Single Antenna Interference Rejection in GSM/EDGE Networks

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***Abstract*—While previous interference rejection techniques suitable for the widely spread GSM/EDGE standard either require multiple antennas or are highly complex, this paper investigates the performance of a low-complexity single antenna interference rejection technique suitable for implementation in today's GSM terminals. The study is performed both on the link level in different scenarios and on the system level with fully dynamic radio network simulations. The link level simulations show significant gains. For example, with a single co-channel interferer, the gain over a conventional receiver is up to 10 dB. On the system level it is shown that the introduction of the proposed interference rejection method in all terminals gives a large increase in downlink speech capacity in a tightly planned GSM network. The strong but sporadic interference in such a network is an ideal environment for efficient interference rejection.**

Keywords— interference rejection; GSM system capacity

I. Introduction

A. Background

The number of subscribers in cellular networks around the world has experienced a rapid growth during the last years. The dominating technology is GSM, which in December 2003 had a subscriber base of 970 million, corresponding to a world market share of over 70% [1]. Traditionally, the design of GSM systems was optimized for coverage and receiver development was focused on combating distortion caused by background thermal noise and the propagation environment, rather than interference from other users. However, the continued subscriber growth in GSM systems and the emergence of new multimedia services has placed increased demands on the scarce radio resource. Means for increasing the spectral efficiency are highly desirable; frequency reuse patterns have continuously been tightened and interference from other users has now become a major limiting factor for optimal system performance. In this context, receivers that perform well in interference limited scenarios are of increasing importance.

B. Interference Rejection

Multiple antennas are widely employed in base stations to improve uplink receiver performance. The multiple diversity branches can be utilized in a variety of interference rejection techniques of varying complexity, e.g. so-called Interference Rejection Combining (IRC) [2]. These techniques generally provide efficient interference rejection in the uplink. Currently, multiple antennas are not as an attractive option for mobile terminals, which means that downlink interference rejection is a more challenging problem. Since much of the future traffic increase in wireless networks is expected to arise from downlink-heavy Internet applications, downlink improvements can be expected to be important for overall system performance. The need for the development of downlink interference rejection methods requiring only one antenna is clear.

Previous work in this area includes different multi-user detection techniques, for example Joint Detection (JD) [3]. In this family of methods, the receiver tries not only to demodulate the signal from the desired user, but also the signal from the interfering user. Since this allows for a complete cancellation of the interfering signal, the result is very effective interference rejection. The drawbacks, however, are high requirements on network synchronism, and that the extreme computational complexity of these methods generally make them unfeasible for practical implementation in terminals.

In this paper, a low-complexity single antenna interference rejection method that still provides significant gains over conventional receiver configurations will be introduced and evaluated. It combines low complexity suitable for implementation in today's terminals with considerable interference rejection capabilities, which will be demonstrated through both link level and system level simulations. The interference rejection method primarily focuses on GMSK modulated interference; 8PSK solutions are not considered in this study. For many years to come, however, GMSK modulated signals can be expected to dominate the traffic in GSM/EDGE networks.

C. Outline

After a brief introduction to the single antenna interference rejection method, some link level simulation results showing the performance in different scenarios are presented. Then, system level simulation results are provided illustrating the system impact of the downlink interference rejection method. The section on system level simulations also includes a brief description of the link-to-system modeling technique that is used. Finally, conclusions are drawn.

II. Single Antenna Interference Rejection

As discussed above, previous interference rejection techniques have either required multiple antennas or high computational complexity. Due to cost reasons, neither of these options is considered attractive for mobile terminals at present.

In this study, a low-complexity single antenna interference rejection method based on the algorithm investigated in [4] will be considered. This method avoids the traditional requirement on multiple antennas for establishment of diversity branches by introducing virtual diversity branches. This is achieved by separating the received signal into its real and imaginary parts [5], i.e. using the I- and Q-components of the signal as diversity branches. This works for one-dimensional modulation schemes, or schemes that can be approximated as one-dimensional [6], such as the GMSK modulation scheme used in GSM.

The estimated baseband signal processing complexity increase of a receiver with the single antenna interference rejection method implemented is only about 30-50% compared to a conventional receiver. This is significantly lower than previously has been possible; e.g. the complexity of a JD receiver is several times that of a conventional receiver.

III. Link Level Simulations

The single antenna interference rejection method has been evaluated by means of link level simulations.

A. Simulation Setup

The link level simulations were conducted with a state-of-the-art GSM/EDGE simulator.

The simulated receiver is depicted in Fig. 1. After the receiver filter, synchronization and channel estimation are performed. After that the interference rejection method is implemented as a pre-processing block. Finally, the signal is fed into the equalizer. As a reference, a conventional receiver without interference rejection capabilities has been simulated as well. The reference receiver is standard compliant.

The desired signal was GMSK modulated, the frequency band was 900 MHz, and E_b/N_0 = 200 dB, unless otherwise specified. Since places where interference rejection is expected to be most useful, i.e. where the level of interference is high, are usually located in urban areas, all results are given for the Typical Urban (TU) [7] channel profile with ideal frequency hopping at 3 km/h. The desired signal utilized GSM Training Sequence Code (TSC) #0 [8], while the interfering signals consisted of random bit streams. All results are presented as raw, i.e. uncoded, Bit Error Rate (BER) performance.

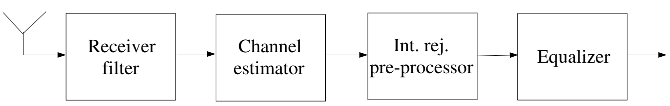

Figure 1. Block diagram of the single antenna interference rejection receiver.

B. Simulation Results

1) GMSK modulated interference

Fig. 2 shows the simulated performance with a single, time-slot synchronized, GMSK modulated, co-channel interferer. It can be seen that the link level gain over the reference receiver is as much as 8-10 dB in this ideal case.

Multiple interferer situations are also common in real networks. Therefore, in Fig. 3 the performance with three time-slot synchronized GMSK modulated interferers is shown. The power distribution is 90% in the strongest interferer, 7% in the second strongest and 3% in the third strongest, which can be seen as an exemplary interference environment in a tight frequency reuse network. In this situation, the interference rejection gain is reduced to 4-4.5 dB, but this is still a significant gain.

Fig. 4 shows the performance with one synchronized GMSK modulated adjacent-channel interferer. It can be seen that the interference rejection gain over the reference receiver is about 2.5-3 dB in this case.

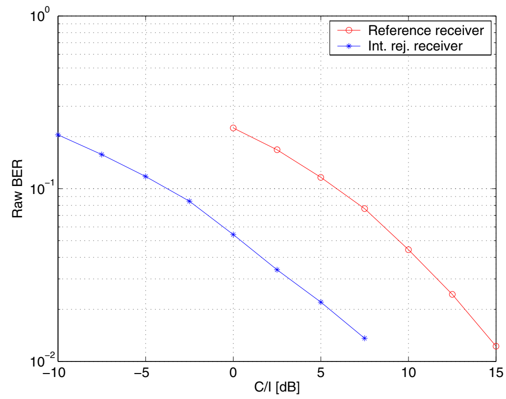

Figure 2. Performance with a single synchronized GMSK modulated co-channel interferer. The channel profile is TU at 3 km/h. Ideal frequency hopping is used.

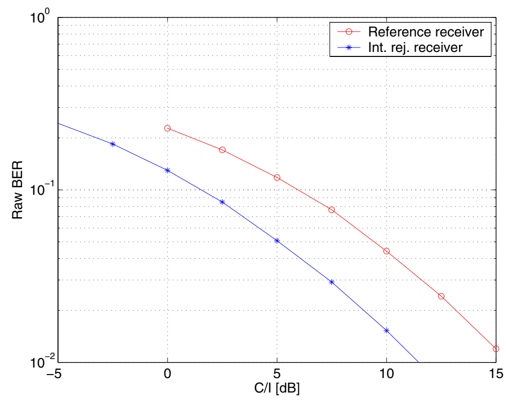

Figure 3. Performance with three synchronized GMSK modulated co-channel interferers. The power distribution for the interferers is 90%-7%-3%. The channel profile is TU at 3 km/h. Ideal frequency hopping is used.

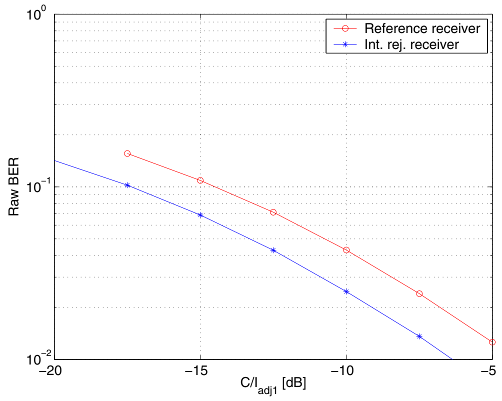

Figure 4. Performance with a single synchronized GMSK modulated adjacent-channel interferer. The channel profile is TU at 3 km/h. Ideal frequency hopping is used.

2) *Sensitivity performance*

It has been seen above that the interference rejection scheme provides significant gains in environments characterized by synchronized GMSK modulated interference. It is, however, important to investigate the performance in other scenarios as well, not the least to make sure that no degradation occurs. One such case is the purely noise limited environment, in which the performance is shown in Fig. 5. It can be seen that there is no degradation compared to the reference receiver.

3) *8PSK modulated interference*

Another scenario, which will occur in GSM networks when EDGE is introduced, is the presence of 8PSK modulated interference. The performance with one time-slot synchronized 8PSK modulated co-channel interferer is shown in Fig. 6. It can be seen that even though the interference rejection method primarily is designed for GMSK modulated signals, it gives a gain of 1.5-2 dB also in this case. The gain is lower than for the case with GMSK modulated interference; however, it should again be emphasized that GMSK modulated interference most likely will dominate in GSM/EDGE networks for many years to come.

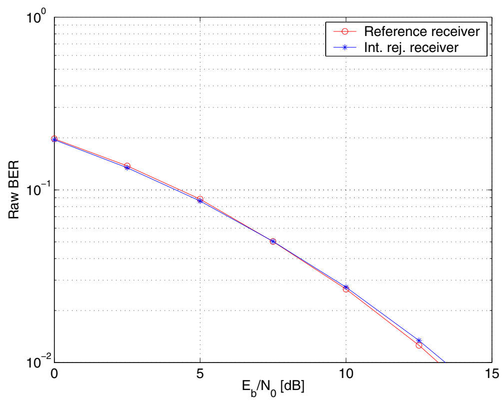

Figure 5. Performance in a purely noise-limited scenario. The channel profile is TU at 3 km/h. Ideal frequency hopping is used.

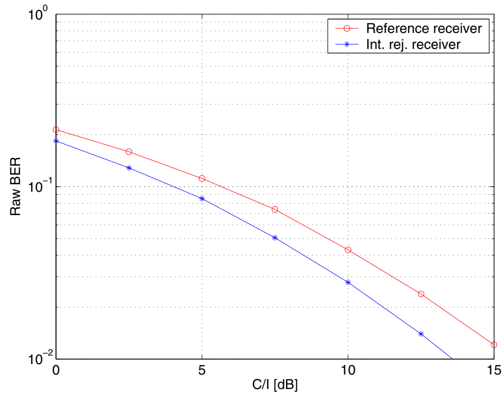

Figure 6. Performance with a single synchronized 8PSK modulated co-channel interferer. The channel profile is TU at 3 km/h. Ideal frequency hopping is used.

IV. System Level Simulations

The introduction of interference rejection in the downlink will have a number of positive impacts on GSM/EDGE system performance. The exact nature of the system gains will depend partly on the configuration of the network, and partly on the policy of the network operator in terms of how the increased robustness of GMSK links is utilized. In this study, the focus will be on GSM speech capacity gains in Fractional Load Planning (FLP) networks [9], but some other system impacts will also be briefly discussed.

A. *Fractional Load Planning*

In an FLP network, tight frequency reuse is used in combination with fractional cell loading and random frequency hopping to enable high spectral efficiency. Even though several cells are potential interferers, the fractional loading and frequency hopping creates an interference environment that is characterized by sporadic bursts of strong interference, often with a single dominant source. Such an environment is ideal for an interference rejection algorithm such as the one considered in this study, as illustrated by the link level simulation results presented above.

B. *Link-to-System Model*

A challenge for system level simulations of interference rejection capable receivers is the modeling of link performance on system level. An attractive technique for conventional receivers is the method described in [10], i.e. a burst level mapping in two steps, from C/I to Bit Error Probability (BEP), and then from BEP to Frame Erasure Probability (FEP). For conventional receivers, the mapping from burst C/I to BEP is independent of the interference environment. This is not true for the interference rejection receiver where the same level of total interference gives different performance depending on, for example, the number of interferers that are present. This means that the interference rejection receiver in principle requires one mapping for each specific interference environment. A single mapping can be used, however, by adding an extra step to the two-step method: From knowledge of the powers of the interferers during a burst, an effective C/I is calculated which is then inserted into the C/I-to-BEP mapping. This effective C/I allows all the different C/I-to-BEP curves that the interference rejection receiver produces in different interference environments to coincide.

The calculation of the effective C/I is based on the fact that the interference rejection method has been shown to be capable of cancel one interfering signal. In the system level simulator this translates into the complete omission of the power of the strongest interferer in the burst C/I calculation. In practice, this often turns out to be too optimistic and a few empirically determined corrections have therefore been introduced. Adjacent-channel interferers are handled like co-channel interferers except for initial power attenuation.

The link-to-system model has been validated and has demonstrated very good accuracy in several interference environments, e.g. for different numbers of co-channel interferers, for different numbers of adjacent-channel interferers, and for mixes thereof. The model is also independent of the system load, which is of great importance for the establishment of accurate results. Impairments, such as training sequences and frequency offsets, are not currently considered in the model, however.

The effective C/I approach is fairly general; the method can model other interference rejection schemes as well [11].

C. *Simulation Setup*

The system level simulations have been performed with a fully dynamic radio network simulator with a regular cell plan. A wrap-around technique was used to avoid border effects. Radio propagation followed the Okumura-Hata model [12] and both shadow and multipath fading were included. GSM frequency hopping [8] was implemented on burst level.

Mobile traffic was created uniformly over the cell area according to a Poisson process. Each terminal tried to connect to the base station with the strongest path gain. If no channels were available, the call was blocked. If successfully connected, each terminal performed a random walk during an exponentially distributed hold time, including cell changes through handover as appropriate. Call dropping due to poor quality followed a leaky bucket algorithm.

The simulated cell plan contained 48 corner-excited cells in three-sector sites. Twelve non-BCCH frequencies were planned in a one-reuse configuration. Each simulation run contained approximately 5000 calls. Both the Enhanced Full-Rate (EFR) codec, and one of the Adaptive Multi-Rate (AMR) codecs, MR59 FR, were considered. The most important simulation parameter settings are summarized in Table I.

System performance was quantified using the mean downlink Frame Erasure Rate (FER) over the course of each call as a quality measure. A user was considered satisfied if the mean downlink FER was below 1%. System capacity was then defined as the average frequency load giving 95% satisfied users. Frequency load was defined as the amount of served traffic per timeslot and frequency. It represents the average fraction of frequencies in the air at any one time assuming 100% voice activity, i.e. ignoring DTX. BCCH frequencies were not included in the capacity evaluations.

TABLE I. SYSTEM LEVEL SIMULATION PARAMETERS

Frequencies per cell	12
Frequency reuse	1
Sectors per site	3
Frequency band	900 MHz
Frequency hopping	GSM pseudo-random [8]
DTX activity factor	0.6
Power control	Quality and signal strength based
Cell radius	500 m
Distance attenuation	35log(d)
Log-normal fading std. dev.	8 dB
Log-normal fading corr. distance	110 m
Mean call hold time	60 s
Average mobile speed	3 m/s

D. *Simulation Results*

Fig. 7 shows the simulated downlink system performance for EFR with and without interference rejection. With interference rejection 100% of the terminals in the network are interference rejection capable. The horizontal dashed line indicates 95% satisfied users and the vertical 2% blocking. It can be seen that the introduction of interference rejection in the terminals approximately doubles the system capacity.

In Fig. 8 the results for MR59 FR are shown. Even in this case it is apparent that the introduction of interference rejection in the terminals significantly increases the downlink speech capacity. The relative gain is, however, lower than for EFR; about 40% compared to 100%. This is largely due to the increased robustness of MR59 FR that allows higher loads in the network. The higher loads create an interference environment where multiple interferers are more common which slightly decreases the efficiency of the interference rejection method as seen in the link level simulation results presented above.

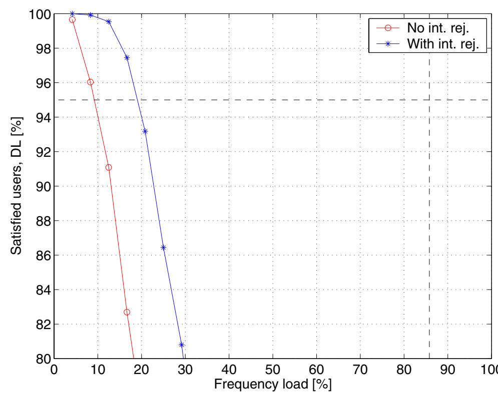

Figure 7. Downlink performance for EFR as a function of frequency load with and without interference rejection.

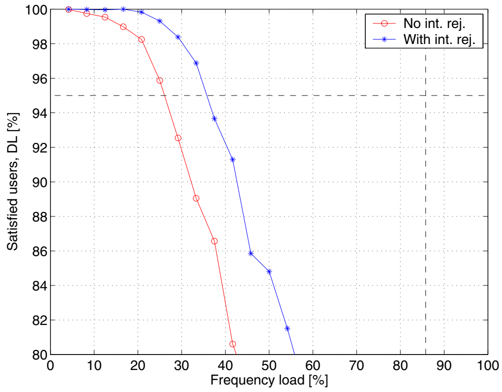

Figure 8. Downlink performance for MR59 FR as a function of frequency load with and without interference rejection.

Nevertheless, these results suggest that the introduction of interference rejection capable terminals and AMR, exemplified here by MR59 FR, in a tightly planned GSM network is highly beneficial and an excellent way to enhance system performance. The two technologies complement each other well since they focus on different parts of the receiver; interference rejection improves demodulation performance, while MR59 FR enhances decoding robustness. In this context, it can be mentioned that it previously has been shown that interference rejection capable terminals can also complement other performance enhancing features, such as adaptive antenna systems, see e.g. [13].

E. Discussion

In this section, it has been shown how FLP networks respond to the introduction of interference rejection capable terminals. The presented results have assumed 100% penetration of interference rejection capable terminals, but gains will also be seen at lower penetration levels. This comes from the fact that the interference rejection capable terminals have a higher interference tolerance, and thus can be served at lower output power, which together with random frequency hopping means lower interference levels to all users. In this way, the power control and frequency hopping functionalities in the system distribute the benefits among all terminals in the network, and thus allow higher loads.

The increased robustness to interference from interference rejection can be used to enhance service quality, instead of, or as well as, system capacity. For speech services, the demonstrated capacity gains can be, partially or fully, traded for improved speech quality, while for data services, the increased robustness to interference can directly be translated into enhanced throughput and shorter transmission times through link adaptation. How much of the link level gain is utilized to improve service quality and capacity and for whom is largely a policy question to be determined by the network operator.

V. CONCLUSIONS

The low-complexity single antenna interference rejection method for GSM investigated in this paper has been shown to provide significant gains, both on link and system level. On link level it has been seen that the interference rejection method gives substantial gains over the reference receiver in GMSK modulated interference, while still being robust to noise and 8PSK modulated interference. For example, with a single GMSK modulated co-channel interferer the observed gain is as large as 8-10 dB.

On system level it has been shown that with the introduction of the proposed interference rejection method, the downlink speech capacity can be significantly increased. This has been shown both for EFR and MR59 FR networks. Another conclusion from this is that the introduction of interference rejection capable terminals and AMR in an EFR network can dramatically boost its capacity. Furthermore, speech quality and data rates can be improved, and all users can benefit from the introduction of interference rejection capable terminals through the use of power control together with random frequency hopping.

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