EGPRS2 Uplink Performance for GERAN Evolution

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***Abstract*— This paper presents a higher performance uplink concept for the evolution of GSM/EDGE Radio Access Network (GERAN). The EGPRS2 UL concept can operate at 1.2 times the current GERAN symbol rate, and employ 4-, 16- and 32-QAM constellations, concatenated with convolutional codes.**

The interference introduced by the higher transmit signal bandwidth is mitigated by the use of interference rejection combining (IRC) receivers. We explore both noise and interference limited scenarios, in link and system level simulations.

The simulation study shows that the user peak data rates can be increased up to 100%, and that the average throughput over practical signal to noise ratio (SNR) conditions can gain up to 50%. Therefore, coverage and user bit rates can be significantly improved without requiring additional radio frequency spectrum.

I. INTRODUCTION

The GERAN evolution is an important step for single mode GSM and multimode GSM/WCDMA or GSM/LTE operators, in order to support the service continuity in GSM networks. This evolution is currently a subject of standardization in the Third Generation Partnership Project (3GPP). The design objectives for the evolved networks include significant improvements on user data rates, spectral efficiency and coverage, while avoiding impacts to the existing GSM networks [1].

The performance objectives [1] aim to increase the spectrum efficiency by 50%, double the peak data rates and obtain a 50% gain in average data rates, for both downlink and uplink. The compatibility objectives target avoiding impacts to the existing GSM/EDGE networks, frequency planning and legacy services. In this sense, it is very important to ensure that the legacy mobile terminals can work properly in the evolved networks. Some mobile station implementation aspects, like complexity and power consumption, have also been specified.

A higher bandwidth transmission concept for the GERAN system was first introduced in [2], and more reasoning and theoretical background information has been presented in [3]. The studies in [2] showed that either an increased number of antennas and/or wider frequency bandwidth are needed, in order to substantially increase the data rates of the GSM links.

In particular, the Dual Symbol Rate (DSR) technique presented in [3] uses twice the signal bandwidth per carrier, compared to the current GSM links.

Another higher symbol rate scheme (the Higher Uplink performance for GERAN Evolution, HUGE) was introduced in [4]. This concept is now included in EGPRS2 Uplink (UL) 3GPP specifications, and differs from the DSR concept in that 1) the symbol rate is 1.2 times the normal GSM symbol rate; and 2) the symbol constellations can be 4-, 16- and 32-QAM, which are coupled with specifically tailored convolutional coding schemes. In this paper, we introduce the EGPRS2 UL concept and provide performance results, for both coverage (sensitivity) and interference limited scenarios.

The paper is organized as follows: Section II presents the EGPRS2/UL concept for GERAN evolution, the simulation scenarios are explained in Section III, and the simulation results are shown in Section IV. Section IV-C studies the impact of increased adjacent interference power on legacy voice services. Conclusions are provided in Section V.

II. EGPRS2 UPLINK CONCEPT

The GERAN consists of a layered protocol structure, and the EGPRS2 UL concept impacts only the radio interface protocols below the Logical Link Control (LCC, Fig. 1) [5]. Therefore, the EGPRS2 UL concept does not require any new base station sites or new spectrum, and has no impact on the existing cell or frequency plans. The EGPRS2 services come with two Network and Mobile Station (NW/MS) support levels, namely Level A and Level B, to ensure support for large amounts of legacy network infrastructure. To further comply EGPRS2 UL with the legacy network hardware, two transmit pulse shaping options for mobile stations are defined for Level B, where either Linearized GMSK pulse [6] or a new spectrally wide pulse [7] can be selected by network.

In GERAN, the symbol duration for GMSK and 8PSK modulation is 3.69 [μs], thus yielding 270 [kHz] signal bandwidth. The EGPRS2 UL symbol duration is either 3.69 [μs] or 3.077 [μs], for MS/NW support Level A and Level B respectively. This leads to 325 [kHz] signal bandwidth for Level B. Figure 2 shows the power spectra for three Level B signals, together with three overlapped GSM/EDGE (or EGPRS2 level A) spectra. The carrier separation is 200 [kHz]. The new modulation scheme for NS/MS Level A is 16-QAM and for Level B QPSK, 16-QAM and 32-QAM are used.

Meeting the performance enhancement objectives [1] can be accomplished through GERAN evolution with the EGPRS2 UL concept. This can be done within the existing spectrum and carrier bandwidth allocation. Note that the adjacent carriers in

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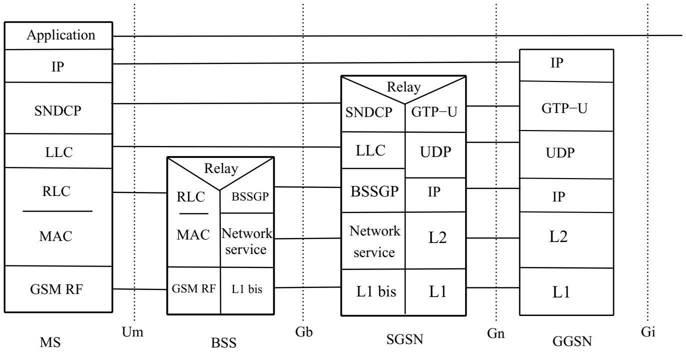

Fig. 1. EGPRS/EGPRS2 user plane protocol stack used in A/Gb mode, according to [5]

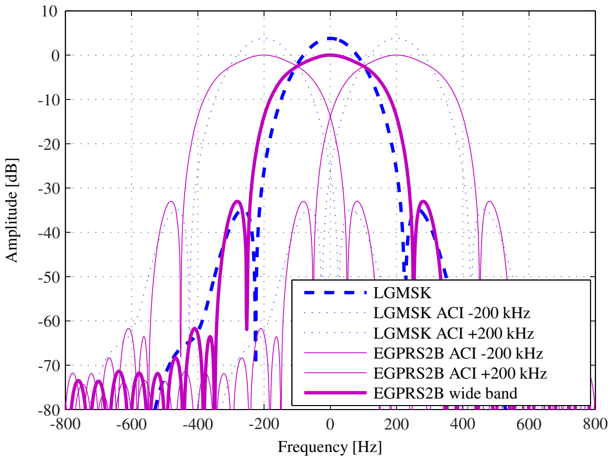

Fig. 2. Comparison of three EGPRS2 UL level B wide band spectra and three EDGE spectra with 200 kHz carrier spacing

TABLE I

EGPRS2 UPLINK CHANNEL CODING PARAMETERS

Scheme	Code rate	Header code rate	M-QAM	RLC blocks per radio block	Family	Data rate kb/s
UAS-11	0.95	0.36	16	3	A	76.8
UAS-10	0.84	0.36	16	3	B	67.2
UAS-9	0.71	0.36	16	2	A	59.2
UAS-8	0.62	0.36	16	2	A	51.2
UAS-7	0.55	0.36	16	2	B	44.8
UBS-12	0.96	0.35	32	4	A	118.4
UBS-11	0.89	0.35	32	4	A	108.8
UBS-10	0.71	0.35	32	3	A	88.8
UBS-9	0.70	0.32	16	3	B	67.2
UBS-8	0.60	0.33	16	2	A	59.2
UBS-7	0.46	0.33	16	2	B	44.8
UBS-6	0.62	0.35	4	1	A	29.6
UBS-5	0.47	0.35	4	1	B	22.4

EGPRS2 UL Level B are designed to overlap, and the additional interference is mitigated by using interference rejection combining (IRC) receivers, e.g. [8]–[10]. The channel coding schemes are described in the new 3GPP standards [11], [12].

Two filter types are specified for EGPRS2 uplink: 1) a spectrally wide pulse, optimized to meet the existing network interference requirements, and 2) the existing linearized GMSK pulse, for scenarios where the wider pulse shape might not be suitable, e.g., on the edge channels in cellular network operator allocations, where there is no guard channel. The chosen wider pulse shape is not based on the theoretical spectrum masks of GMSK or 8PSK modulation, but specified by the typical network frequency planning rules, where the levels of co-channel interference dominate over the adjacent channel levels.

Interference limited networks are co-channel limited in most cases, thus higher adjacent channel interference by a wider transmit spectrum is compensated by lower co-channel interference. The impact of a wider pulse shape on legacy voice services in a mixed voice-data traffic network has been studied in [13]. Dynamic system simulations in an interference limited network showed that higher symbol rate using wider pulse have very similar impact on voice traffic quality, compared to the case when legacy EDGE data is interfering voice traffic.

III. SIMULATION MODEL

The performance of the EGPRS2 UL concept has been studied by means of both link and system level simulations. This section describes the simulation model upon which the results given in Section IV are based.

A. *Link level model*

The link level simulation setup considers both Level A and Level B according to Table I. The base station is assumed to employ two receive antennas due to better balance uplink performance with the downlink, and deployments now assume antenna diversity in the vast majority of cases and an IRC receiver. Channel coding parameters are listed in Table II.

The radio propagation is simulated with multipath fading [14]. Noise limited conditions are simulated with additive white Gaussian noise

B. *System level model*

System level simulations are based on a regular network with 75 cells in urban environment. Reference EGPRS UL is compared to EGPRS2 UL Level B performance. Table I presents studied network scenario and simulation parameters. Frequency reuse factor of 3/9 with file transfer protocol (FTP) traffic data was used. For base station receiver antennas two antenna IRC was assumed for both reference and EGPRS2.

IV. EGPRS2 UPLINK CONCEPT PERFORMANCE

A. *Link level*

The link level performance of the EGPRS2 UL concept was studied in noise limited scenarios in Typical Urban propagation model using 50 km/h mobile station velocity and ideal frequency hopping. Performance results for EGPRS2 UL

TABLE II

EGPRS2 UPLINK PARAMETERS FOR LINK PERFORMANCE EVALUATION

Parameter	Level A	Level B NB	Level B WB
Carrier spacing [kHz]	200	200	200
Symbol rate [symb/s]	270833	325000	325000
Symbol modulations	16-QAM	QPSK, 16-QAM, 32-QAM	QPSK, 16-QAM, 32-QAM
Tx pulse shape	Linearized GMSK	Linearized GMSK	Wideband pulse [7]
Burst duration [μs]	577	577	577
Symbols/burst	156.25	187.5	187.5
Symbol duration [μs]	3.69	3.077	3.077
Frequency [MHz]	900	900	900
Propagation	Typical urban	Typical urban	Typical urban
Speed [km/h]	50	50	50
Frequency hopping	Ideal	Ideal	Ideal
Channel coding	Convolutional	Convolutional	Convolutional
Antenna diversity	IRC	IRC	IRC
Number of antennas	2	2	2

TABLE III

STUDIED NETWORK SCENARIOS AND SIMULATION PARAMETERS

Parameter	Value	Unit/comment
Number of cells	75	25 three sector sites
BS antenna beamwidth	65	deg
Site-to-site distance	1500	m
Number of TRXs/cell	4	
BS antenna diversity	yes	2-way IRC
Bandwidth	7.2	MHz
Frequency	900	MHz
Reuse	3/9	
Hopping	Random FH	
Channel model	Typical urban	TU3
Slow fading correlation distance	50	m
Slow fading σ	6	dB
MS speed	3	km/h
Traffic model	FTP data	120 kB
Data power control	Yes	

Level A and Level B (wideband transmit pulse shape) are presented in Figures 3 and 4, respectively. Figure 5 shows the throughput envelopes of each EGPRS2 UL modulation and for each specified NW/MS support level. Practical signal to noise ratio in typical coverage limited network is characterized to range from 5 to 30 dB, where 5 dB SNR denotes coverage limited conditions, 15 dB average conditions and 22-30 dB for good conditions.

EGPRS2 Level A in Figure 3 outperforms EGPRS with a 30% higher data peak rate per timeslot (76.8 kbit/s vs. 59.2 kbit/s). However, since Level A is not operational below the average network conditions, it is not able to improve the coverage of the packet data services.

EGPRS2 Level B with wide band transmit pulse in Figure 4 outperforms EGPRS with a 100% higher data peak rate per timeslot (118.4 kbit/s vs. 59.2 kbit/s), and reaches about 15 kbit/s better data in average network conditions. Since Level B contains adaptive modulation, it is able to improve the packet data service throughout the whole practical signal to noise ratio (SNR) range of 5 to 30 dB. In good channel conditions, the user data rate can reach over 100 kbit/s per one timeslot.

Figure 5 compares the throughput envelopes of each EGPRS2 UL Level A, Level B with Linearized GMSK transmit filter, and Level B with wideband transmit filter. Level B with wide band transmit filter is providing the best throughput throughout the whole SNR range.

A pulse that has a wider spectrum than the current Linearized GMSK pulse is needed with the higher symbol rate of EGPRS2 UL Level B, because the reduced symbol duration necessitates a filter with a lower inter-symbol interference. A wider spectrum also provides benefits in the coverage and interference performance since it results in lower peak-to-average ratio and lower co-channel interference. The impact of narrow transmit pulse with the higher symbol rate of Level B is seen in Figure 5, where 5 to 10 dB degradation is experienced due to limited bandwidth.

B. *System level*

Data performance was evaluated for different user percentiles (10th, 50th and 90th). The results are shown in Figure 6. The best tenth of the users obtained close to the maximum throughput for all studied load conditions, and, it can be seen that nearly double throughput was achieved with EGPRS2 compared to EGPRS (225 kbit/s for EGPRS and 425 kbit/s for EGPRS2). On the 50th percentile, 90 to 100% throughput gain was also achieved. Furthermore, it can be seen that the worst 10th percentile of the EGPRS2 users achieved better than EGPRS maximum throughput, i.e., EGPRS2 was able to provide higher users throughputs all over the network.

C. *Impact to legacy services*

In this section, we consider the impact to the voice services, due to interfering EGPRS2 connections using the wideband pulse (EGPRS2-B-WB). Since the level A connections use the same bandwidth as the existing services, they do not increase the interference levels in the network.

We assume an interference-limited scenario, where a full-rate speech channel is interfered by two co-channel (CCI) and one adjacent channel (ACI) interferers, as described in the DARP test scenario 2 (DTS-2) [14].

Compared to interferers using the linearized GMSK pulse shape, an EGPRS2-B-WB interferer delivers less CCI power, but more ACI power, as seen in the spectra plots in Figure 2. The impact to voice services depends, however, on the network deployment strategy. We will assume a scenario where the voice and data services are deployed in different layers, and therefore the only possible impact to the voice connections can come from those EGPRS2-B-WB connections at the layer border. Two effects can be observed, namely a) during the time that the EGPRS2 connection is transmitting, a higher ACI power compared to a EGPRS interferer results in a higher frame error ratio (FER) and b) For a given amount of data to be transmitted, the EGPRS2 interferer will interfere during less time, because it has a higher throughput, depending on its own channel conditions. This decrease in time can range from 20% decrease (low SNR conditions) to 50% decrease (high SNR conditions).

Let $F_L(\gamma)$ be the FER under the DTS-2 scenario as function of the signal to noise plus interference ratio (SINR) γ, when all the interferers use linearized GMSK pulses, and let $F_E(\gamma)$ be the FER under the same scenario, but with a EGPRS2-B-WB connection as ACI instead. Let also $F_{cci}(\gamma)$ be the FER with only CCIs and thermal noise, which is the FER expected if the ACI has finished transmitting its data, and no other connection employs the same time slot afterwards.

Let T_E and T_L be the time used by the EGPRS2-B-WB connection and the legacy EGPRS connection, to transmit a given amount of data, and under the same channel conditions. This ratio is related to the ratio of maximum throughput (TP) for the channel conditions. From Figure 5, the ratio of the TP envelopes is about 0.8 on low SINR, 0.65 on medium SINR and 0.5 at high SINR. Therefore, one can expect a 20%, 35% and 50% time reduction, respectively. Let the time reduction factor be $\lambda_T := T_E/T_L$. Assuming that the frame rate is constant for the voice service, the expected FER during the transmission time T_L can be shown to be the convex combination

$$F_T(\gamma) = \lambda_T F_E(\gamma) + (1 - \lambda_T) F_{cci}(\gamma) \qquad (1)$$

where $\lambda_T = 1$ represents the case where another EGPRS2 connection starts after the first EGPRS2 connection has finished transmitting its data (and while the legacy EGPRS connection is still transmitting). The effect of the reduced transmit time on the FER of the legacy services is shown in Figure 7.

On the other hand, we can study the effect of the increased ACI power over the overall FER of a sector. For the layered deployment under consideration, only 1 out of N TRXs will contain voice connections that suffer from increased ACI, compared to the case where all the interferers use the linearized GMSK pulse. Therefore, the expected FER for all the voice connection is the combination

$$F_{sector}(\gamma) = \lambda_N F_E(\gamma) + (1 - \lambda_N) F_L(\gamma), \quad \lambda_N = \frac{1}{N} \qquad (2)$$

Which confirms the intuition that for a sector with a large number of TRXs, the impact of the increased ACI in the overall performance becomes rather small. Note that one can also replace F_E by F_T from (1), to take into account the effect of the reduced transmission time. Figure 8 shows the overall expected FER for $N = 4, 6, 8$ TRXs.

V. CONCLUSIONS

This paper presents a higher uplink performance concept for GERAN Evolution (EGPRS2 UL), which is currently a subject to standardization in the Third Generation Partnership Project (3GPP). The key aspects of the link level transmission techniques were described, and both link and system level performance results were provided.

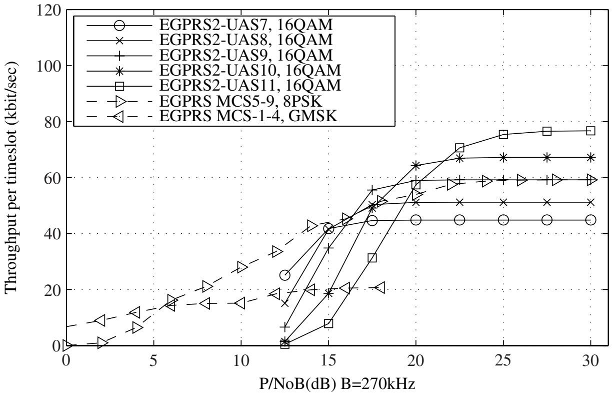

Fig. 3. Throughput comparison of individual EGPRS2 UL level A codecs to EGPRS 8PSK and GMSK throughput envelopes

It was shown that EGPRS2 level A outperforms EGPRS with a 30% higher data peak rate per timeslot, but that it does not improve the coverage of the packet data services. With level B, the peak rate is doubled and the link simulations with wideband transmit pulse showed about 15 kbit/s better data rates in average network conditions (at 15 dB SNR).

The EGPRS2 level A codecs did not provide gain below the average network conditions, whereas the the level B codecs were able to improve the packet data service throughout the whole practical SNR range of 5 to 30 dB. The system level simulations showed that the level B codecs obtain significant gains for all different user percentiles in an regular network with reuse 3/9.

The impact of increased ACI levels (due to the wider pulse shape in level B) on legacy voice services has been considered. It is shown that reduced transmission times associated with the higher throughputs of EGPRS2 UL B can compensate the increased ACI power, in interference limited networks. The use of different layers to deploy voice and data services can further decrease the overall impact of the increased ACI levels on legacy voice connections.

REFERENCES

[1] 3GPP TSG GERAN, "Feasibility study for evolved GSM/EDGE radio access network (GERAN)," 3GPP TR 45.912, Ver.7.1.0. Available at www.3gpp.org.

[2] O. Piirainen, J. Hulkkonen, K. Niemelä, and M. Säily, "Variable bandwidth for GERAN evolution with regular frequency planning," in *Proc. IEEE VTC-Spring*, Melbourne, May 2006.

[3] M. Säily, J. Hulkkonen, K. Niemelä, and O. Piirainen, "Dual symbol rate for GERAN uplink evolution," in *Proc. IEEE PIMRC*, Helsinki, September 2006.

[4] 3GPP TSG GERAN, "Higher uplink performance for GERAN evolution (HUGE), work item description," 3GPP TSG GERAN#31, GP-061901.

[5] 3GPP TSG SA WG2, "General packet radio service (GPRS)," 3GPP TS 23.060.

[6] 3GPP TSG GERAN WG1, "Modulation," 3GPP TS 45.004.

[7] 3GPP TSG GERAN #36, "Wide pulse shaping filter design for HUGE-B," GP-071840.

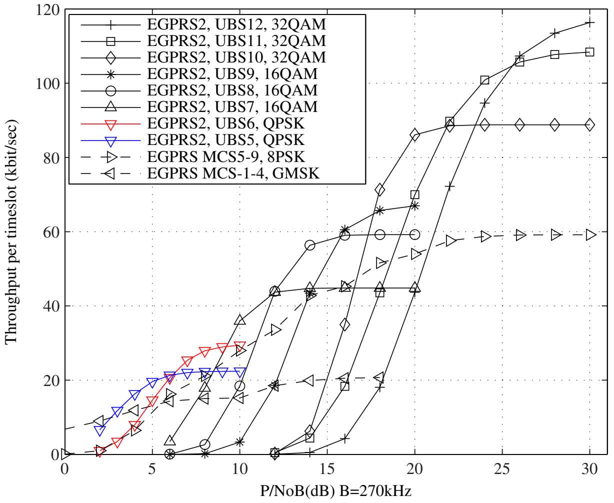

Fig. 4. Throughput comparison of individual EGPRS2 UL level B WB codecs to EGPRS 8PSK and GMSK throughput envelopes

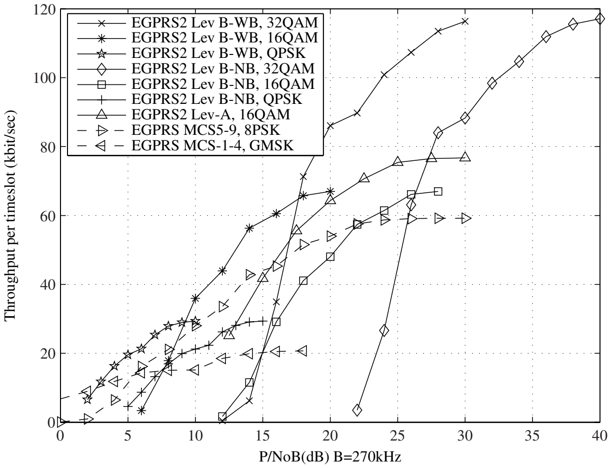

Fig. 5. Throughput comparison of EGPRS2 UL level A, level B LGMSK pulse and level B wideband pulse, with EGPRS GMSK and 8PSK throughput envelopes

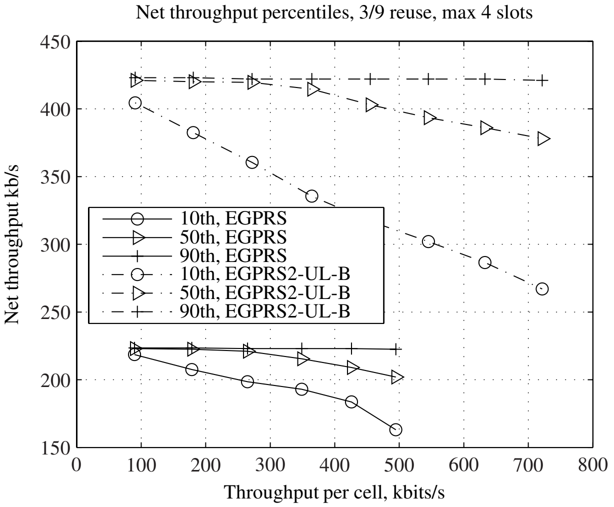

Fig. 6. Network throughput performance for reuse 3/9 and 65° directional antennas

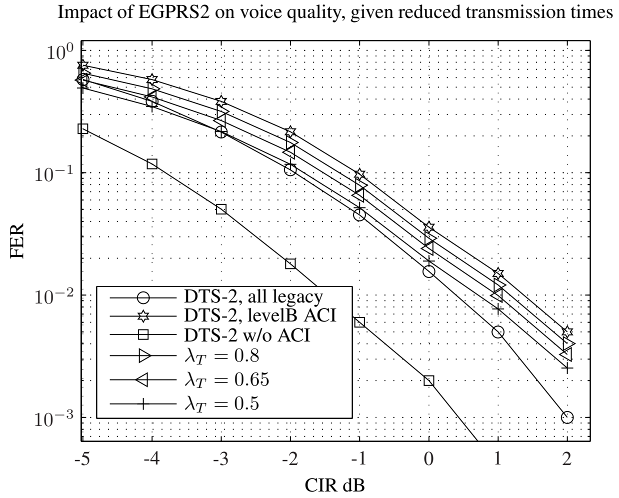

Fig. 7. Impact of increased ACI power at data/voice layer border. The higher throughput of EGPRS2 reduces the time over which the voice connection is interfered

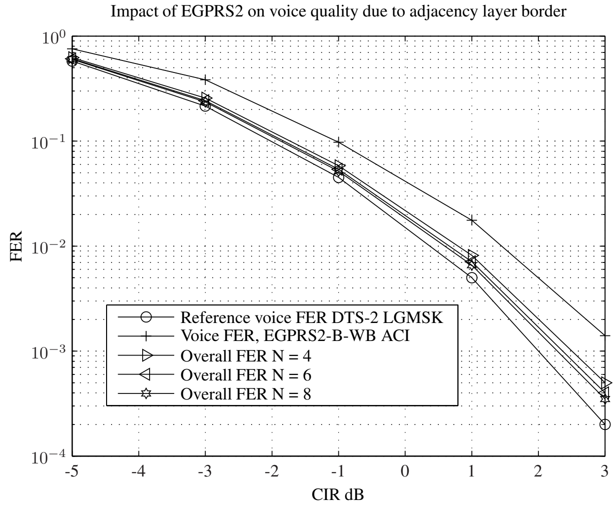

Fig. 8. Impact of increased ACI power on the overall FER of a sector, for sectors containing 4, 6 and 8 TRXs allocated to voice

[8] J. Karlsson and J. Heinegård, "Interference rejection combining for GSM," in *IEEE ICUPC*, 1996.

[9] S. Craig and J. Axäs, "A system performance evaluation of 2-branch interference rejection combining," in *Proc. IEEE VTC-Fall*, 2002.

[10] M. Chiani, M. Win, A. Zanella, R. Mallik, and J. Winters, "Bounds and approximations for optimum combining of signals in the presence of multiple cochannel interferers and thermal noise," *IEEE Trans. Commun.*, vol. 51, no. 2, pp. 296– 307, February 2003.

[11] 3GPP TSG GERAN WG1, "Multiplexing and multiple access on the radio path," 3GPP TS 45.002.

[12] ——, "Channel coding," 3GPP TS 45.003.

[13] 3GPP TSG GERAN #32, "HUGE interference impact on voice quality in a mixed traffic network," GP-062130.

[14] 3GPP TSG GERAN WG1, "Radio transmission and reception," 3GPP TS 45.005.