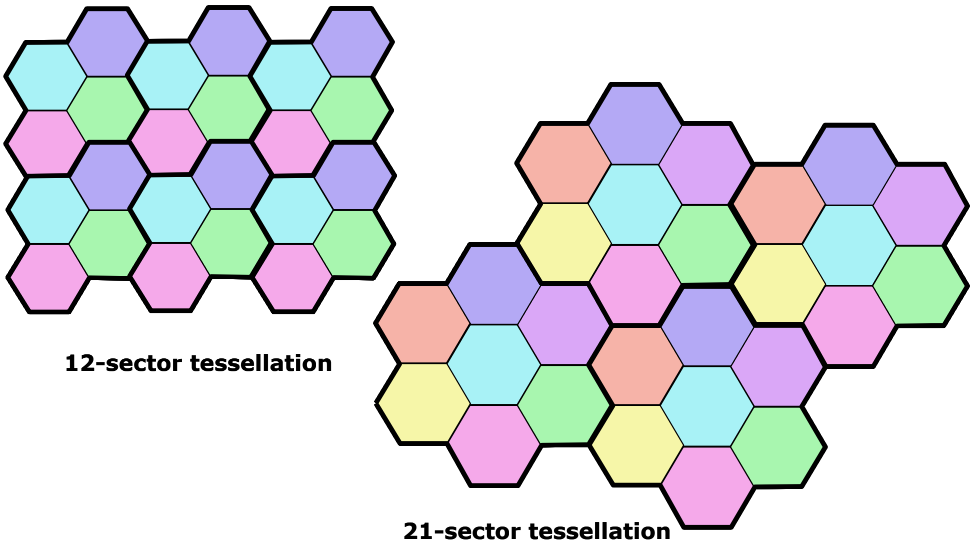


Figure 4: Tessellating Hexagons

In practice however, the effects of factors such as terrain, irregular cell sizes, non-homogenous traffic demand, the inability to choose optimum cell sites and the presence of users in tall buildings all affect the actual C/I that can be achieved in a real network. Modern planning tools such as those used for the simulation study in section 4 allow these effects to be taken into account, and given a number of channels assigned for BCCH frequencies attempt to maximise overall C/I ratio. The effect of varying antenna heights, patterns and tilts are all taken into account by these tools.

In order to produce network frequency plan, techniques such as automatic frequency planning (AFP) are used for frequency assignment. To produce a solution in a relatively short time, engineering skill and judgement is normally used to constrain the optimisation algorithms. Using a subset of the whole network and imposing boundary constraints will also help to simplify the optimisation process. These techniques have been applied to the baseline network chosen for this study.

The remaining channels that are not used as BCCH frequencies are applied to cells as needed by traffic demand. In some cases, such as 1x1 re-use, all channels are used in all cells. The effect of co-channel interference may be minimised by using slow frequency hopping, so that all carriers hop over the remaining frequencies[6]. A consequence of using 1x1 re-use is that network quality and associated Grade of Service can be expected to degrade gradually as the network is more heavily loaded. In other approaches, such as free planning, no particular pattern is imposed on the traffic channel pattern, and the optimising capabilities of the planning tool are used to select traffic channel patterns subject to the constraints of the number of channels required in each cell and the required C/I ratio. Free planning can work especially well where traffic demand is known but is uneven across a number of cells.

[6] The modelling detailed in section 4 assumes static frequency channel plans for each of the scenarios, and slow frequency hopping is not modelled. However, the analysis is based on the relative differences in C/Ic performance between the different network scenarios, this assumption is valid.

2.4 Guard Bands

In the existing GSM900 MHz spectrum assignment shown in Figure 1, ComReg assigned frequencies to operators allowing for a guard band of 0.2 MHz between adjacent operator assignments. Each GSM carrier occupies a bandwidth of 0.2 MHz[7], so this means that within 7.2 MHz of assigned frequency, an operator can use 36 channels. The effect of introducing the guard band along with other licence constraints is to allow each operator to make use of his spectrum assignment without regard to how the spectrum in the adjacent block is used. In other words, operators in adjacent spectrum blocks do not need to co-ordinate their use of spectrum, with the attendant risks and uncertainty that could arise.

When a band is allocated for use by a single technology use, it can be effective to assign guard bands in this manner. In the case of technology neutral assignments such as those proposed in the liberalised 900 MHz spectrum award, guard bands cannot be pre-determined as they depend on the radio technology used within each assigned frequency block. This point is illustrated in Figure 5, which considers the case of GSM and UMTS coexistence in adjacent spectrum blocks assigned to different operators. The separation requirements used in Figure 5 come from the Annex to EC decision 2009/766/EC which states that a centre-frequency carrier separation of 2.8 MHz or more between a neighbouring UMTS network and a GSM network is required 'in the absence of bilateral or multilateral agreements between neighbouring networks without precluding less stringent technical parameters if agreed among the operators of such networks'. The same Annex indicates that a carrier centre frequency separation of 5 MHz or more between two neighbouring UMTS networks is required. As the carriers[8] and spectrum blocks are both 5 MHz wide, UMTS carriers can occupy the assigned spectrum without wastage.

[7] The term 'bandwidth' is used loosely. GSM carriers centre frequencies are assigned on a fixed raster of 200 kHz.

[8] The term 'bandwidth' is used loosely.

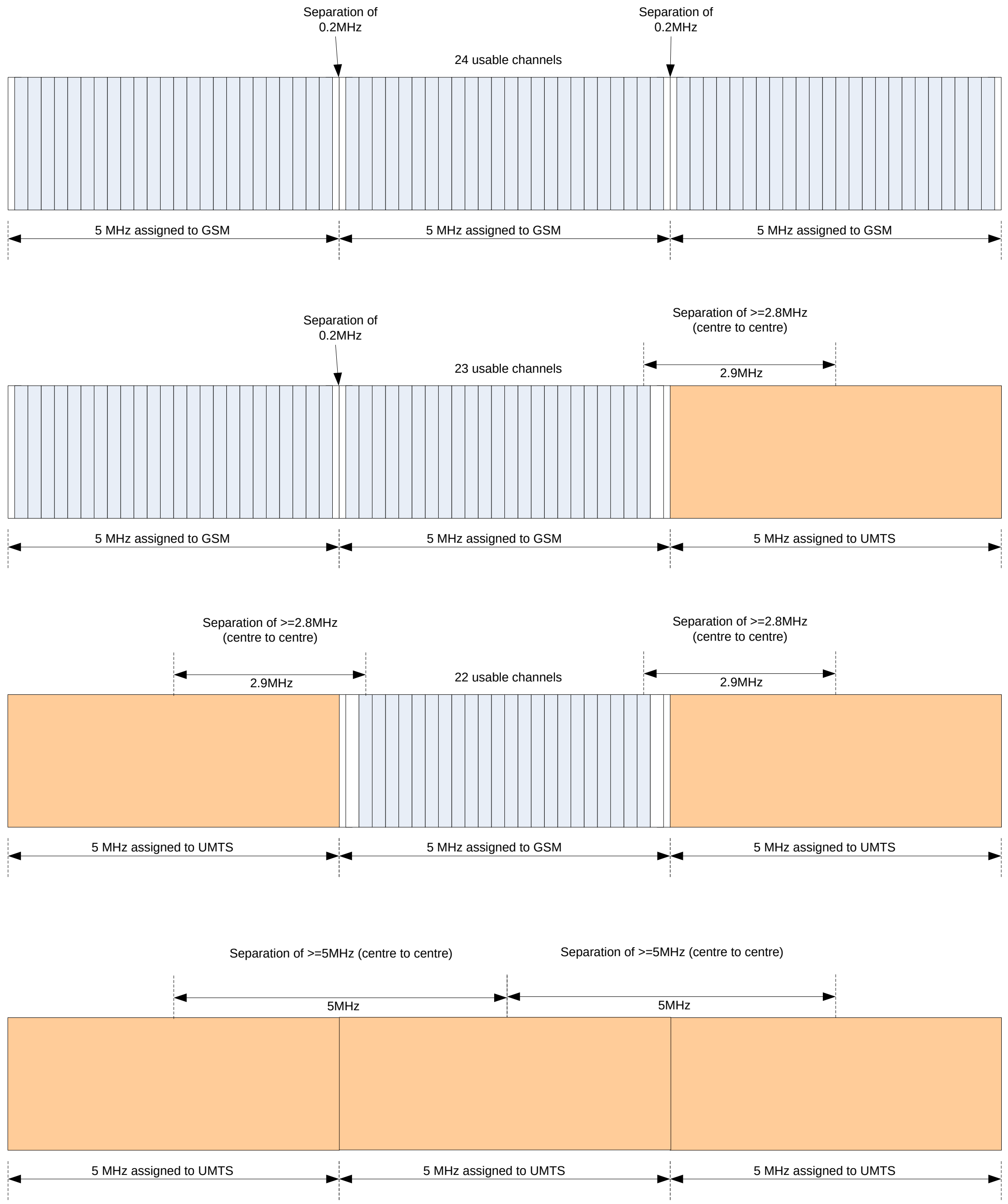


Figure 5: UMTS and GSM Guard Bands for Uncoordinated Operation[9]

[9] In Figure 5, the centre to centre separation between UMTS and GSM carrier blocks is shown as 2.9MHz. The actual separation to the first GSM channel shown as 'usable' is either 2.8MHz or 3.0MHz, as the centre frequencies of both GSM and UMTS carriers are on the same 0.2MHz raster.

For example, consider Block A from 880MHz to 885MHz adjacent to Block B from 885MHz to 890MHz. The UMTS carrier centre frequency in Block A is at 882.4MHz or 882.6MHz. The first GSM carrier shown in Figure 5 as 'usable' has a centre frequency of 885.4MHz. 885.4-882.6MHz = 2.8MHz, meeting the separation requirements from the annex to the EC decision. 885.4MHz-882.4MHz =3.0MHz, exceeding the requirements. If it is known by the user of Block B, through coordination or otherwise, that the UMTS carrier centre frequency in Block A is at 882.4MHz, then the GSM carrier at 885.2MHz can be used since 885.2MHz-882.4MHz = 2.8MHz.

The conclusion from Figure 5 is that heterogeneous co-existence of GSM and UMTS is inefficient in the absence of such bilateral or multi-lateral agreements. To allow for uncoordinated operation, the guard band must be sufficient to accommodate the most stringent scenarios. These would typically include mobiles from an uncoordinated operator on the edge of its cell being very close to the cell of a victim operator, including the possibility of interference from multiple interferers. Co-ordination activity, could then, for example, attempt to ensure that such scenarios cannot occur in practice.

As there are practical co-ordination strategies that offer benefits in terms of spectrum efficiency, the simulation study for Scenario 2 in section 4 assumes that co-ordination is effective, and that the resulting number of channels available is as shown in Table 1.

	Channels Available in Centre Block	
Scenario	**Uncoordinated**	**Coordinated**
GSM-GSM-GSM	24	24/25
GSM-GSM-UMTS	23	24
UMTS-GSM-UMTS	22	24

Table 1: Available GSM Channels

2.5 Adaptive Multi-Rate Codec (AMR)

The Coder – Decoder (CODEC) is the function within the mobile network that takes human speech and converts it to and from a digital code for transmission. When GSM networks were originally deployed there was a choice of two CODECs, Full Rate (FR) and Half Rate (HR). In a 2G circuit switched voice network, the speech transcoding function is performed by the TransCoder Unit (TCU), and is usually co-located with the base station controller (BSC) as indicated in Figure 6. The BSC is often co-located with a Mobile Switching Centre (MSC), which links the mobile network to the Public Switched Telephone Network (PSTN).

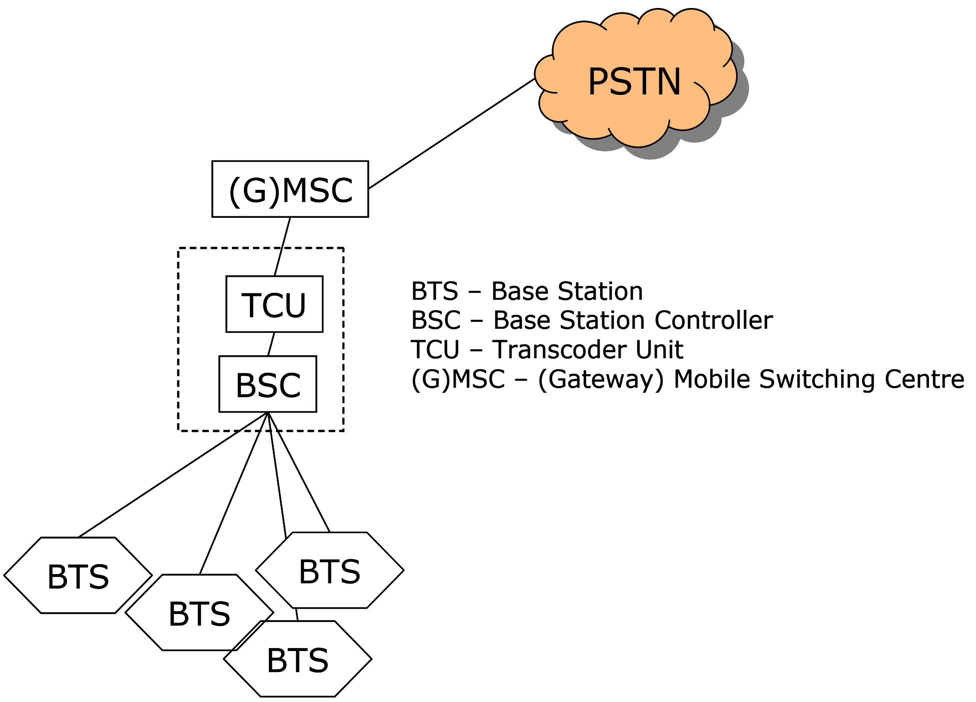


Figure 6: Simplified GSM Circuit Switched Network Topology

A GSM timeslot (of which there are 8 per carrier) can support one call using the full rate CODEC and two calls using the half rate CODEC. Although mobiles were always required to support both CODECs, actual use of the half rate CODEC was at the discretion of the mobile operator. In practice, despite the economic advantages of the half rate CODEC, it saw little use as speech quality was perceived to be unacceptably low. Although the original half–rate CODEC provided acceptable speech quality in the laboratory, in real-world conditions with impaired channels its performance degraded more rapidly than the full rate CODEC.

With the continued development of the GSM standards, an 'enhanced' full rate CODEC (EFR) was developed. Adoption of this CODEC was near universal as all new mobiles supported it and it offered improved speech quality on existing networks. Support for EFR is universal in Irish mobile networks.

GSM standards were further developed, and the Adaptive Multi-Rate (AMR) CODEC was introduced. As a measure of the development of speech coding technology and the power of digital signal processing, the AMR 'half rate' mode offers basic speech quality that is superior to the original full rate CODEC. AMR differs from EFR in that it offers a number of CODEC modes, with switching between CODEC modes being possible based on the quality of the radio link. This switching can be controlled based on network loading so that the operator can choose to degrade average voice quality smoothly during periods of high demand. This flexibility can also complicate the introduction of AMR. AMR has recently been introduced in Irish mobile networks.

A summary of the baseline MOS[10] of each CODEC is shown in Table 2.

CODEC	**MOS**
FR	3.5
HR	3.35
EFR	4.21
AMR-HR mode	3.94

Table 2: Mean Opinion Score for 3GPP CODECs

Increasing the use of AMR throughout a GSM900 MHz 'AMR capable' network offers an attractive way of increasing network capacity without adding infrastructure such as transceivers, cells and/or sites. The marginal cost of increasing AMR usage depends on

[10] Mean opinion score (MOS) provides a numerical indication of the perceived quality of speech. The MOS is a number from 1 to 5 (1 = Bad, 5 = Excellent).

MOS tests for voice are specified by ITU-T recommendation P.800

the details of the commercial deal that allows for its use, but if licensed on a per network basis as is usual today, is negligible.

Although the use of AMR in Ireland is a recent and significant development in the capacity of Irish GSM900 networks, the degree to which AMR can be used to offset a potential future reduction in available 900 MHz spectrum (see below, Scenario 2, section 4) depends on the current usage of AMR within the networks. The current usage figure is proprietary information held by the mobile operators, and only they would be able to accurately assess the potential of AMR to provide the necessary capacity enhancement.

Increased use of AMR has therefore been excluded from the modelling of Scenario 2 in section 4. This means that capacity enhancement for operators' 900MHz networks comes from the addition of base station sites, which is time consuming and costly compared to increasing the use of AMR within the network. In this regard, therefore, analysis of addition of new sites section 4 presents a 'worst case' scenario as it is very likely that operators would be able to increase the use of half rate channels to offset loss of spectrum, though this is not modelled.

2.6 GSM1800 MHz Dual Band Operation

All Irish GSM900 operators have also built GSM1800 networks. As 1800 MHz signals do not propagate as far as 900 MHz[11], 900 MHz has been preferred for build-out in rural areas. In urban areas, 900 MHz has advantages as these signals penetrate buildings more effectively than 1800 MHz signals. Capacity constraints of 900 MHz networks have encouraged operators to build 1800 MHz cells in areas of high demand. In terms of network economics, when network capacity demand increases, it is cheaper to build additional 1800 MHz capacity into an existing 900 MHz cell site than it is to build additional 900 MHz cells.

From where operators currently stand, build-out of 1800 MHz capacity in existing cell sites is less favourable than using increasing half rate usage on existing 900 MHz and 1800 MHz cells because additional hardware investments are required. The 1800 MHz operator licences for O_2 and Vodafone are due to expire in 2014 and for Meteor in 2015, and the regime for renewing and/or liberalising these licences is not known at this point in time. Additional investments in legacy 2G networks at 1800 MHz therefore have additional risks.

[11] Advantages for the use of 900MHz come from a number of sources, which include 6dB less transmission loss in free space, reduced in-building penetration loss of 3-4dB (typical), and potentially 3dB extra uplink power (2watt GSM900 mobiles vs. 1W GSM1800 mobiles).

2.7 UMTS2100 MHz Capacity Enhancement

2100 MHz capacity enhancement offers a potential alternative where the infrastructure investment risk is lower as the existing 3G licence expiry dates are further into the future. Relative to the data demands of mobile broadband networks, the requirements for voice capacity can be relatively modest. In-building penetration at 2100 MHz is intrinsically poorer than 900MHz, although the difference can be partially compensated in some circumstances using the extra flexibility of 3G systems.

Networks are normally configured so that users with 3G Subscriber Identity Modules (SIMs) in 3G compatible handsets make use of the existing 3G network where it is available. This would include most of the dense urban areas, except perhaps in ‘deep indoor’ situations where the intrinsic advantage 900 MHz for in-building penetration might cause 3G users to handover to the 2G network. 3G subscribers generally only use the 2G 900/1800 MHz network when the 3G network is out of range, which could also be the case in more remote rural areas. 2G subscribers (those with 2G SIMs, terminals or both) cannot make use of the 3G network, and so if operators are to plan a large-scale migration to 2100 MHz to offset a significant loss of spectrum at 900 MHz, they must plan for the migration of 2G subscribers to 3G. The speed with which this can be achieved would typically depend on the operator inducements and subsidies to existing subscribers and the resulting consumer behaviour might be difficult to predict accurately even with the detailed proprietary information held by the operators. The process also risks increasing subscriber churn, which represents an additional risk to the operator.

The practical limits of 2100 MHz capacity enhancement are therefore imposed by terminal estate and subscriber behaviour rather than engineering activity.

2.8 Summary of Capacity Enhancement Options for 5 MHz Assignment

An operator's traffic management strategy is dependent on a large number of interdependent factors including

- frequency bands and bandwidths assigned
- the relative timing of the different frequency band assignments to the operator
- customer profiles: use of voice and data services, areas of use, volumes of traffic generated
- Handset types in use
- Mobile broadband usage
- Network hardware types
- Network features and functionalities

These and other influences determine the evolution of an operator's network. For example, an operator that had an initial assignment of GSM900 only may have a different type of network and traffic management strategy to an operator that had later assignment of GSM900 and GSM1800 simultaneously. Therefore, an assignment of 5 MHz at GSM900 will necessitate a change in traffic management strategy for the future.

For example, a possible strategy for a GSM900 network with 5 MHz assignment is for the operator to move towards a predominantly GSM1800 or UMTS network, with GSM900 used selectively for large area coverage or where the characteristics of better signal propagation are required. In this case, contiguous coverage on GSM900 would not be essential. For example, GSM900 could be used on rural high sites to provide "umbrella" coverage, with the use of GSM1800 and/or UMTS increased in towns and villages to serve the more concentrated traffic. Similarly, for urban areas, GSM900 might be used selectively where suitable sites cannot be acquired to serve an area with GSM1800 or UMTS cells.

To adjust to a reduction in 900 MHz spectrum from 2 x 7.2 MHz to 2 x 5 MHz, operators might be expected to take the following steps in the following order:

- Increase use of AMR at 900 MHz and 1800 MHz
- Offload capacity to existing 1800 MHz and 2100 MHz cells where possible
- Add new 1800 MHz & 2100 MHz cells on existing 900 MHz sites where essential
- Add new 1800/2100 MHz sites where absolutely necessary
- Add new 900 MHz sites if completely unavoidable

These steps would be implemented in this order because this is the order of expected increasing marginal cost per unit of additional network capacity.

2.9 Existing Operators and Potential New Entrants in the 900 MHz Band

In the introduction (section 1), the terms of reference for this study are defined as operators having

- 2 x 5 MHz of spectrum at 900 MHz
- 2 x 10 MHz of spectrum at 900 MHz

Examples of potential differing positions of new and existing operators are as follows.

Existing Operator Assigned 2 x 5 MHz of spectrum

- Operator reduces GSM 900 MHz spectrum usage from 2 x 7.2 MHz to 2 x 5 MHz, deploying the techniques listed in section 2.8
- Operator cannot 'liberalise' in the medium term whilst also supporting existing customers
- LTE, with a flexible carrier bandwidth from 1.4MHz to 20MHz may offer a more flexible approach than UMTS, as UMTS requires total migration from 900 MHz 2G network and machine to machine users of GSM900 mobile networks in particular will be difficult to migrate even with generous terminal subsidies.

Existing Operator Assigned 2 x 10 MHz of spectrum

- Operator reduces GSM900 MHz spectrum usage from 2 x 7.2 MHz to 2 x 5 MHz, deploying the techniques listed in section 2.8
- Operator uses 2 x 5 MHz to 'liberalise' early, rolling out UMTS mobile broadband to rural customers and improving coverage depth in urban areas

New Entrant Assigned 2 x 5 MHz of spectrum

- Operator uses 2 x 5 MHz to 'liberalise' early, rolling out UMTS mobile broadband to rural customers and improving coverage depth in urban areas

2.10 Outline Scenarios to Study

The terms of reference for this study are to understand the implication of three main scenarios:

- Scenario 1 – GSM licensee assigned 2 x 10 MHz spectrum
  This scenario is examined in section 3

- Scenario 2 - GSM licensee assigned 2 x 5 MHz spectrum
  This scenario is examined in section 4

- Scenario 3 - Meteor retuning of 200 kHz
  This scenario is examined in section 5

3 Scenario 1 – GSM Licensee assigned 2 x 10 MHz spectrum

3.1 Introduction

In this scenario, an existing GSM licensee is assigned more spectrum than they currently occupy. Particular instances of this scenario are

- The new spectrum assignment fully overlaps the operator's existing assignment (for instance, Vodafone is assigned blocks E and F in Figure 1). This is the most trivial case as the operator has no immediate actions to perform[12].
- The new spectrum assignment partially overlaps the operator's existing assignment (for instance, Vodafone is assigned blocks D and E in Figure 1.). For the purposes of this document, this scenario is called '*retuning*' the frequency assignment. The operator needs to decide the best way to accommodate the new frequency assignment and ensure all of the existing frequencies are vacated as necessary. The operator would move his existing 2G network to the new frequency assignment, and may subsequently choose to liberalise his spectrum by freeing up 5 MHz of contiguous spectrum for 3G operation.
- The new spectrum assignment includes none of the existing assignment (for instance, Vodafone is assigned blocks A and B[13] in Figure 1). For the purposes of this document, this scenario is called '*relocation*' of the frequency assignment. Just like the 'retuning' scenario, the operator would move his existing 2G network to the new frequency assignment, and may subsequently choose to liberalise his spectrum.

The planning and implementation of the 'retuning' and the 'relocation' scenarios are very similar. In the case of high efficiency cell planning structures such as 1x1 fractional re-use, all cells would be affected to some degree irrespective of whether the network needed

[12] The operator may choose to liberalise his spectrum in the medium term by freeing up 5 MHz of contiguous spectrum for 3G operation. This would involve steps similar to those described in Scenario 2 below (see section 4) although the operation could be simplified as it could take place in the medium term after migration of some of the existing GSM900 capacity demand to existing GSM1800 and UMTS networks.

[13] Blocks A and B are in the E-GSM or extended GSM band. The distinction between E-GSM and P-GSM is not significant for the modern equipment in use in Irish mobile operator networks, which can operate across both bands as discussed in section 6.

to be 'relocated' or 'retuned'. Although it would be possible to construct some migration scenarios where '*retuning*' affected only a subset of cells in the network, it is quite likely that a complete translation of all frequencies from one assignment to another would be the simplest to achieve for both the 'relocation' and 'retuning' examples. This is because the reconfiguration of the base stations in the network to use different frequencies can be achieved by a network data-fill[14] change at the Operation and Maintenance Centre (OMC), and those migration strategies where there is a single global relationship mapping a frequency in the old assignment to a corresponding frequency in the new assignment represent the simplest possible manipulation of the network data set. Such a strategy is always possible when an operator with 2 x 10 MHz of spectrum obtains two contiguous blocks of spectrum. The case where the two blocks are not contiguous represents a slightly more complex case, but is less likely as the second stage of the proposed auction format discussed in ComReg document 09/99 is designed to achieve contiguous blocks.

[14] 'Network Datafill' is the combination of all configurable parameters of the equipment to ensure that the network works as a coherent whole and as designed. There is a large quantity of configurable parameters on a modern mobile network which control all aspects of the network's operation.

3.2 Inter-Operator Dependency

There are three main situations in which inter-operator dependency arises as a result of retuning or relocation.

- An operator cannot move to his target spectrum until it is vacated by another operator. The operator assigned blocks A and B should relocate first as these blocks are currently unoccupied, followed by the remaining operators. The relocation of all three existing operators into 2 x 10 MHz of spectrum can be accomplished with as little as one relocation or as many as *four*[15] inter-dependent relocations (e.g. Meteor liberalises early and is assigned blocks F&G, O_2 is assigned blocks D&E and Vodafone is assigned blocks B&C). Assuming the second round auction format should avoid this absolute worst-case, the most complicated practical case, considering a mixture of scenarios 1-3 and the possible acquisition of 900 MHz spectrum by H3GI and/or other new entrants into the market, would be *three* inter-operator dependent moves.

- Co-ordination with other operators who are national roaming partners, and who need to implement any network changes in synchronism.

- Inter-operator dependency along national borders. The networks must co-ordinate their use of spectrum with operators north of the border who share the same spectrum.

Figure 7 illustrates the effect of inter-operator dependency on the overall activities required to organise the 900 MHz band plan after spectrum reassignment.

[15] In this unlikely worst case, each operator ends up taking spectrum partially occupied today by another operator. As a result a fourth relocation is required. The following sequence of moves could accomplish the example allocation described in the text. 1. Vodafone moves to blocks B&C (using 7.2MHz initially). 2. O2 moves to Vodafone's original 7.2MHz in blocks E&F. 3. Meteor moves to O2's original 7.2MHz in blocks F&G. 4. O2 vacates spectrum in block F.

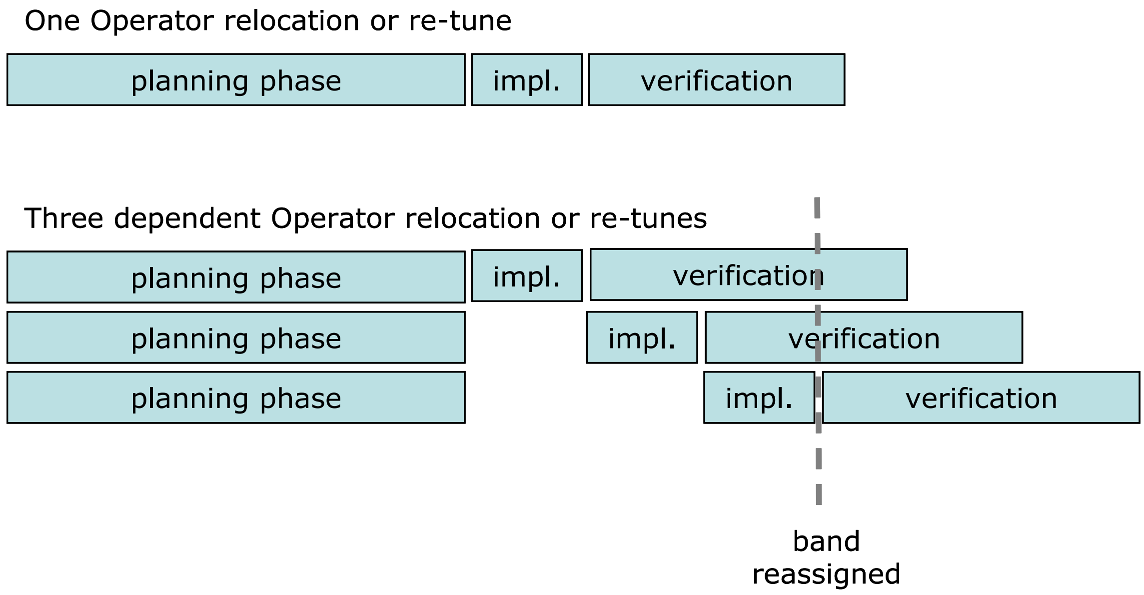


Figure 7: High Level Project for Relocation and Retune activities (not to scale)

In Figure 7, a relocation and re-tune activity is split into three distinct phases, which are:

- **Planning Phase**: During this phase no retune or relocation activity takes place, but other engineering activities on the network are completed. During the planning phase the network enters a period of 'lockdown' so that the network data-fill remains stable for a period, and reference performance of the network can be established.
- **Implementation Phase**: During this relatively short phase (typically overnight), the network is retuned or relocated to the new frequencies. In the early stage of this process a roll-back might be contemplated if there are serious issues. When the implementation is complete, the network has been relocated or retuned.
- **Verification Phase**: Post implementation, this is a phase where the network Grade of Service, call drop rates, etc., are monitored for long enough to identify whether there are any issues that need attention. The network 'lockdown' continues so that issues relating to the relocation/retune can be isolated from other issues associated with network changes.

In relation to inter-operator dependency, Figure 7 indicates that

- Operator planning phases can occur in parallel, as there is no dependency from one operator to another. Significant amounts of the planning exercise can be completed before the operators know exactly which spectrum blocks they have been allocated, since the assigned spectrum block affects only a small part of the activity.
- Implementation phases need to occur sequentially, so that each operator is relocating / retuning to spectrum which is freely available. At the end of the final implementation phase, all 900 MHz spectrum has been reallocated.
- Verification phases will start post implementation, and operators can run verification in parallel as there is no dependency of one operator to another.

3.3 Engineering Activities for Scenario 1 Relocation / Retune

This section outlines the engineering activities that are required for a relocation / retune.

3.3.1 Planning Phase

The following activities need to take place.

- Identify all major upgrade projects on the network, and ensure that these can be planned around the lockdown period. Networks that are managed by engineering teams on a regional basis might require a central team to coordinate this activity.
- Test the relocation / retune processes at the OMC. Typically the relocation / retune process will involve interrogating the data-fill of the live network at the OMC, modifying the data-fill off line, and loading the modified data-fill back onto the network during the implementation period. The only parts of the data-fill that need to be modified during a relocation / retune activity will be those relating to frequency of operation, but changes will have to be made on the GSM900, GSM1800 and UMTS networks. The list of parameters that need to be changed includes BCCH assignment, TCH assignment & hopping sequences, neighbour cell lists & Base Station Identity Code[16] BSIC. A 'dry run' can be performed using sanity checking tools to ensure that the modified data loads correctly on test infrastructure maintained in the operators offices. This test infrastructure is normally used to verify new software releases before they are implemented in the field. Sanity checking tools will normally identify any inconsistencies in the network data, and may highlight issues with the existing network that should be resolved before implementation[17].
- Co-ordinate with national roaming partners. Roaming partners need to know which frequencies are in use in each cell of each others networks to allow handover between networks. The planning activity will include agreeing arrangements for communicating the modified data-fill and verifying processes for loading this

[16] The Base Station Identity Code is a cell identifier used within the GSM system.

[17] Such inconsistencies sometimes arise between areas managed by different regional operation teams for example, and the relocation / retune process offers a good opportunity to sanity check the entire network.

information onto the network of the roaming partner, although as there will be a synchronisation process in place to ensure this happens routinely, the difference is the scale of the changes.

- Identify all radio equipment that cannot be modified during the implementation or planning phases. Such equipment may include band selective repeaters discussed in section 6.3. As these need to be modified by site engineering visits during the implementation phase and immediately following the relocation / retune of the rest of the network, areas of the network that rely on this equipment will suffer network outages. It is important during the planning phase therefore to ensure that the correct inventory is ordered and in stock, and that there is sufficient engineering resource to complete the site visit activity in a short time. Where, for example, the in-building systems of important corporate customers are dependent on such infrastructure, liaison with the customer would be planned so that any enabling installation works could be pre-arranged and any final site visit could take place out of hours immediately following the relocation / retune.
- All band-selective repeaters tuned to the old band need to be turned off as if they are left (for example if their location has been forgotten) and not known about they would potentially cause interference as they will be incorrectly configured for the new operator in the band
- Implement a disaster recovery plan in case of failure
- Generate the final data-fill
- Produce staff and resource plan for Implementation and Verification phases.

3.3.2 Implementation Phase

This is a critical and high-pressure phase of the relocation/retune. All GSM900 cells in the network will be taken out of service, have their data-fill modified, and then be brought back up again. Each cell in the network will therefore suffer a network outage, and so it is essential to plan the implementation for a relatively quiet time on the network. The preferred time is generally early in the morning over a weekend[18], so that the rest of Sunday is available for early verification of the network and essential engineering activity. The GSM1800 and UMTS cells will have considerable parameter changes implemented, but should not require any network outage.

With a large network consisting of tens of thousands of individual cells, some sites may fail to respond as expected. These can be monitored centrally and several attempts can be made to reboot them. If all else fails, it may be necessary to send an engineering team out. In terms of costs of the actual implementation phase, the cost of having engineering teams on standby out of hours is likely to be the dominant factor. The number and location of these teams will be determined during the planning phase.

During the early part of the implementation phase, focus will be on network status and confirming that all cells in the relocated / retuned network are operational. In the latter stages, focus will turn to verifying that the network is operating as expected.

[18] The expected time for the network to recover would typically be in the range of 1-3 minutes per cell, with an overall time from start to finish of 1-3 hours. Precise details are dependent on both the type and configuration of the equipment used and the network topology.

3.3.3 Verification Phase

During the verification phase two key inputs can be used to determine whether there the network is operating as expected

- Network generated Grade of Service (GOS) statistics. An estimation of whether the network is operating as expected can be deduced by comparing the GOS statistics and the locations of all events such as dropped calls with the reference network performance established during the planning period.
- Customer complaint calls fielded by the Customer helpdesk. Customers used to having service in particular areas are very sensitive to any network changes, and customer complaint calls provide a useful input to determine where service has been lost (for example due loss of a repeater).

Following monitoring of network statistics, a small drive-test and optimisation campaign would probably be undertaken to analyse in depth any areas of the network causing concern. This testing would be localised in nature and intended to identify particular issues causing problems. It would not be necessary to undertake a large scale national drive test process.

3.4 Timescales

The following timescales are reasonable for the outline activities presented in the sections above.

- Planning: A total planning phase of approximately four months might be required. As the planning phase does not depend on the exact details of which block of spectrum will be assigned, an operator that knows they will be assigned 2 x 10 MHz of spectrum from the first stage of the auction can then begin to plan.
- Implementation: The relocation / retune could be performed over one weekend. The following week could be used for essential maintenance activity, such as removal of redundant repeaters, so that the following weekend would be available for the next operator to relocate / retune.

- Verification: A verification phase of, say, 2 months would be sufficient to verify that the network is operating successfully. Bearing in mind that the verification is not on the critical path for other operators and that the intensity of the verification could reduce substantially in the few days following implementation, the exact duration of this phase is not of critical importance.

Referring to Figure 7, the overall timescale for the three existing operators to complete their band reassignment activity would therefore be around five months, being approximately

- Four months for planning
- Three weeks for implementation. It would be advisable to allow for a contingency of an additional week in case one of the operator re-assignments goes wrong to the extent that it needs to be rolled back and tried again the following week.

The subsequent verification activity of approximately 2 months occurs after the spectrum has been reassigned, and does not occur on the critical path.

Figure 8 shows a 'to scale' version of the high level project plan of Figure 7 using the timescales and dependencies previously established in this section. The start date of the project shown in Figure 8 is relatively arbitrary as operators can commence the planning phase in advance of the auction.

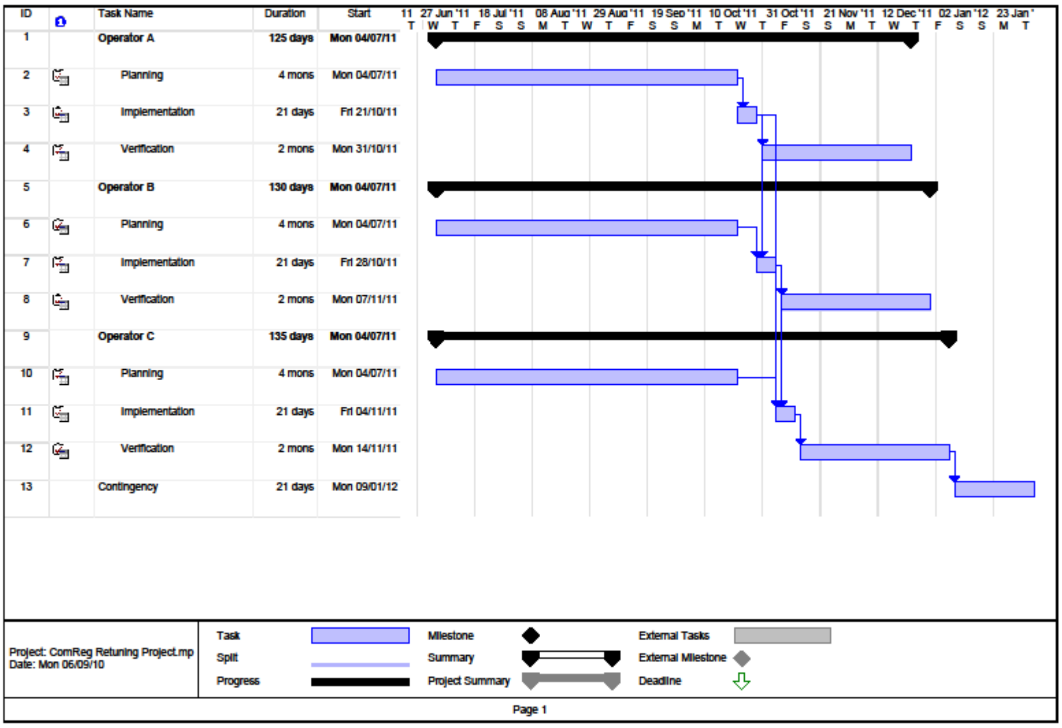


Figure 8: High Level Project for Relocation and Retune activities (to scale)

3.5 Cost Modelling

An outline estimate of the engineering costs to complete a retune/relocation activity for a benchmark mobile network in Ireland is shown in Figure 9.

Task	Detail	Who	Man Days (8hr shift)	Ave Cost / md	Total (Euros)	Qty	Unit Cost	Total Cost	Notes
Planning									
Project Team	0.75 FTE 4 month	Project Management	65	950	61750				1
	3 * 0.75 FTE 4 month	Engineering / RF / Network Operations	195	800	156000				2
Equipment	Band Selective Analogue Repeater					16	2500	40000	3
	Band Selective Digital Repeater					16	4900	78400	4
Implementation									
	Datafill - 3man team - weekend	Network Operations	6	700	4200				
	8 2-man Implemenation Teams - 5 day week	Field Operations	80	600	48000				5
Verification									
Project Team	1 FTE 2 month	Project Management	44	950	41800				
	2 FTE 2 month	OMC-R / Service Management	88	700	61600				
	2-man Implementation Team - as required	Field Operations	20	600	12000				
	Drive Tests / Optimisation	Field Operations	30	600	18000				6
Sutotals					403350			118400	
Overall Total					**521750**				

1. Project Manager responsible for all activity. 'FTE' = full time equivalent
2. Resource not full time on project
3. e.g. Axell2409+24dBm Analogue E-GSM repeater user selectable and tunable (unmanaged). Assume 1 in 50 2G sites supports a repeater that requires replacing. Assume average 2G site count of 1600.
4. e.g. Axell3009 +30dBm Digital E-GSM repeater 12-sub bands (managed). Assume 1 in 50 2G sites supports a repeater that requires replacing and 50% of these are replaced with digital repeaters.
5. Assume 10% of 2G sites need a visit during the implementation period and each team can visit 4 sites per day.
6. Assume 15 days total drive test with 2 man teams.

Figure 9: High Level Cost Estimates for Scenario 1

The cost estimate in Figure 9 is based on a ‘typical’ Irish network which is assumed to have around 1600 2G sites and 1000 3G sites, with 2G/3G site sharing. The model considers the number of man-hours of project management, engineering and field operations activity required, as well as considering the number of band selective repeaters that might be required to operate in the new band. Labour rates are assumed for each activity.

For the overall estimate given in Figure 9, roughly 66% of the total cost relates to man-hours and 33% to new equipment. It should be borne in mind that in those cases where band selective repeaters are replaced with multi-technology remotely tuneable repeaters (discussed in section 6.3), part of the investment could be considered to be in preparation for future liberalisation of the 900 MHz spectrum, and is therefore not solely attributable to the relocation / retuning activity.

4 Scenario 2 - GSM licensee assigned 2 x 5 MHz spectrum

4.1 Introduction

In this scenario, an existing GSM900 Licensee with 2 x 7.2 MHz is assigned of 2 x 5 MHz and thus the GSM Licensee is required to reorganise its GSM network to the new assignment.

The expected degradation in Carrier to Interference (C/I) performance due to the reduction in available bandwidth would result in a direct customer experience impact of, for example, an increase in the percentage of dropped calls, an increase in failures at call setup, and a general deterioration of voice quality. However, it is not possible to directly equate the increase in area of degraded C/I to the direct customer impact and so the increase in dropped call rates, call setup failure rates and the deterioration in voice quality cannot be directly quantified. Please refer to section 2.2 for further information.

Analysis was carried out using the Forsk Atoll planning tool to model the theoretical impact of the reduction in GSM900 bandwidth from 7.2 MHz to 5 MHz. The analysis was conducted for sample networks in rural and urban areas. Whilst it is easier to conduct comparative analysis with a known baseline (in this case, Carrier to Interference levels prior to transitional issues arising) this may not necessarily be the most accurate approach, as it relies on conservative assumptions being made prior to modelling

4.2 Simulation Methodology

The traffic and interference modelling within the planning tool did not include many basic traffic management and interference limiting features and functionalities available for GSM systems and which would commonly be used by operators. Such functionalities include power control, discontinuous transmission (DTX), Hierarchical Cell Structures, half rate channel coding, traffic reason handover and queuing, amongst others.

4.2.1 Sites Used for Analysis

In the absence of a plan of sites for a real GSM900 network, two sample areas were selected and nominal site plans applied based upon equidistant tri-sector sites of hexagonal coverage[19].

Rural Area

The sample rural area included towns and villages and the site densities around these areas would normally be higher than for a fully rural area. The average site-to-site distances used for the rural area modelling were chosen to account for these towns and villages.

The modelled rural area is 10,966 km^2 and includes some large towns such as Athlone and Mullingar. An average site-to-site distance of 9 km was used resulting in 153 sites in the area as shown in Figure 10, below. This was then increased by 30% to 199 sites for analysis of traffic and interference with an assignment of 5 MHz bandwidth at GSM900. This resulted in a site-to-site distance of 7.9 km as in Figure 11, below.

Table 3 shows the rural area and number of site as modelled, along with the total rural area for Ireland and the corresponding total site counts.

	Sample Area Number of Sites		Corresponding Total Area Number of Sites	
	Initial Site Configuration	Increased Site Count	Initial Site Configuration	Increased Site Count
RURAL	*10,966 km^2*		*69,215 km^2*	
	153	199	967	1256

Table 3: Rural Area Site Counts

[19] It should be noted that a network implemented using full interference mitigation techniques will have less serving sites for the same effective C/I coverage than used in the equivalent theoretical model.

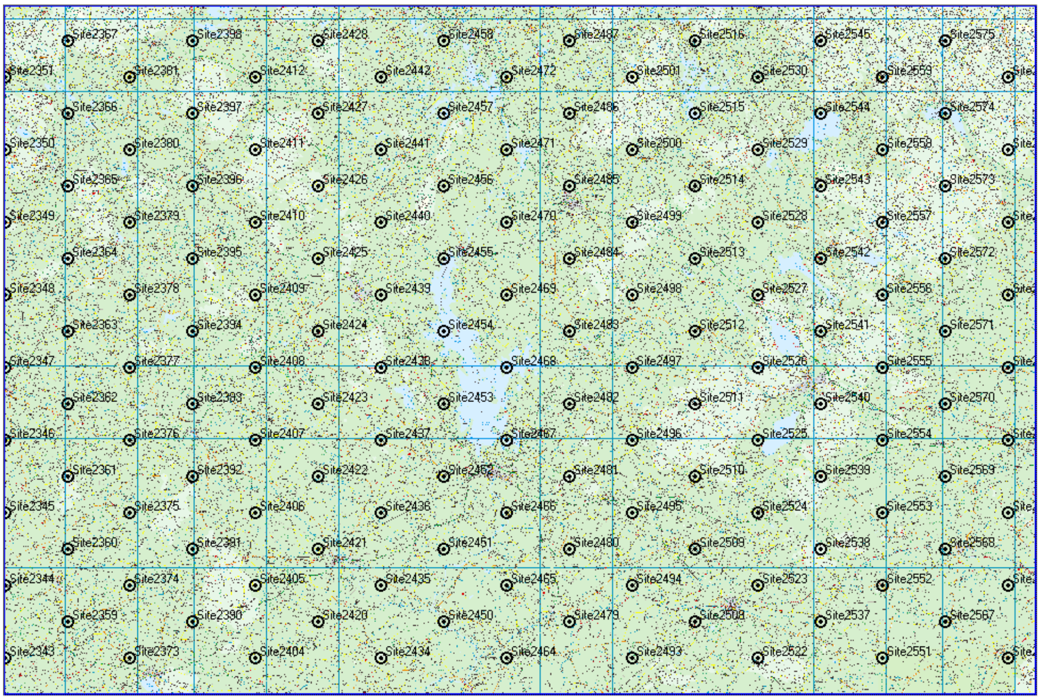


Figure 10: Rural site layout; total site count = 153 sites

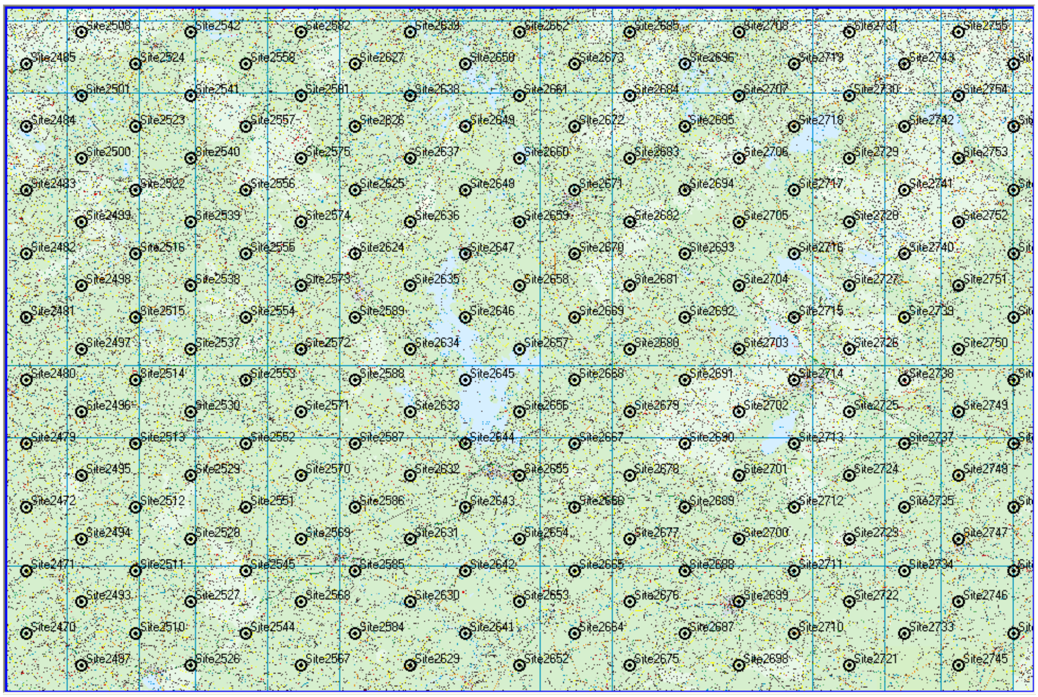


Figure 11 Rural site layout; total site count = 199 sites

Urban Area

The urban area as modelled would also include industrial, business and suburban areas.

An area of south Dublin was selected for the sample urban area. An average site-to-site distance of 1.275 km was used resulting in 45 sites in the area, as shown in Figure 12. This was later increased by 35% to 61 sites for analysis of traffic and interference with an assignment of 5 MHz bandwidth at GSM900. This resulted in a site-to-site distance of 1.147 km as in Figure 13.

Table 4 shows the urban area and number of site as modelled, along with the total urban area for Ireland and the corresponding total site counts. The urban areas included in the total area and site counts are Dublin, Cork, Limerick, Galway and Waterford.

	Sample Area Number of Sites		Corresponding Total Area Number of Sites	
	Initial Site Configuration	Increased Site Count	Initial Site Configuration	Increased Site Count
URBAN	*68.46 km^2*		*534.77 km^2*	
	45	61	351	476

Table 4: Urban Area Site Counts

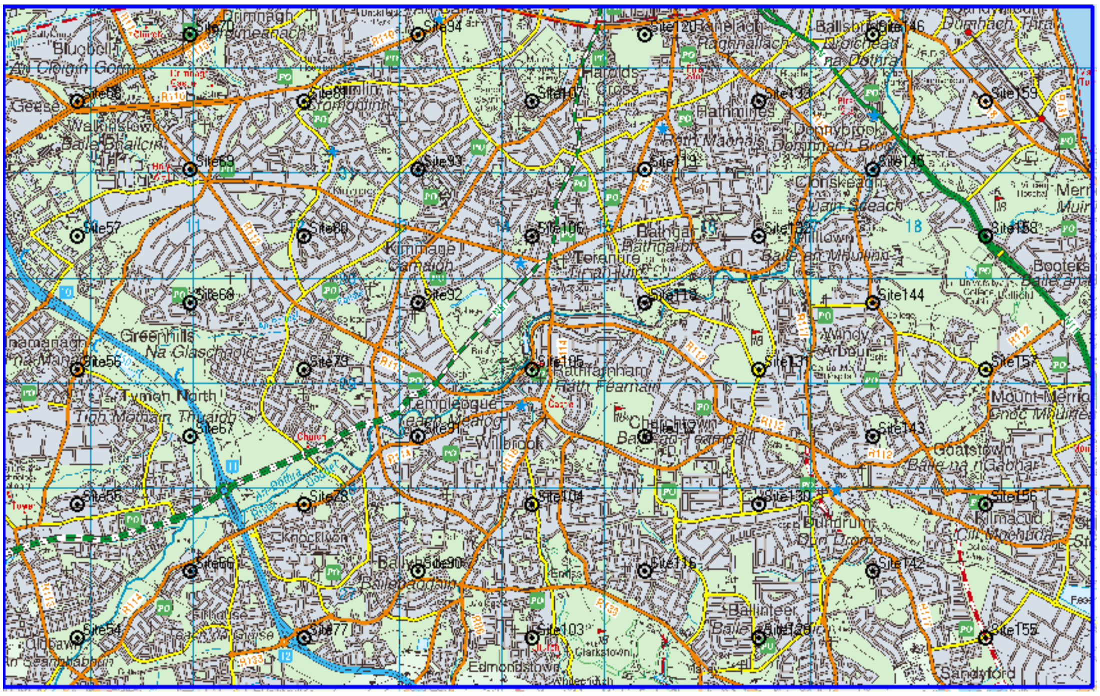


Figure 12: Urban site layout; total site count = 45 sites

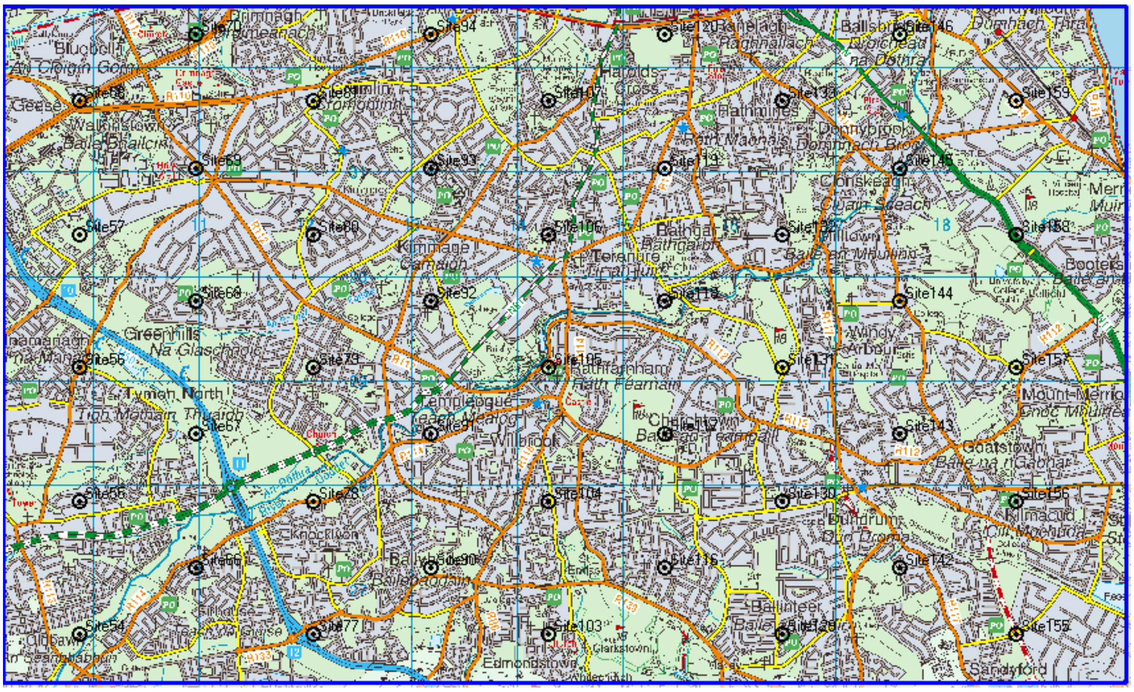


Figure 13: Urban site layout; total site count = 61 sites

Site Distribution

The nominal plan was based on equidistant tri-sector sites of hexagonal coverage. To model an increase in the number of sites, all the sites were again equally distributed. For example, the rural area plan of 153 sites was not used to generate the plan for 199 sites. The 199 new sites were distributed equally over the same area. This would obviously not be the case for a real network. For an operator, increasing the number of sites does not usually affect the pre-existing site locations and so the outlined methodology is not truly representative.

Site Characteristics

Table 5, below details the site parameters used in the planning tool modelling.

	Rural and Urban
Antenna Height	20 m
Antenna Type	17 dBi Cross Polarised 65^{o} Horizontal; 9.5^{o} Vertical Half Power Beam Width
Electrical Antenna Tilt	2^{o} for initial site plan 4^{o} for increased site numbers plan
Sector Orientations	0^{o}; 120^{o}; 240^{o}

Table 5: Site Properties

4.2.2 Voice Traffic Inputs

A traffic model was generated based on the ComReg Quarterly Key Data Report: Data as of Q1 2010[20]. This report presented average minutes of use per month per subscriber, along with subscriber figures and operator market share. Vodafone's market share of subscribers (39.8%) was used for analysis as this is the largest of the operators.

From this, a total weekly traffic figure was calculated. The following adjustments were then made to estimate the hourly traffic per subscriber during the busiest hour on the network. These adjustments are based on assumptions that were considered appropriate for traffic profiles on a voice traffic network.

- The average weekly value was increased by 10% to simulate a busier week.
- The average daily traffic was then calculated, and this increased by 20% to simulate a busiest day.
- 13% of the daily traffic was assumed to be generated in the busy hour of the day.
- The GSM900 network carries 60% of the network voice traffic, with the remaining 40% carried by the GSM1800 and UMTS2100 networks.

The estimated traffic per subscriber during the busy hour for the operator was 25 mE[21], and 15 mE of this estimated to be on the GSM900 network. In the planning tool simulations, this was represented as 2 calls of 26.67 seconds duration each.

The traffic per subscriber model is presented in Table 6, below.

[20] ComReg: Quarterly Key Data Report; Data as of Q1 2010; Document No: 10/43; Date: 17th June 2010

[21] An erlang (E) is a unit of traffic on a telephone network equivalent to 1 call for 1 hour. A milli-erlang (mE) is equivalent to the traffic generated by 1 call for 3.6 seconds.

	Total Voice Traffic	GSM900 Voice Traffic (60% of Total)
MOU per Month	227	
Subscribers (Voice Only)	4,835,905	
Subscribers Share (Vodafone)	39.80%	
Operator Voice Subs	1,924,690.2	
Operator Minutes per Month	436,904,673.1	
Operator Erlang / Month	7,281,744.6	
Operator Erlang / Year	87,380,934.6	
Operator Erlang / Week (52)	1,680,402.6	
Busy Week Adjustment	110%	
Operator Erlang / Busy Week	1,848,442.85	
Operator Erlang / Day	264,063.3	
Busy Day Adjustment	120%	
Operator Erlang / Busy Day	316,875.9	
Operator BH Traffic (13%)	47,531.4	
Operator BH Traffic per Sub (E)	0.025	0.015
Operator BH Traffic per Sub (mE)	24.7	14.8
Calls During BH	**2**	**2**
Minutes per call	**0.74**	**0.44**
Duration (Sec)	**44.45**	**26.67**

Table 6: Generation of Traffic Model from the ComReg Quarterly Key Data Report: Data as of Q1 2010

Data Traffic on GSM Networks

GSM networks normally have the capability to carry customer data traffic in addition to voice traffic. Data traffic is used for services such as email and internet access. This data is carried using GPRS[22]and/or EDGE[23] functionality as may be deployed on the network.

Carrying data on the GSM network usually reduces the voice carrying capacity. As the analysis is based on the relative traffic capacities of the different bandwidth assignments, this reduction in voice capacity due to data traffic was considered small enough to be omitted from the analysis. A degradation in C/I would also have a major impact on the data throughput capability of the GSM900 network. However, this is not part of this analysis.

[22] GRPS – Generalised Packet Radio Service. A GSM network can carry packet data using GPRS.

[23] EDGE – Enhanced Data rates for GSM Evolution, supports improved data transmission rates for GSM packet radio through the use of higher order modulation methods and efficient adaptive data coding schemes.

4.2.3 Subscriber Traffic Distribution

The 2006 population census was used to model the subscriber distribution across the rural and urban areas being analysed. Within the planning tool, calls are simulated occurring at particular locations at particular times, based on the busy-hour traffic per subscriber figure (as in Table 6, above) and the population in that particular area.

The census statistics used are population per District Electoral Divisions (DED). Figure 14 and Figure 15 below show maps of the DEDs for the rural and urban areas as analysed. The number of subscribers in an area was based on the population densities within each DED. That is, the probability of a call being generated at a particular location was proportional to the population within that DED.

The census statistics relate to residential populations and do not reflect the actual mobile phone user distribution. For example, additional network traffic will be generated in urban areas by commuter workers and shoppers, and this is not accounted for in the residential population statistics. However, residential census statistics are widely used as an appropriate distribution method in traffic modelling on mobile networks.

Table 7 below summarises the equivalent daily traffic demand as derived from the simulation analysis.

	URBAN Sample Area	RURAL Sample Area	Units
Sample Area Size	68.46	10,966	*Km^2*
Operator Daily Traffic Demand as Modelled ***GSM900***	178.15	0.32	*Erlang / Km^2*
Operator Daily Traffic Demand as Modelled ***GSM900, GSM1800, UMTS***	296.92	0.54	*Erlang / Km^2*

Table 7: Rural and Urban area Traffic Models

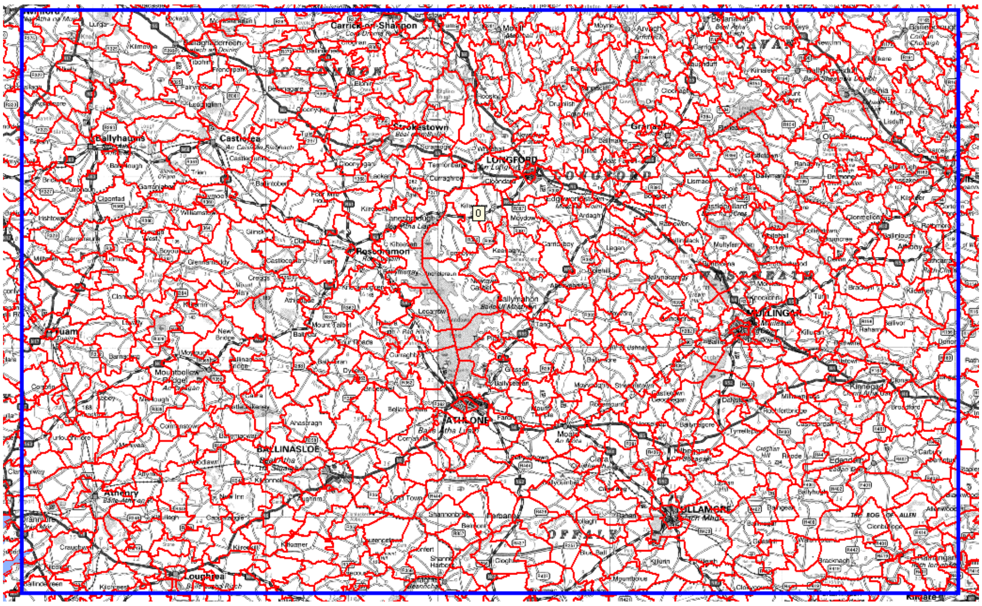


Figure 14: DEDs for midlands, total area = 10,966 km2

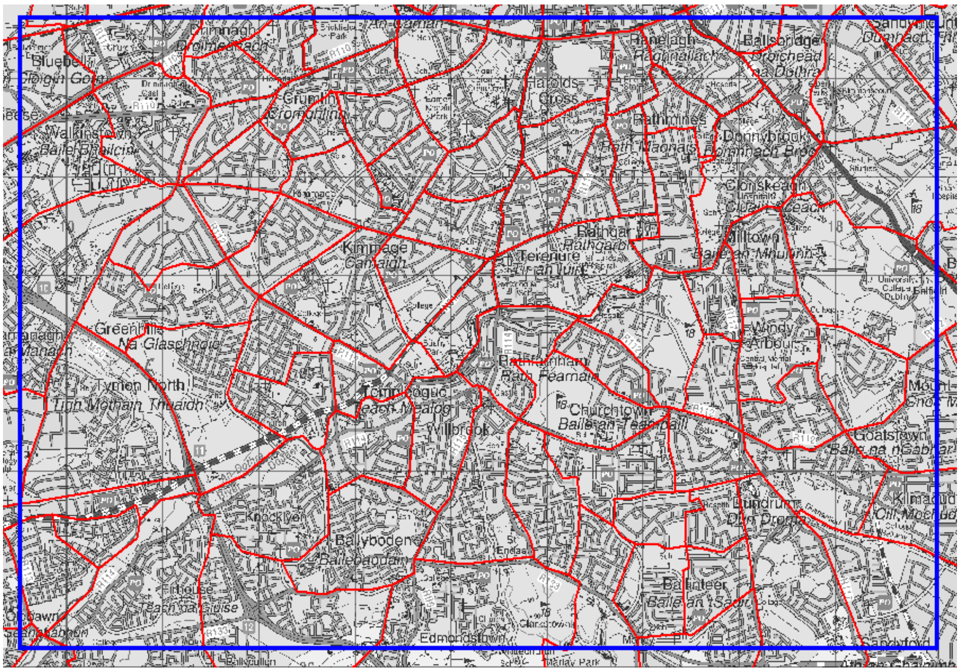


Figure 15: DEDs for urban, total area = 68.46 km2

4.2.4 Frequency Planning Strategy

Frequency planning and interference analysis was carried out with the Forsk Atoll planning tool and its automatic frequency planning (AFP) module.

For the 7.2 MHz bandwidth analysis, 16 channels were allocated for the BCCH band and 20 channels were allocated for the TCH band. (Please refer to section 2.3 for further information).

For the 5 MHz bandwidth analysis, 13 channels were allocated for the BCCH band and 12 channels were allocated for the TCH band. Initially, 11 channels were allocated for the BCCH layer in order to maintain the same ratio of BCCH to TCH channels. However, the BCCH layer interference was very high and it was deemed more realistic to allocate 13 BCCH channels.

Note: The 5 MHz assignment is modelled as 25 GSM channels. As detailed in section 2.4, this assumes the best case scenario in terms of efficient guard band coordination between operators and technologies. The useable number of GSM900 channels in a 5 MHz assignment may be lower depending on adjacent frequency use by the operator and adjacent operators.

Bandwidth Assignment	**7.2 MHz**	**5 MHz**
Number of Channels	36	25
BCCH Channel Band modelled	16	13
TCH Channel Band modelled	20	12

Table 8: Generation of Traffic Model

Frequency Planning Strategy

Within the planning tool, the traffic demand within each cells' coverage area was calculated and from this the total number of transceivers required on each cell determined. The traffic was distributed equally over each transceiver of the cell. In reality, this may not be the case and traffic may be allocated to a transceiver based on channel availability and quality and proprietary algorithms of the network equipment in use.

Within each of the BCCH and TCH layers, the AFP module allocates channels to each cell as static (non-hopping) channels. Within each of the BCCH and TCH layers a "free-planning" strategy was used for allocating channels to the cells. A strict re-use pattern was not employed. For example, for the 7.2 MHz plan, the 16 BCCH channels were allocated to the cells in the sample area such as to minimise the interference for the cells in the overall plan.

The AFP was run for at least four hours for each plan to optimise the frequency plan. Ideally, the AFP should be run for longer, but due to the number of plans and the time available this was considered sufficient.

The BCCH layer of carriers for the sample network was simulated separately from the TCH layer of carriers and the results are presented separately hereafter.

4.2.5 Quality Evaluation: C/I Performance

Please refer to section 2.2 for further details.

Within the planning tool Carrier to Co-Channel Interference (C/Ic), and Carrier to Adjacent-Channel Interference (C/Ia) can be predicted separately. However, it is not possible to combine these different interference types. Although the relative levels of C/Ic and C/Ia will be different, the network scenarios as modelled will affect both metrics similarly, and so the results and analysis of only one metric is sufficient. For this project, C/Ic is used as the basis for the analysis and is representative of the relative performance for different network scenario plans.

A C/Ic threshold of 12 dB is used as the reference level of acceptable performance. The results are presented in terms of area and percentage area where C/Ic is less than 12 dB, in which case the resultant level of service is considered inadequate. (Section 2.2 defines C/I and its relation to Grade of Service).

4.3 Simulation Results

The results of the planning tool simulations are presented in Table 9 and Table 10 below with the area and percentage area where the C/Ic is less than 12 dB illustrated. The tables show the BCCH and TCH layers separately for each of six plans. The last plan for each area is for the increased site number which was modelled at 4^{o} electrical tilt for all antennas. (2^{o} electrical tilt was used for all antennas in plans 1 to 5).

All of the C/Ic plots associated for each plan are contained in an annex document: *Annex – C/I Modelling Results.doc*

Plans 1 and 2 compare the C/Ic performance for 7.2 MHz and 5 MHz bandwidth GSM900 assignments, each carrying 60% of the total voice traffic capacity.

A reduction in the GSM900 band traffic was then modelled, from the starting assumption that the GSM900 network carried 60% of total traffic to levels of 50%, 45% and 40% of total traffic. This equated to a reduction in the GSM900 network traffic of 16.6%, 25% and 33% respectively. However, the analysis shows that even with a decrease in GSM900 band traffic of 33% the C/Ic performance is still significantly worse than for the initial network configuration.

Plan	GSM900 Traffic	Num Sites	Layer	Channels	C/Ic area (km^2) 2^o E-Tilt	% Area C/Ic < 12 dB	C/Ic area (km^2) 4^o E-Tilt	% C/Ic < 12 dB 4^o E-Tilt
1	60%	153	BCCH	16 / 36	19.54	0.18%		
	60%	153	TCH	20 / 36	3.26	0.03%		
2	60%	153	BCCH	13 / 25	79.26	0.72%		
	60%	153	TCH	12 / 25	180.19	1.64%		
3	50%	153	BCCH	13 / 25	73.88	0.67%		
	50%	153	TCH	12 / 25	77.76	0.71%		
4	45%	153	BCCH	13 / 25	72.99	0.67%		
	45%	153	TCH	12 / 25	12.24	0.11%		
5	40%	153	BCCH	13 / 25	93.26	0.85%		
	40%	153	TCH	12 / 25	7.19	0.07%		
6	60%	199	BCCH	13 / 25	95.9	0.87%	82.34	0.75%
	60%	199	TCH	12 / 25	53.88	0.49%	53.69	0.49%

Table 9: Rural Sample Area C/Ic Simulation Results

Plan	GSM900 Traffic	Num Sites	Layer	Channels	C/Ic area (km^2) 2^o E-Tilt	% Area C/Ic < 12 dB	C/Ic area (km^2) 4^o E-Tilt	% C/Ic < 12 dB 4^o E-Tilt
1	60%	45	BCCH	16 / 36	0.15	0.21%		
	60%	45	TCH	20 / 36	1.48	2.17%		
2	60%	45	BCCH	13 / 25	2.10	3.07%		
	60%	45	TCH	12 / 25	9.98	14.58%		
3	50%	45	BCCH	13 / 25	2.76	4.04%		
	50%	45	TCH	12 / 25	6.44	9.40%		
4	45%	45	BCCH	13 / 25	0.78	1.13%		
	45%	45	TCH	12 / 25	7.30	10.67%		
5	40%	45	BCCH	13 / 25	3.16	4.62%		
	40%	45	TCH	12 / 25	5.82	8.49%		
6	60%	61	BCCH	13 / 25	3.11	4.54%	2.73	3.99%
	60%	61	TCH	12 / 25	5.70	8.33%	5.54	8.09%

Table 10: Urban Sample Area C/Ic Simulation Results

Rural Network Analysis

For plan 1, the initial GSM900 traffic level was modelled as 60% of the total operator voice traffic over 7.2 MHz of bandwidth. In plan 2, the impact of reducing the available bandwidth to 5 MHz is modelled for the same traffic level. As can be seen in Table 9, there was a significant increase in the area affected by the degraded C/Ic; for the rural sample network, the area of C/Ic less than 12 dB increased from 19.54 km^2 to 76.26 km^2 for the BCCH layer and from 3.26 km^2 to 180.19 km^2 for the TCH layer. This is equivalent to an increase from 0.18% to 0.72% of the area served by a BCCH with C/Ic less than 12 dB (a 4-fold increase), and an increase from 0.03% to 1.64% of the area served by a TCH with C/Ic less than 12 dB (a 55-fold increase).

Next, the volume of traffic was reduced on the GSM900 sample area. In plans 3, 4 and 5 the percentage traffic on the GSM900 network is decreased to 50%, 45% and 40% of total voice traffic respectively. Comparing the BCCH layer C/Ic performance we can see that there is a relatively small variation for plans 2 to 5. This is as may be expected as the number of BCCH channels and the number of cells is consistent for these plans. The variation in traffic will have very little impact on the BCCH performance as the BCCH transceiver is constantly transmitting as outlined in section 2.3.

For the TCH layer, we can see that there is a significant improvement in C/Ic performance as the traffic decreases for plan 2 to plan 5. This is as would be expected as the number of transceivers would be decreasing and the traffic on each cell would be decreasing. Comparing plan 2 with 60% of the network traffic and plan 5 with 40% of the network traffic, we can see that the area of C/Ic less than 12 dB has decreased from 180.19 km^2 to 7.19 km^2. This decrease in traffic equates to a 33% decrease in GSM900 band traffic for the operator.

For plan 6, the number of sites was increased by 30% from 153 sites to 199 sites. Comparing plan 2 and plan 6 we can see there was an increase in the area of degraded C/Ic for the BCCH layer with the additional sites as there are more cells but the same number of channels. For the TCH layer there is an improvement in C/Ic with the additional sites as the traffic per cell decreases.

Urban Network Analysis

Though difficult to model, some notable differences exist between the urban and rural network configurations. In the urban area, there will generally be a higher percentage of sites with GSM1800 and/or UMTS2100 than would be typically deployed in rural areas, and it would be expected that a lower proportion of the traffic would be carried on GSM900 in urban areas than in rural areas. Whereas this should facilitate easier offload of traffic from GSM900 to GSM1800 and UMTS2100, it could be argued that this solution has already been largely exploited in the urban areas in the current capacity management strategy. Offloading even more traffic from the GSM900 band in these areas may be more difficult.

Comparing plan 1 and plan 2, the reduction to 5 MHz results in a significant increase in the area affected by the degraded C/Ic; for the urban sample network, the area of C/Ic less than 12 dB increased from 0.15 km^2 to 2.10 km^2 for the BCCH layer and from 1.48 km^2 to 9.98 km^2 for the TCH layer. This is equivalent to an increase from 0.21% to 3.07% of the area served by a BCCH with C/Ic less than 12 dB (a 14-fold increase), and an increase from 2.17% to 14.58% of the area served by a TCH with C/Ic less than 12 dB (a more than 6-fold increase).

In plans 3, 4 and 5 the percentage traffic on the GSM900 network is decreased to 50% 45% and 40% respectively. Plan 4 here shows an unexpectedly low area of degraded C/Ic for the BCCH layer, and this may simply be due to the randomness of the AFP process. However, the trend is as expected for the other plans.

Comparing the BCCH layer C/Ic performance we can see that there is a relatively small variation for the plans 2 to 5. As above, this is as expected due as the number of BCCH channels and the number of cells being consistent for these plans.

For the TCH layer, we can see that there is an improvement in C/Ic performance as the traffic decrease from plan 2 to plan 5. However, this improvement is far less dramatic than can be seen in the analysis of the rural area. Comparing plan 2 with 60% of the network traffic and plan 5 with 40% of the network traffic, we can see that the area of C/Ic less than

12 dB has decreased from 9.98 km^2 to 5.82 km^2. This decrease in traffic equates to a 33% decrease in GSM900 band traffic for the operator.

For plan 6, the number of sites was increased by 30% from 45 sites to 61 sites. Comparing plan 2 and plan 6 we can see there was an increase in the area of degraded C/Ic for the BCCH layer with the additional sites as there are more cells but the same number of channels. For the TCH layer there is an improvement in C/Ic with the additional sites as the traffic per cell decreases. Again, these relative differences are not as significant as seen for the rural area sample network.

4.4 Conclusions from Simulations

This degradation in C/Ic performance illustrated above would (unless mitigated using other techniques) result in a direct customer experience impact of, for example, an increase in the percentage of dropped calls, an increase in failures at call setup, and a general deterioration of voice quality. However, as outlined in section 2.2, it is not possible to directly equate the increase in area of degraded C/I to the direct customer impact and so the change to the network Grade of Service cannot be directly quantified.

The results above show that the reduction in GSM900 bandwidth causes a significant increase in the interference on the network modelled[24] (up to a 55-fold increase in area of C/Ic less than 12 dB for the rural TCH layer) which, in the absence of mitigation, would translate to a major degradation in service for the network as configured and dimensioned today. Even with a decrease of 30% in the GSM900 traffic, the interference on the network with 5 MHz of bandwidth is still significantly worse compared to the initial network with 7.2 MHz of bandwidth; for example, the area of C/Ic less than 12 dB increase from 1.48 km^2 to 5.28 km^2 for the urban TCH layer.

Also, increasing the number of sites does improve the C/Ic performance for the network as modelled, but even with a 30% increase in the number of sites, the areas affected by interference is still far greater for the 5 MHz assignment.

As outlined in section 2.8, an operator’s traffic management strategy is dependent on a large number of interdependent factors. This, along with the findings outlined in this section, highlights the fact that there is no single universal solution to managing a transition from 7.2 MHz to 5 MHz bandwidth. The solution would most likely be a combination of methods including:

- Changes to traffic management strategy: configuring the networks such that a higher proportion of traffic is carried on the GSM1800 and UMTS2100 bands.

[24] The modelled network is of tri-sectored, equidistant sites in a hexagon coverage pattern. Real networks will be designed to optimise C/I performance. The real, optimised network will be planned such that the areas of poor C/I will be in areas of lower traffic demand.

- Management of data traffic to reduce the proportion of data traffic on the GSM900 networks where possible.
- Optimising the use of half rate traffic channels with AMR on the GSM900 and GSM1800 networks to allow increase the capacity of the networks allowing existing transceivers to be switched off thereby reducing interference generated.
- Addition of GSM1800 and/or UMTS cells to the existing GSM900 sites to allow transfer of the traffic off the GSM900 cells.
- Addition of new sites in areas where the increases in interference necessitates it. These sites could be GSM900, GSM1800 or UMTS, depending on the network strategy of the operator.
- Removal of GSM900 sites: In order to reduce interference, GSM900 cells and/or sites might be decommissioned from certain areas where the traffic can be carried on alternative frequency bands. It should be noted that decommissioning sites is not trivial for the operator, as considerable network redesign and reconfiguration is required, along with the general planning and implementation of the decommissioning of the site itself.

With a decrease in bandwidth to 5 MHz, the quality of the BCCH layer is degraded as fewer channels are used over the same number of cells. The quality on the TCH layer does improve with a reduction in traffic, but does not attain the same quality as the original 7.2 MHz network. It is not feasible to maintain the same number of GSM900 channels in the BCCH layer with a 5 MHz assignment unless the traffic carried on the TCH layer is very small in which case a contiguous GSM900 network may become unviable from a technical perspective (with GSM900 sites only used selectively where other bands cannot provide the necessary coverage range). Please also refer to section 2.8.

4.5 Cost Modelling

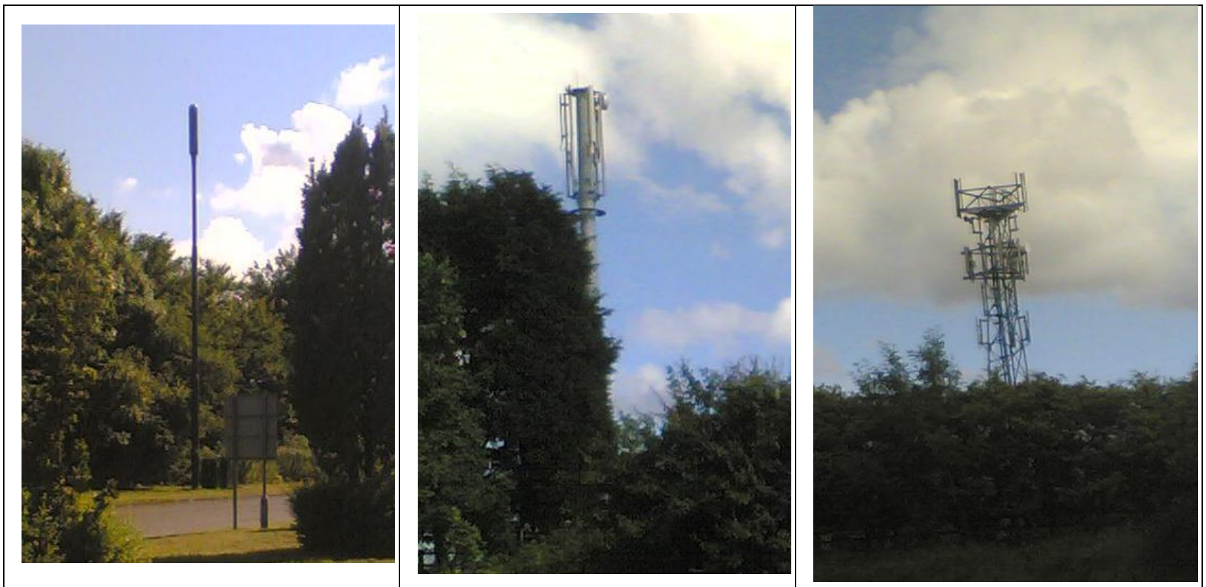
A simple cost modelling exercise was performed for Scenario 2, assuming the operator was to build extra sites according to the numbers identified in Table 3 and Table 4 and summarised below in Table 11. Again, whereas the modelled solution here related to the addition of new sites only, an operator approach would include a combination of solutions, such as, increasing the use of AMR half rate and deploying GSM1800 and UMTS2100 cells on existing GSM900 sites, etc. Please refer to section 2 for further details.

Site Type	Additional Sites
Urban	125
Rural	289
Total	**414**

Table 11: Additional Sites Required

The approach to the cost modelling is to identify how many cells and transceivers need to be built for each site type. Costs for three basic site types are considered:

- Urban Rooftop Site: This type of site uses existing building structures to elevate the site above urban clutter. As use is made of an existing building with close access to utilities construction costs can be lower than other types of site. The main difficulty with rooftop sites is negotiating roof rights with the owner, which generally mean that this type of site is expensive, both to build and operate.
- Urban Streetworks Site: This type of site uses a lamp-post like structure to house the antennas. They can provide relatively low visual impact, but are not generally elevated above urban clutter. Construction costs are contained as site designs are standard and much of the work can be pre-staged. They are a good solution for urban ‘in-fill’ sites of the type that might be required by an operator compensating for loss of spectrum.
- Rural Tower Site: This type of site is appropriate for a rural ‘greenfield’ site. A lattice mast with triangular head frame could be used, or a lower profile design if minimising visual impact was important. This type of site is a good solution for a rural location where it is important to optimise coverage.



Streetworks Site	Slimline Rural Tower	Multi-Operator Rural Lattice

Figure 16: Example Sites

Key assumptions used in the cost modelling exercise are:

- All new sites are built as new single operator GSM900 only sites. This is a 'worst case' assumption as multi-technology multi-operator site sharing arrangements reduce costs and if existing transceivers are removed from existing GSM900 sites then they can be re-used.
- Estimates are made of operator CAPEX for project management, radio planning, network equipment, civil engineering costs, legal costs, transmission network design and implementation costs and network optimisation
- Estimates are made of engineering impact on surrounding sites of introducing a new site into the network Neighbour sites may have to be re-optimised, for example by re-orientation of antennas on existing sites to help to control interference.
- The model excludes OPEX associated with the additional sites, such as site lease costs, ongoing costs for the transmission network or increased maintenance costs arising from the additional sites in the network.
- The model excludes any allowance for other network elements such as BSCs.
- An allowance of 10% of the overall cost for project management is assumed.

A list of the assumptions used to produce the cost model is shown in Figure 17.

Drivers for Cost Model							Notes and assumptions	
		2010	2011	2012	2013	2014		
Per year distribution of effort		5%	45%	40%	7%	3%	Total: 100%	
Project management overhead		10%						
Site Types	Existing Sites affected per new site	6					Existing Sites affected by installation of new s	
	Percentage of Urban Sites as Streetworks	50.0%						
		Sites	Cells	TRx				
GSM 900 Infrastructure Required	Urban Streetworks	63	188	563			Site count based on 3 cells per site	
	Urban Rooftop	63	188	563			S333 max urban ausumed	
	Dense Suburban	0	0	0				
	Suburban	0	0	0				
	Rural Tower	289	867	1734			S222 assumed	
Unit radio planning costs	Coverge and capacity planning	£70					per cell	
	Frequency planning	£30					per cell	
BSS Equipment Marginal Costs	Cabling, Connectors etc	€350					per site	
	Cabinet / Common Infrastructure	€10,000					per new site	
	Antenna	€400					per cell	
	Combiner / Splitter	€500					per TRx	
	TRx	€1,500					per TRx. (re-use would reduce costs)	
Civil Costs	Site Construction (Rural)	€40,000					per site	
	Site Construction (Urban - Rooftop)	€25,000					per site	
	Site Construction (Urban - Streetworks Site)	€15,000					per site	
Legal Costs	Site Acquisition Costs (Rural)	€15,000					per site. Excludes any extra OPEX	
	Site Acquisition Costs (Urban - Rooftop)	€50,000					per site. Excludes any extra OPEX	
	Site Acquisition Costs (Urban - Streetworks)	€20,000					per site. Excludes any extra OPEX	
Unit re-engineering costs	Site survey per site	€750					per site	based upon 2 man days including
	Site preparation	€200					per site	based upon 1 technician 1/2 day +
	Antenna reorientation	€660					per site	based upon 2 riggers 1 day + fuel/
	Antenna install	€660					per site	based upon 2 riggers 1 day + fuel/
	TRX replacement	€300					per site	based upon 1 technician 1/2 day +
	New Site I&C	€3,000					per site	based upon 2 technicials 3 days +
	Remote reconfiguration at NMC	€120					per site	based upon 1 technician 2 hours
Transmission Network	Planning & Design	€375					per site	based on 1 man day
	Microwave LOS Survey	€660					per link	based upon 2 riggers 1
	Microwave Link Capital Cost	€6,000					per link	
	Microwave Link Installation	€1,200					per link	based upon 4 riggers 1
Per site re-Engineering costs		Urban Roo	Urban Stre	Dense Sub	Suburban	Rural		
	New Sites	€117,515	€77,515	-	-	€111,515		
	Modify Existing Sites (per new site)	€10,380	€10,380	-	-	€10,380		
Drive test and optimisation	Total road network length ('000 km)	5400	National Roads and Motorways				from: http://www.erf.be/images/stat/ERF_stats	
	km per drive test day	150						
	Number of drive test days per survey	36.0						
	Number of surveys	2						
	Number of drive test days total	72.0						
	Cost per drive test per day	€650						
	Post processing cost per drive test day	€300						

Figure 17: Scenario 2 Cost Model Assumptions

The resulting costs are shown in Figure 18.

Cost Breakdown per Operator		2010	2011	2012	2013	2014	Notes and assumptions
Radio Planning		€6,210	€55,890	€49,680	€8,694	€3,726	
Implementation	Urban Streetworks	€274,672	€2,472,047	€2,197,375	€384,541	€164,803	
	Urban Rooftop	€399,672	€3,597,047	€3,197,375	€559,541	€239,803	
	Rural Tower	€1,761,383	€15,852,445	€14,091,062	€2,465,936	€1,056,830	
Drive Testing		€2,340	€21,060	€18,720	€3,276	€1,404	
Optimisation		€1,080	€9,720	€8,640	€1,512	€648	
Project Management		€244,536	€2,200,821	€1,956,285	€342,350	€146,721	
Ongoing Site Owner Costs		€0	€0	€0	€0	€0	None Assumed
Service Disruption		€0	€0	€0	€0	€0	Not in this model
Total		€2,689,892	€24,209,029	€21,519,137	€3,765,849	€1,613,935	
Cumulative		€2,689,892	€26,898,922	€48,418,059	€52,183,908	€53,797,843	
Grand Total at 2010 prices						€53,797,843	

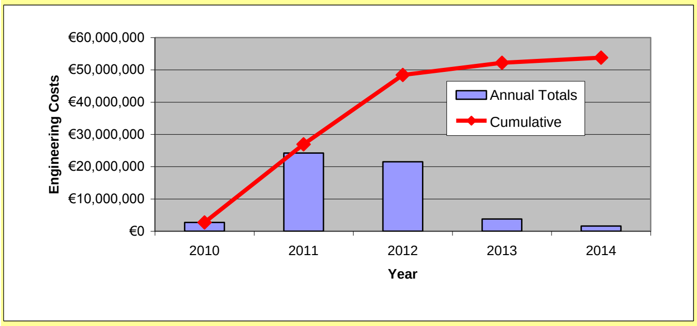


Figure 18: Scenario 2 Cost Model Results

The cost estimate of around €55m in Figure 18 is based on additional numbers of sites (contained in Table 11) required as a result of the simulation exercise. The figure is relative to the size of the initial network, so that of the existing mobile operators, Vodafone (with the largest GSM900 network) should see the highest costs, whilst Meteor (with the smallest GSM900 network) should see the lowest costs.

4.6 Timescales

The timescale to implement the project activities outlined in section 4.5 is somewhat dependent factors beyond the control of the mobile operator, as building of new sites may require planning consents, way leave negotiations and commercial discussions with holders of third party rights. Given the costs identified in section 4.5, it is clear that the activities required to build an additional 414 sites represent a significant amount of work.

A high level process is shown in Figure 19.

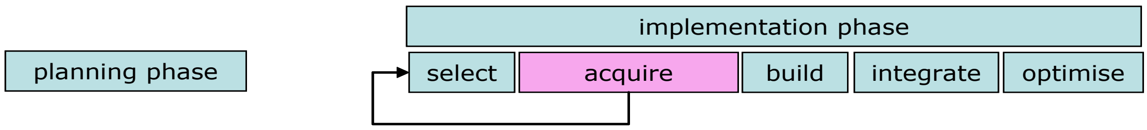


Figure 19: High Level Project for Scenario 2 (not to scale)

In the planning phase, it would be necessary to consider additional recruitment and appointment of subcontractors. The operator might consider how the overall project would be split into regions, and how best to integrate the new activity with 'business as usual activity'.

The 'implementation phase' is concerned with building new sites. A generic five stage 'select – acquire – build –integrate – optimise' approach is described in Figure 19.

- Select – radio planning input is used to determine where additional sites are required. For each new site, the output of this stage is likely to be a number of candidate sites or a zone where an additional site is required.
- Acquire – the process of acquiring the right to use a site from amongst the candidates. As this process involves negotiation with third parties, the time taken is subject to external factors. In case none of the candidate sites is available on reasonable terms, the process of site selection is re-initiated.
- Build – the process of building the site infrastructure. This could include the mast for a rural site, or preparation of an existing equipment room for an urban rooftop site. Deliverables of this stage will normally also include utility supply and the transmission networks.

- Integrate – the process of bringing GSM cell site equipment to site, connecting it to the antennas and commissioning it. This would include all datafill so that existing sites recognise that they have a new neighbour.
- Optimise – the process of ensuring that the new site is performing as expected, by monitoring the traffic carried and performing limited local drive tests. The activity might include re-optimisation of surrounding remotely (reducing output power for example) or through physical intervention (tilting and reorientation of antennas, for example).

As a rule of thumb, the five stage site build process can be completed in around 9 months if it goes according to plan. This five stage process would be repeated 414 times for each additional site to be built. The overall timescale taken will be subject to a number of constraints

- Time taken to acquire problem sites: This is a variable time, and subsequent phases cannot be started until acquisition is complete.
- Resource scheduling constraints: As resource will not be infinite, all sites cannot be built in parallel. There is a time and cost trade-off as if an operator decides to complete the task more quickly by employing extra resource, costs are likely to increase.
- Dependency on third parties. Utilities connections to rural sites can sometimes be time consuming.

In a project to build over 400 sites, it is likely that some 'laggard' sites will suffer several setbacks and take considerably longer than the norm to complete. It is not likely that completion of the final laggard site would be necessary to enable the operator to relinquish spectrum nationally. If the overall project is substantially complete the consequence of not having completed the laggards is that there would be some local reductions in GOS.

Table 12 repeats the year on year site completion percentage that has been assumed for the cost modelling in section 4.5.

Year 0	Year 1	Year 2	Year 3	Year 4
5%	45%	40%	7%	3%

Table 12: Year on Year Site Completion Percentage[25]

Explanation of the percentages are as follows.

- Year 0 – in anticipation of stating a project to reduce the amount of GSM900 spectrum occupied, the operator modifies his 'business as usual' build process over the 12 preceding months. Some of the new sites required are accommodated by this process.
- Year 1 – the project starts in earnest. The operator builds capacity in his team to cope with around 200 new site builds a year, and manages to achieve substantially this number in the first year as most of the sites that can be completed in the 9-months 'rule of thumb' get built. It is expected that substantially more sites are completed in the third and fourth quarters of the year when the team is operating at full capacity.
- Year 2 – sites that did not get built in Year 1 are built in year 2. This includes sites that although acquired did not get built in Year 1 due to resource constraints, and also those sites which took longer to acquire. It is expected that the numbers of sites completed in the first three quarters of the year are approximately similar, with some reduction in the fourth quarter due to constraints in the acquisition process. .
- Year 3 – Early Laggard sites are built. This number of sites represents a significant reduction in quarterly volumes and the required number of site builds might be able to be handled by the 'business as usual' team.
- Year 4 – Late Laggard sites are built.

Given these outline constraints, and assuming the figures in Table 12 represent what can be achieved, roughly 90% of the required number of sites can be built in a 2 year period. It is therefore likely that GSM900 spectrum could be relinquished at the end of the 2 year

[25] Project is assumed to start fully on 1st January in Year 1, so each year represents a full calendar year

period, although there may be minor additional disruption to network subscribers. This additional disruption would be localised to areas where the remaining sites that are required have not been completed.

4.7 Conclusions from Cost and Timescales Modelling

The cost and timescales analysis addressed the solution of building 414 additional GSM900 sites to counteract the increase in interference caused by the reduction in assigned bandwidth. As detailed above, deploying new sites is likely to be only one approach out of a combination of solutions applied by each operator. Therefore, the particular number of new sites to be deployed is only one out of a number of potential alternative scenarios.

Though operators are constantly in building new sites and have efficient processes in place to manage this, adding 414 new sites would be a major undertaking by an operator, representing an increase of approximately 25% in the total number of sites. A significant increase in resources would be required, both internally within the operator’s organisation and externally with subcontracted suppliers.

In addition, simultaneous rollout of such large numbers of sites by more than one operator would put significant demands on the existing industry resources and suppliers adding potential risks of delays to the expansion programmes.

A total capex cost of €55m is estimated. The estimated period for delivery of the 414 sites is four years, but with 90% of the sites being completed by the end of year-2.

5 Scenario 3 - Meteor retuning of 200 kHz

5.1 Introduction

In scenario 3, Meteor would be required to shift its entire 900 MHz assignment one GSM channel lower (down by 200 kHz). This would free up block E for liberalised spectrum use by another operator. The frequency centred on 944.8MHz, absolute radio frequency channel number 49 (ARFCN[26] 49) would be released by Meteor in exchange for 937.6MHz (ARFCN 13).

There are two potential approaches to this task

- Treat the task as a 'relocation'. In this case the methodology described for Scenario 1 (section 3 on page 32) would apply. The 200 kHz retune would be somewhat simpler as band-selective repeaters would continue to operate following the retune.
- Use a similar methodology, but limit the retune to cells and neighbours using the affected channel, ARFCN 49.

Which approach to take would depend on how intensively ARFCN 49 is used in the current network. If the channel were used only selectively, for example as part of a microcellular or in-building pool, then the simplest approach would be to limit the retune to the affected cells and their neighbours. On the other hand, as there is an unused guard channel (channel 50) between the Meteor and Vodafone assignments, there would have been nothing to prevent Meteor making extensive use of channel 49.

If channel 49 was used extensively in Meteor's macro-cellular network, it might be simpler to treat the task as a Scenario 1 relocation / retune, because the affected cells and their neighbours would then constitute a large proportion of the network. It would not be generally advisable to merely replace channel 49 with channel 13 in the network. Channel groups are generally arranged with regard to adjacent channel interference, and it is best practice to avoid as much adjacent channel interference as possible. Adjacent channels are not used at the same time within cells or in co-located cells on sectored sites. For the same

[26] ARFCN is a GSM numbering scheme which uniquely identifies the frequency channel.

reasons, second adjacent channels are also avoided wherever possible. Simply replacing channel 49 with channel 13 in the plan would not guarantee that optimum adjacent channel interference performance of the network would be maintained.

The estimates below assume that

- The same approach is used as outlined in Scenario 1. In other words, no simplification of much of the activity is assumed just because the spectrum assignment is being moved 200 kHz rather than to a different spectrum block. The analysis is therefore 'worst case' in this regard.
- As Scenario 3 will only ever apply to the Meteor network, the network size assumed can reflect the (smaller) Meteor network rather than the 'typical Irish network' used to produce the cost estimates for Scenario 1.

5.2 Inter-Operator Dependency

There is no inter-operator dependency as channel 13 is not currently assigned.

5.3 Engineering Activities for Scenario 3 Retune

The activities are the same as for Scenario 1, and so will include the same three phases

- Planning phase
- Implementation Phase
- Verification Phase

Figure 20: High Level Project for Scenario 3

5.4 Timescales

The estimated 5-month timescale for a full relocation or retune of the GSM900 MHz band plan provided in section 3.4 would allow for Meteor either to perform a complete retune of the network, or to migrate one channel lower. The timescale for Scenario 3, when considered in isolation, would be approximately 4 months:

- Four months for planning. This might be reduced slightly as there will be no need to plan for replacement of any repeaters in the network. Common aspects of the planning phase can start before the auction process, whether or not Meteor decides to opt for the early liberalisation option.
- One week for implementation.

The subsequent verification activity of approximately 2 months occurs after the spectrum has been reassigned, and does not occur on the critical path.

5.5 Cost Modelling

An outline estimate of the engineering costs to complete a 200 kHz retune for Meteor's Irish mobile network is shown in Figure 21.

Task	Detail	Who	Man Days (8hr shift)	Ave Cost / md	Total (Euros)	Qty	Unit Cost	Total Cost	Notes
Planning									
Project Team	0.5 FTE 4 month	Project Management	43	950	41167				1
	2 * 0.75 FTE 4 month	Engineering / RF / Network Operations	130	800	104000				2
Equipment	Band Selective Analogue Repeater								
	Band Selective Digital Repeater								
Implementation									
	Datafill - 3man team - weekend	Network Operations	6	700	4200				
	4 2-man Implemenation Teams - 5 day week	Field Operations	40	600	24000				3
Verification									
Project Team	0.75 FTE 2 month	Project Management	33	950	31350				
	2 FTE 2 month	OMC-R / Service Management	88	700	61600				
	2-man Implementation Team - as required	Field Operations	20	600	12000				
	Drive Tests / Optimisation	Field Operations	30	600	18000				4
Sutotals					296317				
Overall Total					**296317**				

1. Project Manager responsible for all activity. 'FTE' = full time equivalent
2. Resource not full time on project
3. Assume 10% of 2G sites need a visit during the implementation period and each team can visit 4 sites per day.
4. Assume 15 days total drive test with 2 man teams.

Figure 21: High Level Cost Estimates for Scenario 3

This estimate follows the exactly same format as the estimate for Scenario 1 (relocation) given in Figure 9 on page 43, although the Project Management and Field Operations effort has been reduced to reflect the fact that the project is simplified. In particular:

- Meteor has a smaller GSM900 network than the 'typical Irish network', so visiting 10% of unique site locations can be accomplished by a smaller number of implementation teams. Assuming 800 unique[27] 2G sites instead of 1600 sites assumed in Scenario 1, the field operations activity in the implementation phase is halved.
- The project is a 'retuning' project, and there is no requirement to deal with issues specific to 'relocation' (such as those dependent on band selective repeaters.), which simplifies the project as well as removing the associated equipment costs. It has been assumed that the project management effort is reduced by 1/3 in the planning phase and 1/4 in the implementation phase compared to Scenario 1.
- Co-ordination, both nationally and internationally is simplified, as the coordination activity is with the same third parties before and after the retuning activity

The resulting cost estimate in Figure 21 is around €300 000. This is in excess of the figure of around €X[28] estimated by Meteor for the same project. This level of discrepancy is not surprising given the completely independent approaches to estimating costs. The Meteor estimate is more likely to include figures that reflect the actual cost base of Meteor, and the so the figure of €X[29] supplied by Meteor can therefore be accepted as a reasonable estimate of the actual cost of Scenario 3.

[27] Numbers supplied by ComReg

[28] Figure supplied is confidential.

[29] Figure supplied is confidential.

6 Equipment in Use in Ireland

6.1 Introduction

The degree of difficulty and the associated costs of a network relocation / retune can be greatly impacted by the existing equipment used by network operators. If, for example, a network operator is assigned a block of spectrum that is not compatible with some of their existing equipment, then that equipment would need to be replaced. The replacement activity would increase both the time required and the costs associated with the relocation / retune. Fortunately, with only minor exceptions, the equipment currently used in Ireland is sufficiently modern to operate across the entire 900 MHz band.

In considering strategies to maximise the capacity of the 900 MHz spectrum, particularly in the case of Scenario 2 where the amount of spectrum available to an operator reduces, it would be advantageous if there were no restrictions on the range of ‘advanced’ features that could be employed on the network. An example is Slow Frequency Hopping (SFH), which can help increase the quality and capacity of a network by reducing the impact of a dominant interferer on any other single communication. Some combinations of base station and coupling option cannot support synthesised SFH. Fortunately again, with only minor exceptions, the equipment currently used will be able to support all the features that would help operators to maximise the use of 900 MHz spectrum.

The types of equipment considered below are

- Base Stations: The base station and coupling options need to support the new 900 MHz spectrum block allocated to the operator.
- Repeaters: Repeaters come in various types and many of the common lower cost variants will not support relocation / retune and would therefore need to be removed or replaced. The extent of use of repeaters varies across networks, but all operators are likely to be affected by this issue to some extent.
- Mobiles: Practically all mobiles support the entire 900 MHz band, and so do not prevent an operator’s ability to perform a network relocation / retune. In the case of Scenario 2, where the amount of spectrum available to the operator reduces, a number of potential strategies to ‘offload’ traffic currently carried by the 900 MHz

network have been suggested. The installed base of mobiles will have an impact on these strategies. Those strategies involving increased offload to 1800 MHz require a dual band capable mobile. Offload to 3G requires a 3G capable mobile with a 3G SIM, and assignment of an AMR HR channel requires an AMR HR capable mobile.

6.2 Base Station Equipment

6.2.1 Introduction

The 900 MHz band has traditionally been subdivided into the P-GSM band (spectrum blocks C, D, E F & G) and the 'extended' or E-GSM band (spectrum blocks A & B). E-GSM spectrum was allocated for mobile network use after P-GSM spectrum. The reduced frequency separation between the upper edge of the mobile transmit band and the lower band edge of the base transmit band when operating in the E-GSM spectrum blocks originally required upgrades to elements such as duplexers. Based on current information, all the Irish mobile networks now use equipment capable of operating across the whole band.

Base station (BTS) equipment supports simultaneous use of a number of GSM channels to increase capacity. Typical carrier counts in a GSM network would vary from around 2 to more than 8, with the upper limit determined by the amount of spectrum available to an operator and the network hardware capabilities. In a BTS a 'combining' function is required to combine the carriers onto a smaller number of antennas. Two types of combining have traditionally been used, wideband *hybrid* and narrowband *cavity* combiners. Cavity combiners offer lower insertion loss at higher carrier counts. Hybrid combiners are in almost universal use in 900 MHz networks in Ireland because they have lower complexity, impose fewer restrictions on the network channel plan and support synthesised frequency hopping which as discussed above is used to maximise capacity in a GSM network.

The use of modern base station equipment along with wideband combining in Irish mobile networks allows operators to perform a relocation / retuning exercise with less impact on the mobile network.

6.2.2 Ericsson

All of the Irish GSM mobile operators use some Ericsson equipment and Ericsson is the largest supplier to the Irish mobile operators. Ericsson currently supplies three series of BTS equipment:

- RBS2000 series. This is a modern GSM base station family, which supports the entire 900 MHz band and all ‘advanced’ GSM features such as Slow Frequency Hopping.
- RBS3000 series. This is a modern 3G base station family, which can provide a combined 2G/3G site when deployed alongside an RBS2000.
- RBS6000 series. This is Ericsson’s newest modular base station family. Introduced in 2008/09, the RBS6000 series supports both GSM and 3G technologies through a range of modules. According to Ericsson, operators who deploy an RBS6000 are well placed to liberalise the use of their GSM900 spectrum as they can deploy GSM equipment now and upgrade to 3G later through the addition of plug in modules. Ericsson’s marketing claim is that the RBS6000 will also support migration to LTE through plug-in modules.

Older versions of Ericsson equipment, such as the RBS200 range, could have presented some restrictions to network relocation / retune. Where operators originally had these types of equipment, they have now been replaced. Ericsson acquired the GSM assets of Nortel, and the same comment applies to older Nortel equipment such as the S4000.

Meteor, O2 and Vodafone are understood to have deployed a mixture of RBS2000, RBS3000 and RBS6000 equipment. RBS2000 and RBS6000 both support network retune / relocation without restrictions.

6.2.3 Nokia Siemens Networks (formerly Nokia)

Nokia Siemens Networks offer a ‘Flexi Multiradio BTS’, marketed as a module based multi-technology family in a similar manner to the Ericsson RBS6000. None of the existing 2G operators currently deploy this equipment.

Nokia previously had a larger presence in the Irish market, with the Ultrasite and IntraTalk GSM base station families deployed by both O2 and Vodafone. Although these older product families are now in various stages of being replaced and do not support 3G access, they do not pose any significant restrictions to network relocation / retune.

6.2.4 Alcatel Lucent (formerly Lucent)

Alcatel Lucent offers a 9100 Multi-Standard base station, marketed in the same manner as the Ericsson RBS6000 and the NSN Flexi BTS. This equipment is not deployed in the Irish market.

Earlier 2G lucent ‘Flexent’ equipment has been deployed. Although this older product family is expected to be replaced, it does not pose any significant restrictions to network relocation / retune.

6.3 Repeaters

6.3.1 Introduction

Repeaters offer network operators the ability to increase network coverage without the full cost of adding an additional cell site. Repeaters do not need to be connected to the backhaul transmission network, but do not offer any additional network capacity as a result. A repeater can be a flexible tool to improve coverage in otherwise 'hard to reach' areas such as underground car-parks, where expected capacity demand may be insufficient to justify an additional cell.

Simple repeaters can be relatively low cost, but as simpler ones are not remotely tuneable or even, in some circumstances, remotely managed for faults.

6.3.2 Band Selective Repeaters

Band selective repeaters are generally used in situations where large numbers of frequency carriers are to be repeated. They have the advantage of supporting base station synthesized frequency hopping and are therefore the most common type of repeater deployed in Irish mobile networks.

In order to avoid compromising other mobile networks, band selective repeaters are generally tuned to an operator's individual spectrum assignment. This means that when this spectrum assignment changes, the repeater needs to be retuned (if possible) or replaced. As many of the simpler band selective repeaters cannot be retuned in the field, they need to be replaced.

Repeater manufacturers such as Powerwave (formerly Allgon) and Axell Wireless now provide repeaters with remotely adjustable band filters. This feature allows new frequency plans to be adopted easily and remotely, which eliminates the need to visit any repeater sites. These types of equipment are not universally deployed because they have been introduced more recently and because they are more expensive. They are, however, increasing in relative popularity both because of availability and the because of the fact that some models can support both 2G and 3G.

It is therefore estimated that most, if not all, of the existing band selective repeaters would have to be removed from the network following a relocation / retune. If these repeaters were still required, they would have to be replaced with new equipment either specifically designed for the new spectrum block, or by a repeater of remotely tuneable design.

The cost modelling in section 3.5 uses replacement costs for repeaters provided by the supplier. Although there are a wide range of equipment options possible, the cost model uses just two repeater models, which are:

- Axell 2409 +24dBm Analogue E-GSM repeater, with user selectable and tuneable bandwidth. The cost estimate used for this device is €2500. This is a simple, low-cost unmanaged repeater useful for applications where cost is at a premium. Although unmanaged repeaters do not themselves provide the network operations centre any information on their state of health, a go/no-go status can be reported remotely by any suitable device in the repeaters coverage area.
- Axell3009 +30dBm Digital E-GSM repeater, supporting up to 12-sub bands in the E-GSM spectrum bands. The cost estimate used for this device is €4900. This is a more sophisticated managed repeater, which supports GSM and 900 MHz 3G technologies in one unit. As it can support non-contiguous spectrum blocks within the 900 MHz band it could find applications in cases where more than one operator with non-contiguous spectrum shared a site and the repeater application required a multi-operator capability.

6.3.3 Channel Selective Repeaters

Channel-selective repeaters are commonly used in off-air applications where high selectivity is important. The high selectivity allows higher output power, and reduces the chance of rebroadcasting noise and interference.

The disadvantage of channel selective repeaters is that they are inflexible in response to evolving capacity demand and they do not support Slow Frequency Hopping. Channel selective repeaters are affected by any changes to the donor cells frequency assignment, not just by a relocation / retuning activity. When a mobile operator has lots of spectrum and can dedicate some channels for special coverage purposes, this is disadvantage can be accommodated, but this arrangement would be especially difficult to support in the example of Scenario 2 where an operator needs to reduce the amount of spectrum they use. For these reasons channel selective repeaters are much less commonly used in Irish mobile networks than in other applications such as Private Mobile Radio (PMR) where their restrictions are less important.

It is therefore estimated that most, if not all, of the existing channel selective repeaters would have to be removed from the network following a relocation / retune. If these repeaters were still required, they would probably have to be replaced with new band selective equipment either specifically designed for the new spectrum block, or by a band selective repeater of remotely tuneable design.

6.3.4 Other Equipment

Other equipment such as passive diplexers / triplexers have been used as site specific solutions to retrofitting 3G equipment to an existing 2G site. They allow multiple base stations to be connected to a single feeder, and when used along with items such as dual-band cross polar antennas, provide a way of adding 3G equipment to an existing 2G site whilst minimising additional site works and visual impact. The 3G and 2G equipment does not have to be from the same manufacturer.

Increasing use of multi-technology BTS such as Ericsson's RBS6000 means that the prevalence of such site specific solutions is decreasing. Most such site solutions are expected to have been designed to support the entire 2G 900 MHz spectrum, and so should not pose significant restrictions to a relocation / retune on the network. If some site specific passive elements needed to be replaced, this activity could be done during the early planning phase of the relocate / retune project.

6.4 User Handsets

Practically all mobiles support the entire 900 MHz band, and so do not affect an operator's ability to perform a relocation / retune on the network. In the case of Scenario 2, where the amount of spectrum available to the operator reduces, a number of potential strategies to 'offload' traffic currently carried by the 900 MHz network have been suggested.

The customer base of mobiles will have an impact on these strategies. Those strategies involving increased offload to 1800 MHz require a dual band capable mobile. Offload to 3G requires a 3G capable mobile with a 3G SIM, and assignment of an AMR HR channel requires an AMR HR capable mobile.

Operators will have accurate statistics for the installed base of mobiles on their network, and will be able to accurately predict the amount of traffic generated by each category. Even though mobiles move around the network and their traffic is supplemented by that generated by international roaming, the estimates should allow relatively accurate estimation of the amount of traffic that can be offloaded by each potential strategy.

The operator information is proprietary, but nevertheless the following qualitative assertions can be made with confidence:

- There are no or almost no handsets in use that do not support E-GSM (blocks A&B), but that would otherwise be supported on the operators network.
- The percentage of mobiles supporting AMR HR will be a high percentage, even though not all mobiles will support this mode. Strategies maximising capacity of

the 900 MHz network by involving high usage of AMR HR modes in the busy hour are therefore likely to be successful.

- The percentage of mobiles supporting 900/1800 MHz dual band operation will be nearly 100%. Strategies involving offload of traffic to 1800 MHz networks are therefore likely to be limited by other factors such as 1800 MHz in-building penetration.
- The percentage of mobiles supporting 3G for 2100 MHz offload, and equipped with 3G SIMS will be in the 20-50% range. Strategies involving offload of traffic to 2100 MHz will therefore be limited by the fact that there are large numbers of mobiles who cannot use 3G networks and the fact that those that can will already be making use of the 3G network where it is available.

7 Glossary

2.5G	Refers to packet data on GSM (GPRS) and its evolution such as EDGE.
2G	2nd Generation mobile phone technology, such as GSM
3G	3rd Generation mobile phone technology, such as UMTS
AFP	Automatic Frequency Planning.
AMR	Adaptive Multi Rate CODEC. A relatively new CODEC with advanced features that can provide additional capacity to existing GSM networks.
ARFCN	Absolute Radio Frequency Channel Number. A channel numbering scheme which uniquely identifies the frequency channel.
BCCH	Broadcast Common Control Channel. A signal used by mobiles to determine where they are in a GSM network
BSC	Base Station Controller.
BSIC	Base Station Identity Code
BTS	Base Transceiver Station. The basic radio building block of a GSM network.
C/I	Carrier to Interference ratio (C/I) is a measure of the relative magnitude of the wanted signal (C) required to sustain a communication and an interfering signal (I) which exists because the same spectrum is being used elsewhere in the network.
C/Ic	Carrier to Co-Channel Interference ratio (C/Ic) is a measure of the relative magnitude of the wanted signal (C) required to sustain a communication and an interfering signal on the same frequency (Ic)
C/Ia	Carrier to Adjacent-Channel Interference ratio (C/Ia) is a measure of the relative magnitude of the wanted signal (C) required to sustain a communication and an interfering signal on the next adjacent channel (Ia).

CODEC	Coder – Decoder. The function within the mobile network that takes human speech and converts it to and from a digital code for transmission.
Coordinate	The process by which network exchange mutual information on how their frequency assignments are used in order to help prevent mutual interference.
Downlink	The radio link from BTS to mobile handset.
DTX	Discontinuous transmission – a process by which a GSM transmission is suppressed on either the uplink, downlink or both when there is no data to transmit (phone user not speaking for example). The use of DTX can improve network capacity and/or GOS by reducing unwanted interference.
Dual Band	Using more than one frequency allocation together. (e.g. GSM 900 and GSM 1800)
EDGE	Enhanced Data rates for GSM Evolution. A development which supports improved data transmission rates for GSM packet radio through the use of higher order modulation methods and efficient adaptive data coding schemes.
EFR	Enhanced Full Rate CODEC. Provided improved speech quality on GSM networks when it was introduced.
Erlang (E)	An erlang (E) is a unit of traffic on a telephone network equivalent to 1 call for 1 hour.
(Frequency) Allocation:	Entry in the Table of Frequency Allocations of a given frequency band for the purpose of its use by one or more radio communication services. This term is also be applied to the frequency band concerned
(Frequency) Allotment	Details of how a frequency is to be used within an allocation.
(Frequency) Assignment	The part of an allocation or allotment awarded to an individual organisation by the regulator.
Frequency Reuse	The concept of using any radio frequency multiple times within a network.
Full Rate (FR)	An original GSM CODEC using one timeslot per voice call.
GOS	Grade of Service

GPRS	Generalised Packet Radio Service. A GSM network can carry packet data using GPRS.
GSM	Group Special Mobile, the 2G mobile phone standard used in Ireland.
Half Rate (HR)	An original GSM CODEC using one timeslot for two voice calls.
Hierarchical Cell Structures	An approach to mobile network design to enable increased capacities by incorporating smaller cells.
IMSI	International Mobile Subscriber Identity
MOS	Mean Opinion Score provides a numerical indication of the perceived quality of speech. The MOS is a number from 1 to 5 (1 = Bad, 5 = Excellent).
MSC	Mobile Switching Centre. Links the mobile network to the PSTN
OMC	Operation and Maintenance Centre. A network element used to control the others through human interaction.
Power Control	The process of varying the radio power of a transmitted signal in order to reduce unnecessary interference in a mobile network.
PSTN	Public Switched Telephone Network
PSTN	Public Switched Telephone Network
SIM	Subscriber Identity Module. A removable chip inside a mobile phone containing subscriber details such as the IMSI
TCH	Traffic Channel
TCU	Transcoder Unit. A GSM network element that performs speech transcoding.
TDMA	Time Division Multiple Access. A GSM system is a TDMA system because the GSM carrier is split into timeslots.
Timeslot	A subdivision of a GSM carrier. Each GSM carrier is subdivided into 8 timeslots.
Transceiver	A transceiver ('‘transmitter – receiver') is a basic hardware building block of a BTS, supporting simultaneous radio transmission and reception occupying one channel of spectrum

UMTS	Universal Mobile Telecommunications System, the 3G mobile phone standard used in Ireland.
Uncoordinated	See Coordinated.
Uplink	The radio link from mobile handset to BTS.

Retuning and Relocating GSM900 Spectrum Assignments in Ireland

Joint Report for ComReg
By

ANNEX: Carrier to Interference Simulation Results for Scenario 2

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Appendix 1 – Rural Sample Network C/Ic Interference Results

The plots of carrier to interference less than 12 dB are presented hereafter for the BCCH layer and the TCH layer for each traffic and site count plan. This gives a visual illustration of the extent of and distribution of the interference.

The table details the area and percentage area where C/Ic is less than 12 dB for each plan. The highlighted row is associated with the accompanying plot.

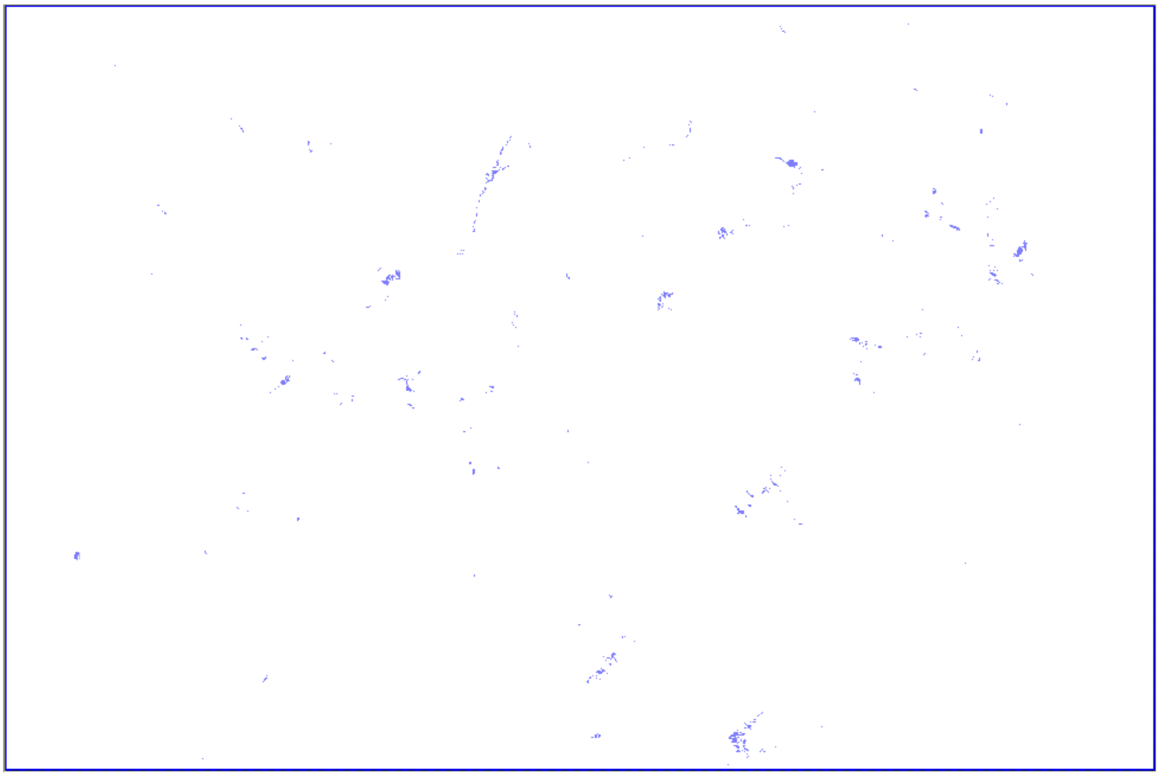

Figure 22: Rural Area C/Ic < 12 dB Interference Map;
60% GSM900 Traffic; 36 GSM channels; 16 BCCH Channels
C/Ic < 12 dB = 19.54 km^2

Plan	GSM900 Traffic	Num Sites	Layer	Channels	C/Ic area (km^2) 2^o E-Tilt	% Area C/Ic < 12 dB
1	***60%***	***153***	***BCCH***	***16 / 36***	***19.54***	***0.18%***
	60%	153	TCH	20 / 36	3.26	0.03%
2	60%	153	BCCH	13 / 25	79.26	0.72%
	60%	153	TCH	12 / 25	180.19	1.64%
3	50%	153	BCCH	13 / 25	73.88	0.67%
	50%	153	TCH	12 / 25	77.76	0.71%
4	45%	153	BCCH	13 / 25	72.99	0.67%
	45%	153	TCH	12 / 25	12.24	0.11%
5	40%	153	BCCH	13 / 25	93.26	0.85%
	40%	153	TCH	12 / 25	7.19	0.07%
6	60%	199	BCCH	13 / 25	95.9	0.87%
	60%	199	TCH	12 / 25	53.88	0.49%

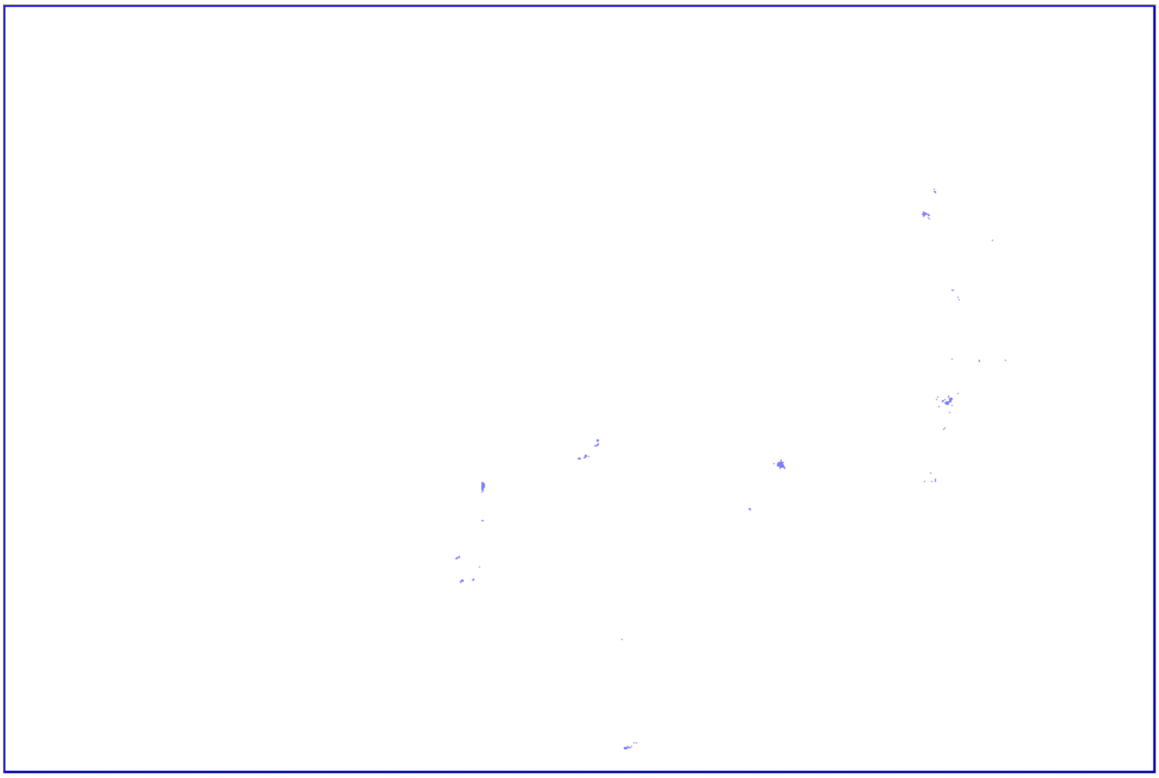

Figure 23: Rural Area C/Ic < 12 dB Interference Map;

60% GSM900 Traffic; 36 GSM channels; 20 TCH Channels

C/Ic < 12 dB = 3.26 km^2

Plan	GSM900 Traffic	Num Sites	Layer	Channels	C/Ic area (km^2) 2^o E-Tilt	% Area C/Ic < 12 dB
1	60%	153	BCCH	16 / 36	19.54	0.18%
	60%	***153***	***TCH***	***20 / 36***	***3.26***	***0.03%***
2	60%	153	BCCH	13 / 25	79.26	0.72%
	60%	153	TCH	12 / 25	180.19	1.64%
3	50%	153	BCCH	13 / 25	73.88	0.67%
	50%	153	TCH	12 / 25	77.76	0.71%
4	45%	153	BCCH	13 / 25	72.99	0.67%
	45%	153	TCH	12 / 25	12.24	0.11%
5	40%	153	BCCH	13 / 25	93.26	0.85%
	40%	153	TCH	12 / 25	7.19	0.07%
6	60%	199	BCCH	13 / 25	95.9	0.87%
	60%	199	TCH	12 / 25	53.88	0.49%

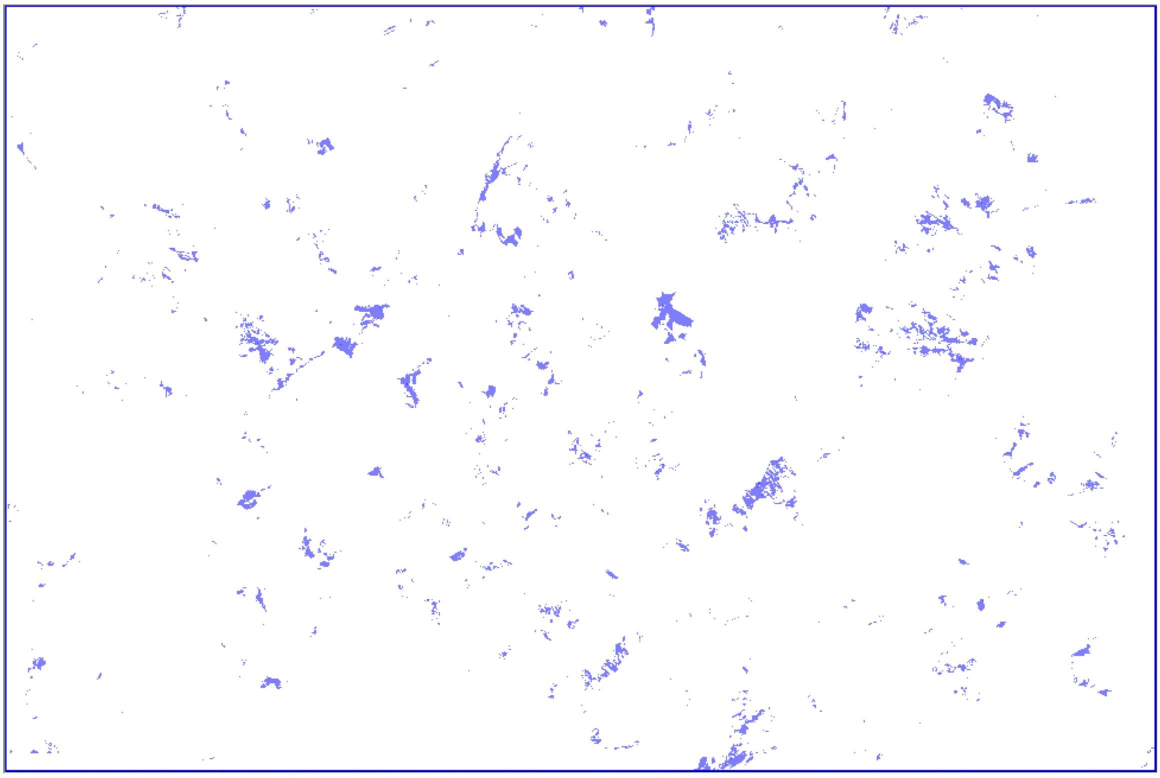

Figure 24: Rural Area C/Ic < 12 dB Interference Map;
60% GSM900 Traffic; 25 GSM channels; 13 BCCH Channels
C/Ic < 12 dB = 79.26 km^2

Plan	GSM900 Traffic	Num Sites	Layer	Channels	C/Ic area (km^2) 2^o E-Tilt	% Area C/Ic < 12 dB
1	60%	153	BCCH	16 / 36	19.54	0.18%
	60%	153	TCH	20 / 36	3.26	0.03%
2	***60%***	***153***	***BCCH***	***13 / 25***	***79.26***	***0.72%***
	60%	153	TCH	12 / 25	180.19	1.64%
3	50%	153	BCCH	13 / 25	73.88	0.67%
	50%	153	TCH	12 / 25	77.76	0.71%
4	45%	153	BCCH	13 / 25	72.99	0.67%
	45%	153	TCH	12 / 25	12.24	0.11%
5	40%	153	BCCH	13 / 25	93.26	0.85%
	40%	153	TCH	12 / 25	7.19	0.07%
6	60%	199	BCCH	13 / 25	95.9	0.87%
	60%	199	TCH	12 / 25	53.88	0.49%

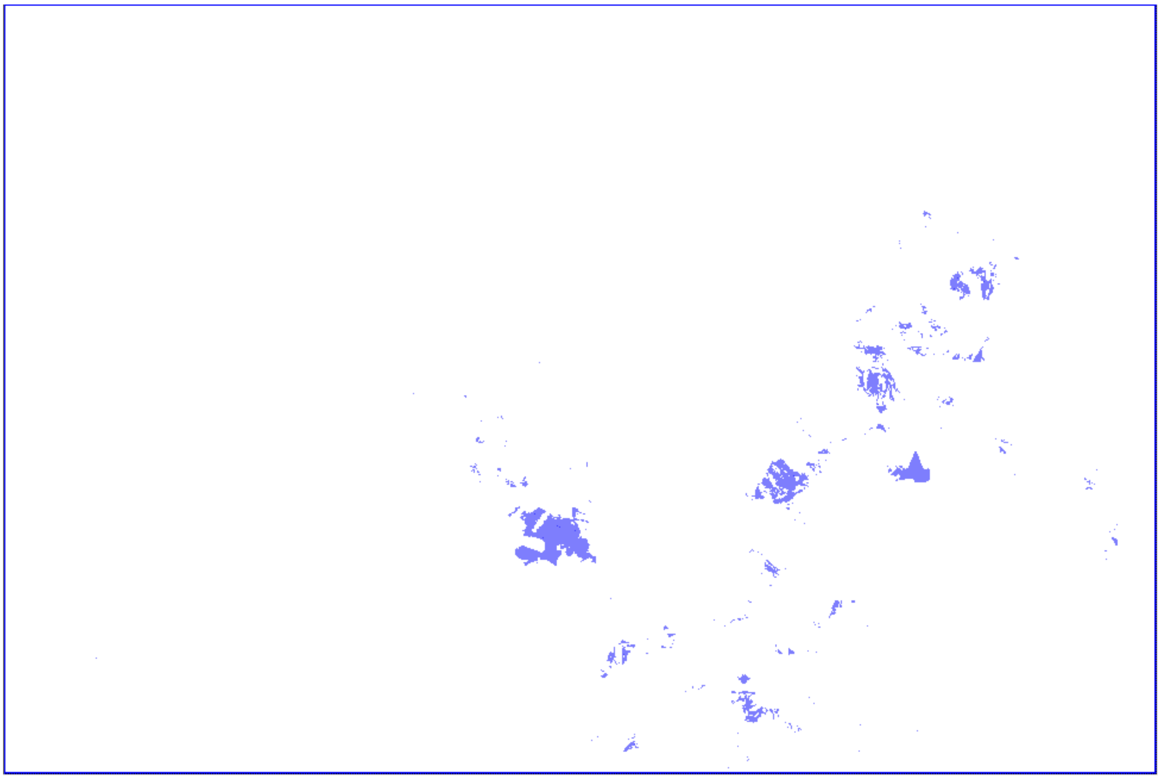

Figure 25: Rural Area C/Ic < 12 dB Interference Map;
60% GSM900 Traffic; 25 GSM channels; 12 TCH Channels
C/Ic < 12 dB = 180.19 km^2

Plan	GSM900 Traffic	Num Sites	Layer	Channels	C/Ic area (km^2) 2^o E-Tilt	% Area C/Ic < 12 dB
1	60%	153	BCCH	16 / 36	19.54	0.18%
	60%	153	TCH	20 / 36	3.26	0.03%
2	60%	153	BCCH	13 / 25	79.26	0.72%
	60%	***153***	***TCH***	***12 / 25***	***180.19***	***1.64%***
3	50%	153	BCCH	13 / 25	73.88	0.67%
	50%	153	TCH	12 / 25	77.76	0.71%
4	45%	153	BCCH	13 / 25	72.99	0.67%
	45%	153	TCH	12 / 25	12.24	0.11%
5	40%	153	BCCH	13 / 25	93.26	0.85%
	40%	153	TCH	12 / 25	7.19	0.07%
6	60%	199	BCCH	13 / 25	95.9	0.87%
	60%	199	TCH	12 / 25	53.88	0.49%

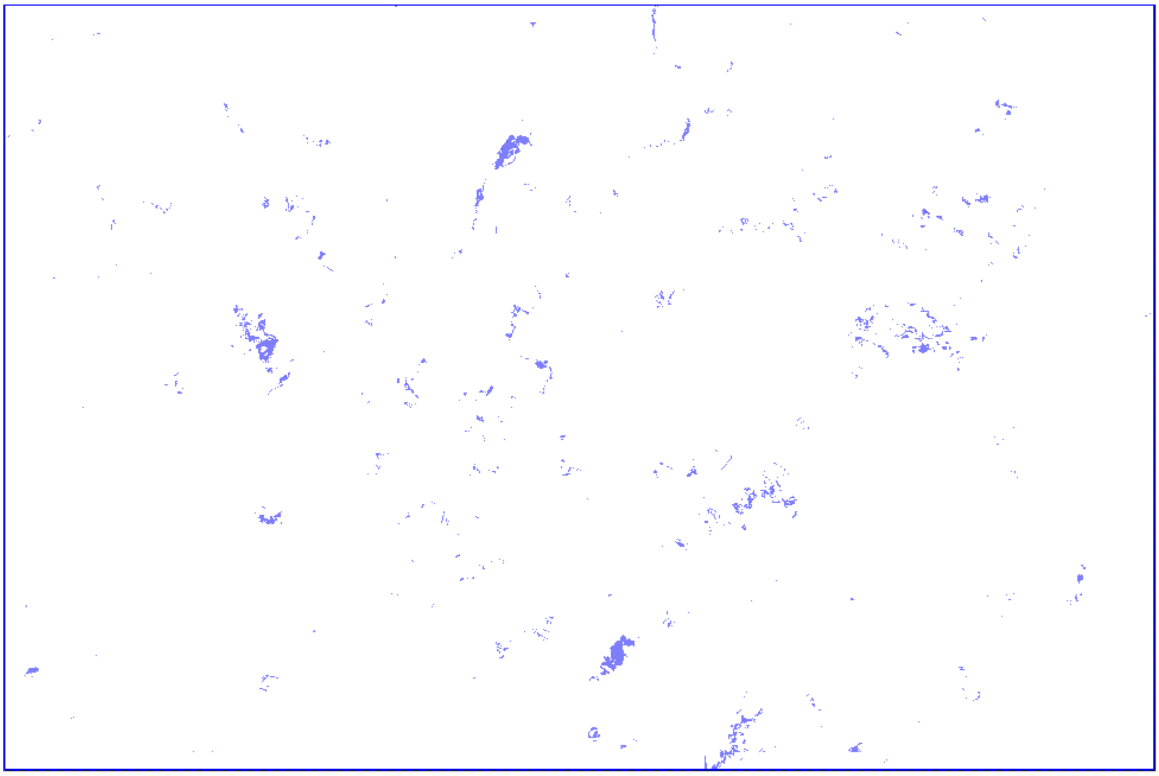

Figure 26: Rural Area C/Ic < 12 dB Interference Map;

50% GSM900 Traffic; 25 GSM channels; 13 BCCH Channels

C/Ic < 12 dB = 73.88 km^2

Plan	GSM900 Traffic	Num Sites	Layer	Channels	C/Ic area (km^2) 2° E-Tilt	% Area C/Ic < 12 dB
1	60%	153	BCCH	16 / 36	19.54	0.18%
	60%	153	TCH	20 / 36	3.26	0.03%
2	60%	153	BCCH	13 / 25	79.26	0.72%
	60%	153	TCH	12 / 25	180.19	1.64%
3	***50%***	***153***	***BCCH***	***13 / 25***	***73.88***	***0.67%***
	50%	153	TCH	12 / 25	77.76	0.71%
4	45%	153	BCCH	13 / 25	72.99	0.67%
	45%	153	TCH	12 / 25	12.24	0.11%
5	40%	153	BCCH	13 / 25	93.26	0.85%
	40%	153	TCH	12 / 25	7.19	0.07%
6	60%	199	BCCH	13 / 25	95.9	0.87%
	60%	199	TCH	12 / 25	53.88	0.49%

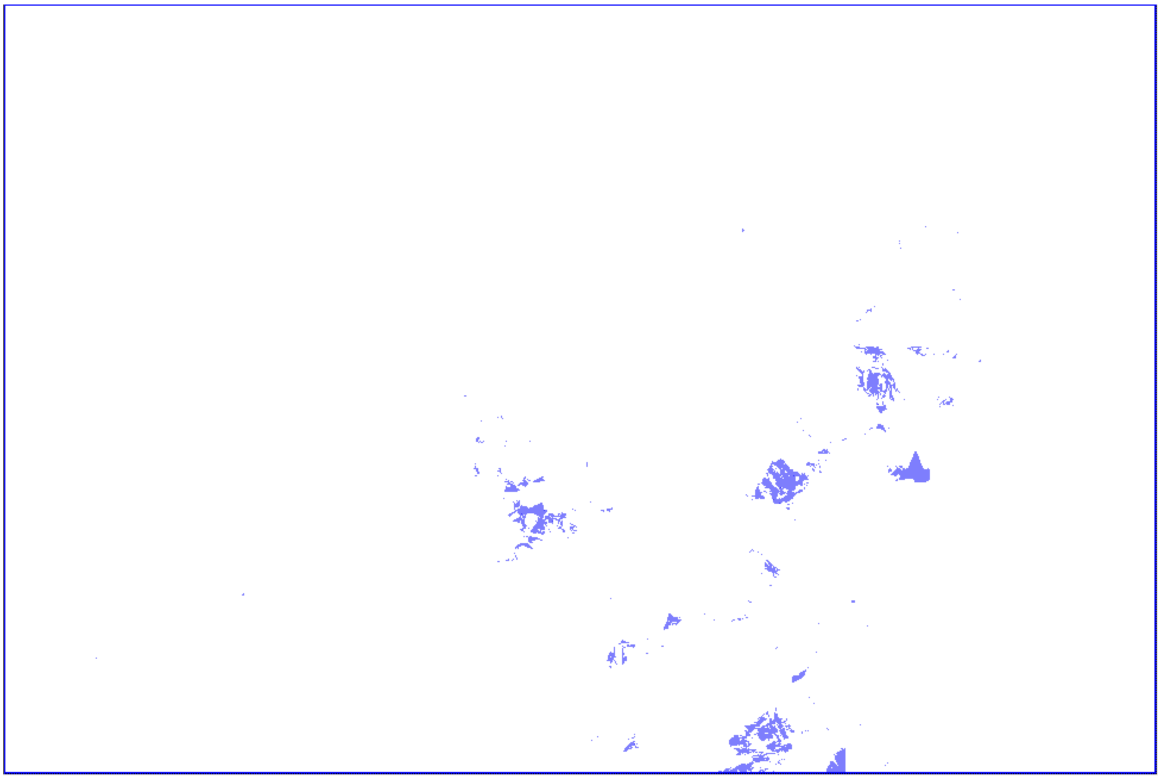

Figure 27: Rural Area C/Ic < 12 dB Interference Map;
50% GSM900 Traffic; 25 GSM channels; 12 TCH Channels
C/Ic < 12 dB = 77.76 km^2

Plan	GSM900 Traffic	Num Sites	Layer	Channels	C/Ic area (km^2) 2^o E-Tilt	% Area C/Ic < 12 dB
1	60%	153	BCCH	16 / 36	19.54	0.18%
	60%	153	TCH	20 / 36	3.26	0.03%
2	60%	153	BCCH	13 / 25	79.26	0.72%
	60%	153	TCH	12 / 25	180.19	1.64%
3	50%	153	BCCH	13 / 25	73.88	0.67%
	50%	***153***	***TCH***	***12 / 25***	***77.76***	***0.71%***
4	45%	153	BCCH	13 / 25	72.99	0.67%
	45%	153	TCH	12 / 25	12.24	0.11%
5	40%	153	BCCH	13 / 25	93.26	0.85%
	40%	153	TCH	12 / 25	7.19	0.07%
6	60%	199	BCCH	13 / 25	95.9	0.87%
	60%	199	TCH	12 / 25	53.88	0.49%

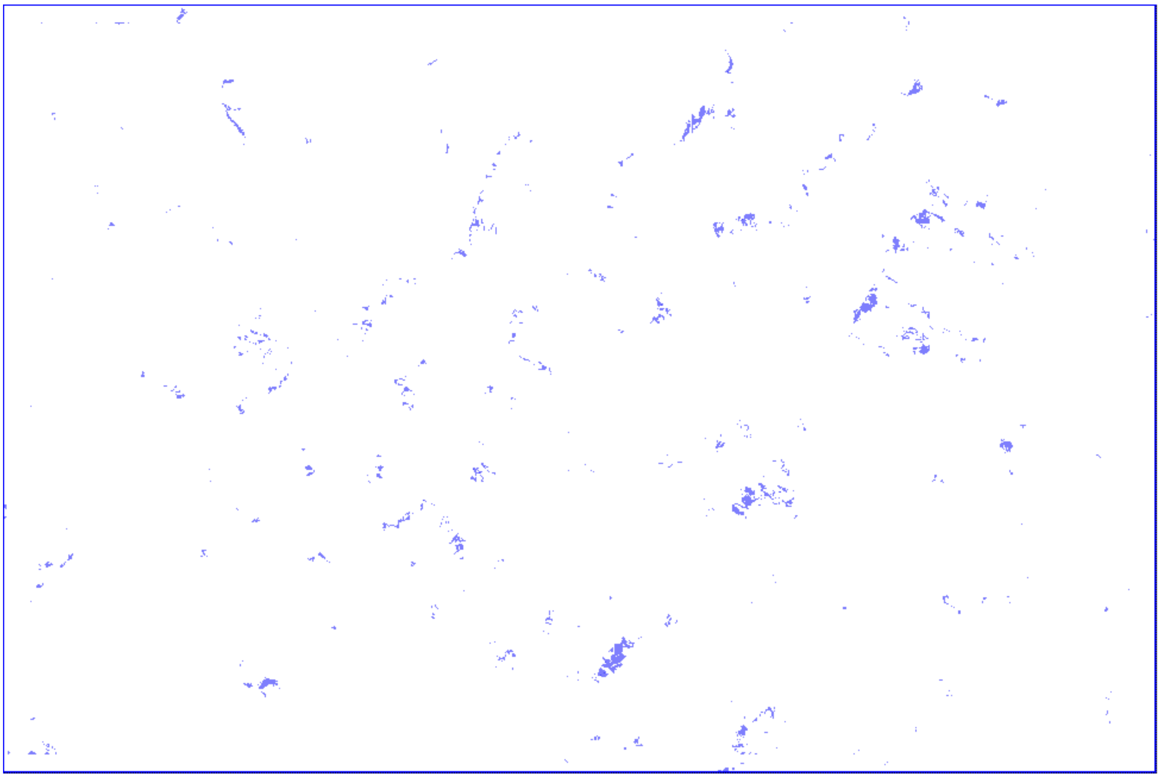

Figure 28: Rural Area C/Ic < 12 dB Interference Map;
45% GSM900 Traffic; 25 GSM channels; 13 BCCH Channels
C/Ic < 12 dB = 72.99 km^2

Plan	GSM900 Traffic	Num Sites	Layer	Channels	C/Ic area (km^2) 2^o E-Tilt	% Area C/Ic < 12 dB
1	60%	153	BCCH	16 / 36	19.54	0.18%
	60%	153	TCH	20 / 36	3.26	0.03%
2	60%	153	BCCH	13 / 25	79.26	0.72%
	60%	153	TCH	12 / 25	180.19	1.64%
3	50%	153	BCCH	13 / 25	73.88	0.67%
	50%	153	TCH	12 / 25	77.76	0.71%
4	***45%***	***153***	***BCCH***	***13 / 25***	***72.99***	***0.67%***
	45%	153	TCH	12 / 25	12.24	0.11%
5	40%	153	BCCH	13 / 25	93.26	0.85%
	40%	153	TCH	12 / 25	7.19	0.07%
6	60%	199	BCCH	13 / 25	95.9	0.87%
	60%	199	TCH	12 / 25	53.88	0.49%

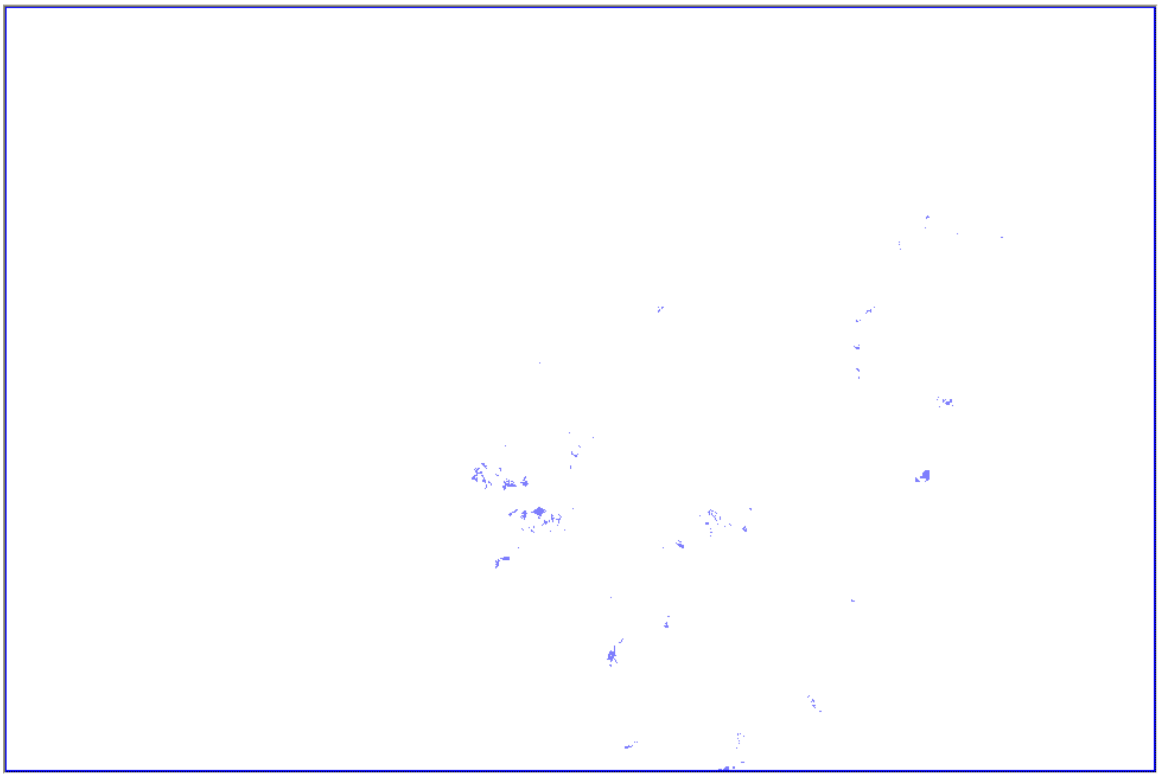

Figure 29: Rural Area C/Ic < 12 dB Interference Map;
45% GSM900 Traffic; 25 GSM channels; 12 TCH Channels
C/Ic < 12 dB = 12.24 km^2

Plan	GSM900 Traffic	Num Sites	Layer	Channels	C/Ic area (km^2) 2^o E-Tilt	% Area C/Ic < 12 dB
1	60%	153	BCCH	16 / 36	19.54	0.18%
	60%	153	TCH	20 / 36	3.26	0.03%
2	60%	153	BCCH	13 / 25	79.26	0.72%
	60%	153	TCH	12 / 25	180.19	1.64%
3	50%	153	BCCH	13 / 25	73.88	0.67%
	50%	153	TCH	12 / 25	77.76	0.71%
4	45%	153	BCCH	13 / 25	72.99	0.67%
	45%	***153***	***TCH***	***12 / 25***	***12.24***	***0.11%***
5	40%	153	BCCH	13 / 25	93.26	0.85%
	40%	153	TCH	12 / 25	7.19	0.07%
6	60%	199	BCCH	13 / 25	95.9	0.87%
	60%	199	TCH	12 / 25	53.88	0.49%

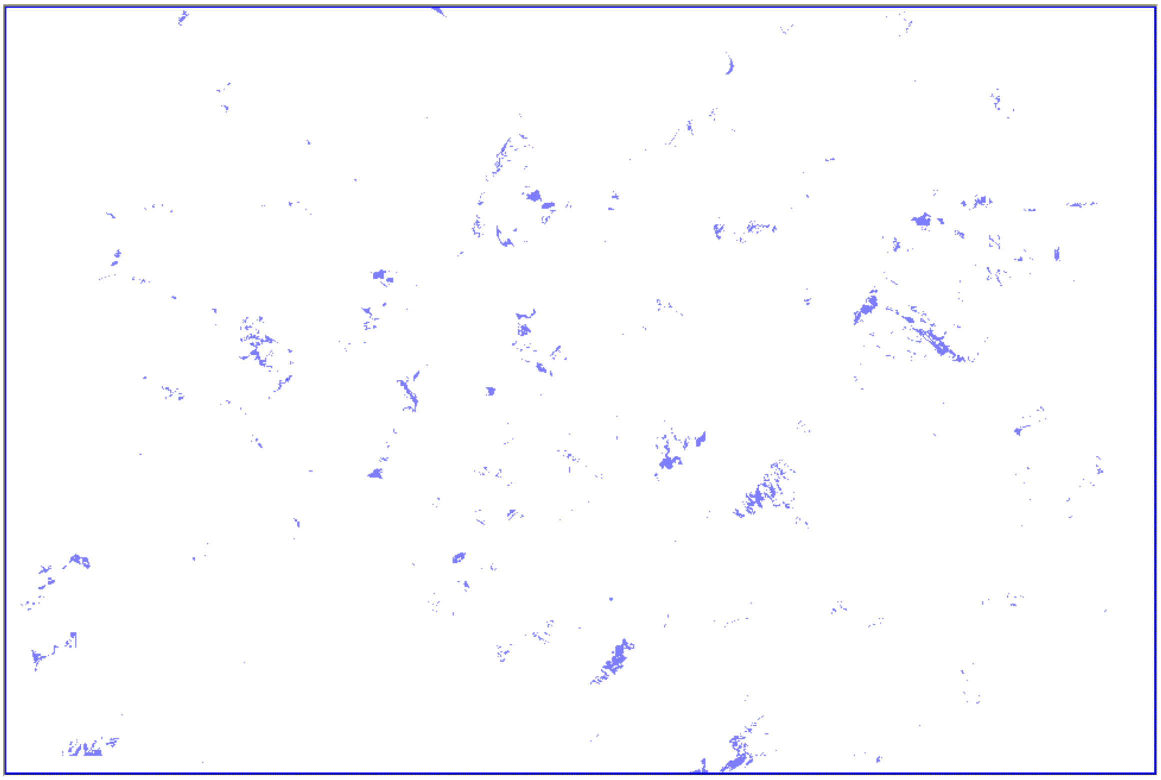

Figure 30: Rural Area C/Ic < 12 dB Interference Map;
40% GSM900 Traffic; 25 GSM channels; 13 BCCH Channels
C/Ic < 12 dB = 93.26 km^2

Plan	GSM900 Traffic	Num Sites	Layer	Channels	C/Ic area (km^2) 2^o E-Tilt	% Area C/Ic < 12 dB
1	60%	153	BCCH	16 / 36	19.54	0.18%
	60%	153	TCH	20 / 36	3.26	0.03%
2	60%	153	BCCH	13 / 25	79.26	0.72%
	60%	153	TCH	12 / 25	180.19	1.64%
3	50%	153	BCCH	13 / 25	73.88	0.67%
	50%	153	TCH	12 / 25	77.76	0.71%
4	45%	153	BCCH	13 / 25	72.99	0.67%
	45%	153	TCH	12 / 25	12.24	0.11%
5	***40%***	***153***	***BCCH***	***13 / 25***	***93.26***	***0.85%***
	40%	153	TCH	12 / 25	7.19	0.07%
6	60%	199	BCCH	13 / 25	95.9	0.87%
	60%	199	TCH	12 / 25	53.88	0.49%

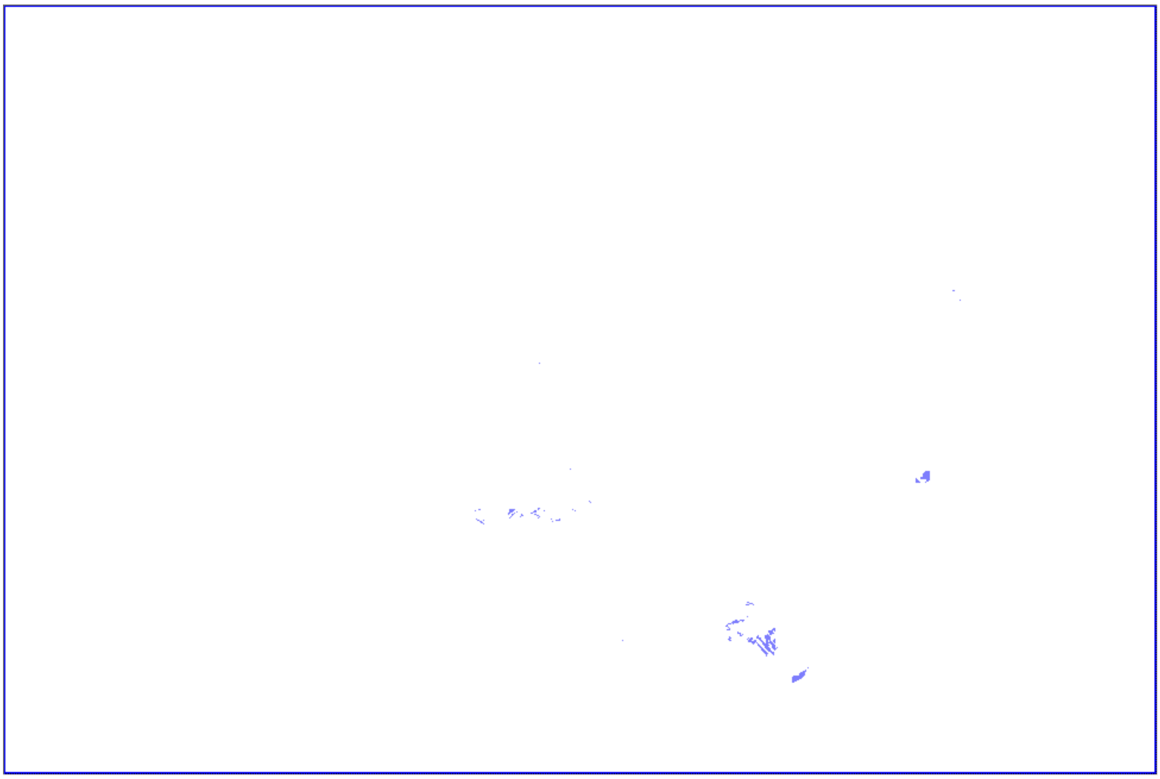

Figure 31: Rural Area C/Ic < 12 dB Interference Map;
40% GSM900 Traffic; 25 GSM channels; 12 TCH Channels
C/Ic < 12 dB = 7.19 km^2

Plan	GSM900 Traffic	Num Sites	Layer	Channels	C/Ic area (km^2) 2^o E-Tilt	% Area C/Ic < 12 dB
1	60%	153	BCCH	16 / 36	19.54	0.18%
	60%	153	TCH	20 / 36	3.26	0.03%
2	60%	153	BCCH	13 / 25	79.26	0.72%
	60%	153	TCH	12 / 25	180.19	1.64%
3	50%	153	BCCH	13 / 25	73.88	0.67%
	50%	153	TCH	12 / 25	77.76	0.71%
4	45%	153	BCCH	13 / 25	72.99	0.67%
	45%	153	TCH	12 / 25	12.24	0.11%
5	40%	153	BCCH	13 / 25	93.26	0.85%
	40%	***153***	***TCH***	***12 / 25***	***7.19***	***0.07%***
6	60%	199	BCCH	13 / 25	95.9	0.87%
	60%	199	TCH	12 / 25	53.88	0.49%

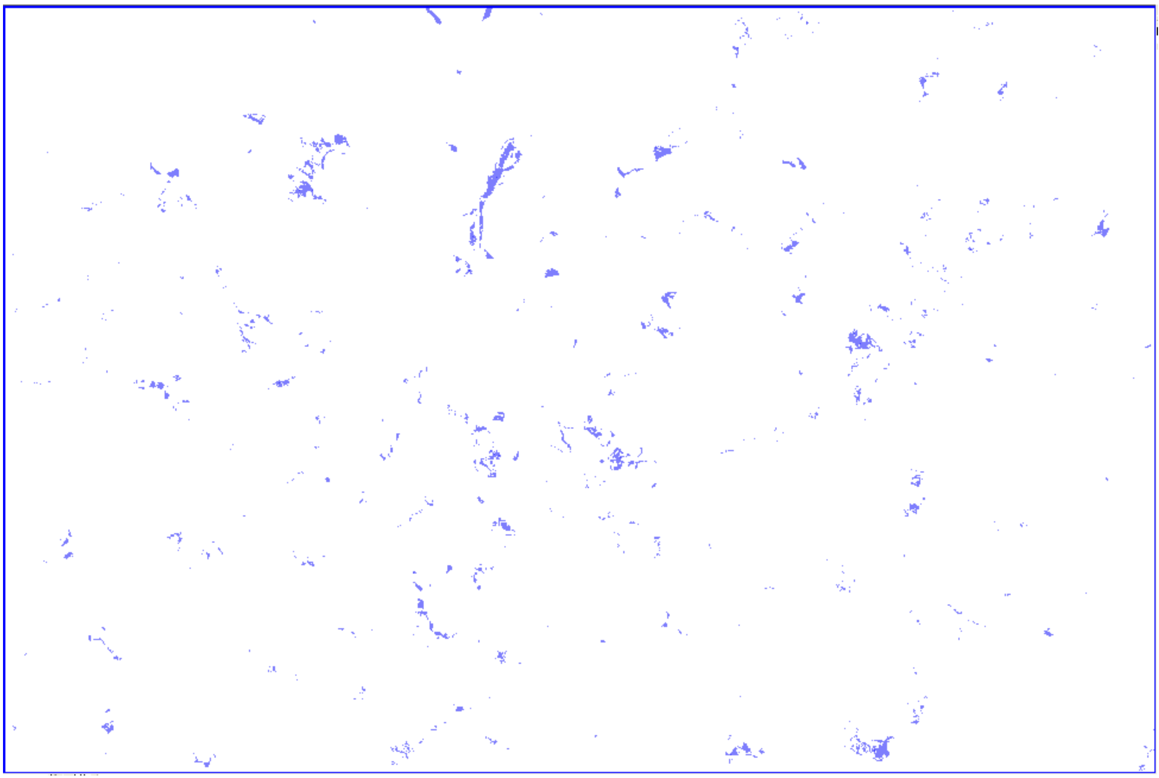

Figure 32: Rural Area C/Ic < 12 dB Interference Map;
60% GSM900 Traffic; 25 GSM channels; 13 BCCH Channels
199 Sites; C/Ic < 12 dB = 95.9 km^2

Plan	GSM900 Traffic	Num Sites	Layer	Channels	C/Ic area (km^2) 2^o E-Tilt	% Area C/Ic < 12 dB
1	60%	153	BCCH	16 / 36	19.54	0.18%
	60%	153	TCH	20 / 36	3.26	0.03%
2	60%	153	BCCH	13 / 25	79.26	0.72%
	60%	153	TCH	12 / 25	180.19	1.64%
3	50%	153	BCCH	13 / 25	73.88	0.67%
	50%	153	TCH	12 / 25	77.76	0.71%
4	45%	153	BCCH	13 / 25	72.99	0.67%
	45%	153	TCH	12 / 25	12.24	0.11%
5	40%	153	BCCH	13 / 25	93.26	0.85%
	40%	153	TCH	12 / 25	7.19	0.07%
6	***60%***	***199***	***BCCH***	***13 / 25***	***95.9***	***0.87%***
	60%	199	TCH	12 / 25	53.88	0.49%

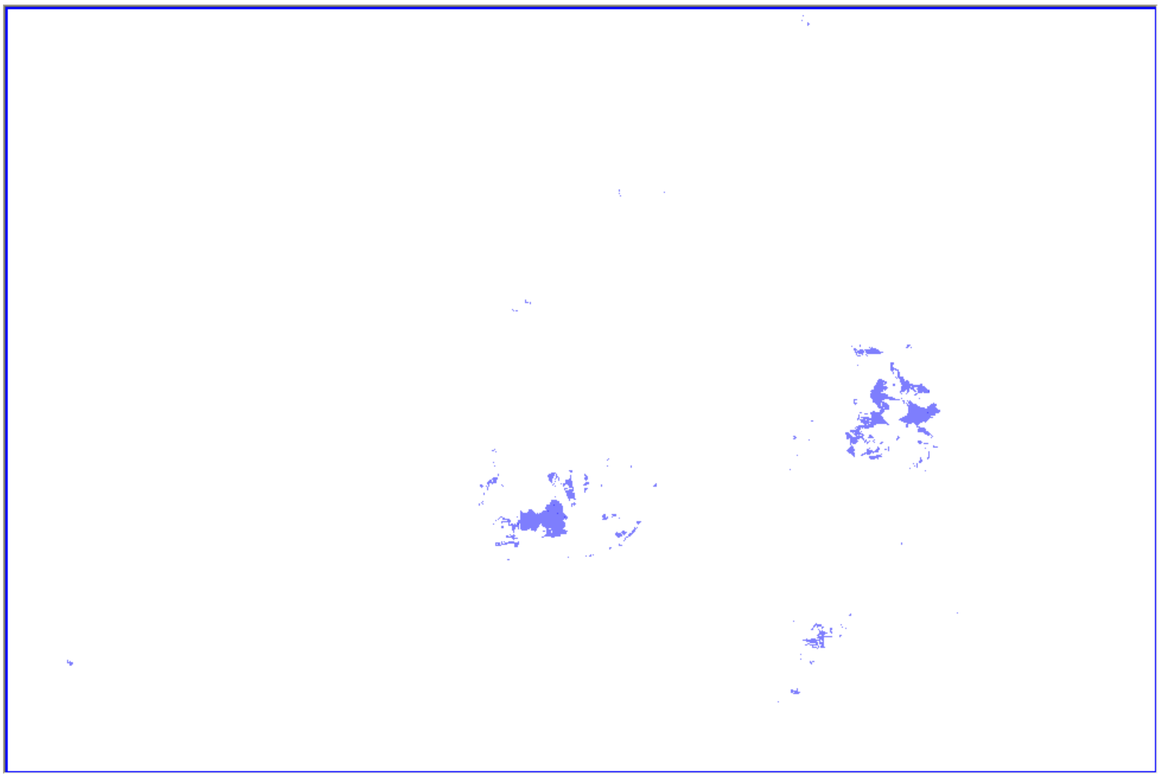

Figure 33: Rural Area C/Ic < 12 dB Interference Map;
60% GSM900 Traffic; 25 GSM channels; 12 TCH Channels
199 Sites; C/Ic < 12 dB = 53.88 km^2

Plan	GSM900 Traffic	Num Sites	Layer	Channels	C/Ic area (km^2) 2^o E-Tilt	% Area C/Ic < 12 dB
1	60%	153	BCCH	16 / 36	19.54	0.18%
	60%	153	TCH	20 / 36	3.26	0.03%
2	60%	153	BCCH	13 / 25	79.26	0.72%
	60%	153	TCH	12 / 25	180.19	1.64%
3	50%	153	BCCH	13 / 25	73.88	0.67%
	50%	153	TCH	12 / 25	77.76	0.71%
4	45%	153	BCCH	13 / 25	72.99	0.67%
	45%	153	TCH	12 / 25	12.24	0.11%
5	40%	153	BCCH	13 / 25	93.26	0.85%
	40%	153	TCH	12 / 25	7.19	0.07%
6	60%	199	BCCH	13 / 25	95.9	0.87%
	60%	***199***	***TCH***	***12 / 25***	***53.88***	***0.49%***

Appendix 2 – Urban Sample Network C/Ic Interference Results

The plots of carrier to interference less than 12 dB are presented hereafter for the BCCH layer and the TCH layer for each traffic and site count plan. This gives a visual illustration of the extent of and distribution of the interference.

The table details the area and percentage area where C/Ic is less than 12 dB for each plan. The highlighted row is associated with the accompanying plot.

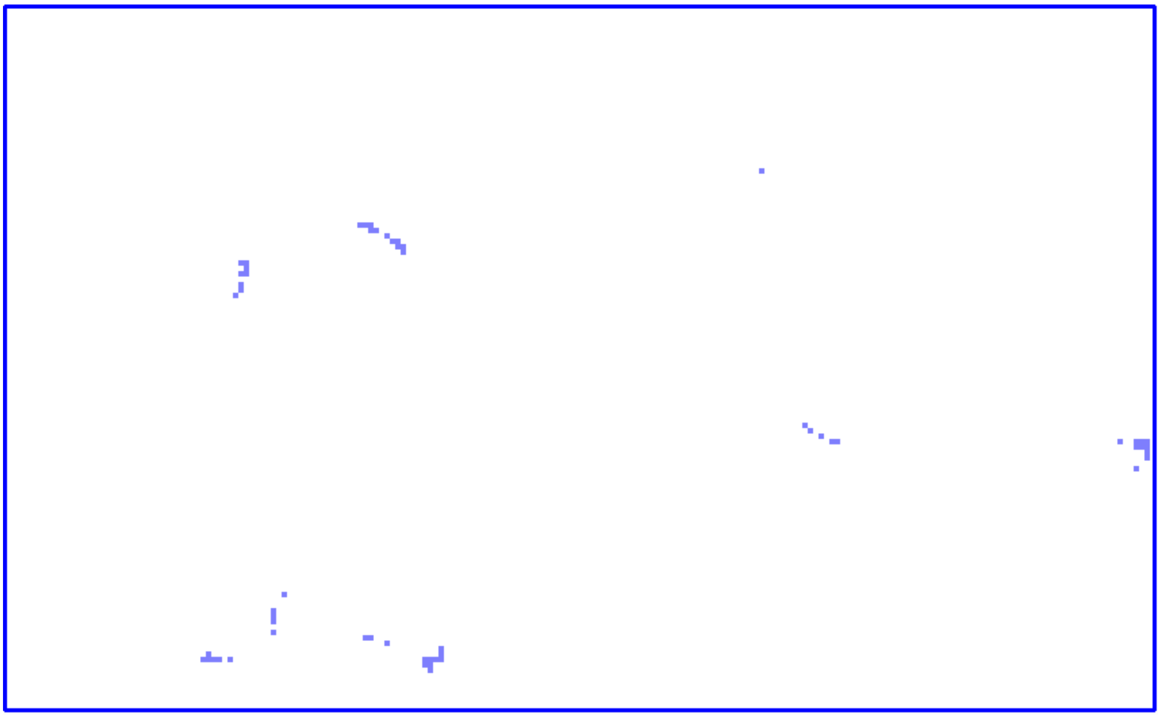

Figure 34: Urban Area C/Ic < 12 dB Interference Map;

60% GSM900 Traffic; 36 GSM channels; 16 BCCH Channels

45 Sites; C/Ic < 12 dB = 0.15 km^2

Plan	GSM900 Traffic	Num Sites	Layer	Channels	C/Ic area (km^2) 2^o E-Tilt	% Area C/Ic < 12 dB
1	***60%***	***45***	***BCCH***	***16 / 36***	***0.15***	***0.21%***
	60%	45	TCH	20 / 36	1.48	2.17%
2	60%	45	BCCH	13 / 25	2.10	3.07%
	60%	45	TCH	12 / 25	9.98	14.58%
3	50%	45	BCCH	13 / 25	2.76	4.04%
	50%	45	TCH	12 / 25	6.44	9.40%
4	45%	45	BCCH	13 / 25	0.78	1.13%
	45%	45	TCH	12 / 25	7.30	10.67%
5	40%	45	BCCH	13 / 25	3.16	4.62%
	40%	45	TCH	12 / 25	5.82	8.49%
6	60%	61	BCCH	13 / 25	3.11	4.54%
	60%	61	TCH	12 / 25	5.70	8.33%

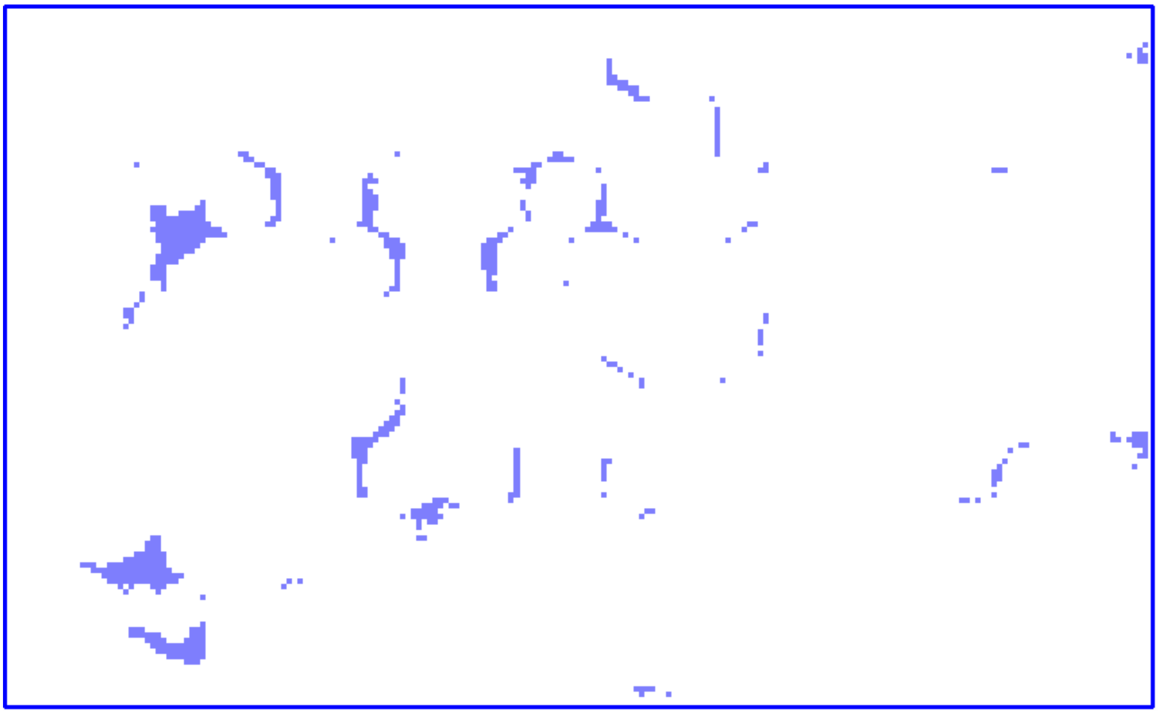

Figure 35: Urban Area C/Ic < 12 dB Interference Map;

60% GSM900 Traffic; 36 GSM channels; 20 TCH Channels

45 Sites; C/Ic < 12 dB = 1.48 km^2

Plan	GSM900 Traffic	Num Sites	Layer	Channels	C/Ic area (km^2) 2^o E-Tilt	% Area C/Ic < 12 dB
1	60%	45	BCCH	16 / 36	0.15	0.21%
	60%	***45***	***TCH***	***20 / 36***	***1.48***	***2.17%***
2	60%	45	BCCH	13 / 25	2.10	3.07%
	60%	45	TCH	12 / 25	9.98	14.58%
3	50%	45	BCCH	13 / 25	2.76	4.04%
	50%	45	TCH	12 / 25	6.44	9.40%
4	45%	45	BCCH	13 / 25	0.78	1.13%
	45%	45	TCH	12 / 25	7.30	10.67%
5	40%	45	BCCH	13 / 25	3.16	4.62%
	40%	45	TCH	12 / 25	5.82	8.49%
6	60%	61	BCCH	13 / 25	3.11	4.54%
	60%	61	TCH	12 / 25	5.70	8.33%

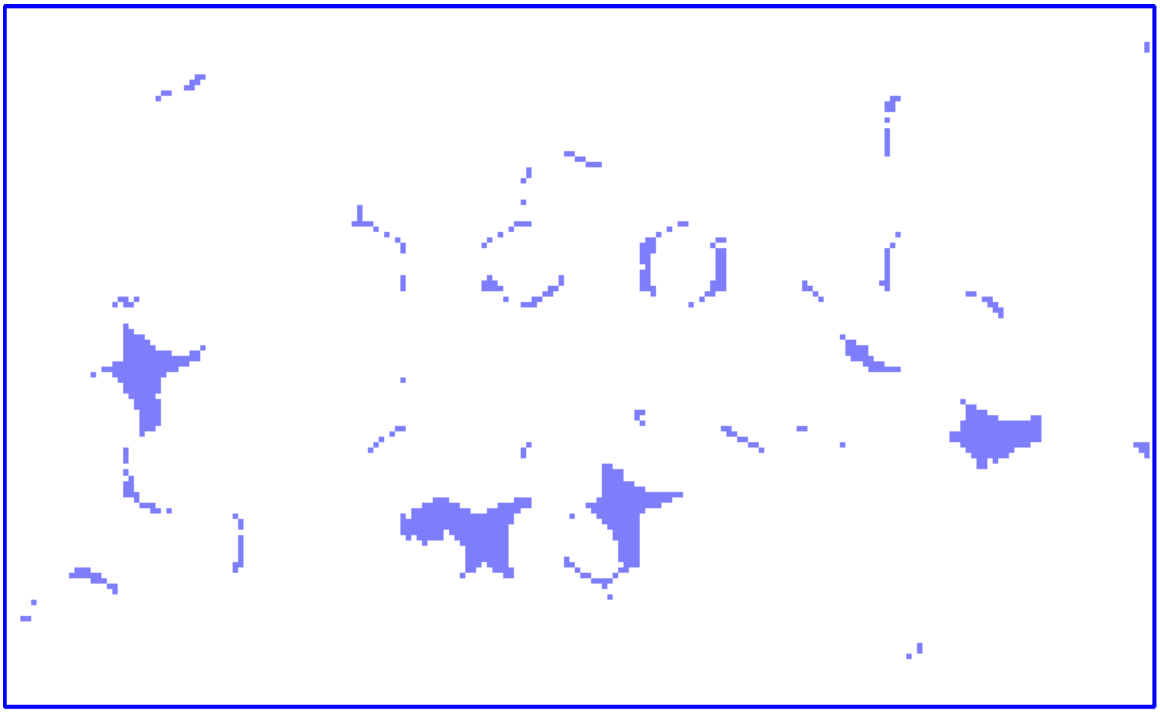

Figure 36: Urban Area C/Ic < 12 dB Interference Map;
60% GSM900 Traffic; 25 GSM channels; 13 BCCH Channels
45 Sites; C/Ic < 12 dB = 2.1 km²

Plan	GSM900 Traffic	Num Sites	Layer	Channels	C/Ic area (km^2) 2° E-Tilt	% Area C/Ic < 12 dB
1	60%	45	BCCH	16 / 36	0.15	0.21%
	60%	45	TCH	20 / 36	1.48	2.17%
2	***60%***	***45***	***BCCH***	***13 / 25***	***2.10***	***3.07%***
	60%	45	TCH	12 / 25	9.98	14.58%
3	50%	45	BCCH	13 / 25	2.76	4.04%
	50%	45	TCH	12 / 25	6.44	9.40%
4	45%	45	BCCH	13 / 25	0.78	1.13%
	45%	45	TCH	12 / 25	7.30	10.67%
5	40%	45	BCCH	13 / 25	3.16	4.62%
	40%	45	TCH	12 / 25	5.82	8.49%
6	60%	61	BCCH	13 / 25	3.11	4.54%
	60%	61	TCH	12 / 25	5.70	8.33%

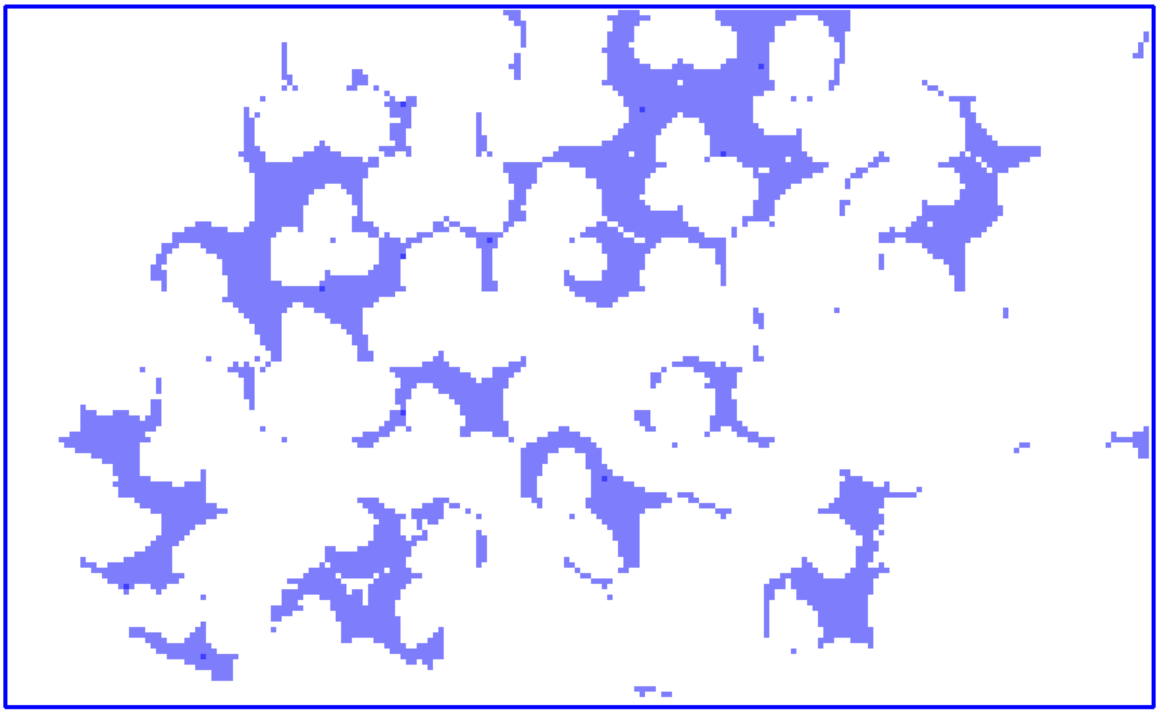

Figure 37: Urban Area C/Ic < 12 dB Interference Map;

60% GSM900 Traffic; 25 GSM channels; 12 TCH Channels

45 Sites; C/Ic < 12 dB = 9.98 km^2

Plan	GSM900 Traffic	Num Sites	Layer	Channels	C/Ic area (km^2) 2^o E-Tilt	% Area C/Ic < 12 dB
1	60%	45	BCCH	16 / 36	0.15	0.21%
	60%	45	TCH	20 / 36	1.48	2.17%
2	60%	45	BCCH	13 / 25	2.10	3.07%
	60%	***45***	***TCH***	***12 / 25***	***9.98***	***14.58%***
3	50%	45	BCCH	13 / 25	2.76	4.04%
	50%	45	TCH	12 / 25	6.44	9.40%
4	45%	45	BCCH	13 / 25	0.78	1.13%
	45%	45	TCH	12 / 25	7.30	10.67%
5	40%	45	BCCH	13 / 25	3.16	4.62%
	40%	45	TCH	12 / 25	5.82	8.49%
6	60%	61	BCCH	13 / 25	3.11	4.54%
	60%	61	TCH	12 / 25	5.70	8.33%

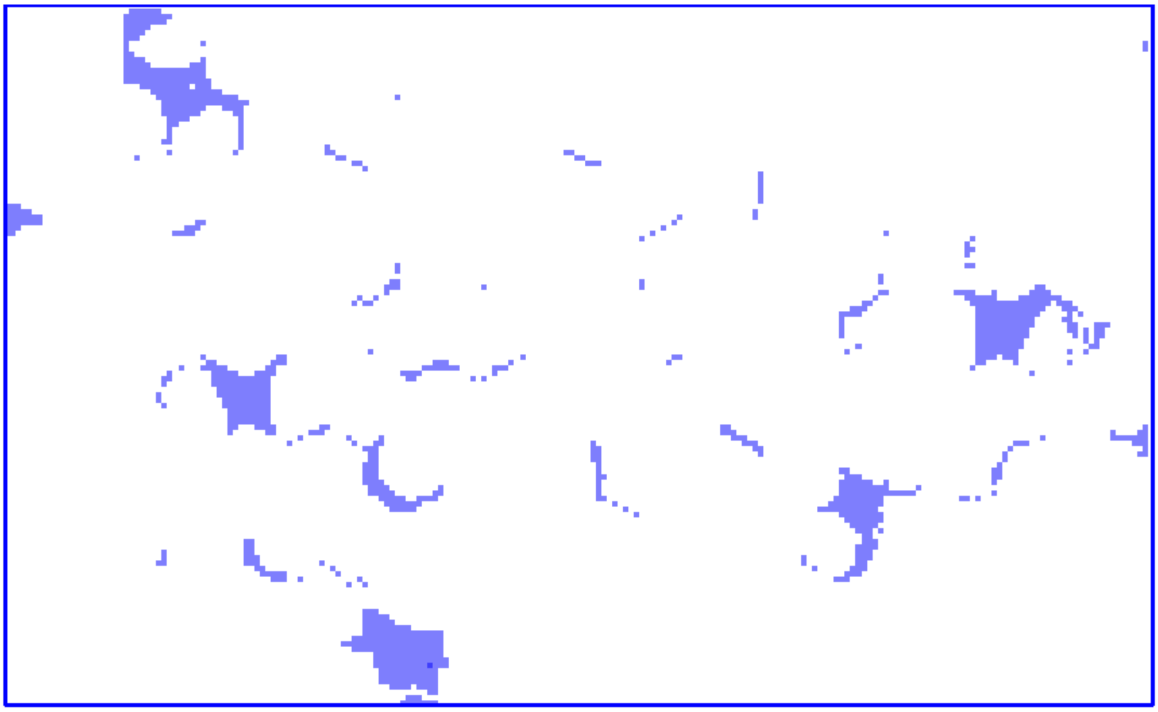

Figure 38: Urban Area C/Ic < 12 dB Interference Map;
50% GSM900 Traffic; 25 GSM channels; 13 BCCH Channels
45 Sites; C/Ic < 12 dB = 2.76 km²

Plan	GSM900 Traffic	Num Sites	Layer	Channels	C/Ic area (km^2) 2^o E-Tilt	% Area C/Ic < 12 dB
1	60%	45	BCCH	16 / 36	0.15	0.21%
	60%	45	TCH	20 / 36	1.48	2.17%
2	60%	45	BCCH	13 / 25	2.10	3.07%
	60%	45	TCH	12 / 25	9.98	14.58%
3	***50%***	***45***	***BCCH***	***13 / 25***	***2.76***	***4.04%***
	50%	45	TCH	12 / 25	6.44	9.40%
4	45%	45	BCCH	13 / 25	0.78	1.13%
	45%	45	TCH	12 / 25	7.30	10.67%
5	40%	45	BCCH	13 / 25	3.16	4.62%
	40%	45	TCH	12 / 25	5.82	8.49%
6	60%	61	BCCH	13 / 25	3.11	4.54%
	60%	61	TCH	12 / 25	5.70	8.33%

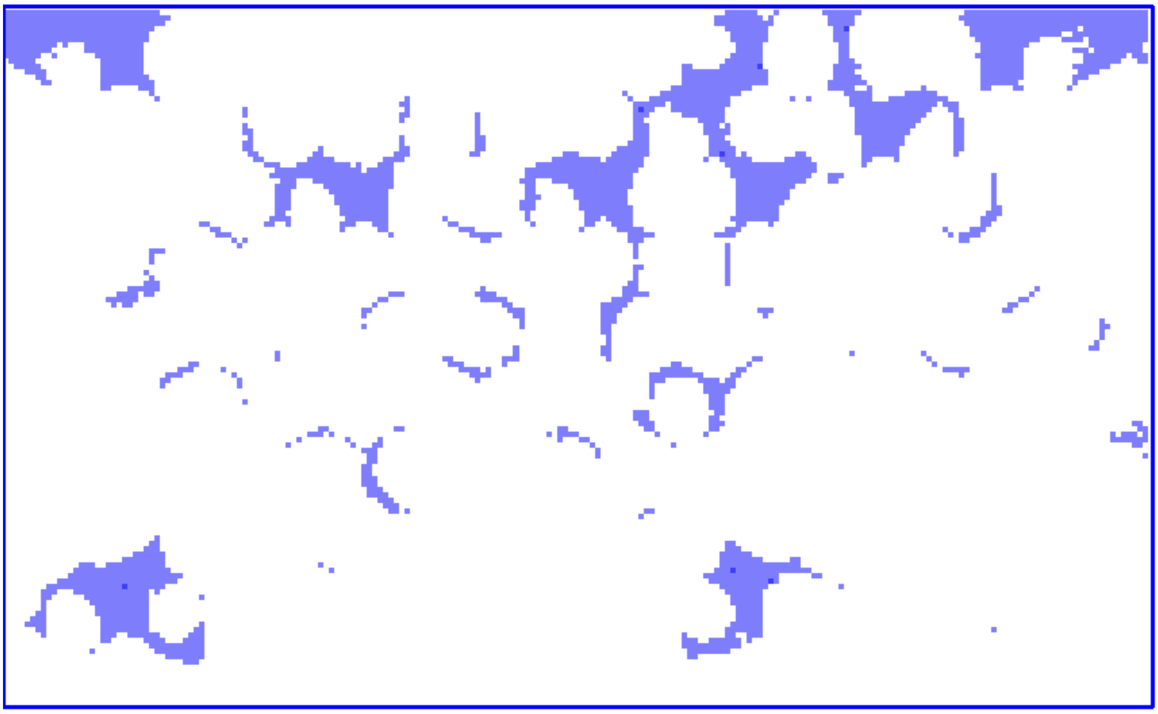

Figure 39: Urban Area C/Ic < 12 dB Interference Map;
50% GSM900 Traffic; 25 GSM channels; 12 TCH Channels
45 Sites; C/Ic < 12 dB = 6.44 km^2

Plan	GSM900 Traffic	Num Sites	Layer	Channels	C/Ic area (km^2) 2^o E-Tilt	% Area C/Ic < 12 dB
1	60%	45	BCCH	16 / 36	0.15	0.21%
	60%	45	TCH	20 / 36	1.48	2.17%
2	60%	45	BCCH	13 / 25	2.10	3.07%
	60%	45	TCH	12 / 25	9.98	14.58%
3	50%	45	BCCH	13 / 25	2.76	4.04%
	50%	***45***	***TCH***	***12 / 25***	***6.44***	***9.40%***
4	45%	45	BCCH	13 / 25	0.78	1.13%
	45%	45	TCH	12 / 25	7.30	10.67%
5	40%	45	BCCH	13 / 25	3.16	4.62%
	40%	45	TCH	12 / 25	5.82	8.49%
6	60%	61	BCCH	13 / 25	3.11	4.54%
	60%	61	TCH	12 / 25	5.70	8.33%

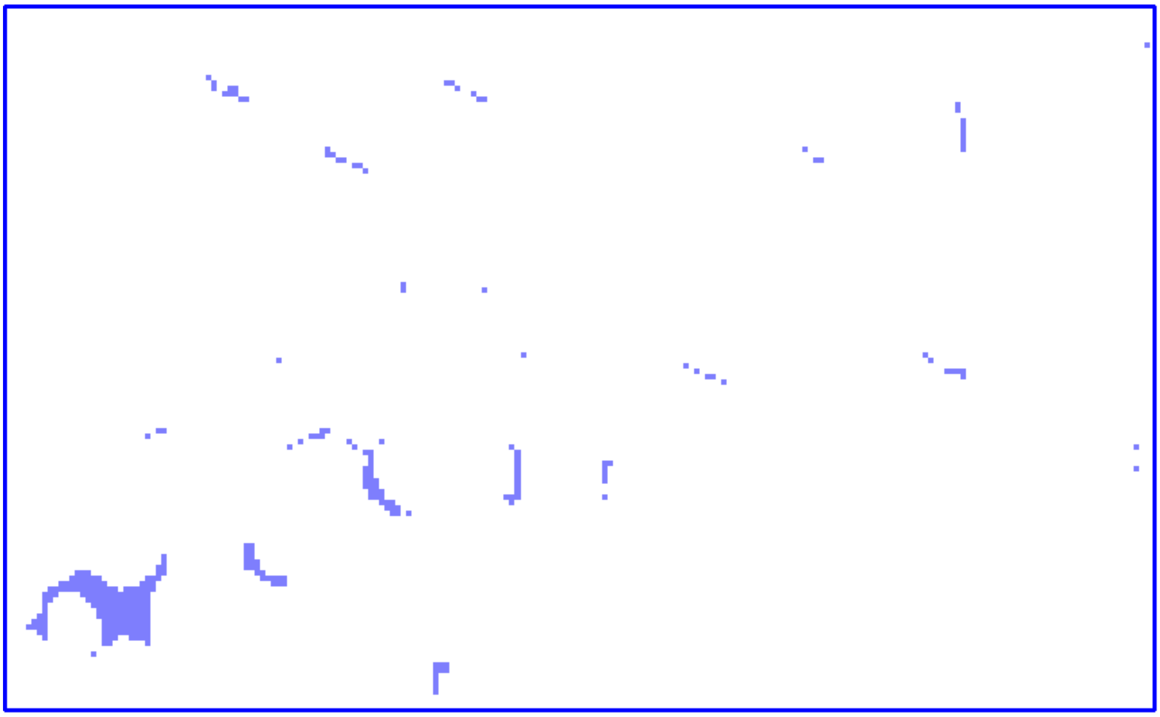

Figure 40: Urban Area C/Ic < 12 dB Interference Map;
45% GSM900 Traffic; 25 GSM channels; 13 BCCH Channels
45 Sites; C/Ic < 12 dB = 0.78 km^2

Plan	GSM900 Traffic	Num Sites	Layer	Channels	C/Ic area (km^2) 2^o E-Tilt	% Area C/Ic < 12 dB
1	60%	45	BCCH	16 / 36	0.15	0.21%
	60%	45	TCH	20 / 36	1.48	2.17%
2	60%	45	BCCH	13 / 25	2.10	3.07%
	60%	45	TCH	12 / 25	9.98	14.58%
3	50%	45	BCCH	13 / 25	2.76	4.04%
	50%	45	TCH	12 / 25	6.44	9.40%
4	***45%***	***45***	***BCCH***	***13 / 25***	***0.78***	***1.13%***
	45%	45	TCH	12 / 25	7.30	10.67%
5	40%	45	BCCH	13 / 25	3.16	4.62%
	40%	45	TCH	12 / 25	5.82	8.49%
6	60%	61	BCCH	13 / 25	3.11	4.54%
	60%	61	TCH	12 / 25	5.70	8.33%

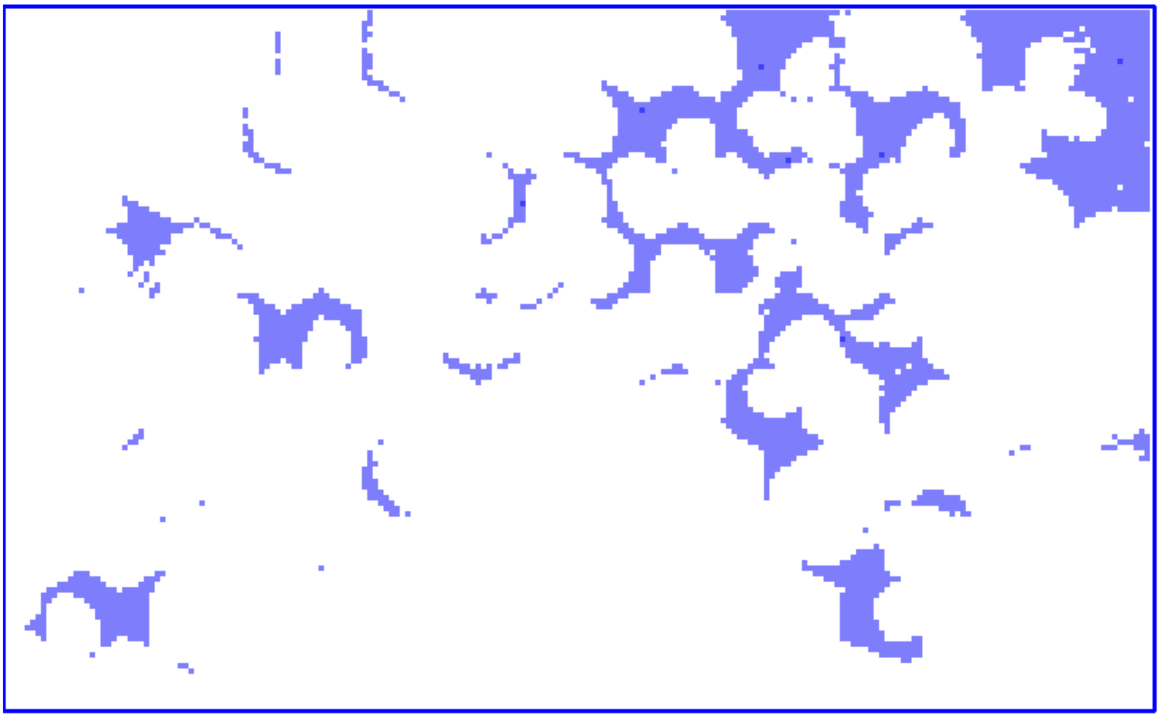

Figure 41: Urban Area C/Ic < 12 dB Interference Map;
45% GSM900 Traffic; 25 GSM channels; 12 TCH Channels
45 Sites; C/Ic < 12 dB = 7.3 km^2

Plan	GSM900 Traffic	Num Sites	Layer	Channels	C/Ic area (km^2) 2^o E-Tilt	% Area C/Ic < 12 dB
1	60%	45	BCCH	16 / 36	0.15	0.21%
	60%	45	TCH	20 / 36	1.48	2.17%
2	60%	45	BCCH	13 / 25	2.10	3.07%
	60%	45	TCH	12 / 25	9.98	14.58%
3	50%	45	BCCH	13 / 25	2.76	4.04%
	50%	45	TCH	12 / 25	6.44	9.40%
4	45%	45	BCCH	13 / 25	0.78	1.13%
	45%	***45***	***TCH***	***12 / 25***	***7.30***	***10.67%***
5	40%	45	BCCH	13 / 25	3.16	4.62%
	40%	45	TCH	12 / 25	5.82	8.49%
6	60%	61	BCCH	13 / 25	3.11	4.54%
	60%	61	TCH	12 / 25	5.70	8.33%

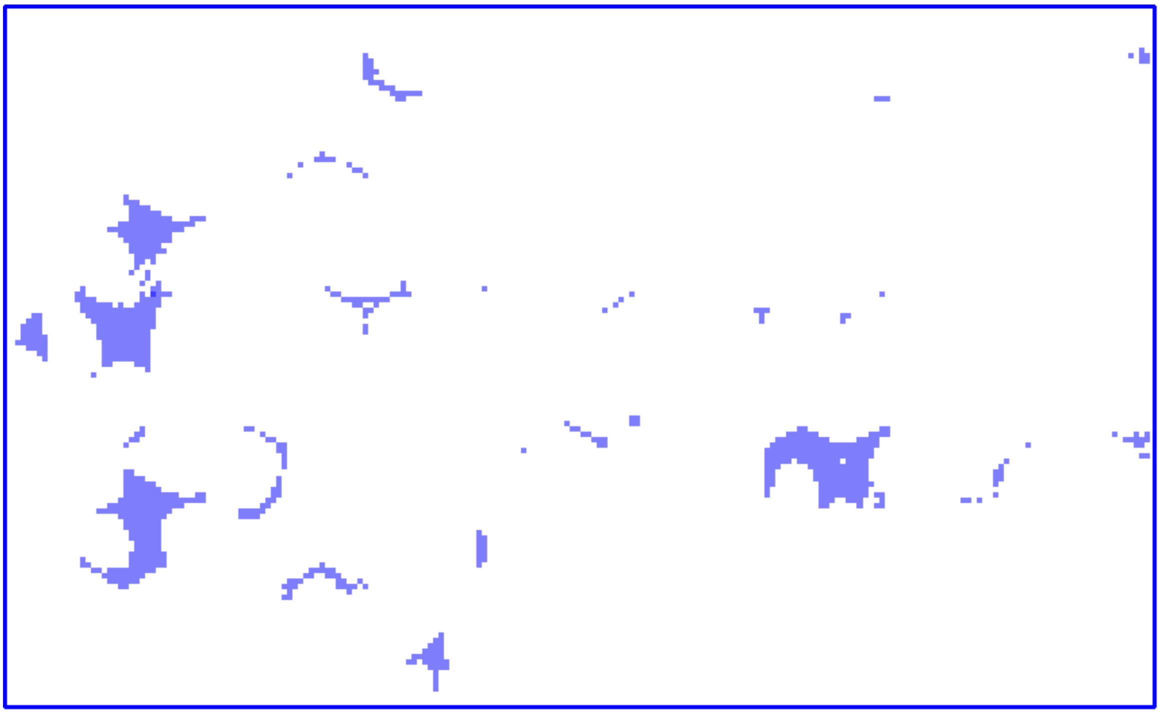

Figure 42: Urban Area C/Ic < 12 dB Interference Map;
40% GSM900 Traffic; 25 GSM channels; 13 BCCH Channels
45 Sites; C/Ic < 12 dB = 3.16 km^2

Plan	GSM900 Traffic	Num Sites	Layer	Channels	C/Ic area (km^2) 2° E-Tilt	% Area C/Ic < 12 dB
1	60%	45	BCCH	16 / 36	0.15	0.21%
	60%	45	TCH	20 / 36	1.48	2.17%
2	60%	45	BCCH	13 / 25	2.10	3.07%
	60%	45	TCH	12 / 25	9.98	14.58%
3	50%	45	BCCH	13 / 25	2.76	4.04%
	50%	45	TCH	12 / 25	6.44	9.40%
4	45%	45	BCCH	13 / 25	0.78	1.13%
	45%	45	TCH	12 / 25	7.30	10.67%
5	***40%***	***45***	***BCCH***	***13 / 25***	***3.16***	***4.62%***
	40%	45	TCH	12 / 25	5.82	8.49%
6	60%	61	BCCH	13 / 25	3.11	4.54%
	60%	61	TCH	12 / 25	5.70	8.33%

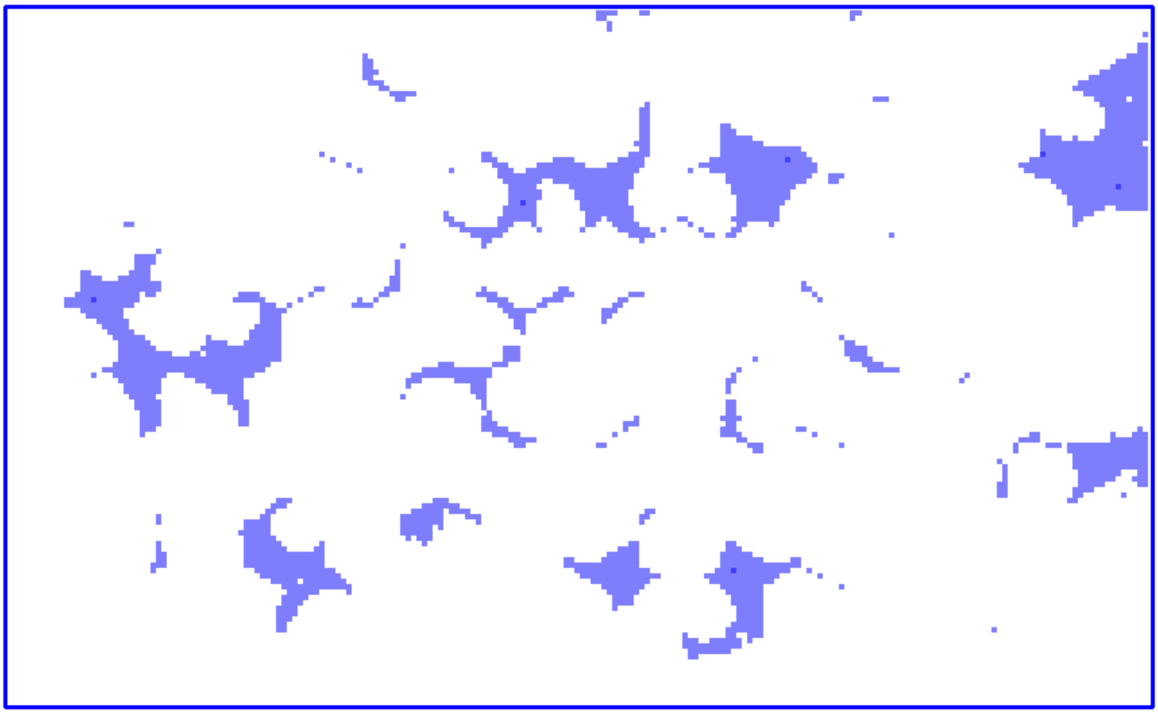

Figure 43: Urban Area C/Ic < 12 dB Interference Map;
40% GSM900 Traffic; 25 GSM channels; 12 TCH Channels
45 Sites; C/Ic < 12 dB = 5.82 km^2

Plan	GSM900 Traffic	Num Sites	Layer	Channels	C/Ic area (km^2) 2^o E-Tilt	% Area C/Ic < 12 dB
1	60%	45	BCCH	16 / 36	0.15	0.21%
	60%	45	TCH	20 / 36	1.48	2.17%
2	60%	45	BCCH	13 / 25	2.10	3.07%
	60%	45	TCH	12 / 25	9.98	14.58%
3	50%	45	BCCH	13 / 25	2.76	4.04%
	50%	45	TCH	12 / 25	6.44	9.40%
4	45%	45	BCCH	13 / 25	0.78	1.13%
	45%	45	TCH	12 / 25	7.30	10.67%
5	40%	45	BCCH	13 / 25	3.16	4.62%
	40%	***45***	***TCH***	***12 / 25***	***5.82***	***8.49%***
6	60%	61	BCCH	13 / 25	3.11	4.54%
	60%	61	TCH	12 / 25	5.70	8.33%

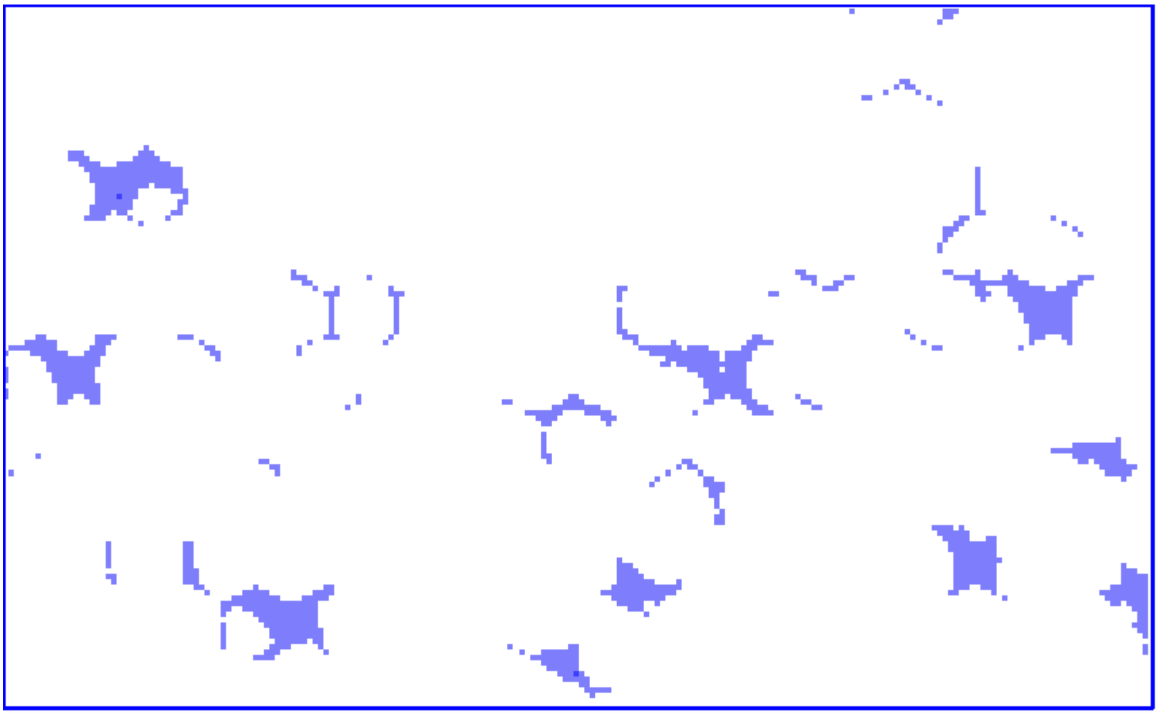

Figure 44: Urban Area C/Ic < 12 dB Interference Map;
60% GSM900 Traffic; 25 GSM channels; 13 BCCH Channels
61 Sites; C/Ic < 12 dB = 3.11 km^2

Plan	GSM900 Traffic	Num Sites	Layer	Channels	C/Ic area (km^2) 2° E-Tilt	% Area C/Ic < 12 dB
1	60%	45	BCCH	16 / 36	0.15	0.21%
	60%	45	TCH	20 / 36	1.48	2.17%
2	60%	45	BCCH	13 / 25	2.10	3.07%
	60%	45	TCH	12 / 25	9.98	14.58%
3	50%	45	BCCH	13 / 25	2.76	4.04%
	50%	45	TCH	12 / 25	6.44	9.40%
4	45%	45	BCCH	13 / 25	0.78	1.13%
	45%	45	TCH	12 / 25	7.30	10.67%
5	40%	45	BCCH	13 / 25	3.16	4.62%
	40%	45	TCH	12 / 25	5.82	8.49%
6	***60%***	***61***	***BCCH***	***13 / 25***	***3.11***	***4.54%***
	60%	61	TCH	12 / 25	5.70	8.33%

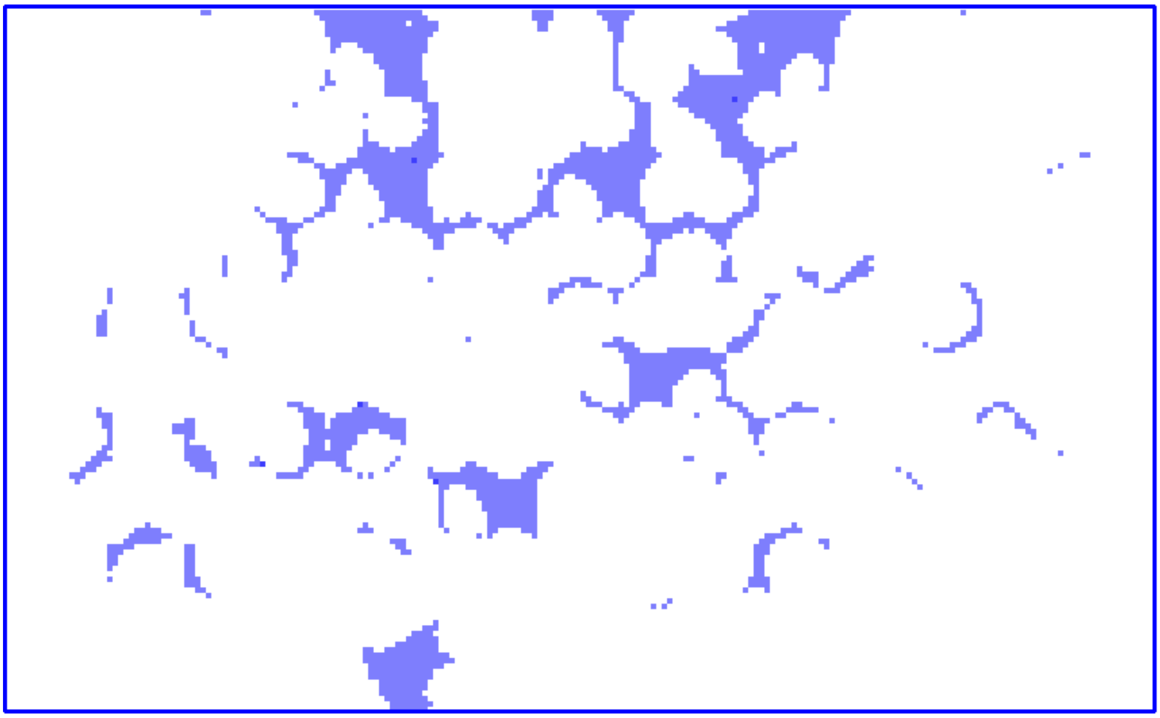

Figure 45: Urban Area C/Ic < 12 dB Interference Map;
60% GSM900 Traffic; 25 GSM channels; 12 TCH Channels
61 Sites; C/Ic < 12 dB = 5.7 km²

Plan	GSM900 Traffic	Num Sites	Layer	Channels	C/Ic area (km^2) 2^o E-Tilt	% Area C/Ic < 12 dB
1	60%	45	BCCH	16 / 36	0.15	0.21%
	60%	45	TCH	20 / 36	1.48	2.17%
2	60%	45	BCCH	13 / 25	2.10	3.07%
	60%	45	TCH	12 / 25	9.98	14.58%
3	50%	45	BCCH	13 / 25	2.76	4.04%
	50%	45	TCH	12 / 25	6.44	9.40%
4	45%	45	BCCH	13 / 25	0.78	1.13%
	45%	45	TCH	12 / 25	7.30	10.67%
5	40%	45	BCCH	13 / 25	3.16	4.62%
	40%	45	TCH	12 / 25	5.82	8.49%
6	60%	61	BCCH	13 / 25	3.11	4.54%
	60%	***61***	***TCH***	***12 / 25***	***5.70***	***8.33%***