Capacity and QoS Enhancement for Data Transmission in EGPRS through Packet Scheduling and Smart Antennas*

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Abstract – **The capacity of the GSM/EDGE Radio Access Network (GERAN) is expected to be limited by interference, particularly in urban areas, and by the quality of service (QoS) requirements demanded by the users. Smart antenna arrays employing beam-forming techniques, commonly known as adaptive antennas (AA), are an efficient technology in mitigating interference in urban areas with low azimuth spread. In EGPRS, the packet data service of GERAN, resource scheduling is responsible for multiplexing users on shared physical channels in order to best fulfill QoS requirements. By using more efficient scheduling algorithms, the resulting QoS is enhanced and, ultimately, it may be exchanged for capacity. In this work, the QoS and capacity gains provided by an AA system and two scheduling algorithms in several EGPRS system configurations are shown. Furthermore, it is demonstrated that, when combined, a tighter reuse scheme, a base station AA system, and an enhanced scheduling algorithm can result in a capacity gain of up to approximately 450% over the reference scenario.**

I. INTRODUCTION

As mobile communications move into the third generation (3G), it is expected that mobile phone users surpass the one billion mark and packet-based multimedia services, including IP telephony, dominate wireless traffic, which will continue to push the ever increasing demand for capacity and bandwidth [1]. But, although new spectrum has been reserved for 3G systems worldwide, spectral efficiency remains a vital issue in next generation wireless technologies. The Universal Mobile Telecommunications System (UMTS), one of the leading 3G standards, has been designed to work on both existing 2G and new 3G spectra. The UMTS network consists of a radio access network (RAN) and an IP-based core network, composed of a circuit-switched and a packet-switched domain.

The RAN technology, according to release R00, may be either a GSM/EDGE RAN (GERAN) or a WCDMA RAN (UTRAN). Both RANs may share the same core network, which, in turn, may be connected to other access networks, such as wireless local area networks (WLANs) and broadband radio access networks (BRANs). It is expected that UTRAN will be solely deployed on new spectrum, while GERAN may also be implemented on existing 2G frequency bands, especially in those networks whose operators have chosen the General Packet Radio Service (GPRS), a technology that allows for packet transmission in GSM or TDMA IS-136 systems, as a 2.5G interim data transport solution.

The packet-switched service of GERAN is called Enhanced GPRS (EGPRS) and it is able to provide 3G services with data rates up to 384 kbps for wide area coverage. EGPRS achieves higher data rates and spectral efficiency than GPRS because it is built on top of the Enhanced Data Rates for Global Evolution (EDGE) concept, which uses 8-PSK modulation in addition to GMSK and an efficient Link Quality Control (LQC) mechanism. There are two LQC modes in EDGE, namely Link Adaptation (LA) and Incremental Redundancy (IR). Link Adaptation is a type I automatic repeat request (ARQ) mechanism that allows for the retransmission of erroneous data and the selection of a modulation and coding scheme that maximizes data throughput according to the link quality. IR is a type II hybrid ARQ mechanism that also allows for the retransmission of erroneous data, but combines information from previously transmitted and recently retransmitted data in the decoding process. This is possible because retransmissions use different puncturing patterns. As a result, IR outperforms LA due to its faster response to variations in the link quality at the cost of increased complexity and implementation costs (e.g. memory buffers for storing received data, computational power for the joint decoding of transmitted and retransmitted data). For more flexibility in the implementation of the LQC mechanism, LA has been specified as mandatory and IR as optional.

The capacity of GERAN is expected to be limited by interference, particularly in urban areas, and by the quality of service (QoS) requirements demanded by the users. Therefore, two ways of increasing system capacity are reducing the interference power level and optimizing radio resource sharing in order to best fulfill QoS requirements.

Intelligent or smart antenna arrays employing beam-forming techniques, commonly known as adaptive antennas (AA), are an efficient technology in mitigating interference in urban areas with low azimuth spread. When applied at the base station side of the radio communication link, the AA beam-forming network generates a radiation

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pattern with a narrow beam pointing at the estimated user direction, thus reducing the interference power level in other azimuth directions. This strategy may be explored in circuit-switched as well as in packet-switched systems, although it may be more complicated to do so in the latter due to in-band control signaling in the shared packet data channel.

EGPRS shares a physical data channel among several users exploring the bursty nature of packet-switched data and its tolerance to system delay. Resource scheduling is responsible for multiplexing users on the shared channel in order to best fulfill their QoS requirements. By using more efficient scheduling algorithms, the resulting QoS is enhanced and, ultimately, it may be exchanged for capacity.

This work studies the performance of resource scheduling in EGPRS combined with smart antennas technology. Several scheduling algorithms have already been evaluated in EGPRS systems [2] and advanced antenna technology has been shown to provide significant performance gains in such systems [3]. Section II describes the simulation tool and the scheduling algorithms used in this system performance evaluation. Section III shows the smart antenna model and the simulation parameters. In section IV, results are presented and discussed. Finally, conclusions are drawn in section V.

TABLE I
RADIO ENVIRONMENT SIMULATOR PARAMETERS

Parameter	Value
Frequency reuse patterns	1/1, 1/3, 3/9 or 4/12
Sector radius	500 m
System frequency	2,000 MHz
Path loss model	37.6 log(d) + 128.1 [4]
Long term fading standard deviation	6.84 dB
Long term fading correlation distance	20 m
Correlation of long term fading between one MS and different BSs	0
Thermal noise density	-174 dBm/Hz
BS antenna height	15 m above rooftop

II. EDGESIM: EDGE SYSTEM-LEVEL SIMULATOR

EdgeSim is a dynamic discrete-time system-level simulation tool developed for the evaluation of EGPRS in the forward link (downlink). It consists of two main blocks: a radio environment simulator and a data traffic simulator. Only the forward link is considered since packet-switched mobile services are expected to be downlink-limited. This is due to the limited signal-processing capability in the MSs (constrained by size and power consumption) and the expected amount of asymmetrical data traffic.

A. Radio Environment Simulator

The radio environment simulator models the service area, user mobility, the radio channel and measures the radio quality perceived by each mobile terminal following recommendations from [4]. It models a macro cellular vehicular environment consisting of a uniform grid with a finite number of hexagonal tri-sectored cells, which may be organized in different frequency reuse patterns. Each sector has a radius of 500 m and the distance between two base stations (BSs) is 1500 m. Mobility is characterized by mobile speeds of 120 km/h, 20% chance of changing direction (maximum turning angle of 45 degrees), and long term fading (shadow fading) decorrelation length of 20 m. Table I presents a summary of the radio environment simulator parameters used in this work.

Mobile users arrive at each cell sector according to a Poisson process, the parameter of which is used to control the offered load. Mobile stations are positioned in their sectors according to a uniform area distribution. Every simulation time step, mobile stations (MSs) move a distance equivalent to the time of four GSM radio frames, which is modeled as 20 ms when the effect of idle radio frames is taken into account.

Border effects are avoided by means of a wrap-around technique (torus-shape model) [5,6]. The size of the grid depends on the number of interfering cells to be taken into account in the signal-to-interference ratio (SIR) calculation. It has been demonstrated that, for simulations not including power control, using 18 interfering cells (i.e. two co-channel tiers) gives a good approximation of the actual SIR value [7]. In order to speed up simulations, though, we have used a grid supporting only one tier of co-channel interference.

Path loss calculation is used for the purposes of both the link budget and for the simplified handover algorithm as proposed by [4]. Handover margins are not considered. The long term fading is dependent on the mobile's master base station only and is correlated throughout its path according to a model proposed by [8]. Short term fading power is exponentially distributed (the amplitude of the received signal is Rayleigh distributed) and averaged over four GSM bursts. The base station power level is constant and equal to the maximum transmitter power (35 dBm).

The SIR calculation requires information of which channels are active at each time step (20 ms). This information is particularly dependent on characteristics of the data traffic, traffic load, and scheduling algorithm. The traffic simulator described in section II-B provides this data. SIR figures are used in assessing the quality of transmitted radio blocks and in executing the LQC mechanism, which is assumed in pure LA mode. LA is considered ideal in all simulations, i.e., the network selects the modulation and coding scheme maximizing the throughput for the mean channel quality (SIR) that will be experienced during the transmission.

B. Traffic Simulator

The data traffic simulator is responsible for the generation and management of user data traffic, and also responds for functions of the Radio Resource (RR) sublayer. It consists of a traffic generator, simplified implementation of the MS-BS protocol hierarchy, transmission queues for each physical channel (time slot), and traffic scheduler. In this work, we consider a World Wide Web (WWW) traffic model found also in other publications [3,9], making it easier to compare results. The traffic service considered in the simulations corresponds to 8 kbps web browsing. Table II shows the parameters of the WWW traffic model used.

TABLE II
TRAFFIC MODEL PARAMETERS

Sessions	
Distribution for number of packet calls per session	Geometric
Mean number of packet calls per session	10 packet calls
Packet Calls	
Distribution for reading times between packet calls	Truncated Pareto
Mean reading time between consecutive packet calls	10 s
Pareto parameters: alpha, k, cut-off value	1.4, 3.45, 120 s
Number of packets within a packet call	1 packet
Packets	
Distribution for packet size	Lognormal
Mean packet size	4,100 bytes
Standard deviation of packet size	30,000 bytes
Added TCP/IP header	50 bytes
Maximum packet size	100,000 bytes

The RR sublayer provides the necessary functions for RR management of packet data channels (PDCHs), Radio Link Control (RLC) and Medium Access Control (MAC) on PDCHs. The MAC function defines the procedures for cell selection and re-selection, resource allocation (queuing and scheduling of access attempts) and the provision of Temporary Block Flows (TBFs) that allow point-to-point transfer of data within a cell between the network and a mobile station. The RLC function is responsible for Backward Error Correction (BEC) enabling the selective retransmission of unsuccessfully delivered RLC/MAC blocks, and for the interface between the Logical Link Control (LLC) layer and the MAC function [10].

Resource allocation in EdgeSim explores the concept of the TBF, which is assigned to one (single slot allocation) or more (multi slot allocation) PDCHs and comprises a number of RLC/MAC blocks carrying one or more LLC protocol data units (LLC frames). When a network protocol data unit, which will be referred here simply as a packet, arrives at the base station it is either allocated radio resources for immediate transmission or it is queued for later transmission.

The decision of which PDCH(s) to associate with a new TBF is based on the criterion of minimizing queue load. When a packet is first scheduled for transmission, it is assumed that a TBF has been established for the transfer of data between the BS and the destination MS and that the MS has been notified of which PDCH(s) to monitor. We further assume that a TBF is maintained until there are no more RLC/MAC blocks to be transmitted or retransmitted (only the RLC acknowledged mode is considered). Therefore, a TBF is maintained until all data for a particular user is exhausted, which includes any packets arriving at a later time but before release of the TBF. In EdgeSim, packet downlink reassignments are not considered, except in the case of cell re-selection (handover).

The traffic scheduler decides the priority of transmission among the packets assigned to each physical channel. The scheduling algorithms are presented in section II-C. In previous versions of EdgeSim [2], RLC/MAC blocks could be scheduled for transmission on any PDCH at any time. This of course could only be accomplished if the MS monitored all PDCHs or if packet reassignments occurred continuously. We understand that this situation does not hold in a real implementation considering single slot capable terminals.

C. Scheduling Algorithms

There are four different scheduling algorithms in EdgeSim. Their performance has been previously evaluated in EGPRS without smart antennas [2]. In this work, we examine those algorithms that achieved, respectively, the worst and the best performance in [2], namely:

- First In First Served (FIFS): traffic is scheduled according to the order of arrival of packets.
- Least Bits left First Served (LBFS): packets with the least bits left to transmit are scheduled with higher priority.

The FIFS algorithm serves as a reference for comparison. We shall use the FIFS algorithm in a system without adaptive antennas as the reference scenario.

III. SIMULATION MODELS AND PARAMETERS

The system level simulations are performed with the parameters shown in Table III. System capacity is evaluated as the spectral efficiency achieved for a QoS of 10 kbps at the 10th percentile of the average packet throughput per user. Average throughput per user was chosen as the dominant QoS parameter despite the fact that it does not accurately describe the user’s effective experienced delay [11,12]. Nonetheless, it was pondered that it is a widely used measure, thus enabling comparisons with a larger set of similar works.

A. Adaptive Antenna Model

Smart antennas are among the many methods of improving the performance and capacity of mobile communications systems. AA is a beam-forming approach among the several smart antennas categories [13]. An AA system consists of an antenna array, usually composed of a number of equally spaced antenna elements, and a beam-forming network, responsible for the adjustment of the gains of the individual elements of the antenna array. The set of tap gains of the array determines the AA system's radiation pattern, which gives the amount of amplification or attenuation in all azimuth directions (horizontal polarization only is considered in this work). The procedure adopted in order to control the set of tap gains of the antenna array, and that ultimately generates a desired radiation pattern, is called the beam-forming algorithm.

TABLE III
SIMULATION PARAMETERS

Parameter	Value
Simulation time step	20 ms
Number of iterations for transient state	50,000
Number of iterations for drawing statistics	50,000 (high loads) 100,000 (low loads)
Tiers of interference	1
Carriers per sector	1
Traffic channels	7
Data transfer direction	Downlink only
MS multi slot capability	Single slot only
BS antenna system	90^o sector antenna AA system
Stepped function beam width (*BW*)	30^o
Stepped function side lobe level (*SLL*)	-18 dB
Polling frequency for the acknowledgement message	16 RLC/MAC blocks
LQC mechanism	LA mode
MCS selection	Ideal (no delays and SIR is known a priori)
MCS update frequency	20 ms
Traffic scheduling algorithms	FIFS LBFS

A simple AA system model is used in EdgeSim avoiding time-consuming beam-forming algorithms. It corresponds to a simplification of the normalized radiation pattern of an eight-element ULA (Uniform Linear Array) with a spacing of half the wavelength between the elements. The choice for an antenna array with eight elements meets financial costs and implementation complexity restrictions as well as the fact that it was shown in [14] that only a minor improvement is achieved by using antenna arrays with more than 6-8 horizontal elements in urban environments with reasonable azimuth spread. All array elements correspond to a typical GSM network antenna with a horizontal pattern corresponding to a main sector of 90 degrees, as shown in Fig. 1.

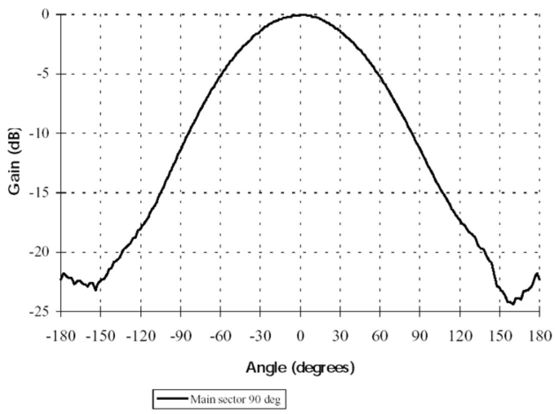

Fig. 1. Horizontal antenna pattern of the sector antenna.

The normalized radiation pattern of the AA system is obtained from the superposition of the radiation patterns of the sector antenna in Fig. 1 and a stepped function. The stepped function simplifies the normalized adaptive radiation pattern of an 8-element ULA, using omni directional antenna elements, under the assumptions that the power level within the beam width *BW* (null-to-null) is constant at 0 dB, and also constant outside it at *SLL* (side lobe level) decibels, *SLL* < 0. The constant side lobe level assumes the pattern nulls to be filled up to *SLL* and the front-to-back ratio to be also equal to *SLL*. The stepped function is described as (see Fig. 2) [15]:

$$G(\phi)_{dB} = \begin{cases} 0 & for \quad -BW/2 \le \phi - \phi_0 \le BW/2 \\ SLL & otherwise, \end{cases} \qquad (1)$$

in which $G(\phi)_{dB}$ is the antenna gain in decibel units in the direction ϕ, *BW* is the beam width, *SLL* is the average side lobe level in dB, and the angle ϕ_o is the direction towards the desired mobile.

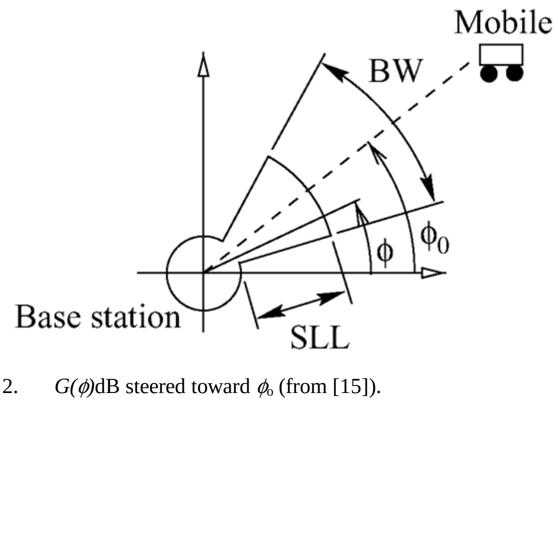

Fig. 2. $G(\phi)$dB steered toward ϕ_o (from [15]).

IV. Simulation Results

Fig. 3 illustrates the QoS and capacity gains provided by the introduction of the AA system in 1/1, 1/3, 3/9, and 4/12 frequency reuse patterns using the FIFS scheduling algorithm. At the 10 kbps QoS measure adopted for evaluation of spectral efficiency, the AA system yields capacity gains of 425% (a factor of 5.25), 172%, 72%, and 47%, respectively. It results that the tighter the frequency reuse pattern and, consequently, the higher the co-channel interference levels, the greater the gains provided by the adaptive antennas.

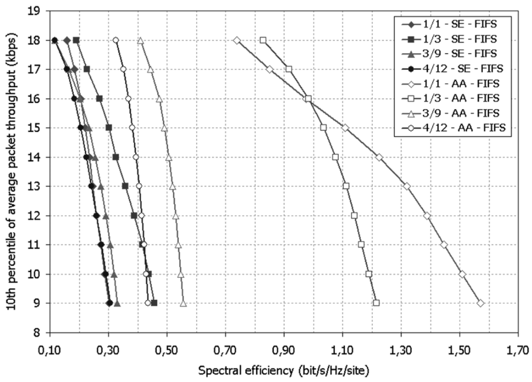

Fig. 3. QoS requirement versus spectral efficiency for the sector antenna (SE) and the AA system in 1/1, 1/3, 3/9, and 4/12 reuse patterns using the FIFS scheduling algorithm.

Fig. 4 compares the performance of FIFS and LBFS in systems with sector and adaptive antennas. Only the 1/1 and 1/3 reuse patterns were evaluated. Note that in systems with high co-channel interference (1/1 SE and 1/3 SE), both scheduling algorithms perform the same. The explanation lies in the fact that there is little or no queuing in these scenarios even at loads close to the QoS limit and, therefore, any scheduling method will result in similar performance. As queues build up, in lower interference scenarios such as those with the AA system, the performance difference of both scheduling algorithms stands out, LBFS achieving better results in both 1/1 and 1/3 reuse patterns. Note the smaller spectral efficiency gain provided by LBFS over FIFS in 1/1 AA in comparison to the 1/3 AA, even though 1/1 AA yields higher capacity figures. Fig. 5 elucidates this fact depicting QoS versus offered load per sector, i.e., per carrier, instead of spectral efficiency, which is a measure normalized by the total system bandwidth. Since the interference level in 1/3 AA is lower than in the 1/1 AA case, the queues are larger in 1/3 AA, resulting in more room for optimization of radio resources through scheduling.

Fig. 4 also shows the performance of the reference scenario (4/12 SE + FIFS), which is similar to 1/1 SE, in particular close to the QoS limit. Fig. 6 shows the trade-off in capacity and QoS gains of several scenarios relative to the 10 kbps QoS parameter and the respective system capacity of the reference scenario. This graph is particularly useful in showing the QoS gain immediately provided by the introduction of a new system-enhancing concept, such as changing the frequency reuse pattern, introducing an AA system or changing the scheduling algorithm, and observing QoS degradation as the system load is increased towards the capacity limit.

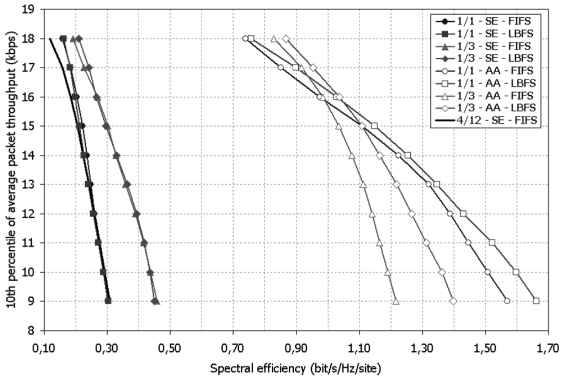

Fig. 4. QoS requirement versus spectral efficiency for the sector antenna (SE) and the AA system in 1/1 and 1/3 reuse patterns using the FIFS and LBFS scheduling algorithms (4/12 SE + FIFS is shown in the graph as the reference scenario).

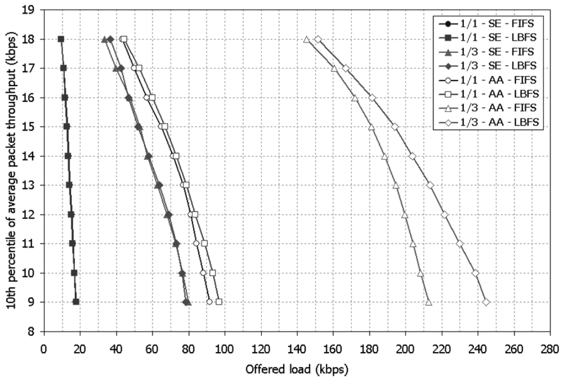

Fig. 5. QoS requirement versus offered load per sector for the sector antenna (SE) and the AA system in 1/1 and 1/3 reuse patterns using the FIFS and LBFS scheduling algorithms.

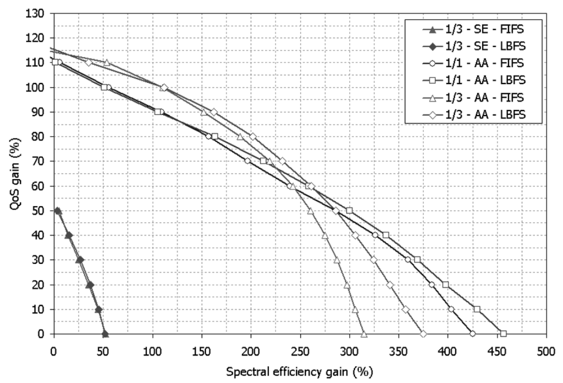

Fig. 6. Trade-off between QoS and capacity gains provided by enhancing technology concepts relative to the reference scenario.

V. CONCLUSIONS

This paper presents performance results of an AA system and two scheduling algorithms in EGPRS systems. EdgeSim, a dynamic discrete-time system-level simulation tool, was used to evaluate the performance of several scenarios combining frequency reuse pattern, BS antenna type and scheduling algorithm. It has been shown that AA systems provide high QoS and capacity gains. Also, tighter reuse patterns result in higher gains. The FIFS scheduling algorithm achieves the same performance as LBFS for high interference scenarios, such as 1/1 and 1/3 reuse patterns with sector antennas, in which the offered loads per sector are low and the channel queues are negligible. At lower interference scenarios, such as the cases of systems employing adaptive antennas, queuing is significant and the LBFS algorithm outperforms FIFS. It has been shown that, combined, a tighter reuse scheme, a BS AA system, and LBFS scheduling can provide a capacity gain of up to approximately 450% over the reference scenario.

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