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Link Level Performance of EDGE with Adaptive Antenna Systems

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***Abstract*–GSM has grown to dominate the world cellular market from its humble beginnings about a decade ago. In parallel with that, the number of world cellular subscribers is growing at an astonishing rate. To meet the increasing demand for network capacity, network operators and suppliers alike are investigating different measures to satisfy the demand. One measure calls for the use of adaptive antenna systems. Apart from its ability to alleviate network congestion in existing systems, the adaptive antenna system concept is also expected to be an enabling technology in third generation cellular systems. In this paper, we investigate the link performance of EDGE for a fixed multi-beam adaptive antenna system. In particular, we evaluate and compare the performance of different adaptive antenna system receiver configurations in the spatial dimension under the realistic COST259 channel model.**

I. Introduction

The success story of GSM is clearly seen in its domination of the world cellular market (around 65%) and its subscriber base of 457 millions (Jan 2001) [1]. Furthermore, the latest forecast shows that the subscriber base will continue to grow rapidly and the figure is expected to double by the end of 2004 [1]. To meet the increasing demand for network capacity, and given the limited available spectrum, network operators and suppliers alike are investigating different measures by which the capacity demand may be satisfied.

One popular measure calls for the use of adaptive antenna systems (AASs) that are traditionally of interest only in radar and sonar applications. However, numerous research efforts have demonstrated that AASs could be utilized to increase the capacity of cellular networks, e.g. [2,3,4,5]. In the case of time division multiple access systems such as GSM, AASs located at base stations (BSs) can be used to tolerate a higher level of co-channel, inter-cell interference in the uplink and reduce the level of such interference in the downlink. As a result, for a constant quality of service requirement, tighter frequency reuse schemes may be used to increase network capacity. In particular, limited-complexity switched-beam AASs have been shown in field trials and simulations to increase GSM network capacity by more than 100% [5].

While AASs have the potential to play an important role in supporting the growth of conventional circuit-switched GSM, they are also widely expected to be used in third generation systems. This is because AASs can assist the new systems to fulfill more challenging requirements such as the support of high bit rate packet-switched services and a large number of subscribers.

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For GSM, the evolution to provide packet-switched services began early this year in the first global commercial deployment of General Packet Radio Services (GPRS) [6]. The next step in the evolutionary path is known as Enhanced Data rates for Global Evolution (EDGE) [7,8] which has been accepted as a third generation standard. EDGE uses 8-PSK modulation to increase data rates and offers a best effort data rate of 473.6kbps for wide area coverage.

Recently, we showed that AASs can vastly improve the downlink performance of EDGE packet data networks on the system level [4]. The link performance of EDGE with single-antenna receivers [7] and two-antenna diversity receivers [9] has been reported in previous studies. However, to date, no work has been done on the link performance of EDGE with AASs. Moreover, the channel models used in all previous simulation studies, including those on GSM [2], do not incorporate a realistic spatial channel model such as that made available by the COST259 project [10].

In this paper, we present a simulation methodology for evaluating link level performance of EDGE for a fixed multi-beam AAS. We then show the uplink performance of several AAS receiver configurations in different channel types. The aim is to evaluate their relative merits and conditions in which performance gains are achieved. Moreover, we will qualitatively explain the obtained performance with reference to the different AAS receiver configurations and the characteristics of the propagation channels.

II. Simulation Methodology

In this section, we detail a simulation methodology to evaluate the link level performance of an AAS in EDGE.

A. Simulation Scenario

In the simulator, all mobile stations (MSs) generate and transmit continuous data streams that are structured according to the EDGE radio interface specifications [8]. The signals are passed through the COST259 channel and received at a BS equipped with a fixed multi-beam AAS. The AAS consists of two Butler beamforming networks where a number of the beam outputs are fed into a diversity receiver. In the receiver, the transmitted symbols are recovered and checked for errors. A reference two-antenna sectorized system is also implemented.

In the study, we investigate a scenario with one desired MS and one synchronized interfering MS in the 900MHz frequency band. We find the carrier-to-interference ratio (C/I) that the different AAS receiver configurations require in order to achieve a quality performance of 8% raw bit error rate (BER). The required C/I value is obtained for the desired MS (placed at a fixed position at 0°) and the interfering MS (moved along radial positions) separated by an angle θ (see Fig. 1). The procedure is carried out for a set of angular separations θ's between 0° and 30°.

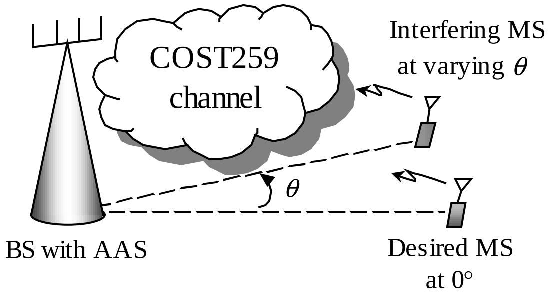

Fig. 1. Simulation scenario: a BS, a desired MS and an interfering MS.

B. *Fixed Multi-Beam Configuration*

The front-end of the simulated AAS is a fixed multi-beam configuration comprising eight interleaved beams from two Butler beamforming networks. These networks are fed from two orthogonally polarized four-element uniform linear arrays (ULAs) with an inter-element distance of half a wavelength [5]. All the antenna elements have a sectorized gain pattern. The pattern is obtained from software calculations (see Fig. 2). The multi-beam patterns are also shown in Fig. 2.

The multi-beam configuration is a simple but effective solution to perform spatial processing. This is because it not only allows the diversity receiver to operate on spatially filtered outputs (a "beamspace") in the uplink, it can form a system integrated solution that enables the selection (on the radio frequency level) of one of the pre-formed fixed narrow beams for downlink transmission. This minimizes the coherence requirements and removes the need for calibration involved in baseband processing [2].

C. *Multi-beam Diversity Receiver*

As part of the AAS, a multi-beam (beamspace and polarization) diversity receiver is devised in the simulator. It conforms fully to the specifications [8]. Receiver filtering, channel estimation and symbol level synchronization are performed on each of the eight beam outputs. We then select M (M = 2, 4 or 8) of these beam outputs based on one of two different selection criteria: received signal power (SP) or signal quality (SQ). These quantities are estimated based on the received signals. The selected beam outputs are then passed through a single-tap pre-combiner [9] where either maximum ratio combining (MRC) or interference rejection combining (IRC) [9] is applied.

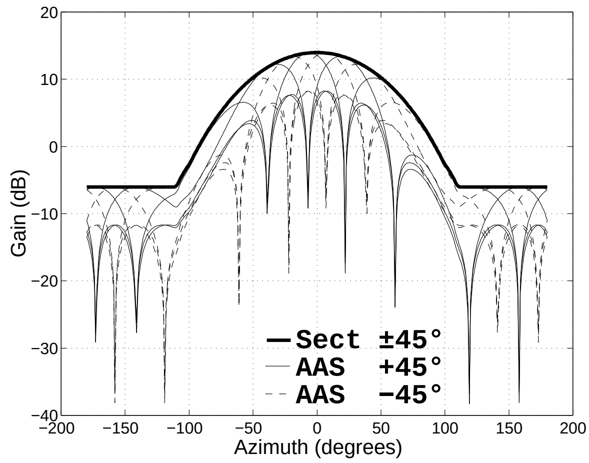

Fig. 2. Antenna gain patterns for the sectorized antennas (±45° polarization) and the AAS (four beams with +45° polarization, and four beams with -45° polarization).

After combining, the signal is passed through an equalizer where the raw BER is determined. Fig. 3 shows a block diagram of the AAS receiver. In the reference two-antenna sectorized system, the outputs of two orthogonally polarized sectorized antennas (see Fig. 2) are fed directly into the diversity receiver. Further, in this study we consider only 8-PSK modulation. The simulation results are thus directly relevant to modulation and coding schemes (MCSs) 5 to 9.

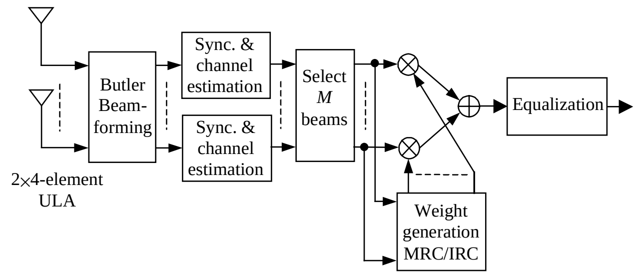

Fig. 3. AAS – Butler beamforming networks and multi-beam pre-combining diversity receiver.

D. *COST259 Channel Model*

The COST259 channel model [10] is a versatile channel model devised under the COST259 project of the European Community. COST259 has been validated using measurements in the 1GHz to 2GHz range, but is expected to be applicable at least in the range 450MHz to 5GHz. It is a wideband directional channel model capable of providing channel impulse responses in both spatial (azimuth and elevation) and temporal domains. It can also provide these in vertical and horizontal polarization components.

The COST259 channel model incorporates, among others, the effects of path loss, fast fading and shadow fading, even though shadow fading is not used for link level evaluations. The radio environment currently implemented is macrocell. The channel types modeled are typical urban (TU), bad urban

(BU), rural area (RA) and hilly terrain (HT), which are generalizations of the GSM channel models with the same names. Examples of the parameter settings are given in Table I. The model inputs include e.g. mobile and base station heights, positions of the mobiles, and carrier frequency of interest. Some input parameters are summarized in Table II. An example of a BU channel realization with two clusters is shown in Fig 4.

TABLE I
EXAMPLES OF COST259 CHANNEL PARAMETERS

Channel type	Parameter		
	Average number of clusters	Typical azimuth spread per cluster (degrees)	Average channel V/H polarization power ratio (dB)
TU	1.17	10	0
BU	2.18	10	0
RA	1.06	5	0
HT	2.00	5	0

TABLE II
EXAMPLES OF COST259 INPUT PARAMETERS

Channel type	Parameter		
	MS height (m)	MS speed (km/h)	BS height (m)
TU	2	3	30
BU	2	3	50
RA	2	250	50
HT	2	100	50

III. SIMULATION RESULTS

As mentioned previously, we use the C/I required for 8% raw BER as the benchmark for comparing the AAS receivers against one another and the sectorized system. The C/I used here is defined as the average power (over all transmitted bursts) of the desired MS signal and the interfering MS signal received at each of the two orthogonally polarized sectorized antennas (of the reference sectorized system), i.e.

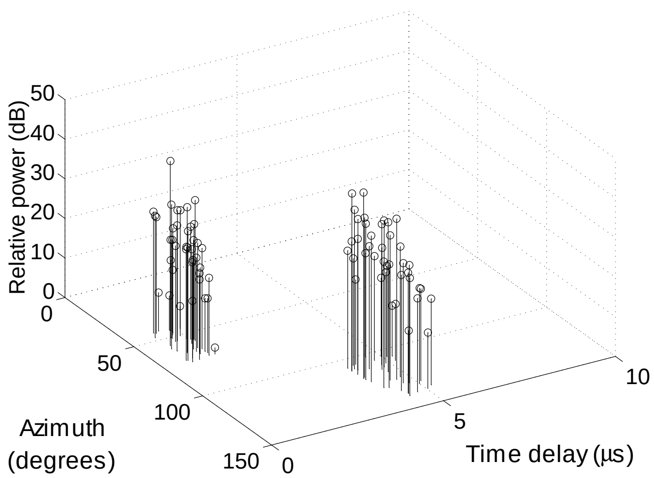

Fig. 4. Example of a BU channel realization with two clusters in the temporal/azimuthal plane.

$$\mathrm{C/I}=10\log_{10}\left(\frac{\mathrm{C}_1+\mathrm{C}_2}{\mathrm{I}_1+\mathrm{I}_2}\right)\ \mathrm{(dB)}, \quad (1)$$

where C_i and I_i are the average powers of the desired MS signal and the interfering MS signal at the *i*th sectorized antenna (*i*=1,2), respectively. In addition, for each spatial (angular and radial) position, a fixed number of Radio Link Control (RLC) blocks (a RLC block consists of four bursts) are used to obtain raw BER. We subject each RLC block to a different scattering and fast fading environment so that an average behavior is obtained.

First, we obtain the C/I curves of interest for the reference two-antenna sectorized system. In Fig. 5, we show the normalized C/I for 8% raw BER of a two-antenna diversity receiver that applies MRC and IRC for different propagation channels. A quick observation of Fig. 5 confirms that on average MRC and IRC are both independent of the angular separation between the desired MS and the interfering MS [2]. Further, the sectorized antenna pattern (see Fig. 2) does not come into play here since both the desired MS signal and the interfering MS signal are measured after the receiver filters. In Fig. 5, we see that the MRC performance does not differ among the different channels by more than 2 dB. This suggests that there is some degree of robustness in the performance of MRC. The performance of MRC appears similar in TU and BU, while it is slightly worse in RA and HT. We postulate that this is mainly due to delay diversity: MRC yields more delay diversity gain in TU and BU than in RA and HT, due to larger cluster delay spread.

The performance of IRC (see Fig. 5), on the other hand, is highly dependent on the type of channel used. The difference is as large as 6 dB between TU and HT. In this case, TU is about 4 dB better than BU while RA and HT are respectively about 1 dB and 2 dB worse than BU. The observed behavior can be explained in terms of delay diversity gain and interference rejection property of the IRC algorithm. First we note that the optimal performance for this channel/receiver setup is obtained when the desired MS signal has a large time dispersion (giving delay diversity gain) while the interfering MS signal is a single ray (allowing optimal cancellation by the single-tap IRC [9]). For the COST259 model, the time dispersion is proportional to the square root of the distance. This means that when we move the interfering MS, we change its time dispersion. In the case of TU, even though the interfering MS has a significant time dispersion in comparison to the RA case, the time dispersion decreases when it is moved closer to the BS to obtain the 8% raw BER point. Therefore, TU presents the best condition for the IRC receiver and gives the best performance. RA gives the same IRC gain but no delay diversity gain, since both the desired MS and the interfering MS have a small delay spread. In BU and HT, both the desired MS and the interfering MS have a significant delay spread. In BU, the spread is due to the large time dispersion in both the first and the additional clusters, while in HT, the delay spread is due to the occurrence of more than one narrow cluster. In this case, the interference rejection property of IRC gives a small gain in both BU and HT, while a high delay diversity gain is realized in BU.

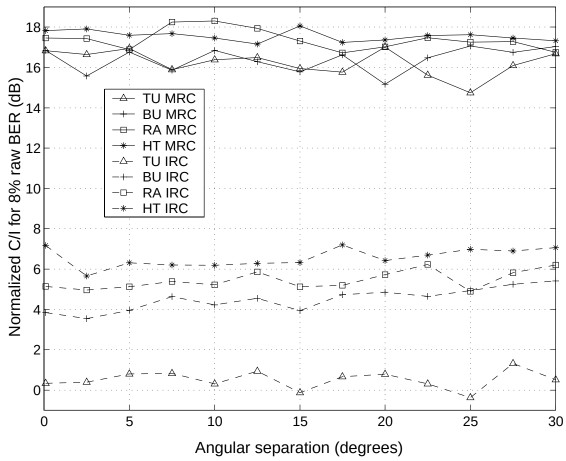

Fig. 5. Normalized angular performance of the two-antenna diversity receiver using MRC and IRC for different channel types.

In the following, we present results in terms of the C/I gains (at 8% raw BER) of AASs relative to the reference two-antenna sectorized system. Although we have investigated all possible AAS receiver configurations (pre-combining of all eight beams or pre-combining of four beams or two beams, selected based on SP or SQ) in the propagation channels TU, BU, RA and HT, we only summarize our main findings in the few examples below.

The performance gains of different AAS receivers relative to the sectorized receiver (all using MRC pre-combining) in the TU channel are shown in Fig. 6. The different receiver configurations are two-, four- or eight-beam pre-combining, where the beams are selected based on SP or SQ. We note that the receivers that select beams based on signal quality (four-beam SQ and two-beam SQ) give the best performance. The two-beam SQ outperforms the four-beam SQ, which in turn outperforms the eight-beam case. This is because most of the desired signal power is contained within two beams. The selection of more beams with poor signal quality only contributes to a higher level of noise in the pre-combining process. On the other hand, the situation is reversed for the SP beam selection cases. This is because the beams with higher signal power not necessarily correspond to those of good signal quality. The selection of more beams in the SP case thus picks up the better quality signals and improves the performance. In this example, we see that the AAS not only outperforms the sectorized system, we can optimize the AAS by careful consideration of the receiver configuration. Further, we observe that the AAS has positive C/I gain even at $\theta = 0°$. This is due to the different instantaneous angular (and temporal) spread of the desired MS signal and the interfering MS signal. Fig. 6 shows that in general the performance gains of the AAS receivers increase with angular separation. This is due to the spatial filtering provided by the Butler beamforming networks of the AAS. However, the pattern nulls at separation angles of 7.5° and 22.5° (see Fig. 2) are not reflected in the two-beam SP case. This follows from the previous argument that beams of good signal quality (those giving high gain for the desired MS and nulls or low gain for the interfering MS) may not correspond to the beams with high signal power. We illustrate this with a simple example in Fig. 7. The desired MS is placed at 0° while the interfering MS is placed at 22.5°, i.e. at the pattern null of beam 1. It is clear that beam 1 has better signal quality than beam 2, while beam 2 has higher received power than beam 1. Further, it appears that the SP criterion has failed to perform favorably compared to the SQ criterion in all cases investigated. Therefore we now focus on the SQ cases.

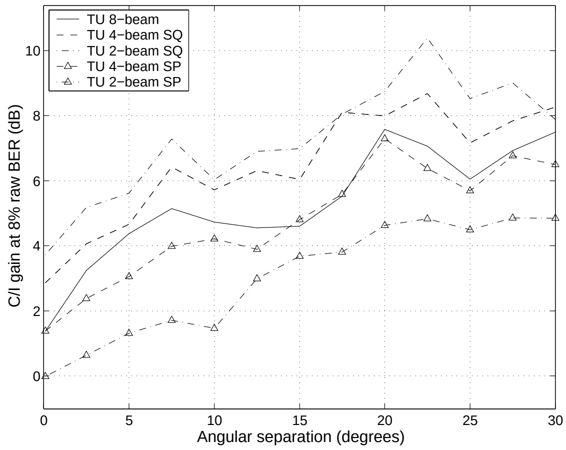

Fig. 6. Performance gain of AAS MRC receivers in the TU channel (SQ and SP).

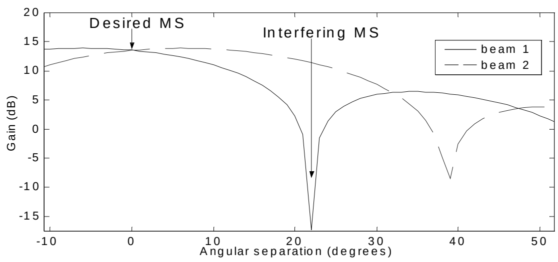

Fig. 7. Scenario for comparing SQ and SP.

For the case of IRC, Fig. 8 shows the C/I gains of three AAS receiver configurations (pre-combining of two, four or eight beams, selected based on SQ) relative to the two-antenna IRC diversity receiver in TU and RA, respectively. Note that the performance gains of these AAS IRC receivers are far larger if compared to the two-antenna MRC diversity receiver (see Fig. 5). Again, we note the performance gain with larger angular separations. As pointed out in the previous example, this is due to the spatial filtering effect of the AAS. It is interesting to note that the two-antenna diversity receiver outperforms the two-beam AAS receiver for small angular separations. This can be accounted for by the different angular distributions of the signals. The two-beam AAS receiver favors the two beams with the best signal quality, of which one beam has far weaker signal strength than the other beam. This deteriorates the interference rejection property of IRC in the two-beam AAS receiver compared to the two-antenna diversity receiver. We also note that the performance of the two-beam AAS receiver does not deteriorate as much in TU as in RA for this scenario. This can be explained by the larger angular and delay spread of TU compared to RA, which results in diversity gain. As can be observed, the larger angular diversity of TU also reduces the effect of the pattern nulls of the AAS. We further note that on the system level, we expect an averaging of the angular link performance gain due to aspects such as frequency hopping, distribution of traffic, etc.

In Fig. 9, we compare the performance of AAS IRC receivers (utilizing SQ for beam selection) relative to the two-antenna IRC diversity receiver in TU and BU, respectively. We observe that by going from the two-beam to the four-beam receiver configuration, the receiver gains 2 dB more in terms of C/I in BU than in TU. This is due to the more frequent occurrence of second clusters for both the desired MS and the interfering MS in BU. The four-beam IRC receiver is able to cancel more interfering signal clusters than the two-beam counterpart. On the other hand, the average number of clusters in TU is 1.17 (see Table I). Hence, while the larger number of beams increases the ability of IRC to cancel more than one interfering signal, there is a low probability of having more than one interfering signal cluster to deal with in TU. As a result, the achieved gain is larger in BU than in TU. In general, we note that IRC receivers perform better by using more beams, as is expected from the increasing degree of freedom the receivers gain for interference cancellation.

IV. CONCLUSIONS

Even though GSM is the dominant player in today's mobile market, the future of GSM rests on its ability to provide third generation services. EDGE has been agreed upon as the evolution path to achieve this goal. This paper investigates the link performance of EDGE used in conjunction with the promising AAS technology. The study shows that while, in general, a simple AAS is able to provide a large performance C/I gain, the gain differs according to the receiver architecture and the propagation environment. Finally, we note that the deployment of EDGE will focus on urban areas, i.e. TU and BU channels, where a good link level performance is obtained with the AAS receivers investigated.

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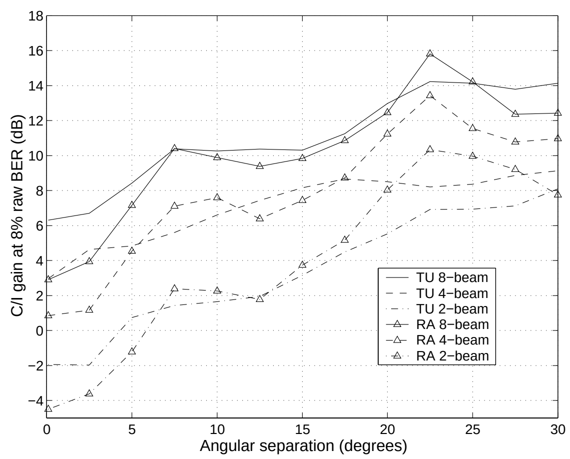

Fig. 8. Performance gain of AAS IRC receivers in the TU and the RA channels (SQ).

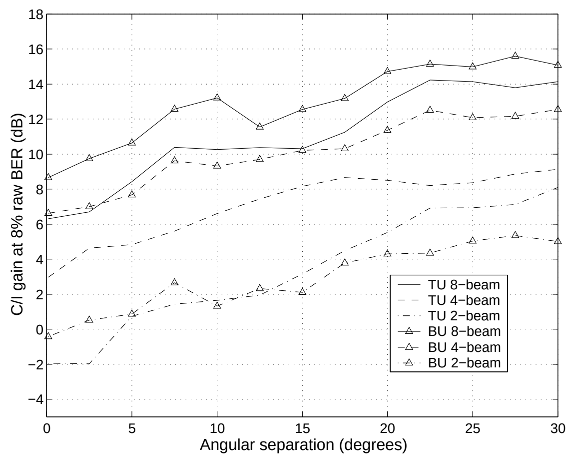

Fig. 9. Performance gain of AAS IRC receivers in the TU and the BU channels (SQ).