The Challenges of Obtaining an Accurate Model of your Network for Input to AFP Tools

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1 INTRODUCTION

Advanced Automatic Frequency Planning Tools (AFPs) have been around for the last six-(6) years. Their use has proved to significantly improve the network quality, when compared to the more conventional methods of the time [1]. Now these tools are no longer considered new, but are widely used to determine the best possible frequency allocation it can find in the allocated time, based on the inputs provided to it. Although the time that these tools take to reach the best possible solution, still leaves room for improvement, it is the improvement of the input data to these tools that will prove to effect the quality of the frequency plan that they produce most. The purpose of this paper is to investigate ways to most accurately model a GSM network to determine the best frequency allocation. The first thing that will be considered is to determine what do we need to model. This is often considered as known and self-evident, but it might prove worth while to reconsider the fundamental purpose and philosophy of frequency planning. This will be the topic of Section 2. Section 3 considers possible ways to represent the network most accurately. Ideas on how to represent interference and how to determine different penalties are considered in this section. Other important modelling issues such as the size and selection of a allocated frequency set for the control channel, how to avoid inter-modulation products and modelling limitations of current AFP tools are discussed in section 4. To generate an accurate matrix or interference list is most probably the most important task in frequency planning, but also the one that provides the most challenges and problems. In Section 5 we will be investigating the different data sources for the interference matrix with their limitations, problems and advantages. In Section 6 a comparison is drawn between a plan based on measurements are evaluated.

2 WHAT DO WE WANT TO MODEL?

The primary aim of the frequency assignment process is to assign frequencies in such a way that it will maximise the network quality parameters, such as number of dropped calls, call set-up failures and voice quality. The frequency planning process has as its input a representation of the network as it stands and can only change the carriers assigned to each cell. Depending on the operator preferences there might be a number of other desired

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- MTN SA. Mobile Telephone Networks, South Africa outcomes that must be modelled, planning for a BCCH block is a typical example. To achieve the above goals the following need to be modelled as accurately as possible:

1) The effect on the network quality if two carriers are assigned on the same frequency. This is normally modelled as co-channel interference.

2) The effect on the network if two carriers are assigned on adjacent frequencies. This is normally modelled as adjacent-channel interference.

3) The effect on the network quality if a certain combination of frequencies are assigned to a particular cell. This becomes important is when, for example, the cell planner wishes to maximise on the advantages of frequency diversity in a frequency hopping network.

4) The effect on the network if the same set or combination of frequencies are used on two cells. This becomes particularly important when the planner wishes to maximise on interference diversity in a frequency-hopping network.

5) Limitation set by the hardware in the network, e.g. separation requirements of the combiners.

6) Requirements to avoid inter-modulation products on the same combiner-duplexer, on the same sector or on the same site. When sites are shared with operators other systems this can become particularly important.

7) Avoidance of particular frequencies in particular areas due to cross border agreements.

8) For future planning and optimisation purposes, many operators often prefer the use of a fixed BCCH-block.

9) To ease optimisation some operators prefer to use frequency groups.

Because of the limited spectrum available these requirements are often in conflict with one another. One of the major challenges of frequency planning is to rank or model these requirements accurately as to obtain the most desirable outcome. This is the subject of Section 3.

3 HOW DOES ONE MODEL THE NETWORK MOST ACCURATELY?

3.1 How should one model the Interference Matrix?

Many ways of presenting the effect that two carriers assigned to the same frequency would have on the network have been used in the passed. The two most often used presentations of the interference are the interfered **area** and the interfered **traffic**, with the latter being the preferred method. At the foundation of both methods lies the required Carrier to Interference Ratio (**C/I**) to have satisfactory communications. The simplest implementation of this method would be to merely determine the total area where the C/I was calculated or measured to be below the allowable level (e.g. 9dB for co-channel interference and –9dB for adjacent channel interference). The method that is more often followed is to scale it with the **probability** that the required level was not achieved. The probability distribution used should depend on the variability of the signal level due to multipath fading in the particular area and the accuracy of the propagation prediction tool. An example of such a curve is shown in Figure 1.

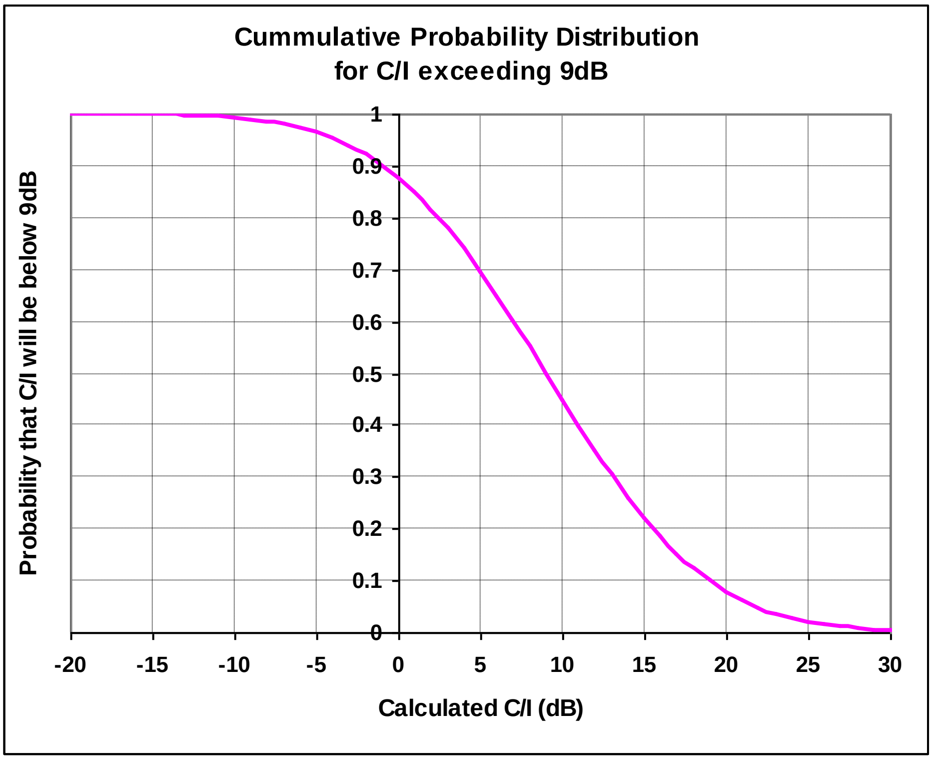

Figure 1: "C/I weights curve"

It is not in the scope of this paper to consider the entire theory of how to derive these probability curves, hence we rather proceed to discuss a method less often used to model the effect that interference will have on network quality. The most accurate representation of the effect of interference is the resulting Frame Erasure Rate (FER), Figure 2 shows the FER against the Channel to Interference ratio (C/I) curve. This will give the most direct reflection of the effect that interference would have on the network quality, as the FER influences not only the voice quality, but also the drop call rate and the call set-up failures. Two curves are shown on the graph, the one is for a normal non-hopping channel, this graph would be used to model the interference for the BCCH channels in a synthesized frequency hopping network. The second curve represents the effect of frequency diversity on a channel that hops over eight (8) frequencies*. From these two curves the need to have separate interference lists for BCCH and non-BCCH carriers arises.

* For system that has antenna diversity employed these curves will differ.

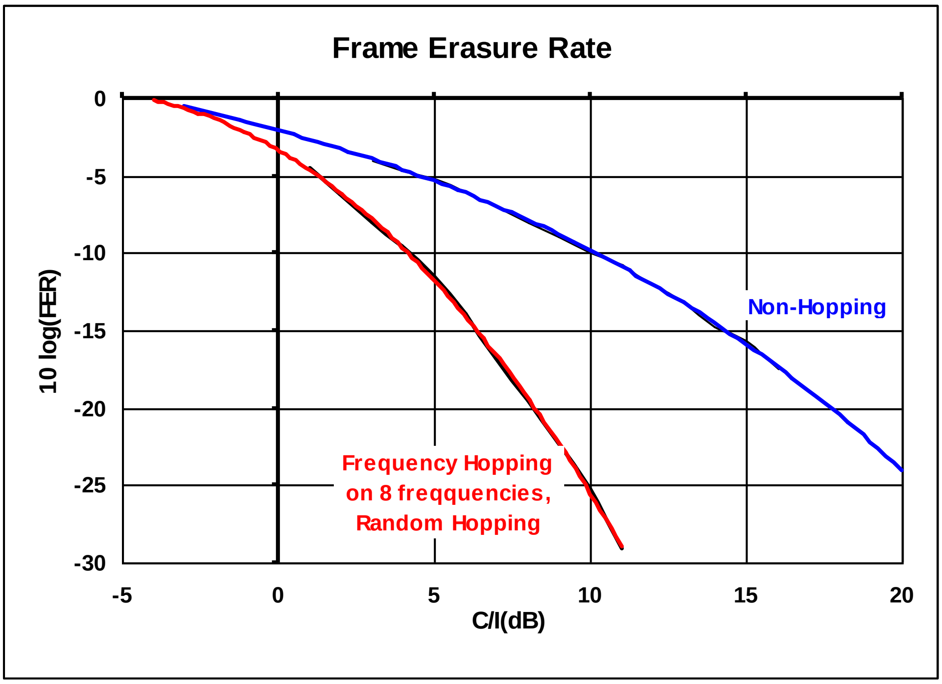

Figure 2: Frame Erasure Rate versus Carrier to Interference Ratio.

3.2 How to decide on penalties?

The purpose of penalties is to impose certain rules that you would like the AFP to plan in. An important 'philosophical' note to make here is that the penalties should be kept to a bare minimum, and penalties should only be assigned if it is 'required by law' or it will improve the quality of the network, either directly or by easing and improving the optimisation process. By taking this 'bare necessity' approach one can ensure that the interference, or average FER in the network is minimized and not kept high at the cost of some unnecessarily rule. The value of these penalties must reflect their importance or effect on quality in relation to the potential interference in the matrix. To really understand the effect that a particular penalty would have on the AFP and the frequency assignment process, one needs to understand the distribution of interference in the network. Figure 3 shows the distribution of the interference or cost in all the server to interference relations in the network as was measured and calculated for the measurement based frequency plan described in Section 6. Table 1 presents the interference values or, which are exceeded by which percentage of relations that exceeds the particular level. Note that this include server to neighbour relations, but excludes self-interference. Using Figure 3 and Table 1 as point of departure we proceed to determine a number of penalties for a particular frequency plan:

- ❖ To effect an all-overriding rule or limitation, a penalty bigger than 4420 must be used.
  - ➢ This type of penalty would be used to ensure that all of the frequencies assigned to the carriers are within the spectrum allocated to the operator.
  - ➢ If self-interference does not form part of interference matrix, this can also be used to ensure that the same frequency is not assigned twice in the same sector.

- Penalties that would take effect after 50% of the interference was eliminated can be used:
  - to implement the rules imposed by equipment limitations, such as the separation requirements of combiners on carriers in the same sector.
  - Cross border frequency co-operation would also be affected using a penalty of about 500.
- Penalties that could be considered as important as avoiding 70% of the interference would include:
  - If the AFP tool can detect assignments that would cause inter-modulation products (a complete discussion on this will follow in Section 3.5), this penalty would be used to avoid such an assignment as it can potentially have a negative effect on the quality of the network.
- Most of the penalties on the optimisation team's wish-list would be implemented using a penalty, such that it is not considered more important than 80% of the potential interference in the network, but still has a very good change of being implemented in the frequency plan:
  - The implementation of a BCCH block or a specific frequency set allocated to the control channel has many advantages for optimisation purposes. It limits the number of frequencies that have to be measured on when collecting data for a "measured" interference list, or when re-evaluating the neighbour list of a cell. When the size and selection of the BCCH list is considered carefully this limitation would not result in much additional interference added in the network. (This will be discussed further in Section 3.3.)
- Penalties to reflect server to interference relations, that is not included by the interference matrix, possibly due shortcomings of the method used to calculate the interference matrix, can be added using the low penalty of about twenty (20).
  - The avoidance of interference from neighbours and other interferers not identified in the interference matrix are best implemented on this level. It is however important to note that in some AFP tools these penalties are added to the already existing server-interference relation, and including such an 'exception' penalty might skew the interference matrix in that case.
- Additional penalties, which are specifically implemented to skew the interference matrix, because the importance of some relations might not be sufficiently reflected in the interference matrix/list, can be implemented with the very low penalty of eight (8).

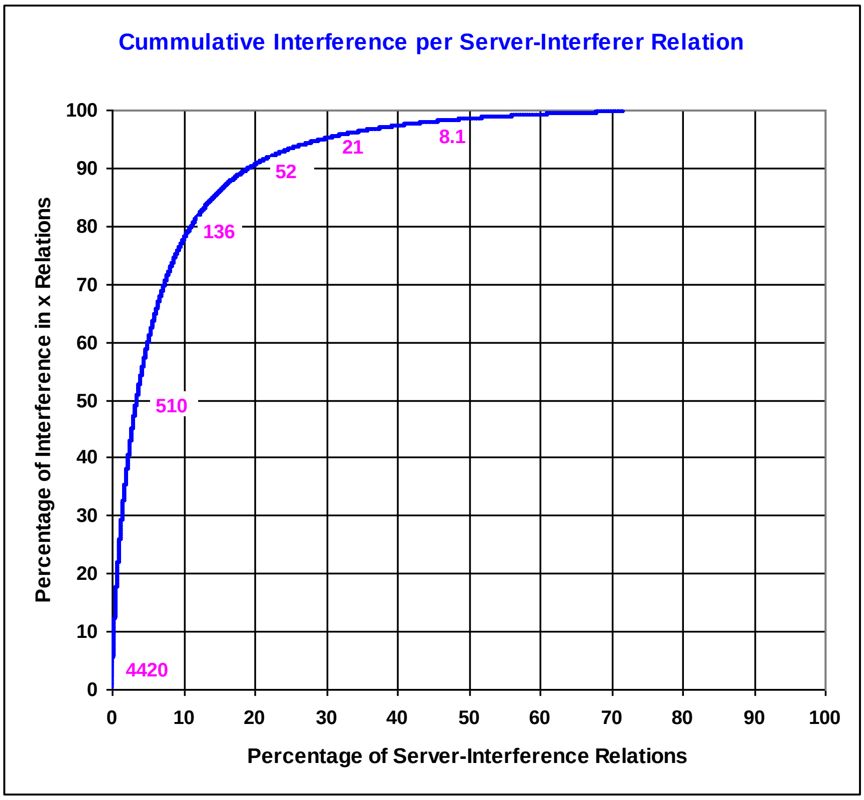

Figure 3:
Percentage of interference introduced by Percentage of Server-Interferer relations

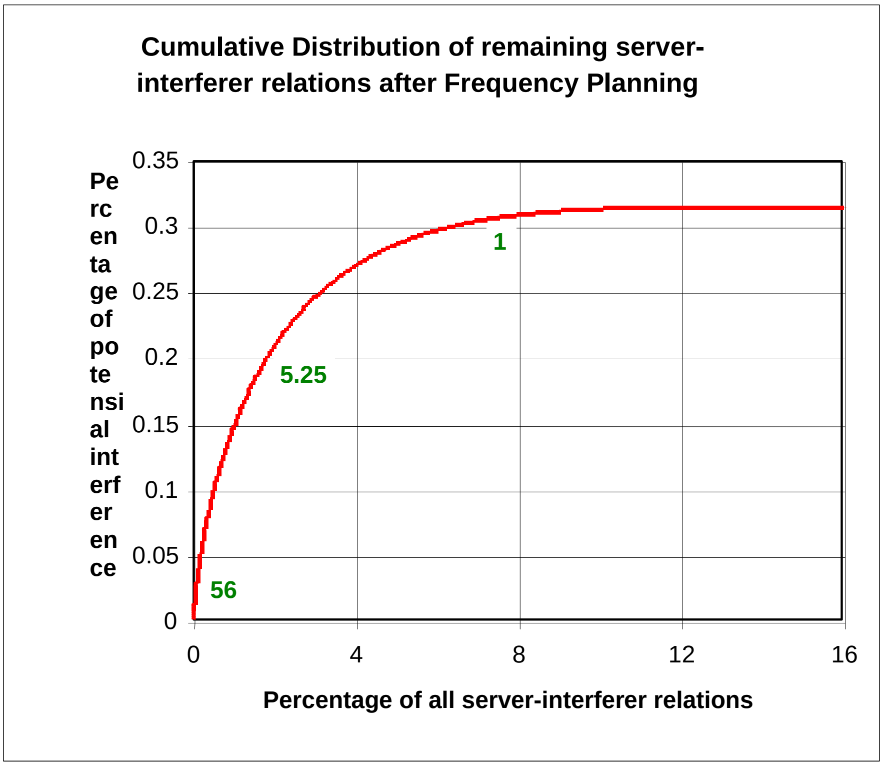

Figure 4: Distribution of remaining server-interferer relations after a Frequency Plan

Interference Level or Cost in Server to Interferer Relation	Percentage of relations that exceeds the Interference Level	Accumulating to which percentage of total potential interference
4420	0%	0%
510	3.5%	50%
448	7.4%	70%
136	11.2%	80%
52	19.3%	90%
21	30%	95%
8.1	45.5%	98%

Figure 4 provides the cummulative distribution of the remaining interference or costs in the network after the frequency plan. This provides some further insight as to what effect the penalties would have on the system and how much of the penalties would have been implemeted. The distributions diplayed in Figures 3 and 4 will of course be unique for each area and data collection method. It is therefor recommended that a record of the distribution both before and after the plan is kept, as this will help in the assignment of penalties in the future.

3.3 Applying Scaling Factors for Different Layers and Carrier Types.

Since most AFP tools don't support separate interference matrixes for different layers or carrier types, it is necessary to scale the interference to reflect the difference in interference that they introduce into the network, as well as their immunity to interference:

- ❖ Since control channels are transmitting constantly, while traffic channels only transmit when calls are being made, one need to reflect this difference in interference introduced. This would be of particular interest if the network is set on "BCCH-preferred".
- ❖ Power control and discontinuous transmission (DTX) would also be modelled using scaling factors on the traffic channels. A scaling factor 0.5 is often used.
- ❖ Carriers in an over-laid cell would for example introduce less interference into the matrix than those on under-laid. This scaling factor would depend largely on the effectiveness of the over-laid – under-laid implementation and on the traffic distribution. This factor can be determined by measuring the average power level on the over-laid and comparing it the level on the under-laid.
- ❖ The interference that a frequency used in a synthesized frequency hopping cell introduce on that specific frequency can be modelled by scaling with the fractional load on that cell.
- ❖ The difference in immunity is dependent on the features that were implemented on the different carrier types – this is well illustrated in Figure 2 where the immunity that frequency-hopping carriers have to interference is illustrated. Any form of diversity that is implemented on only part of the carriers can be roughly modelled by the diversity gain that these carriers have over the rest. For a carrier hopping over eight (8) frequency

a frequency diversity gain of at least 6dB can be expected, which bring the appropriate scaling factor to 0.25.

The different penalties, where applicable should also be scaled to reflect the interference immunity and the interference introduced by the different carrier types or layers. Depending on the AFP tool this could be done either explicitly by the user or in the background by the AFP tool itself.

4 OTHER ASPECTS TO BE CONSIDERED

4.1 Selecting a Frequency Set for the Control Channel.

There are many advantages for having a specific set of frequencies for the control channel or a BCCH-block as it is often refer to.

- For fault finding or interference identification it is very useful if the frequencies used for the control channels, which are constantly transmitting, is not shared by TCH channels on which transmission is dependent on the traffic load at the particular time.
- When determining undefined neighbours is often convenient to have only a limited set of frequencies to measure on,
- likewise it eases the process of data collection for a “measured” interference matrix considerably if all the control channel transmit in a specific block. (Section 6 deals with this process)

But what is the optimum size for such a frequency block? This question has been asked before, but no one has attempted a generally applicable answer thus far. To avoid the implementing a BCCH-block at the cost of the interference that could be avoided, to remain in the network after the frequency plan, it is important to have the optimum BCCH-block size. The optimum point is where a change in assignment of a control carrier would introduce on average the same amount of additional interference into the network as would a change in a normal traffic channel. A good estimation of the optimum size would be:

$$\text{Size\_of\_BCCHblock} = \frac{\text{Total\_Number\_of\_Frequencies\_Available}}{(\text{Average\_\#Carriers/Cell} - 1) * \text{Scaling\_Factor\_for\_TCH} + 1}$$

For a network with only discontinuous transmission and power control implemented on the traffic channels and a random allocation of calls on traffic aor control channels, an average number of 2.3 transceivers per cell and a total of 55 carriers available the optimum BCCH-block size would be:

$$\text{Size\_of\_BCCHblock} = \frac{55}{(2.3 - 1) * 0.5 + 1} = 33$$

Although very few operators would have the luxury to be tempted to do so, the size of the BCCH-block should not be made larger than thirty two (32), without careful consideration of whether this is really necessary; since thirty two (32) is maximum number of control channels that a mobile can measure on.

4.2 Inter-modulation and harmonics

Since the occurrence of inter-modulation is very unlikely in a single band system this is a topic that have often been neglected in the past. Inter-modulation occurs when two or more carriers are unintentionally mixed or modulated by a non-linear component. This mixing component may be combiner-duplexer or a rusted bolt on the antenna. If signals of carrier frequencies, $f_{1,}$ f_2 and f_3 are mixed through an element that has a quadratic non-linearity, inter-modulations products with frequencies of:

- $f_m = 2f_1$
- $f_m = f_1 + f_2$
- $f_m = f_1 – f_2$

would result. This is known as second order harmonics or inter-modulation products (the '1' or two could be replaced by a '3') If these signals are passed together through a non-linearity of the third order the following third order inter-modulation products (IM3) would result:

- $f_m = 2f_1 – f_2$
- $f_m = 2f_1 + f_2$
- $f_m = f_1 + f_2 + f_3$
- $f_m = f_1 + f_2 – f_3$

The problem arises when one of these inter-modulation products from the transmit frequencies from a sector fall on one of the receive frequencies of the sector. These inter-modulation products might be significantly high and over-shadow the real receive signal. The degree of inter-modulation that would occur is evidently dependent on the quality of the equipment and how well they are maintained, but it is still virtually impossible to eliminate the occurrence of inter-modulation entirely and equipment suppliers specify that the assignment of 3rd order inter-modulation products must be avoided. Figure 5 illustrates at which frequencies inter-modulation can occur. In green the frequencies where possible inter-modulation products resulting from frequencies in the GSM900-band are shown, the possible inter-modulation products resulting from a GSM1800 network are shown in blue, while the red indicate areas where inter-modulation products from a dual-band system may cause a problem.

It is now evident that the assignment of frequencies that would result in a inter-modulation product occurring on one of the receive frequencies would definitely result in a degradation of the network quality and should be avoided by a good AFP tool. This is of particular interest in a dual-band network.

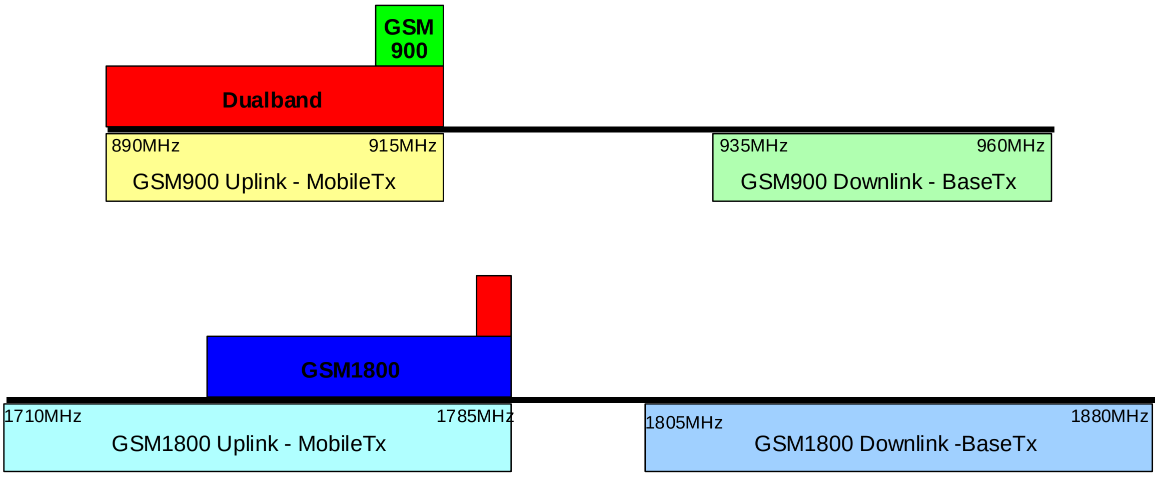

Figure 5: Inter-modulation products resulting from the Base-Tx that might cause interference in the respective Base-Rx bands

4.3 Perceived shortcomings of current AFP tools

The focus of AFP tools has always been to assign the best frequencies to the cells, as to minimise interference. This interference includes adjacent channel or co-channel interference from the cell itself or from adjacent cells. A number of aspects that relate to the combination of frequencies on a cell have however not received much attention:

- The avoidance certain combinations of frequencies on the cell (apart from what could be specified as a separation), as is required to avoid inter-modulation products.
- To enforce or encourage the assignment of frequencies in groups, if the operator would prefer to do so for optimisation purposes. (Although this might not be optimal for a frequency hopping network)
- To maximise on interference or space diversity in a frequency-hopping network, it is desirable that one avoid frequency groups, i.e. avoid the situation where the same frequencies are being re-used on the same two cells. This might become a problem where a tight re-use frequency plan is implemented.
- To maximise on frequency diversity in a frequency-hopping network the separation between the frequencies must be kept to a maximum. A separation penalty that is constant for all separations up the specified separation is possible on most AFP tools, but is definitely not as elegant a penalty that is dependant on separation between the frequencies.

5 DATA SOURCES FOR THE INTERFERENCE MATRIX/LIST

The most essential requirement for any data source for the interference matrix is that it must be able to express or calculate the cost in quality of having two carriers on the same or adjacent frequencies in some form or another. The more accurate the data is able to reflect that the better will the resulting frequency plan be. Traditionally this cost in quality has been based on the C/I (Signal to Interference Ratio), but this could easily be translated to a more accurate measure namely the Frame Erasure Rate (FER). When the C/I can not be calculated some other estimation of the cost can be used.

5.1 Propagation Predictions

This is still the method used most often as data source for AFP tools. Propagation prediction models, which often need to be tuned to adapt to specific area type, require accurate elevation - and clutter data. The C/I at every spot is calculated from these predictions, and the clutter data can be used to estimate the traffic at that point. From these data the cost of having two carriers on the same frequency are calculated. In essence this data is a representation of the area that is being interfered on, but with estimations on the traffic distribution based on the clutter type the data can be converted to represent the interfered traffic.

<u>Possibilities:</u>

- This conventional method is very well suited for planning a new network or implementing a plan when a large number of new sites need to be planned in.
- The fact that the propagation prediction tool is often integrated in the frequency planning tool simplifies and eases the frequency planning process considerably.
- The generation of the data is only dependant on the speed of the propagation prediction module of the frequency planning tool.

<u>Limitations:</u>

The accuracy of the data generated with this method is highly dependent on the accuracy of a number of things:

- the propagation prediction algorithm,
- the elevation data,
- the clutter data,
- and the distribution of the traffic by clutter type.

All of the before mentioned normally have a limited accuracy and the improvement quality of the data can be costly – both monetary and time wise.

<u>Implementation:</u>

This method is widely implemented in almost all frequency planning tools.

5.2 Neighbour relations statistics

A lot can be learned on what the cost of assigning two neighbours on the same or adjacent frequencies from the neighbour relation statistics, i.e. the number of times that mobiles were handed over to a particular neighbour. Unfortunately only statistics from the neighbours and not from all possible interferers are available

Possibilities:

- This data source would be well suited for a very tight frequency re-use plan, when it is likely that all the frequencies used on a cell will also be used on one of its neighbouring cells.

Limitations:

- Although some cost estimation can be made from this data, it is not directly related to the signal to interference ratio that would be seen by the traffic.
- It is not well suited for a system loose re-use system.
- nor for a system where some patches of coverage away from the main coverage area exist, that is often the case in hilly or mountainous terrain

Implementation:

This data can be readily obtained from the OMC.

5.3 Drive tests

From this data the signal strength of the serving cell, as well as from the six strongest neighbouring or interfering cells can be obtained. These measurements would be restricted to the areas where the drive tests were performed

Possibilities:

- This data provide actual measured data, and is independent on accurate information such as elevation data and clutter classification.
- It can be used as an additional interference matrix or an exception list.
- When extensive measurements have been performed it can be used to represent the area interfered.

Limitations:

- This data can not be easily converted to represent the traffic that is affected by interference
- To obtain an entire interference matrix from this data extensive and very expensive measurements need to be performed.
- To convert the data into a format that can be entered into the AFP might prove to be a challenge.

Implementation:

This data source is used in MTN in addition to the predicted interference matrix as an exceptions list. The author is unaware of any implementation where this data source is used to as the primary source on which a frequency plan is based. To ensure that all possible interferers are picked up, it is important that the mobile measure over the whole BCCH-block.

5.4 Live Data: Mobile Measurements Reports.

As is the case with drive test data the signal strength of the serving cell and the signal strength of the six strongest neighbours are measured by the mobile phones. In the case of the live data however the data are as is measured by the "customers", where ever they find themselves. This data source is not only independent of the accuracy of elevation and clutter data, but inherently reflects the traffic distribution.

Possibilities:

- This data provide actual measured data, and is independent on accurate information such as elevation data and clutter classification. This data is as the "customer perceive" it – that is, it inherently contains information regarding the traffic distribution and the propagation characteristics.
- When sufficient data is collected for all the sites in the plan this data can be compiled as a very accurate interference matrix that truly reflects the status on the network itself. No additional exceptions files would be required.
- It is particularly well suited for a mature network where the number of new sites is small compared to the number of existing sites.

Limitations:

- At the moment the process of collecting the data is slow.
- The introduction of new sites might be problematic, as no measurements are available for them.

Implementation:

This data source has been used with great success by MTN (see Section 6). Data was collected using the Cell Traffic Recordings in the Ericsson system and processed to form an interference matrix that could be imported into the AFP tool. The collection of the data took about a month. No additional exceptions or neighbour list was added. As no data is available for new sites, ways have to be found to obtain data for these sites. Some ideas include bringing the site up on temporary frequencies so that one can obtain measurements on the site or to estimate its interference list from the interference lists of its neighbours.

5.5 Combining Data Sources

Each data source has its shortcomings and advantages.

- For example, the live data measurements are a very accurate data source and reflect the true network very accurately, but it is very difficult to estimate data for a new cell. The propagation predictions are the one data source that can provide data for new cells to the same accuracy as it does for existing cells.

- ❖ Live data measurements and drive tests are both time consuming. Not enough data might hence be available when the plan is due. You might need to combine your data with predictions.

There are many more examples where one would like to combine different data sources. There are however a things that need to be kept in mind when combining data:

- ❖ Don't spoil good data with bad data.
- ❖ Don't skew the matrix. This is might happen if an unbalanced data source is used e.g. drive tests that were only performed for part of the network.

And these are the challenges of modelling your network …

6 EVALUATING A PLAN BASED ON LIVE DATA AND FER BASED INTERFERENCE MATRIX

For this evaluation live network data using Cell Traffic Recordings was used as the source of information as was suggested in [2]. The network was set-up such that the mobiles were measuring on the entire BCCH-block, so that all possible interference could be picked up. The data was collected over a period of about a month. From all the collected mobile measurement reports the Signal to Interference ratio was calculated from the serving cell's signal strength and the reported neighbours signal strength for each reported neighbour and converted to the FER rate. The data on each cell was then normalised to the amount of data that was collected on that cell to be then multiplied by the expected traffic on the cell. In essence the "units" for the interference or cost is Average FER times Traffic.

The plan based on the live network data was implemented in the Johannesburg Central Business District. The area of the plan was a twelve by twelve kilometers area. The number of sites in the plan was sixty-five (65) with 477 carriers to be planned. The accuracy of the clutter data and some of the models has been discussed and questioned for some time. Previous plans were based on predictions, neighbour list and some exceptions based on experience. After the plan a few (less than five (5)) carriers always needed to be changed.

As a "sanity check" a normal interference plot was generated based on the prediction models and clutter data normally used. This is shown in Figure 6. Most of the areas, where severe interference was predicted, were identified as areas with low traffic density, although some areas gave raise to concern.

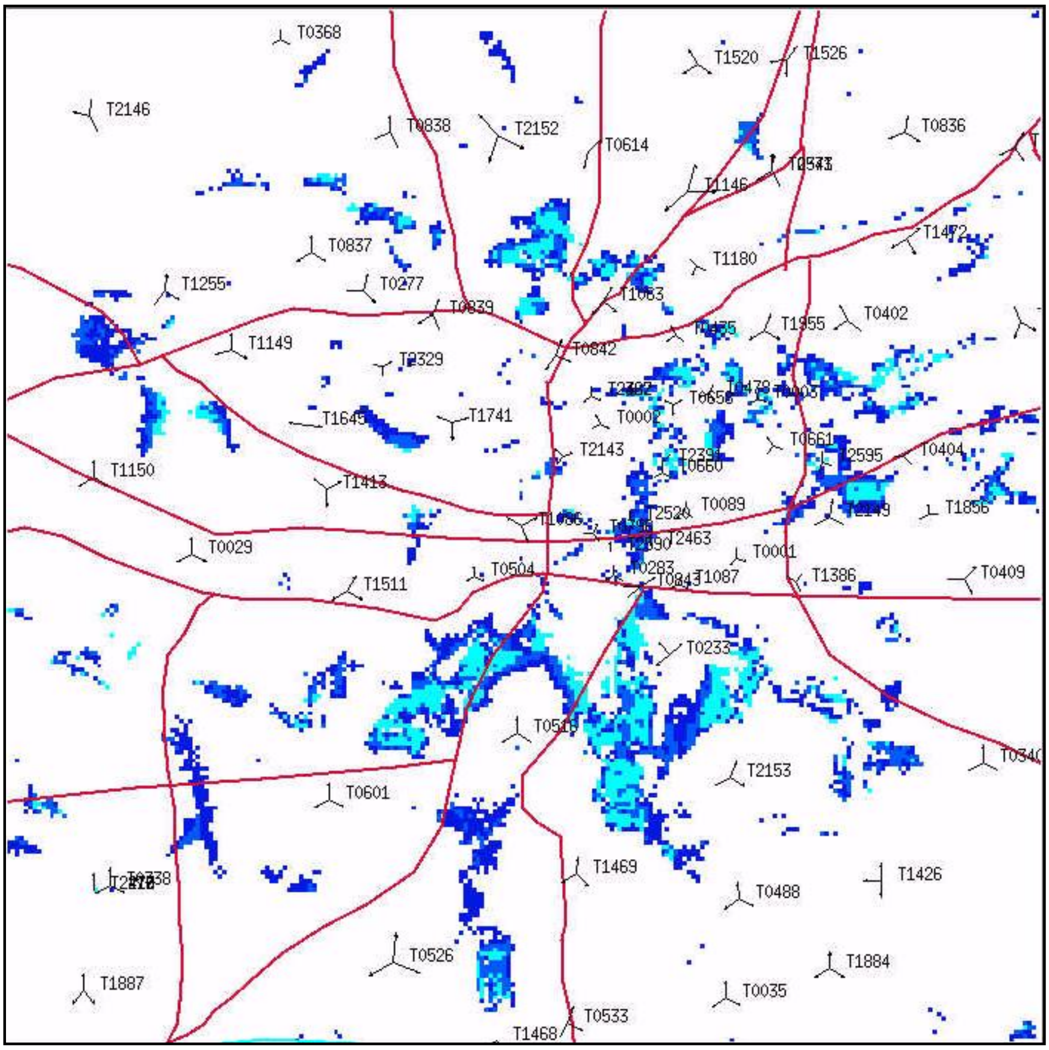

Figure 6: Signal to Co-channel interference plot of measurement based plan

No additional input, like the neighbour list, was added to the interference matrix to calculate the frequency plan, and no frequency changes were required.

Despite the limitations in the predictions models and clutter data available, this area has always had a very low drop call rate of round about 1.40%, with the previous **lowest** dropped call rate for a normal business day of 1.29% on September the 8th, 1998. Figure 7 shows the improvement in the dropped call rate after the plan was implemented. The **highest** daily average since the plan is 1.14% - this is an improvement of 11.5% on the previous record and 18.5% improvement on the dropped call rate normally experienced.

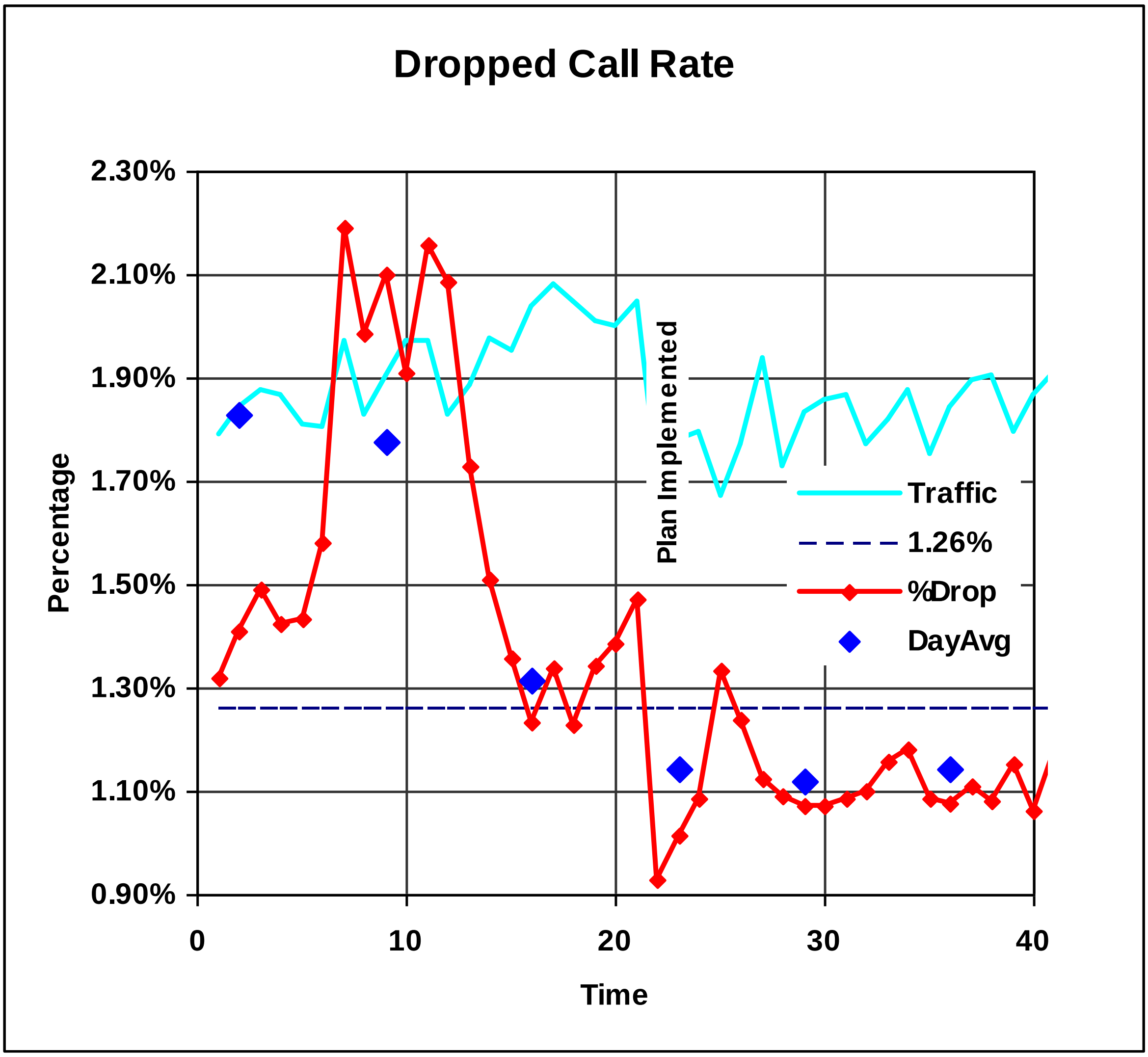

Figure 7: Improvement in the dropped call rate after a measurement based plan was implemented

Figure 8 shows a number of parameters that reflect the quality improvements. The intra-cell hand-overs due to bad quality declined by about 35%, while the dropped calls due to bad quality declined with about 40%. These parameters are a good indication of the improvement that would be felt on voice quality.

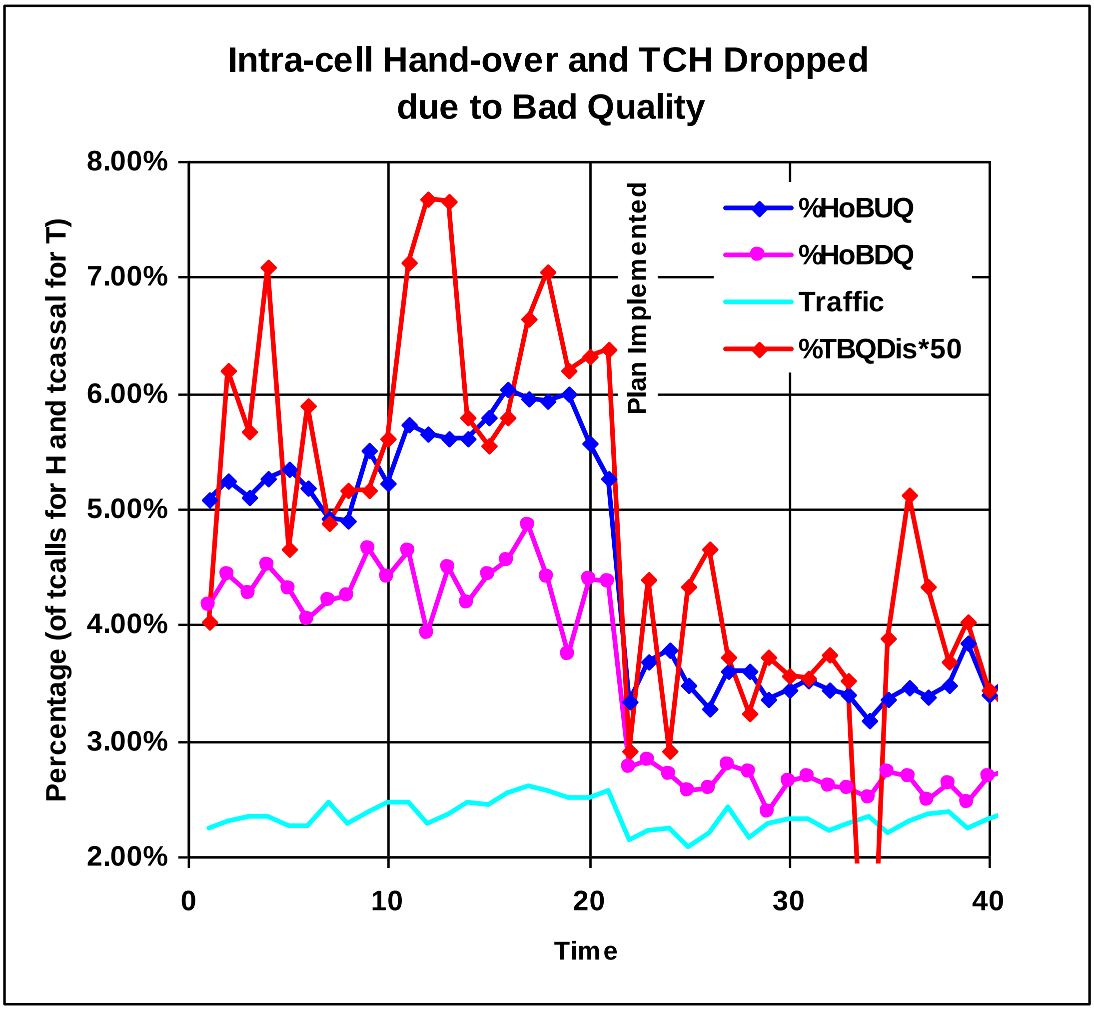

Figure 8: The drop in the percentage of intra-cell hand-overs due to bad quality that reflect the improvement in voice quality

The measurements can also provide some additional information that would assist in the improvement of the network. Figure 9 displays the distribution of the interference caused by the different cells as well as a list on the major interferers. This could help in improving the basic cell plan. Using this information major interferes can be identify and dealt with in a appropriate way.

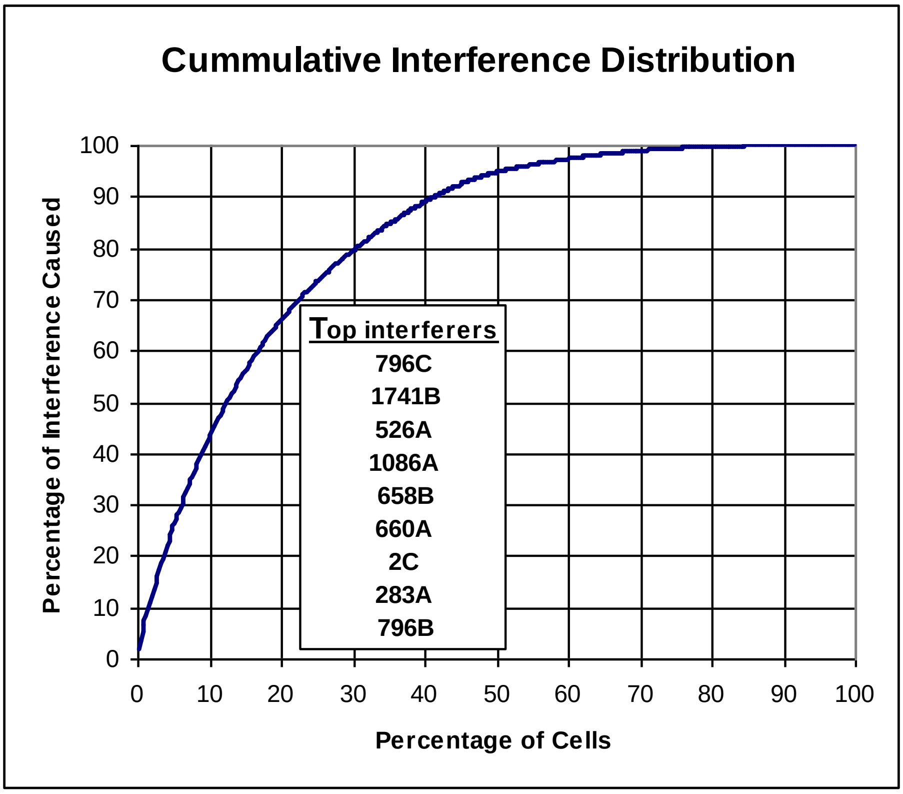

Figure 8: Information of cells that cause the most interference

6.1 Acknowledgments

Thanks and acknowledgment is due to the Johannesburg Planning and Optimisation team, for not only taking the risk of putting the plan (shown in Figure 6)in, put also spent the time after hours to ensure that the plan went in well. People that assisted are John Henry, Owen Turnbull, Vikash Barath and Henri van der Merwe and Thaigan Govender.

7 CONCLUSIONS

To model a network accurately is indeed a challenging task, but when it is done well the benefits in network quality is significant. This is well illustrated by the measurement-based plan that was implemented where the benefits was not only in quality but also in simplicity. Some issues, such as correctly combining different data sources, remain a challenge and a opportunely for ingenuity.

[1] H.Goodhead , D.Griggs, J.Maipath, J. Sameulson, "Examining the Features of Next Generation Automatic Frequency Planning Tools.", *IIR Exploiting Rapid and Advanced Radio Frequency Planning*, September 1997

[2] M. Snyman, "Optimising the Use of OMC Statistics for Performance Evaluation and Network Optimisation" *IIR's Optimising GSM Networks.* September 1998