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1. Introduction

Results presented to the GERAN Evolution Workshop [1][2][3][4] suggest that the creation of a performance specification based on mobile station receive diversity (MSRD) techniques may represent a significant opportunity to improve GSM/GPRS/EDGE downlink performance, and to progress the goal – initially addressed by the DARP/SAIC Feasibility Study and Work Item – of further enhancing GSM/GPRS/EDGE system performance through advanced mobile receiver design.

This contribution discusses issues relating to MSRD network performance prediction, channel and interference modelling, and signalling and testability, and addresses how the issue of MSRD performance specification might be most efficiently progressed within GERAN.

2. Network Performance Prediction

Notwithstanding the consistent link-level performance gains attributable to MSRD identified in [1]-[4], it is still desirable – in the interests of creating momentum toward a GERAN MSRD performance specification and of normalising industry performance expectations – that GERAN should identify a commonly agreed estimate of the MSRD network capacity and throughput improvements.

For the GMSK-based voice (AMR) system scenarios studied closely in the DARP Feasibility Study (FS) [5], the simulation methodology by which this can be achieved is clear provided that:

a) the reference system simulation scenarios identified during the DARP FS remain appropriate, and

b) an appropriate and accurate link-system mapping can be identified for MSRD devices.

Note that this assumes GERAN should not be concerned that the network uplink (UL) will become the limiting link in terms of total GSM/GPRS/EDGE network performance, but this appears to be a reasonable assumption given the ongoing emphasis on downlink (DL) user and system data throughput and the opportunity for proprietary improvements to BTS receiver performance.

2.1. Reference System Scenarios

Previous work in 3GPP (e.g. on UTRA MIMO system concepts and in EUTRA/EUTRAN [11]) suggests that accurately capturing network performance gains attributable to MSRD – especially when interference suppression is considered – could require the adoption of more advanced spatial channel models (such as [6][7]) than those adopted during the DARP FS.

It is well understood that system attributes such as MS antenna configuration, angle of arrival of the desired and interfering signals, local and distant scattering geometries and angular spread all have a fundamental effect on both a) the inter-antenna correlation of the desired and interfering waveforms, and b) the correlation between the desired signal and each interfering signal. Indeed, contemporary propagation studies suggest it is unlikely that a) each received signal would observe the same spatial correlation coefficient, and b) each desired and interfering signal would fade independently.

Nevertheless, given that a reference receiver (such as the RAKE and MMSE reference receivers used by 3GPP RAN WG4 [9]) is not yet available in GERAN (and may not become available), agreeing on the achievable receiver SNR, even when the spatial channel impulse response to the desired and interfering base stations is known, could be a time-consuming task. It may be possible for companies to develop link-system mappings (analogous to the Stage-1 mapping applied during the DARP FS) which incorporate the desired and interfering base station channel impulse responses when computing the input CIR or DIR parameters (or equivalent), and companies should be free to present such results, but should not be required to do so.

Accordingly, the reference system scenarios identified during the DARP FS would appear feasible as the basis for GMSK voice service network performance enhancement.

2.2. Candidate MSRD Link-System Mapping

As discussed above, a viable link-system mapping methodology is the second component required to generate MSRD network performance enhancement estimates. The methodology used during the DARP FS without receive diversity is, however, not directly applicable to DARP with receive diversity. One possible modified methodology, which re-uses as much of the DARP FS work as possible, is to a) combine the received Co-channel Interference Ratio (CIR) and Dominant Interference Ratio (DIR) metrics from each antenna in a max-ratio fashion, and then b) apply the resulting CIR and DIR metrics to a single-antenna DARP receiver link-system mapping. Note that – as for the DARP FS – this mapping does not of course imply a particular MS receiver architecture, but simply an equivalent performance model.

In more detail, without receive diversity, the CIR and DIR measures are mapped directly to burst Bit Error Probability (BEP), and then the mean and variance of the BEP values comprising each logical channel frame (e.g. 8 for TCH/AFS) are mapped to Frame Error Probability (FEP).

With receive diversity, a possible approach is to combine the CIR and DIR measures on each antenna via maximal ratio combining (MRC) but this must be combined with interference suppression. With MRC, the desired signals are co-phased, scaled, and added. Notably, the resulting desired signal has the property that the CIR is the sum of the branch CIR’s. Unfortunately, there is not a similar relationship for the resulting DIR.

Using the subscripts ‘a’ and ‘b’ to denote two available antennas, the desired signal on each branch is scaled by the branch voltage gain, and then summed and squared to estimate the resultant desired signal power. The interfering powers are scaled by the branch power gains. In detail:

$$C = \left(\sqrt{C_a}\, g_a + \sqrt{C_b}\, g_b\right)^2 \tag{1.1}$$

$$I_1 = I_{1a} g_a^2 + I_{1b} g_b^2 \qquad I_2 = I_{2a} g_a^2 + I_{2b} g_b^2 \tag{1.2}$$

With a single interferer I_1, the CIR’s are:

$$CIR_a = C_a / I_{1a}, \quad CIR_b = C_b / I_{1b}, \quad CIR = C / I_1 \tag{1.3}$$

The branch gains are:

$$g_a = \sqrt{C_a} / I_a \qquad g_b = \sqrt{C_b} / I_b \tag{1.4}$$

The output CIR is, as expected:

$$
\begin{aligned}
CIR = \frac{C}{I} &= \frac{\left(\sqrt{C_a}\, g_a + \sqrt{C_b}\, g_b\right)^2}{I_a g_a^2 + I_b g_b^2} \\
&= \frac{\left(C_a / I_a + C_b / I_b\right)^2}{C_a / I_a + C_b / I_b} = \frac{C_a}{I_a} + \frac{C_b}{I_b} = CIR_a + CIR_b
\end{aligned} \tag{1.5}
$$

In the multi-interferer case, however, consider the ratio of I_1/I_2 at the output (assuming $I_1 > I_2 > I_3 = 0$).

$$
\frac{I_1}{I_2} = \frac{I_{1a} g_a^2 + I_{1b} g_b^2}{I_{2a} g_a^2 + I_{2b} g_b^2} \tag{1.6}
$$

Clearly, the power ratio of any two interferers at the combiner output depends on the branch gains. This holds for all other interferers. To obtain the ratio of the dominant interferer to the remainder (the effective post-combiner DIR), we must determine the resultant power for all interferers, and then sort and select the largest. This process is straightforward in simulation, although the ability to predict DIR based solely on the branch CIR's and DIR's is not available.

The system simulation envisaged by this methodology begins by generating the channel associated with the desired and interfering signals on each MS antenna branch, where specific values of antenna imbalance and correlation can be included. The MRC branch gains are determined and applied to each signal on the two branches before combining. The output CIR and DIR are determined after sorting and selecting the (possibly new) dominant and remaining interferers. The burst CIR and DIR are mapped into BEP, and then into FEP as in the non-diversity DARP case. In this procedure, the Stage 1 and Stage 2 link-system mappings are prepared as for the non-diversity DARP case.

2.2.1. Example

Figure 1 (which includes an implementation margin) shows a specific example of this methodology, where the figure compares the actual (i.e. link-level simulated) and estimated (via the mapping described above) FER for a) a single-branch DARP receiver, and b) a dual-branch DARP receiver operating on the TCH/AFS5.9 logical channel in the DARP FS Configuration 2/3 40% loaded interference environment with uncorrelated antenna branches and 0dB antenna gain imbalance (AGI). Note that while the mapping predicts the single antenna case well, for the dual-antenna case the simulated receiver FER is about 1 dB better than the estimated FER. This inaccuracy is the subject of ongoing work, but the mapping is at least capable of providing a lower-bound on MSRD network performance enhancement.

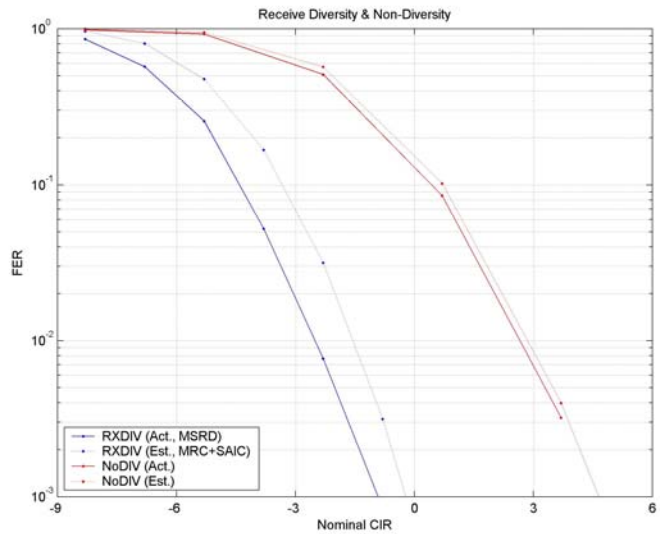

Figure 1 – Example single-antenna and dual-antenna link-system mappings.

3. Interference Modelling for Heterogeneous Modulation Types

Establishing interference models for GMSK voice services was an essential element in defining appropriate performance requirements during the DARP FS. Appropriate interference scenarios for the 8PSK case are, however, insufficiently developed at present.

Interference statistics associated with GMSK-8PSK, 8PSK-GMSK and 8PSK-8PSK combinations were studied during the DARP FS. [8] reported – for heterogeneous voice and GPRS/EGPRS networks – a relatively small number of modulation type “collisions” other than GMSK-GMSK combinations, but this was based on specific assumptions concerning network traffic types. One undesirable conclusion from this might be that a MSRD receiver capable only of dealing efficiently with GMSK-GMSK combinations would perform as well as a more sophisticated approach, and evaluation criteria such as that suggested in [2] – where heterogeneous interference environments are modelled by ‘toggling’ the modulation state of the interfering signals – would presumably also be incapable of reliably discriminating receiver performance since the probability of synthesising an 8PSK interferer would be low based on the *available* data.

Accordingly, the specification – by operators – of reference scenarios for GMSK-8PSK traffic combinations is highly desirable. The number of such scenarios should be strictly limited, but should – in addition to the standard definitions of cell radius, radiated power etc. – include details on:

a) voice and data traffic models, including mappings to logical channels (such as octal voice services)

b) radio resource allocation arrangements, re-use patterns, and traffic partitioning.

Note that the generation of reference interference models for the heterogeneous modulation cases could proceed in parallel with the definition of MSRD performance requirements for the GMSK cases already specified by phase 1 of DARP.

4. Link Level Performance and Testing of MSRD

Previously, [4] reported MSRD reference link performance data for noise-limited conditions. Similar observations on interference-limited conditions are useful.

As before, and as indicated in Figure 2, the diversity signals $\mathbf{Y}_{1,x}$ and $\mathbf{Y}_{2,x}$ for signal x ($x=0$ for the desired user and $0 < x \le N$ for an interferer) may be correlated with an antenna correlation[1] of ρ_x. One possible simplification is to assume the same inter-antenna correlation between all received signals so that $\rho_0 = \rho_1 = \cdots = \rho_N$, although as discussed above this may well not reflect actual field operating conditions. In addition, as discussed in [1], the gain of the second antenna is subject to Antenna Gain Imbalance (AGI) G.

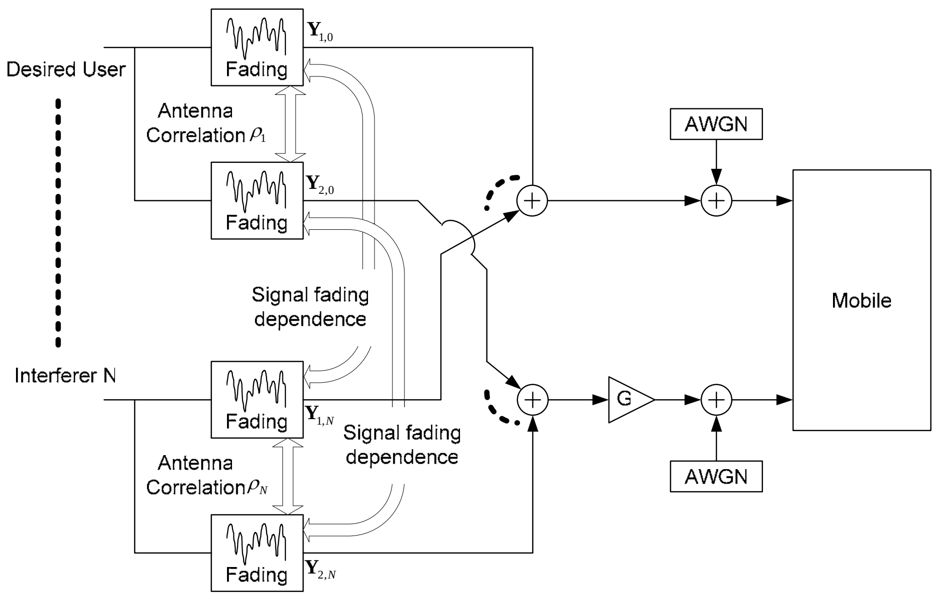

Figure 2 – Link-level model of mobile station receiver diversity.

Assuming independent fading between each desired or interfering signal, the impact of the antenna correlation and antenna gain imbalance is shown in Figure 3 for an exemplary interference limited environment (Configuration 2/3 40% loaded) with ideal frequency hopping at a carrier frequency of 1900 MHz. The AGI G and antenna correlation used are listed in the legend using the couple $(GdB, \rho \sim x)$. The antenna correlation is randomly generated for each burst and for each interferer over the range $\rho - 0.5x$ to $\rho + 0.5x$. Therefore $(4dB, 0.5 \sim 0.1)$ indicates the antenna correlation is generated over the range 0.45 to 0.55 while $(4dB, 0.5 \sim 0)$ indicates the antenna correlation for all bursts and interferers is 0.5. Based upon the values assessed, it can be seen that neither antenna correlation (constant or randomly generated among interferers) nor AGI has a significant impact in an interference limited environment for the particular dual-antenna DARP receiver used in the simulations.

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[1] *Defined as magnitude of correlation coefficient.*

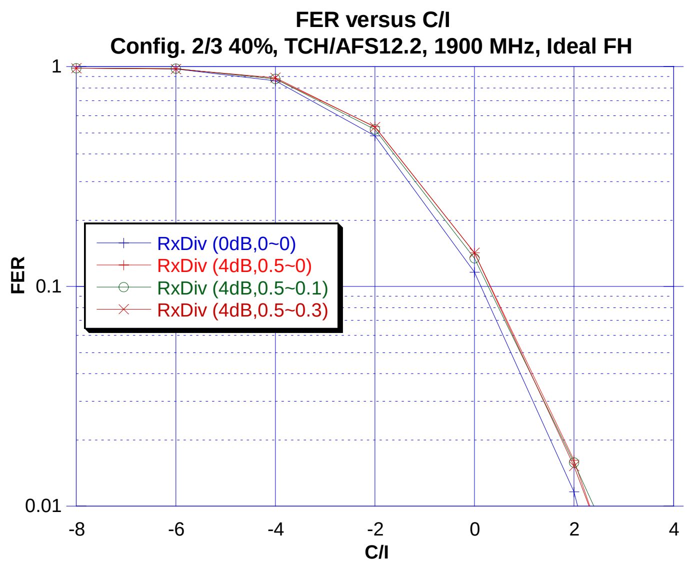

Figure 3 – $\left(GdB,\rho\right)$ Antenna Impairments impact on receive diversity performance

These results are in contrast to those presented in [4] for the noise-limited case where both antenna correlation and to a larger extent AGI had a significant impact on performance. This suggests it may be more important to consider correlation and AGI effects for the noise-limited case than for the interference-limited case.

In fact, the application of antenna correlation and AGI effects in establishing receiver conformance was discussed at the outset of the advanced receiver work on HSDPA in 3GPP RAN WG4 [9], with views expressed both for [10] and against [11] the need to include antenna correlation as a fundamental requirement of performance test cases.

At present, given the more important effort that will be required in GERAN to generate adequate interference models for heterogeneous modulation operation, the simplest approach may be to identify receiver performance requirements on the basis of uncorrelated fading and without AGI, but include those effects in the network performance evaluation work. Given the straightforward feasibility, however, of generating correlated fading waveforms in real-time for conformance testing, one possible solution if GERAN judged correlation to be an essential component of testing, would be to apply correlation only to sensitivity testing, leaving the interference-limited scenarios as uncorrelated test cases.

5. Conclusions

There has been consensus amongst the contributions offered so far to GERAN concerning the potential link-level performance of MSRD. As next steps this contribution suggests that GERAN:

a) establish clearly the network-level benefits of MSRD, including identification of appropriate link-system mappings for the GMSK-GMSK voice service cases already dealt with in the DARP FS.

b) work to identify the necessary reference system scenarios, traffic models and radio resource configurations to permit the construction of heterogeneous or ‘mixed’ modulation interference scenarios. This will require input from system operators, but should leverage the work of the DARP FS to the greatest possible extent.

c) immediately commence work to specify performance requirements for reference GMSK-only test configurations already identified by the DARP WI and embedded in TS 45.005 and TS 51.010, *in parallel* with items a) and b).

6. References

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[3] Philips, AHGEV-018, “Link Level Simulation Specification for MS RX Diversity”, 3GPP GERAN Evolution Ad Hoc, Copenhagen, Denmark, 18-19 May 2005

[4] Motorola, AHGEV-021, “Mobile Station Receive Diversity Considerations”, 3GPP GERAN Evolution Ad Hoc, Copenhagen, Denmark, 18-19 May 2005

[5] 3GPP TR 45.903v6.0.1 (2004-11), “Feasibility Study on Single Antenna Interference Cancellation (SAIC) for GSM networks (Release 6)”

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[10] Nokia, R4-040085, “Consideration of Assumptions to be used for Performance Assessment of HSDPA with Receive Diversity”, 3GPP TSG RAN WG4#30, Munich, Germany, 9-13 February 2004

[11] Motorola, R4-040103, “Simulation Assumptions for HSDPA Rx Diversity”, 3GPP TSG RAN WG4#30, Munich, Germany, 9-13 February 2004

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