Speech Capacity Enhancements in the GSM/EDGE Radio Access Network (GERAN)

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ABSTRACT

Abstract - **The standardization of the GSM/EDGE radio access network (GERAN) is currently being carried out within 3GPP. Two new features had been standardized for an enhanced support of speech services in GERAN Release 5: a new half rate channel using the 8PSK (Phase Shift Keying) modulation and an enhanced power control which reduces the power control loop delay by a factor 4. This paper presents both techniques and shows the improvements they provide from a speech quality and a network capacity point of views.**

***Keywords*: GERAN, 8PSK modulation, half rate AMR speech channel, speech quality, Enhanced Power Control, SACCH, FIRE code, CRC, error detection.**

I. INTRODUCTION

Mobile voice traffic continues to grow and already today many networks are stressed with capacity challenges. Although growth in revenue will mainly come from data services, it is foreseen that voice will still generate 60% of the global operator revenue in 2006. Improvements to optimise the capacity of speech services are therefore very important. GERAN Release 5 includes such improvements.

The introduction of EDGE (Enhanced Data Rates for Global Evolution) with 8PSK modulation increases the gross bit rate of a full-rate (FR) single slot connection from 22.8 kbits/s to 69.2 kbits/s. Current AMR narrow-band speech services do not require such a large bandwidth since the highest speech codec rate is 12.2 kbits/s. However by combining the 8PSK modulation with a half-rate (HR) + half-rate configuration, it is possible to increase the capacity twofold, having one user on each HR channel. The performance of this new 8PSK HR channel is analysed in this paper both on link level and system level. A speech quality study is also included.

Another enhancement for speech services that is discussed in this paper is the power control. Currently in GSM, the downlink power control commands and the uplink measurement reports are sent every 480ms on the slow associated control channel (SACCH). By reducing this delay, few advantages can be foreseen: improvement of the signal quality, decrease of the interference to other users, and decrease of the mobile power consumption. This paper presents a solution to reduce the power control interval to 120ms for both GMSK and 8PSK modulated speech traffic channels and also shows the improvement on the network capacity.

II. HALF RATE 8PSK SPEECH TRAFFIC CHANNELS

II.1 Link Level Performance

The channel coding used in the simulation for 8PSK HR channels is fully described in the specification [5]. Different AMR speech codecs have been simulated on both GMSK and 8PSK HR channels. For co-channel interference study, 20000 frames have been simulated on TU3 channel with ideal frequency hopping.

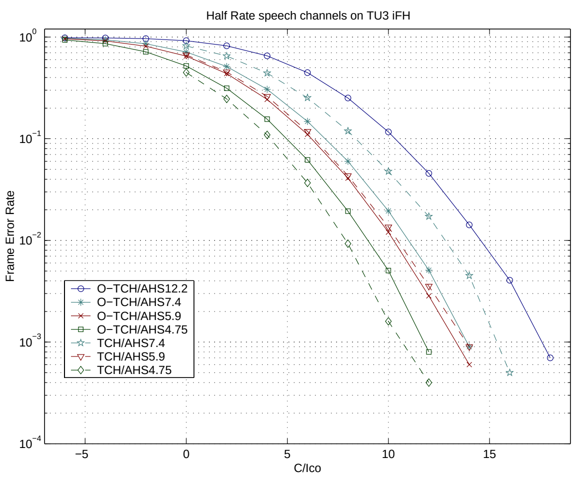

Figure 1. Link level performance for HR speech channel with GMSK and 8PSK modulation

As shown on Figure 1, depending on the AMR mode, either 8PSK HR channel or GMSK HR channel performs better. For AMR7.4, the C/Ico level at 1% FER is 1.8 dB better with 8PSK than with GMSK, because the coding rate with GMSK is higher than 0.5. Indeed for a coding rate above 0.5 in GMSK, e.g. 0.59 with TCH/AHS7.4, not all the bits are repeated at least once. Therefore 8PSK HR channel can benefit from the interleaving. On the other hand, for coding rate below 0.5, e.g. 0.42 with TCH/AHS4.75, C/Ico at 1% FER is 1.1 dB better with GMSK than with 8PSK.

II.2 Subjective results

Listening tests were made to estimate the improvement of 8PSK half-rate channels on the speech quality. The results presented in Figure 2 show that the performance of 8PSK HR channels is significantly and consistently better than the performance of GMSK HR channels. It indicates also that no handover is required from 8PSK HR channels to GMSK HR channels in terms of subjective quality when the channel conditions get worse. Furthermore, 8PSK HR channels offers better subjective speech quality in good channel conditions by allowing the usage of higher speech codec mode.

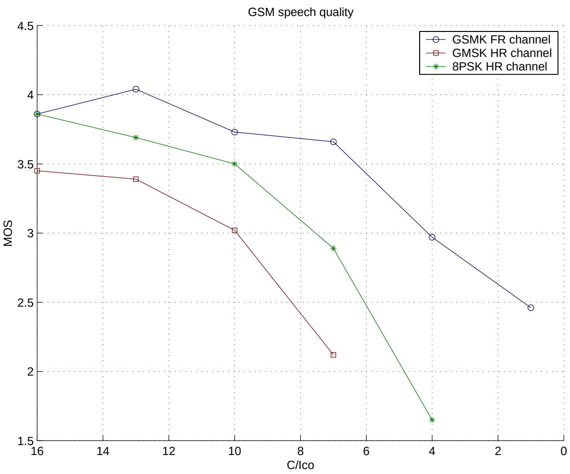

Figure 2. Speech quality performance in MOS

It should also be noted that this test has been performed with clean speech only (no background noise) and the quality difference between GMSK and 8-PSK HR channels would be even higher in presence of background noise because of higher modes. Finally the listening test also shows that 8-PSK HR channels are somewhat worse than GMSK FR channels.

II.3 System Level Performance

It is quite difficult to quantify the system level gains of 8-PSK HR compared to GMSK HR. First of all, pure FER-based comparison is not fair, since the available codecs are different in both modes. The 12.2 mode available with 8-PSK brings quality, not capacity. A MOS-based capacity evaluation [3] could be used, where the channel quality is mapped on to MOS values like the ones in Figure 2. However, due to lack of proper input MOS-data for all the codecs, the system level performance analysis is made by analyzing the simulated channel and codec proportions in the network.

Figure 3 shows how different AMR modes are used in a typical interference-limited GERAN network. It also shows the HR channel usage. The simulation setup is the same as in Chapter III.4.

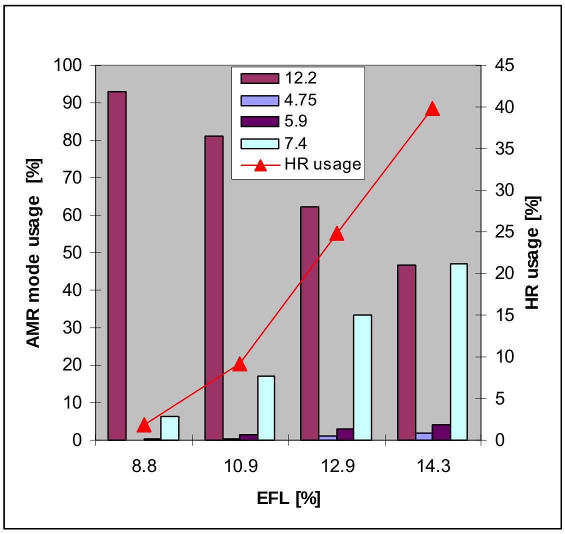

Figure 3. Simulated AMR codec mode usage in mixed FR/HR case.

The highest load point in the simulations (Effective Frequency Load of 14.3%) is already at the soft blocking limit of the network. It can be seen that high-quality AMR12.2 codec is selected almost 50% of the time even with the highest operating point and with increasing load it will be downgraded mostly to AMR7.4. The proportions of lower rate codecs remain small even with high load.

When the network simulation results presented above is analyzed together with the subjective and objective link level results presented earlier, it can be said that 8-PSK HR should clearly improve both the network capacity and quality. The quality improvement comes mostly from the available 12.2 mode that is not available in GMSK HR. On the other hand, results show also that the gain from AMR7.4 mode will have the dominant role when transferring link level gains to capacity gains since it is used much more often than the lower rate codecs (where 8-PSK gain is non-existent or even negative). 1.8 dB link level gain corresponds to over 50% capacity increase [3], based on similar simulations than presented here. Potential capacity loss comes from O-TCH/HS4.75 channel but the usage of it can be avoided.

It can be concluded that capacity gains of few tens of percents could be reachable with the introduction of 8-PSK HR channels. At the same time the overall network quality improves.

III. Enhanced Power Control

Power control for dedicated basic physical subchannels (DBPSCH) is available in GSM through the SACCH, which enables a power control interval of 480ms. Every SACCH block carries a Layer 1 header containing signalling for power control procedures [1]. In the uplink, the MS sends measurements reports to the BTS, while in the downlink the BTS sends power control commands to the MS.

The release 1999 of GSM/EDGE introduced the fast power control (FPC) for the enhanced circuit switched data (ECSD) traffic channels [2]. The FPC signalling is made in-band, allowing a control interval of 20ms (24 times faster than through the SACCH). The advantages of fast power control are twofold. Not only the signal quality is enhanced, but the level of interference to other users is also reduced [3].

In order to increase the overall spectral efficiency even further, the release 5 of GERAN introduces fast power control for DBPSCH in general and speech services in particular (referred to as EPC). The EPC signalling is mapped onto every SACCH burst, allowing a control interval of 120ms (four times faster than through the SACCH). Unlike in-band signalling, it can be used with any speech traffic channel (both 8PSK and GMSK modulated) and does not impact the speech channel coding.

III.1EPC Signalling

Both FPC and EPC are based on differential control to adjust the employed RF power level. In the downlink, 3 bits power control commands are sent to the MS (see Table 1) while in the uplink, the MS transmits 3 bits quality reports to the BSS (see Table 2).

Table 1. EPC Commands (downlink)

Code	Power Control (PC) command
0	not used
1	increase output power by 4 PC levels
2	increase output power by 3 PC levels
3	increase output power by 2 PC levels
4	increase output power by 1 PC level
5	no output power level change
6	decrease output power by 1 PC level
7	decrease output power by 2 PC levels

Table 2. EPC Quality Reports (uplink)

Quality Band	Range of actual BER
RXQUAL_0	Less than 0,1 %
RXQUAL_1	0,26 % to 0,30 %
RXQUAL_2	0,51 % to 0,64 %
RXQUAL_3	1,0 % to 1,3 %
RXQUAL_4	1,9 % to 2,7 %
RXQUAL_5	3,8 % to 5,4 %
RXQUAL_6	7,6 % to 11,0 %
RXQUAL_7	Greater than 15,0 %

III.2Channel Coding for EPC Signalling

Before transmission, the 3 bits messages are protected in channel coding with a block code of rate ¼

In order to convey the EPC signalling, 12 bits have therefore to be released on every SACCH burst. Either the SACCH channel coding is simply punctured or it can be modified to limit the link level performance degradation. In any case, the question is where to map these bits. Five different types of mapping were assessed:

- ATS where the 12 bits are punctured around the training Sequence of each burst on bit positions 52, 53, 54, 55, 57, 58, 56, 59, 60, 61, 62, 63.
- Spread where the 12 bits are as spread as possible over the burst (bit positions 10, 19, 28, 37, 46, 57, 58, 69, 78, 87, 96, 105)
- P1 which is somewhat between ATS and Spread (47, 49, 51, 54, 55, 57, 58, 60, 62, 64, 66, 68)
- P2 which is also between ATS and Spread (41, 45, 49, 52, 55, 57, 58, 60, 63, 66, 70, 74)
- and finally P3 (44, 47, 50, 53, 55, 57, 58, 60, 62, 65, 68, 71)

Link level simulations were run to assess the performance of these five puncturing schemes for different channel profiles. It clearly appears that ATS and Spread should be avoided while P3 provides the best compromise.

Table 3. EPC Performance (dB C/Ico at 1% of WER)

Channel	ATS	P1	P2	P3	Spread
TU3	12.6	12.3	12.2	12.1	12.1
TU50	12.8	12.2	12.2	12.2	12.2
RA250	13.9	14.0	14.0	14.0	14.8

III.3Channel coding for SACCH

The puncturing of 12 bits on every SACCH burst decreases the performance of the SACCH as shown on Figure 4 .The required C/Ico to reach 1% of BLER in TU3iFH actually increases by 1.1dB. In this section, a method to avoid such performance degradation is proposed.

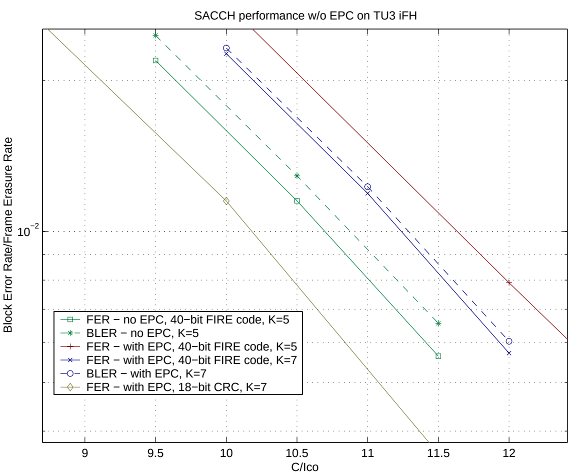

Figure 4. SACCH Performance with and without EPC

III.3.1 Constraint Length Increase

The channel coding of the SACCH includes a convolutional encoder of which the constraint length is K=5 [5]. The increase of available processing power of MS allows the constraint length to be brought from 5 to 7 in order to compensate for the loss. Figure 4 shows that when the constraint length is increased to 7, a 0.5dB gain is achieved. It is therefore an interesting and simple mean to reduce the SACCH performance loss when EPC is used. But it is not enough. Something else has to be done to suppress the loss.

III.3.2 Error Detection

The SACCH block of 184 information bits is protected by a 40 bits FIRE code, which is used for error correction and detection. The Fire code is a shortened binary cyclic code using the generator polynomial:

$$G(D) = (D^{23} + 1)*(D^{17} + D^{3} + 1)$$

This block code is a 12-burst error correcting code. This means that it is capable of correcting all error bursts of length 12 or less [6]. At the same time the fire code can detect error burst of length 12 or less.

Figure 4 shows the detection and correction performance for the two following cases:

- constraint length 7 and 12 bits are punctured on every burst for EPC signalling (new coding)
- constraint length 5 and no bits are punctured for the EPC signalling (existing coding)

The results show that thanks to the burst error correction capability of the FIRE code, a 0.2 dB gain appears at 1% BLER for the existing SACCH. However when some bits are punctured to convey the EPC signalling (and the constraint length is increased), the fire code only brings a 0.05 dB gain. It demonstrates that because of the puncturing, not only the number of errors increases, but also the length of the error bursts increases. And as a result the FIRE code can hardly correct the errors. In such conditions it clearly appears that it is not worth having a 40-bit FIRE code when a smaller CRC code would allow the transmission of the EPC signalling without or limited puncturing on SACCH.

To determine how many CRC bits are needed, we have to estimate first the probability of undetected errors, which according to the requirements in the specifications [7] has to be less than 2.10^{-5}. The following equation gives the probability of undetected errors depending on the number of CRC bits:

$$P_{ue} = (1 - p)^{n} \sum_{i=1}^{n} A_i \left(\frac{p}{1-p} \right)^{i}$$

where A is the weight distribution function of the CRC code depending of the generator; n is the block size including the CRC bits and p is the bit error probability.

To get P_{ue} below 2.10^{-5} for all possible bit error probability, 16 CRC bits are needed at least. To transmit EPC without puncturing SACCH, 40 encoded bits need to be freed, which means that the FIRE code can be replaced by a 18-bit CRC, which fully fulfil the requirements as said before.

Finally, when combining the 18-bit CRC code, with the mapping P3 of section III.2, the new channel coding for SACCH becomes:

1) Add 18 bits CRC code (184 + 18 = 202)

2) Add 6 tail bits (200 + 6 = 208)

3) Apply ½ convolutional code (206 * 2 = 416)

4) Insert 40 dummy bits in order to have 456 bits (3, 32, 40, 46, 47, 68, 89, 96, 97, 103, 124, 125, 132, 146, 153, 154, 181, 182, 189, 203, 210, 211, 232, 238, 239, 246, 267, 288, 289, 295, 303, 332, 345, 346, 388, 389, 402, 403, 445, 446)

5) Interleave the 456 bits. On every burst, the dummy bits occupy the same positions that are the bit numbers 44, 47, 50, 53, 55, 57, 58, 60, 62, 65, 68, 71

6) Replace the interleaved dummy bits on every burst by the EPC signalling.

The link level performance of the resulting SACCH is given in Figure 4. It can be seen that not only all the losses are suppressed but even a 0.6dB gain appears.

III.4System Level Simulations

A series of extensive network level simulations were performed to quantify the possible capacity gain of the 4-fold PC signalling rate of EPC. A sophisticated burst-level simulator was used which captures all the important factors that affect to the network level capacity. Both downlink and uplink were simulated but the statistics were collected only from the hopping non-BCCH layer. The most important simulation algorithms and parameters are listed in Table 4 and Table 5. GMSK AMR codecs were used with the possibility to switch between Full Rate and Half rate modes during the call. AMR codec modes were switched during the call based on filtered link quality samples.

Table 4. Simulation algorithms

Algorithm	Description
Frequency hopping	Random 1/1 RF-hopping with MAIO Management
Power control	Based on RxQual and RxLev measurement reports.
DTX	Not used
Codec Mode Adaptation	Based on FIR filter of measured C/I samples
Channel Mode Adaptation	Based on cell load and channel quality. Initial mode always Full Rate.

Table 5. Simulation parameters

Parameter	Value	Unit	Comment
Available bandwidth	4.8	MHz	BCCH-TRX disabled
Cell radius	1000	meters	Sectorized
Antenna • beamwidth • gain	 65 18	 degrees dBi	
Number of TRXs per sector	5		Blocking avoided
MS speed	3 and 50	km/h	
Slow fading standard deviation	8	dB	
FR AMR Codec Modes:	12.2, 7.4, 5.9, 4.75	kbps	
HR AMR Codec Modes:	7.4, 5.9, 4.75	kbps	
FER limit (Class 1a bits) for a successful call	1	%	Average of downlink and uplink

As a benchmark, a standard 480 ms RxQual/RxLev-based power control is used. The achieved capacity is compared with the case where all the MSs use EPC. Mobile speeds of both 3 and 50 km/h were studied. The errors in SACCH were not considered.

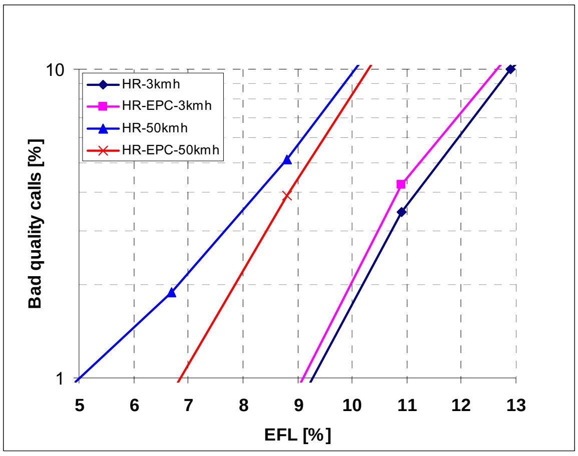

Figure 5. EPC system level performance over GMSK channels.

Figure 5 shows the capacity (in terms of Effective Frequency Load) versus bad quality call ratio for both EPC and no-EPC case with the two MS speeds. For fast moving MS there is a clear gain from EPC while for slow moving case there is even a slight degradation in capacity. If we consider 98% overall user satisfaction ratio, the capacity gains are +16% and –2% for 50 km/h and 3 km/h, respectively.

Finally, thanks to EPC, a significant power reduction is also reached: for example, with medium load about 20% less energy is transmitted on uplink.

IV. CONCLUSION

This paper has presented two new features that had been included in GERAN Release 5 for an enhanced support of speech services: a new 8PSK HR channel and the Enhanced Power Control. Compared to existing GMSK HR channels, the new 8PSK HR channels allow higher AMR modes to be transmitted and increase the coding rate for the lower ones. As a result, the speech quality of HR channels improves, and this improvement can be turned into capacity gains. The Enhanced Power Control decreases by a factor 4 the power control loop of speech services. Gains were shown to be especially interesting for fast moving mobiles with an estimated capacity gain of 16%. Furthermore not only the Enhanced Power Control increases the capacity of speech services but it also allows for lower battery consumption with about 20% decrease of the transmitted power.

For GERAN Release 6 additional techniques such as single antenna interference cancellation are being studied for even greater capacity improvements.

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