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Performance of an Adaptive Antenna System in EGPRS Networks

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Abstract

The ever growing demand for mobile communications is pushing the technology towards its very limits. In addition, the current technology is optimized for circuit-switched voice rather than bandwidth hungry services such as wireless Internet and multimedia applications. The third generation mobile systems that will be introduced in the near future are designed specifically to address these limitations. In this paper, we focus on EGPRS, the evolutionary path for the GSM and the TDMA IS-136 systems to provide third generation packet-switched services. We outline a simulation methodology which can be used to evaluate the system level performance of EGPRS for an adaptive antenna system. We then show, via simulations, that the use of the adaptive antenna system can significantly enhance the quality of service and the network capacity of EGPRS. For example, a capacity gain of over 200% can be achieved for the 1/3 frequency reuse scheme.

1. Introduction

The number of subscribers in cellular networks around the world is currently experiencing an enormous growth. It is predicted that by the end of 2000, this figure would reach a stunning 655 million [1]. This growth is putting an increasing demand on network capacity. The two standards currently dominating the cellular market are Global Systems for Mobile Communications (GSM) (61%) and TDMA IS-136 (10%) [1]. Both are based on the time division multiple access technology. Due to the capacity demand and the limited amount of available spectrum, GSM and TDMA IS-136 operators are forced to tighten the frequency reuse as much as possible resulting in interference-limited networks.

Adaptive antenna (AA) systems have been demonstrated in field trials [2] and simulations [3] to be an effective method for reducing downlink interference in GSM systems. Such reduction occurs even for AA systems with limited complexity. These studies have shown that the capacity can be increased by more than 100% in GSM circuit-switched systems. Significant performance improvements have also been obtained in studies carried out in TDMA IS-136 systems [4,5].

The development of GSM is currently focused on packet-switched services. The aim is to enable service providers to offer more wireless data applications for both consumers and business users, including wireless Internet, e-mail, web infotainment, interactive services and multimedia applications.

For GSM, the first solution to provide such packet-switched services is known as the General Packet Radio Services (GPRS) [6]. GPRS is due for global commercial deployment in the beginning of 2001. A further step to improve packet-switched services in GSM comes with the development of Enhanced Data Rates for Global Evolution (EDGE) [7]. EDGE has recently been renamed GSM/EDGE Radio Access Network (GERAN) in the standardization process. EDGE uses 8-PSK modulation to further increase best effort data rates and is able to provide third generation services with data rates up to 384 kbps for wide area coverage. Moreover, in January 1998, EDGE was also accepted as the third generation evolutionary path for TDMA IS-136.

EDGE is designed to coexist with GSM and TDMA IS-136 in their frequency spectra. This is unlike other third generation standards such as WCDMA and cdma2000 which are based on completely different technology and will initially be deployed in the new 2 GHz frequency band. Introducing EDGE will have limited technical impact on the existing infrastructure, particularly GSM, because it is fully based on GSM and consequently will require relatively small changes to network hardware and software. Operators do not have to make large changes to the network structure, or invest in new licenses. For example, EDGE uses the same frame structure, logic channel and 200 kHz carrier bandwidth as today's GSM networks, which allows existing cell plans to remain intact. This makes the technology particularly beneficial to existing operators seeking a way to roll out third generation services rapidly and cost-effectively across large areas of existing networks.

As with the second generation systems, the capacity of EDGE is expected to be interference-limited, particularly in urban areas. Since AA systems are known to be effective in mitigating interference in such scenarios [3] and thus allowing tighter frequency reuse and higher network capacity, we can expect AA systems to significantly improve the performance of EDGE. However, the combination of packet-switched systems and AA systems has so far received relatively little attention and only a few studies on the system level performance is available, e.g. [8].

In this paper, we describe a simulation methodology to study the system level performance of an AA system for EDGE. In particular, we focus on the downlink system level performance of the packet-switched component[1] of EDGE called Enhanced GPRS (EGPRS). We then present simulation results to demonstrate the attainable performance improvements and the influence of the AA system on packet delays. We consider two different types of link quality control (LQC) within the standard, i.e. link adaptation (LA) and the more advanced incremental redundancy (IR) [9,10]. We also discuss how the AA system can achieve large performance improvements in EGPRS.

2. Simulation Methodology

In this section, we detail a simulation methodology to evaluate the system level performance of an AA system in EGPRS networks.

2.1 System setup

We investigate homogeneous systems consisting of 3-sector base station (BS) sites. A conventional sector configuration (100% sectorized antennas) is compared to an AA system configuration (100% AA). For both configurations, we examine the performance of EGPRS for three different frequency reuse schemes: 4/12, 3/9, and 1/3. The three system setups are shown in Table 2.1.

Cell plan	1	2	3
Frequency reuse	4/12	3/9	1/3
Number of clusters	9	9	16
Number of BSs	36	27	16
Number of cells	108	81	48

Table 2.1 Parameters for the system cell plans

All three systems have a cell radius of 1000 m and 7 time slots per cell are used for packet traffic. A wrap-around technique, which tiles copies of the network together with the original, is used to counter border effects. It should be noted that only the downlink traffic is examined since packet-switched mobile services are expected to be downlink-limited. The downlink limitation is due to the limited signal-processing capability in the MSs (constrained by size and power consumption) and the expected asymmetrical world wide web (www) traffic.

[1] There are two components within EDGE, the packet-switched EGPRS and the circuit-switched Enhanced Circuit Switched Data (ECSD). ECSD also uses 8-PSK modulation to increase data rates, though it is not unlike GSM due to its circuit-switched operation.

2.2 Link quality control

In EGPRS systems, LQC exists to take advantage of the wide range of link quality experienced by MSs located at different positions across the cell to increase packet throughput [9]. When LQC is in operation, each packet is transmitted under one of 9 different modulation and coding schemes (MCSs) chosen according to the measured channel or link quality to give the maximum possible throughput. In the simulations, we assumed the case of ideal LQC though in reality the delay and imperfections in channel quality measurements are expected to degrade system level performance. Ideal LQC implies perfect and instantaneous adjustment of MCSs for each packet (or radio block) according to the channel quality measured by carrier-to-interference ratio (C/I). The 9 MCSs are detailed in Table 2.2 [7].

Scheme	Modulation	Code rate	Maximum rate (kbps)
MCS9	8-PSK	1.0	59.2
MCS8	8-PSK	0.92	54.4
MCS7	8-PSK	0.76	44.8
MCS6	8-PSK	0.49	29.6
MCS5	8-PSK	0.37	22.4
MCS4	GMSK	1.0	17.6
MCS3	GMSK	0.80	14.8
MCS2	GMSK	0.66	11.2
MCS1	GMSK	0.53	8.8

Table 2.2 MCSs for EGPRS

Two types of LQC are specified in the EGPRS standard [10]. The first type is LA. It is based on a basic automatic repeat request (ARQ) scheme where an erroneous packet is discarded and a retransmission is requested. The second type, known as IR, does not discard the erroneous packet. Instead, it uses the erroneous packet together with a retransmitted packet(s) that has the same amount of coding but different punctured positions to improve decoding.

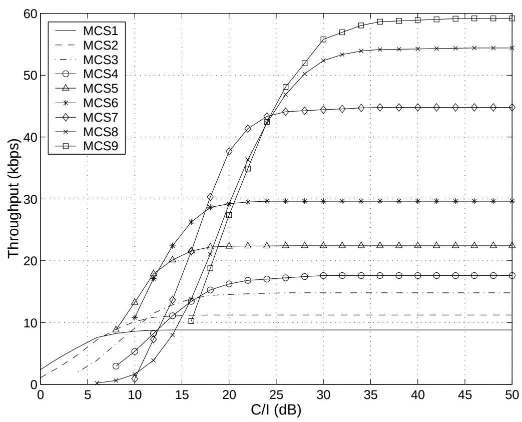

Fig. 2.1 Throughput vs. C/I curves for LA

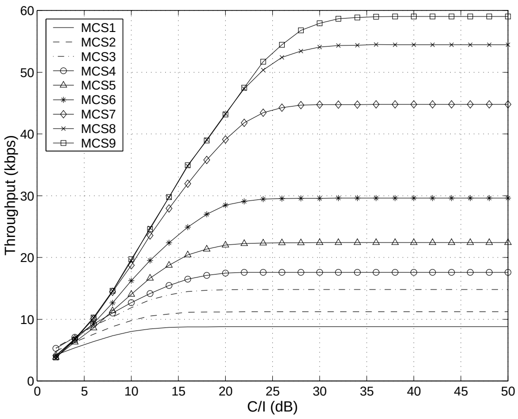

Fig. 2.2 Throughput vs. C/I curves for IR

In the case of LA, the link quality performance curves for the 9 MCSs (see Figure 2.1) are obtained from link level simulations. These link simulations are carried out using the Rayleigh fading ETSI typical urban channel for 3 km/h (TU3) and ideal frequency hopping. The performance curves are used in the system level simulations to map C/I to throughput for each transmitted packet.

The link quality performance curves are also obtained for IR and these are shown in Figure 2.2. These are obtained under the same prerequisites as LA except that no frequency hopping is used. However, despite this disadvantage (ideal frequency hopping outperforms no frequency hopping due to diversity gain), IR is still several decibels better than LA for a given throughput.

2.3 Adaptive antenna system configuration

The AA system investigated is based on a fixed multi-beam configuration comprising of 8 interleaved beams from two Butler beamforming networks. These networks are fed from two orthogonally polarized 4-element uniform linear arrays with an inter-element distance of half a wavelength [2]. The sectorized and the multi-beam antenna patterns used in the simulations are obtained from measurements (see Figure 2.3).

The multi-beam configuration is a simple but effective solution to perform spatial processing. This is due to a system integrated solution enabling the selection (on the radio frequency level) of one of the pre-formed fixed narrow multi-beams for downlink transmission. This minimizes the coherence requirements and removes the need for calibration involved in baseband processing [3]. In the uplink, however, all beams are of course available for diversity reception. Moreover, AA are most probably first needed and deployed in urban environments where the significant angular spread and the existence of multipath mean that more sophisticated array configurations such as a steerable beam solution (an AA system solution that requires baseband processing) could only offer small gains compared to the basic fixed multi-beam configuration [11]. For such cellular frequency reuse networks, higher complexity (more sophisticated) solutions may not be economically viable for operators.

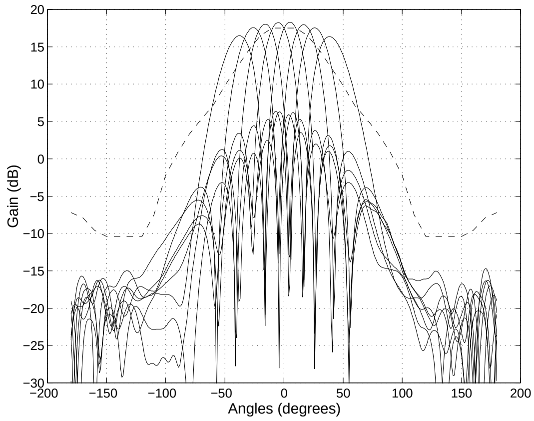

Fig. 2.3 The gains of a sectorized antenna (dashed line) and a fixed multi-beam AA system (solid line) as obtained from measurements.

2.4 Propagation model

As is typical of propagation models for system level simulations, we only take into account large scale lognormal fading and distance attenuation. In particular, the propagation model uses the parameters in Table 2.3. Also note that we only model co-channel interference in the simulations.

Parameters	
System frequency	900 MHz
BS height	30 m
Thermal noise	1.58×10^{-15} W
Distance independent term in Okumara-Hata formula	21
Distance attenuation	3.5
Lognormal fading standard deviation	6
Correlation of lognormal fading between one MS and different BSs	0
Lognormal fading correlation distance	110 m

Table 2.3 Parameters for the propagation model

2.5 Traffic model

Since a packet network is expected to carry primarily www traffic, the corresponding traffic model is designed to mimic this behavior [12]. In essence, MSs are introduced into the system according to a Poisson process. The MSs then receive downlink packets with Pareto-distributed inter-arrival times. The packet sizes are drawn from a truncated lognormal distribution. The parameters used are summarized in Table 2.4.

MS arrival	
Distribution	Poisson
Mean number of MSs	Variable
Packet arrival	
Distribution	Pareto
Packets/MS/second	0.1
Pareto shape, alpha	1.4
Mean number of packets per MS	10
Packet size	
Distribution	Lognormal
Mean	4,100 bytes
Max	100,000 bytes
Added TCP/IP header	50 bytes

Table 2.4 Parameters for the traffic model

2.6 Assumptions

The system level simulations are performed under the following assumptions.

- Perfect beam selection based on gain and shadow fading. The shadow fading in the beams are equal in the same cell.
- No admission control, i.e. all MSs generating packets are either allocated resources or put in the queue.
- First-in-first-out (FIFO) is used for scheduling
- No angular spread over the channel.
- No multi-slot allocation.
- No transmission in idle slots.
- All BSs are time-synchronized with one another.
- Perfect synchronization between MSs and BSs.
- No receiver diversity in the MSs.
- MSs are placed in the systems according to a uniform area distribution.
- Same output power used for GMSK and 8-PSK modulations.
- Only the traffic channel carriers are considered

3. Simulation Results

The simulation results show that the fixed multi-beam AA system provides significant capacity gains in all the systems examined. The gain is largest for the 1/3 reuse scheme, followed by the 3/9 and the 4/12 reuse schemes. This implies that the tighter the reuse scheme, the higher the resulting gain. This is because a tighter reuse scheme has higher inter-cell interference. Since AA systems can effectively reduce co-channel interference, a more marked improvement is seen where the interference is higher.

In Figure 3.1, we show packet throughput performance versus average capacity for the three reuse schemes when LA is used. Note that in this section, the term *packet throughput* takes into account both the queuing delay and the transmission delay (which includes retransmissions) of the transmitted packets. If the benchmark of acceptable quality for MSs is that 90% of the transmitted packets achieve 20kbps per time slot, the plot shows that AA will give a capacity gain of 260% (a factor of 3.6) in the 1/3 reuse case, while the gains are 80% and 50% respectively for the 3/9 and 4/12 reuse schemes.

On the other hand, if we fix the average number of MSs, for example, at 20, then the packet throughput, i.e. quality of service (QoS), is increased from 8.4 kbps to 25 kbps for 1/3 reuse, a gain of 200% (a factor of 3).

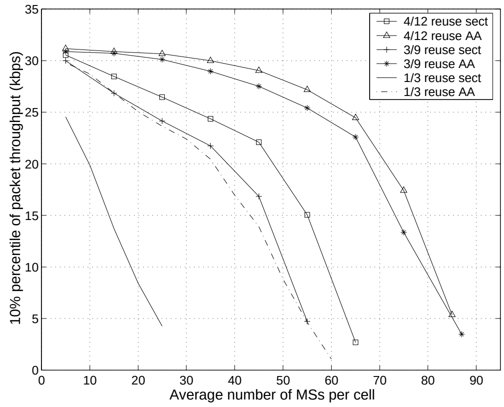

Fig. 3.1 Average packet throughput vs. average number of MSs for the sectorized antennas (sect) and the AA system in 1/3, 3/9 and 4/12 reuse schemes for LA

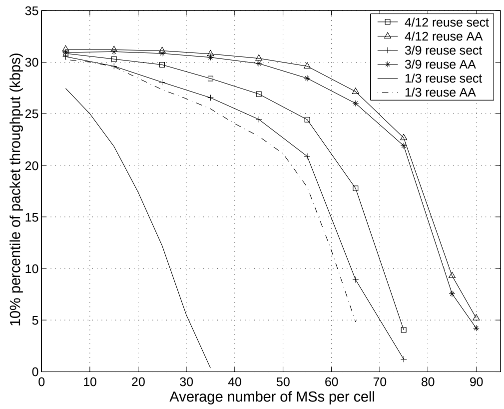

Fig. 3.2 Average packet throughput vs. average number of MSs for the sect and the AA system in 1/3, 3/9 and 4/12 reuse schemes for IR

Using the above benchmark for the results when IR is applied (see Figure 3.2), the capacity gains are 200%, 38% and 26% respectively for the 1/3, the 3/9 and the 4/12 reuse schemes. Note also that in absolute terms the performance of IR is consistently better than LA even though its relative capacity gains are lower.

As is apparent, all the systems investigated here are interference-limited, i.e. C/I determines the system capacity. When the average number of MSs per cell is high, the interference experienced by the MSs is high. Therefore, even though the channel utilization is high, the poorer C/I performance reduces the channel (or over-the-air) throughput, causing the number of packets being queued to increase dramatically. This effect can be seen in the increasing average transmission delay with the increasing average number of MSs, as is exemplified in Figures 3.3 for the 1/3 reuse scheme using LA. Note however that these increases are small, especially in comparison to the increases in queuing delay, suggesting that these systems are very sensitive towards changes in the channel throughput. Simulations have shown that further increases in traffic load would result in continuously growing queues, i.e. an unstable system. Of course, in a real system, we could implement admission control to circumvent this undesirable effect.

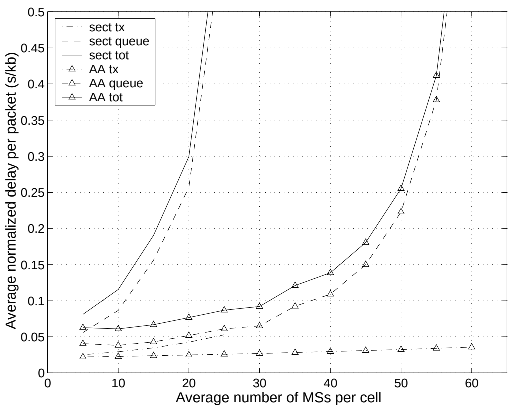

Fig. 3.3 Average normalized delays per packet, i.e. transmission delay (tx), queuing delay (queue) and total delay (tot) for the sect and the AA system in 1/3 reuse for LA.

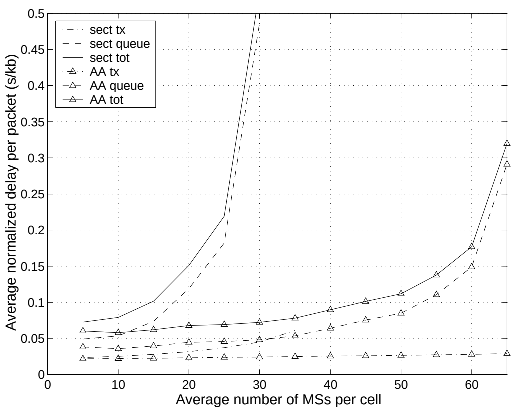

Fig. 3.4 Average normalized delays for the sect and the AA system in 1/3 reuse for IR.

Figure 3.3 also shows that the use of the AA system is effective in reducing interference as can be seen in the flatter slope in the corresponding transmission delay curves. For instance, for the case of the 1/3 reuse scheme and 25 MSs, the use of the AA system reduces the transmission delay from 0.053 s/kbyte to 0.025 s/kbyte. As a result, the system is able to accommodate many more MSs (giving large performance improvements) before this interference-queuing limiting point is again reached. A similar behavior has also been obtained for the 1/3 reuse scheme using IR, as shown in Figure 3.4.

4. Conclusions

This paper outlines the use of AA systems to enhance the ability of EGPRS to provide third generation packet-switched mobile services. A simulation methodology to evaluate and to compare the system level performance of a conventional sector configuration to that of an AA system is described. We have shown that huge QoS and capacity gains can be achieved through the use of AA systems employing a fixed multi-beam configuration. For the 1/3 reuse scheme, a capacity gain of over 200% has been realized for the relatively low complexity AA system compared to the sector configuration.

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