Analysis of mobile measurement-based interference matrices in GSM networks

R.Barco*, F.J.Cañete*, L.Diez*, R.Ferrer**, V.Wille[+]
* Dpt. Ingeniería de Comunicaciones. Universidad de Málaga.
Campus de Teatinos s/n
29070 Málaga (Spain), rbm@ic.uma.es
**Nokia Networks (Málaga, Spain)
[+]Nokia Networks (Cambridge, UK)

***Abstract*- Frequency plans (FPs) based on mobile measurements present several advantages compared to those based on propagation predictions. These FPs use Interference Matrices (IMs) created from Measurement Reports (MMRs). MMRs, as described in the GSM Specifications, present some limitations: quantization and truncation of measured values, only six strongest neighbours reported and BSIC (Base Station Identity Code) decoding procedure. In addition, different types of IMs, depending on the processing of the raw data, can be considered. In this paper, MMRs limitations and their impact on different types of IMs are analyzed. Simulations for macrocell and microcell scenarios have been carried out to reinforce the conclusions.**

I. Introduction

An optimized frequency plan (FP) is essential to increase capacity and quality in cellular networks, specially in dense urban areas. All planning tools have the same basic objective: to assign frequency channels to cells in an optimum way, i.e. to maximize global quality of service.

FPs are based on Interference Matrices (IMs), which quantify the interaction among cells. That is, the element x_{ij} in the matrix is an indicator of the potential interference produced by cell *j* on mobiles attached to cell *i*, supposing that both use the same frequency channel. Therefore, an important issue is how to build accurate IMs in order to obtain good FPs.

IMs for traditional FPs are based on propagation predictions, which present several limitations due to the inaccuracy of the models and the difficulty to take into account the actual traffic. This is the reason for proposing FPs based on mobile measurements [1-3]. Data acquired in this way are more accurate than those supplied by prediction-based planning tools because they are provided by mobiles from the entire serving area of the cell.

As stated in the GSM standards [4], mobile phones send Measurement Reports (MMRs) to the BTS every 480 ms, which contain signal level measurements from the serving cell and the 6 strongest BCCH of neighbouring cells. Therefore, MMRs are a good source of measurement information and can be used to build IMs. But MMRs as described in [4] introduce some limitations. The first issue is that only downlink information is being considered. Another problem is due to the mapping from real values to RXLEV (Received power level). Although effects of quantization are negligible in most cases, truncation can cause systematic errors, mainly upper truncation in dense urban areas, where values greater than -47 dBm may be common. Another potentially serious problem arises due to the fact that mobiles only provide information about the six strongest interfering cells, and therefore other potential strong intereferers are not reported. The BSIC decoding process also has an influence in the FP because the MS has to identify the main interfering cells among all the ones sharing the same frequency, which can fail if the interference is too low or there is not a dominant interfering cell on that frequency.

From the MMRs several types of IMs can be constructed: expected values or percentiles IMs; received power, carrier to interference ratio (CIR) or Frame Erasure Probability (FEP), etc.

In this paper the effects of the limitations in MMRs described above are studied for different types of IMs. Simulations are performed for two different scenarios: macrocell and microcell. Other kinds of MMRs which appear in recent versions of [4] are also considered (Extended MMRs, Enhanced MMRs, etc.).

In Section II concepts about interference matrices and measurement reports are reviewed. Section III describes the simulation scenarios and Section IV presents the simulation results regarding MMRs limitations, IMs types and MMRs types. Finally, the main conclusions are reviewed in Section V.

II. Interference matrices

A FP is created by minimizing a cost function, which is a linear combination of elements in IMs. For this reason, it is very convenient that the IMs comply with the superposition property, i.e. the total interference produced by two cells using the same frequency is the sum of the interference that each one produces.

It is important to distinguish between the raw data used to build the IM, i.e. MMRs, and the processing done to the raw data in order to obtain the final IM.

A. Measurement Reports

MMRs are the available measurements from mobiles. Some properties of MMRs produce limitations in IMs. First, only downlink information is being considered, not taking into account what is happening in the uplink (although there is a certain degree of correlation between both radio links). Nevertheless, this is not a big problem because GSM networks tend to be downlink interference-limited.

On the other hand, the mobile station (MS) is not an accurate measurer and may generate big systematic errors.

This work has been done as part of a cooperation agreement between Nokia and the University of Malaga.

Systematic errors that appear on both carrier and interferer are almost the same and, therefore, CIR values are almost free of systematic errors. This is a good reason to use CIR instead of separate values of C and I.

Another source of inaccuracies is the quantization and truncation of measurements. It has been observed that quantization noise does not affect MMRs substantially, but saturation may cause systematic errors. Upper saturation essentially affects the received power of the serving cell, whereas lower saturation has an impact on the received power from low level interfering cells.

One of the most serious problems in creating an accurate IM estimation is that mobiles only report the six strongest neighbour cells. The mean power of each interfering cell is slightly overestimated for the strongest interferers and very much overestimated for the weakest ones. This is due to the fact that interfering cells are only reported when its value is one of the six strongest ones and, therefore, its average is higher than the real one (low level samples are not taken into account to calculate the average). This can be observed in Fig.1 (see B for an explanation).

Finally, the MS has to identify the neighbour that is generating the interference among the ones sharing the same frequency before reporting the measurement. In order to do that, the MS decodes the BSIC. This can also generate inaccuracies.

B. Estimators

The purpose of estimators is to accurately describe 'interference' using measurement reports. Two types of estimators have been considered: mean and normalized mean.

The mean is the average of the reported values, e.g. for each reported cell, it is the sum of values (Si) divided by the number of times that cell is reported (Mi). The normalized mean is the sum of values (Si) divided by the total number of possible measurements (N). N is larger or equal to Mi as it includes also those cases where other cells are reported.

The mean overestimates the expected values, whereas the normalized mean underestimates them. Combinations of both estimators have also been analyzed, but the obtained results are worse than those obtained exclusively using the normalized mean.

In order to justify the use of the normalized mean, the CIR distribution function and the normalized distribution function are compared. The normalized distribution function is the distribution function multiplied by the factor Mi/N, so its relation with the normalized mean is the same as the one the distribution function has with the mean.

Fig.1 shows CIR distribution functions for four interfering cells. Solid lines correspond to ideal measurements, whereas dashed lines are distribution functions of real measurements (MMRs with limitations). It can be observed that the distribution functions (and also the mean) of real measurements have very little information about the interference level.

Fig.2 shows the distribution functions for ideal measurements and the normalized distribution function for

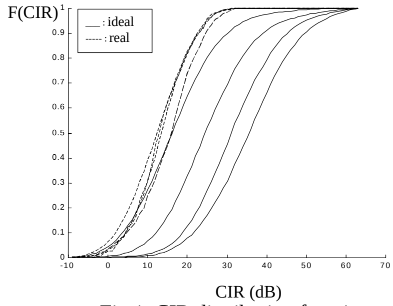

Fig.1. CIR distribution function

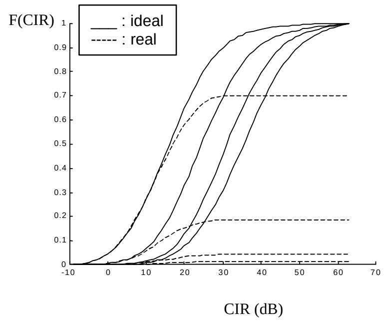

Fig.2. Normalized CIR distribution function

real MMRs. It can be observed that for low C/I values (<10 dB) ideal and real measurements are very similar.

These results justify the use of normalized mean instead of pure mean. They also justify the use of ICD and FER because the contribution of high CIR values to these estimators is negligible.

C. Interference Matrix Types

Three types of interference matrices have been evaluated in this study: CCF, FER and ICD.

The first type represents interference only. Potential interference from neighbouring cells (obtained by measuring BCCH carriers) is processed to obtain a magnitude named CCFR (Cell Coverage Factor Ratio) [1]. CCFR is the ratio of CCF from one neighbouring cell to the total CCF obtained for all cells, where CCF (Cell Coverage Factor) describes the level of coverage provided from a neighbouring cell within the analyzed serving area. CCFn is CCF normalized by the total number of MMRs received by the cell.

$$CCF_{ij} = \sum_{k=1}^{N_{ij}} p_{ij}(k) + StDev(p_{ij}) \cdot N_{ij} \qquad (1)$$

$$CCFn_{ij} = \frac{1}{N} CCF_{ij} \qquad (2)$$

$$CCFR_{ij} = \frac{CCF_{ij}}{\sum_{j=1}^{M} CCF_{ij}} \cdot 100 \qquad (3)$$

where

CCF = Cell Coverage Factor

CCFR = Cell Coverage Factor Ratio

N_{ij} = number of measurements reported of interfering cell j to serving cell i

$p_{ij}(k)$ = k interfering power level (dBm) from cell j reported to serving cell i

N = total number of measurement reports received by serving cell i

M = Number of cells

The second term in the CCF calculation can be omitted without much error, as was verified in the simulations.

Another type of IM is the FER (Frame Erasure Rate) matrix [3]. FER is used because it is a very good indicator of speech quality. It represents the percentage of frames being dropped due to their high number of non corrected bit errors. In order to obtain FER, CIR values are calculated for each MMR and then mapped to FEP (Frame Erasure Probability). FEP represents the probability of frame erasure associated to the current MMR. FER is obtained by processing FEP corresponding to multiple MMRs.

$$FEP_{ij}(k) = f_{FEP}(CIR_{ij}(k)) \quad (4)$$

$$FERn_{ij} = \frac{1}{N}\sum_{k=1}^{N_{ij}} FEP_{ij}(k) \quad (5)$$

where f_{FEP} is a mapping function from CIR to FEP [7].

The last analyzed IM is the ICD matrix [2]. ICD is an estimation of the probability of CIR being lower than a threshold (9 dB). It can be seen as a rough approximation to a FEP-CIR mapping function.

$$ICDn_{ij} = \frac{1}{N}\sum_{k=1}^{N_{ij}} f_{ICD}(CIR_{ij}(k)) \quad (6)$$

$$f_{ICD}(x) = \begin{cases} 0 & x \geq 9\ dB \\ 1 & x < 9\ dB \end{cases} \quad (7)$$

Normalized mean is considered in the previous FERn and ICDn definitions.

D. Other types of measurement reports

Extended Measurement Reports [4] allow to measure the power level of selected frequency channels. Only quantization restriction applies, but neither BSIC decoding or six-strongest restriction affects this type of measurements.

Enhanced Measurement Reports [4] improve the estimation of IM because they allow to report more than six interfering cells and they introduce the SCALE parameter, which permits to change the range of the power level quantization. In that way, the quantization error can be minimized by adjusting the SCALE parameter.

III. Simulation Scenarios

The simulation tool used in this study has been a GSM/EDGE network simulator [5,6], developed by Nokia Research Center.

Two different scenarios have been analyzed: macrocell and microcell with regular and irregular configurations.

Macrocell scenario consists of 75 hexagonal cells (tri-sector sites) with a cell radius of 500 m. Frequency reuse is 1/3 for traffic channels and 1/15 for BCCH and there are 2 TRX (Transmitter-Receiver) per sector.

Microcell scenario, Manhattan type, is an urban area of 6.5 km^2, with 72 omnidirectional base stations, placed on perpendicular streets 30m wide and blocks of 200m x 200m. 9 frequencies are used for TCHs and 6 for BCCHs and there are 4 TRX per cell.

Table I shows some simulation parameters.

IV. Simulation Results

A. Measurement Reports limitations

One of the aims of the simulations was to analyze the effects of MMRs restrictions on IMs. In order to do so, ideal mobile measurements have been compared with those subject to the limitations mentioned before. Fig.3 shows the FER value for the 46 strongest interfering cells to one serving cell in macrocell scenario.

It can been observed that quantization does not have relevant effects because the measured power is in most cases inside the margins. When studying the effects on the CIR, it can be pointed out that quantization always underestimates CIR, due to the fact that C is underestimated when its value is higher than –47 dBm and I is overestimated for those interfering cells whose level is under –110 dBm.

Fig.3 also shows the effect of reporting only the six strongest interfering cells. Its impact is clearer in the low-level interferers. It has also been observed that FERn is less sensible to this effect than CCFn because FEP is negligible for low-level interfering cells (due to the exponential relation between FEP and CIR). In that case, assuming that all the non-reported values are zero is more accurate for FERn than for CCFn.

TABLE I

Simulation Parameters

Power control	Not used
Frequency hoping	Not used
Slow fading (log normal) Standard Deviation Decorrelation length	 6 dB 50 m
Antenna	120º, 15 m
Simulation time	25 min
Average Call Length	99.54 s
Call arrival rate	5 calls/terminal/hour
Number of measurements	120206
Received MMRs	20043

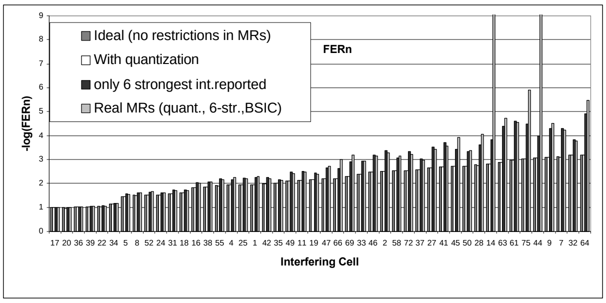

Fig.3. FER for ideal MMRs vs. MMRs with limitations

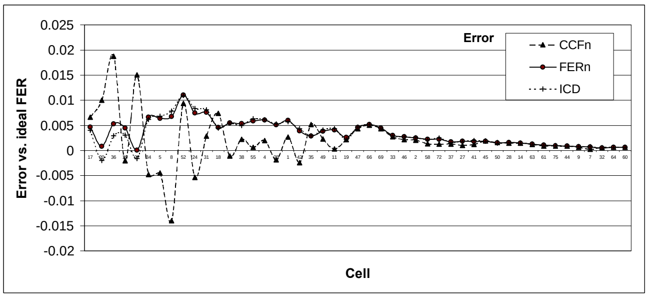

Fig.4. Error in ideal FER. vs. real FERn, CCFn, ICDn

Another result of the simulations is that the BSIC decoding procedure causes two opposite effects. First, if BSIC is decoded, a power level higher than the real one is reported. This is due to the fact that the reported power is not only the one from the cell whose BSIC is decoded, but also the sum of powers from other cells that share the same BCCH. This can be observed on high-level interfering cells. On the other hand, if BSIC is not decoded, zero power level is assumed, which is less than the real one. This effect is more important on low-level interfering cells because the interference level received from cells sharing the same BCCH is usually very similar.

B. Interference Matrix Types

Matrices based on ideal and real MMRs have been compared for all matrix types considered. It was observed that for FERn and ICDn matrices real values are closer to the ideal ones than for CCFR/CCFn matrices (no graphic shown).

On the other hand, assuming that FERn is the best indicator of interference in cellular networks, FERn based on ideal measurements is used as a benchmark.

Fig.4 shows the absolute error between the ideal FERn and the real FERn, ICDn and CCFn. In order to compare them, a scale factor has been introduced. In Fig.4 it can be seen that FERn and ICDn display a very similar error pattern while the error of CCFn shows quite a different characteristic. Table II shows the error statistics for the whole network in macrocell scenario. It can be seen that the ratio of RMS error to ideal value is about 0.12 for FERn and ICDn, while for CCF based method this value is twice as large.

It has been verified that, as expected, FERn is the best real matrix, but ICDn is very similar and far easier to implement. Real CCFR is not very different to ideal FERn and it is closer to ideal FERn than to ideal CCFR.

TABLE II

ERROR STATISTICS FOR DIFFERENT TYPES OF IM

	FERn	ICDn	CCFn	CCFR
Average error	0.0014	0.0015	0.0002	0.0003
StdDev error	0.0031	0.0032	0.0061	0.0068
Rms error	0.0034	0.0035	0.0061	0.0068
Rms error/ideal	**0.121**	**0.123**	**0.216**	**0.240**

C. Other Measurement Reports

1)*Extended measurement reports* are not very useful for MMR-based frequency planning because measurements are associated to frequency channels, not to cells.

In order to use these measurements for MMR based frequency planning each frequency should be associated to a cell. The first drawback is that only information for a restricted set of cells is available (one for each BCCH frequency).

The most logical procedure is to associate each frequency to the cell with the highest interfering level among the ones sharing that frequency.

Fig.5 shows a comparison of the FERn obtained from ideal, real and extended measurement reports, for the macrocell scenario. It can be observed that extended measurement reports overestimate the ideal value of interference, because they include interference from all cells sharing the same frequency.

2)*Number of neighbours reported*: Once it has been proven that the lowest error is achieved using the FERn approach, the different FERn matrices obtained have been compared taking the number of neighbours reported as a parameter. Fig.6 shows the comparison among the ideal case (all neighbours reported) and only the 3, 5, 6 or 12 highest neighbours reported. It can be observed that, logically, the higher the number of neighbours reported the closer the results are to the ideal values. But even when the number of neighbours reported is low the results are still quite accurate for high interfering cells.

3)*Effect of the SCALE parameter*: In Enhanced Measurement Reports it is possible to choose the window of power that can be quantified without saturation. The window for normal MMRs is (-110, -48) dBm, whereas for Enhanced MMRs is (-110+SCALE, -48+SCALE).

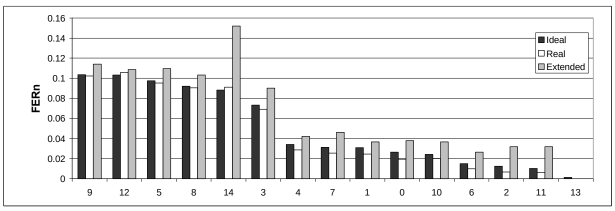

Fig.5. Comparison of FERn for ideal, real and extended MMRs.

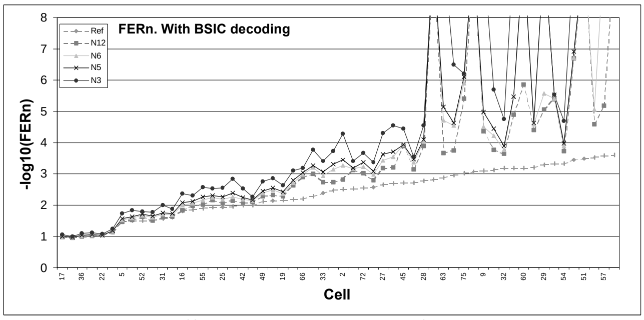

Fig.6. FERn with different maximum number of reported neighbours.

In order to evaluate the impact of the SCALE parameter, the only restriction applied to MMR is quantization and truncation (Fig.7). Quantization always underestimates real values: it makes carrier power lower, due to upper saturation, and interfering power higher, due to lower saturation.

The first effect is predominant on high interfering cells, while the second is appreciated on low interfering cells. It can also be observed that SCALE 10 is better than SCALE 0 for high interfering cells because it reduces carrier saturation. The opposite effect occurs for lower level interferers, where SCALE 0 is better than SCALE 10, due to the predominance of the lower saturation effect. The former is more important than the latter as it affects to the highest interferers.

Another interesting effect is that CIR tends to be almost constant for lower interfering cells, due to the lower saturation. This effect is better appreciated in the microcell scenario.

V. Conclusions

In this paper, different types of IMs based on measurement reports have been evaluated using simulations.

The inaccuracies in the IMs due to limitations in MMRs have been studied. Several types of MMRs described in the GSM Specifications have also been considered.

Regarding the type of matrix, it can be concluded that the normalized mean is more meaningful than the conventional mean because the latter is usually the same for all interferers, despite its level. FERn and ICDn are preferred to CCFR/CCFn matrices because they provide a better approach to the quality perceived by users and they better verify the superposition property.

When studying the effect of the MMRs limitations, it has been concluded that "the six strongest interferers reported" seems to be the worst restriction. On the other hand, CCFR and CCFn obtained from real MMRs are coarse estimators of ideal FERn matrix, while FERn and ICDn are closer to the ideal FERn matrix.

FERn and ICDn matrices are very similar, but ICDn is easier to implement and it facilitates taking into account several types of services (by changing only the threshold).

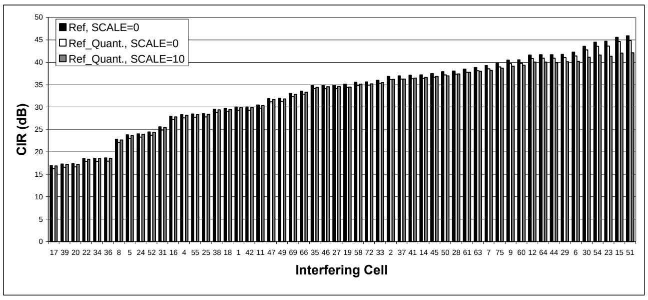

Fig.7. Comparison ideal vs. quantified CIR for SCALE=0 & 10.

With regard to another types of MMRs, Extended Measurement Reports do not seem to be too useful to improve IMs. Enhanced Measurement Reports can improve IMs by reporting more than the six strongest neighbours and by using the SCALE parameter.

In conclusion, it is shown that IMs based on MMRs can be used to create FPs. Moreover, measurement limitations do not cause a significant reduction in the accuracy of IMs. Trials have shown that MMRs-based IMs can improve network performance in actual networks.

Acknowledgment

This work has been performed as part of the cooperation agreement between Nokia and the University of Malaga. This agreement is partially supported by the Program to promote technical research (Programa de Fomento de la Investigación Técnica, PROFIT) of the Spanish Ministry of Science and Technology.

The authors would like to thank Antti Kuurne and J.Manuel Melero for their support and also the SMART developers in the NRC Helsinki (specially Antti Sevon).

References

[1]V.Wille, H.Multimaki, and S.Irons, “A practical approach to 'channel borrowing' for microcells in GCS systems", VTC'98, pp.144–148.

[2]Y.Timmer, M.Bergenlid, "Estimating the Inter Cell Dependency Matrix in a GSM network", VTC'99, pp.3024-3028.

[3]A.Kuurne, "Mobile Measurement based frequency planning in GSM network", PhD Thesis, 2001

[4]ETSI GSM 05.08 version 8.4.0, May 2000

[5]M.Moisio, T.Kojo, S.Nikkarinen, E.Pernilä, A.Sevon and J.Sipola, "SMART GSM Network Simulator. Functional Description", NRC, 2000

[6]M.Moisio, E.Saario, E.Pernilä, "SMART GSM Network Simulator. User's Guide", NRC, 2000

[7] Nielsen, T.T., Wigard, J., "Performance Enhancements in a Frequency Hoping GSM Network", Kluwers Academic Publishers April 2000, ISBN: 0792378199