# GSM EFR BASED MULTI-RATE CODEC FAMILY

*J. Vainio, H. Mikkola, K. Järvinen, P. Haavisto*
Nokia Research Center, Tampere, Finland
kari.järvinen@research.nokia.com

## ABSTRACT

This paper describes a multi-rate codec family developed as a potential candidate for the GSM Adaptive Multi Rate (AMR) codec standard. The codec family consists of the GSM Enhanced Full Rate (EFR) codec [1] and lower bit-rate extensions thereof. The codec family consists of several codecs, i.e., modes that have different bit-rate partitionings between source coding and error protection. All the source codecs use the same ACELP-method (Algebraic Code Excited Linear Predictive Coding) used also in the GSM EFR codec. The codec operates at gross bit-rates of 22.8 kbit/s in the GSM full rate (FR) channel and 11.4 kbit/s in the GSM half rate (HR) channel. In the full rate channel, the codec provides improved error robustness over the GSM Enhanced Full Rate (EFR) codec. It extends wireline quality (equal to or better than G.726-32 ADPCM) to poor channel error conditions with low C/I-ratios of 7 dB or even below. When operated in the half rate channel, the codec provides improved channel capacity while still providing wireline quality at high C/I-ratios above 16-19 dB.

## 1. INTRODUCTION

European Telecommunications Standards Institute (ETSI) started a standardisation program in October 1997 to develop an Adaptive Multi Rate (AMR) codec for GSM. The codec would operate in the full rate (22.8 kbit/s) and half rate (11.4 kbit/s) speech traffic channels of GSM and would adapt the source coding and error protection (channel coding) bit-rates according to the quality of the radio channel. The adaptation could be based also on other measures such as background noise [2]. The standardisation program in ETSI aims at specifying the main parts of the GSM AMR codec by the end of 1998.

Most speech codecs employed in communication systems such as the existing GSM speech codecs (full rate, half rate, and enhanced full rate) operate at a fixed bit-rate trade-off between source coding and error protection. This has been chosen as a compromise between error-free channel performance and robustness to channel errors. Estimating channel quality and adjusting the bit-rate trade-off adaptively according to channel error conditions gives potential for improved error robustness and improved speech quality.

The GSM enhanced full rate (EFR) codec provides substantial improvement over the GSM full rate and half rate codecs. It provides wireline quality in error-free conditions and also in the most typical channel error conditions (C/I equal to or better than 10 dB) [1]. In more severe transmission conditions (10 dB > C/I > 7 dB) the EFR codec still gives high quality and a substantial improvement over the full rate and half rate codecs. In out-of-cell conditions (C/I = 4 dB) the EFR codec has approximately the same performance as the full rate codec.

The AMR codec can be expected to provide improved error robustness over the EFR codec. By switching the codec to operate in the GSM half rate channel during good channel conditions, the AMR codec can also provide channel capacity gain over the EFR codec.

This study presents a codec family developed as a potential candidate for the GSM Adaptive Multi Rate codec standard. The codec family is based on the GSM EFR codec and lower bit-rate extensions thereof. When used in the GSM full rate channel, the AMR codec extends wireline quality to poor channel error conditions with low C/I-ratios of 7 dB or even below. In the GSM half rate channel, the codec family provides substantial speech quality improvement over the GSM FR and HR codecs maintaining wireline speech quality at low error-rates with C/I-ratios above 16-19 dB. Due to using the same basic algorithm in all the codecs, no audible effects are produced when switching between codecs. The complexity of the EFR based AMR codec family is comparable to that of the GSM EFR codec.

## 2. GSM EFR BASED MULTI RATE CODEC FAMILY

The codec family consists of the GSM Enhanced Full Rate (EFR) codec [1] and additional lower bit-rate extensions. The codec family contains several source codecs from 6.05 to 12.2 kbit/s with bit-rate granularity of about 1 kbit/s. The family of codecs with such high granularity of bit-rates can be seen as a toolbox from where the best set of codecs can be chosen for different application scenarios and for different systems [2]. In the codec family, four codecs can be used in the full rate channel and two codecs in the half rate channel. The source codec with the highest bit-rate in the codec family is the same as the GSM EFR source codec. By including it as the highest bit-rate source codec, the same high basic speech quality is provided as with the EFR codec. This also gives the AMR codec compatibility with the EFR codec and provides interoperability advantages between the codecs such as potential for tandem free operation. In all codecs, the source coding is based on the GSM EFR ACELP algorithm [1], [4].

### 2.1 Source codecs

The codecs used in the GSM full rate channel employ source coding bit-rates of 12.2, 10.4, 7.4 and 6.05 kbit/s. In the half rate channel the same two source codecs with the lowest bit-rates (7.4 and 6.05 kbit/s) are used.

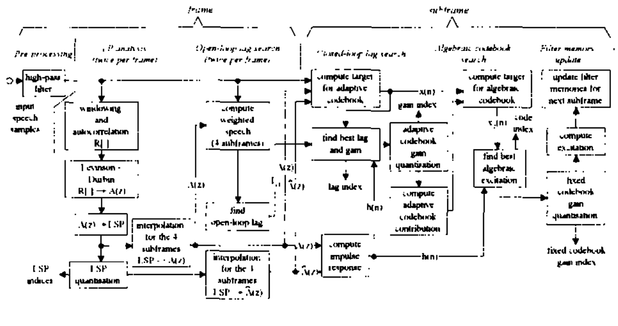

Figure 1. Block diagram of the GSM EFR codec

The basic structure of all the source codecs is similar to the one used in GSM EFR codec and is shown in Figure 1 [1]. Short term spectral parameters are quantised as LSPs (Line Spectral Pairs). In the two lowest bit-rate source codecs (7.4 and 6.05 kbit/s), 26 bits are used for the LSPs while the two other modes use 38 bits. All the source codecs operate with 20 ms frame lengths.

The LTP-search is carried out with combined open-loop/closed-loop approach. Integer lag is first determined in the open-loop search and fractional lag is then searched around the open-loop lag. The accuracy of the fractional lag in the two lowest bit-rate source codecs has been reduced to 1/3rd sample from the 1/6th sample accuracy of the GSM EFR codec.

The ACELP codebook structure has been modified to achieve bit-rate reduction in the algebraic excitation. The reduction in the bit-rate of the overall codec has been mainly achieved by reducing the bit-rate needed for algebraic excitation. For example, in the 7.4 kbit/s codec only 4.2 kbit/s is used for excitation while the 12.2 kbit/s codec needs 8.0 kbit/s. In the two lowest bit-rate codecs the algebraic codebook and LTP-gains are jointly vector quantised for more efficient quantisation.

## 2.2 Channel codecs

The EFR based codec family has six different channel codecs, one for each four source codec in the full rate channel and one for the two lowest bit-rate source codecs in the half rate channel. All channel codecs are based on error protection by convolutional coding together with Cyclic Redundancy Check (CRC) used for bad frame detection.

Source encoded bits are first re-ordered according to subjective importance and then divided into three classes according to level of error protection and/or detection: [1)] Class 1a: Bits protected by the CRC and convolutional code. [2)] Class 1b: Bits protected by the convolutional code. [3)] Class 2: Bits left without error protection. The actual bit allocation between protection classes depends on how much the channel coder is able to add redundancy without exceeding the channel cross bit-rate (full-rate 22.8 kbit/s, half-rate 11.4 kbit/s) and what is the level of protection within the class (convolution code-rate).

The general structure of the channel encoders used for different source codecs is shown in Figure 2. Three protection classes can bee seen in the figure, but they are not all in use in all the codecs and the level of protection within the class varies from one channel codec to another. In the channel codecs we are using the code rates from 1/2 to 1/4 for the convolution code and 3-8 bits for the CRC parity information. In order to minimize the implementation costs in the network, the channel codecs use convolution polynomials specified for the current GSM system (either for speech or data channels).

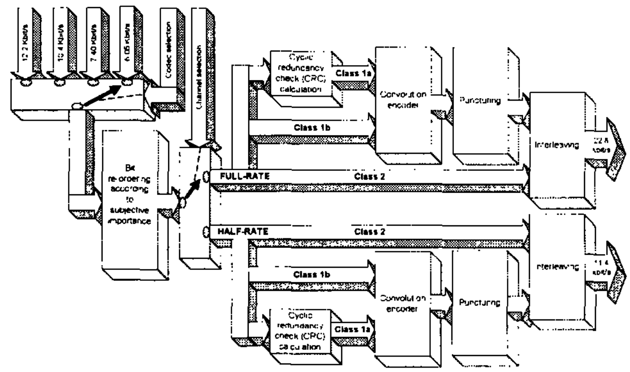


Figure 2. The basic structure of the channel codec

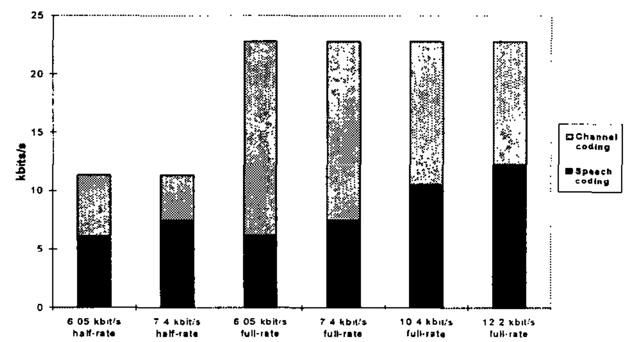


Figure 3. Bit allocation between speech and channel codec

Figure 3 shows the bit-allocations between source and channel coding for the four full rate and the two half rate codecs. Codec adaptation should choose the optimal bit-rate for each channel condition to provide the best speech quality. Results of a study of codec selection are given in Chapter 4. The speech quality provided by several codecs both in the full and half rate channels were studied and the C/I-ratios of the optimal switching locations were identified.

# 3. COMPLEXITY

The complexity of the EFR based AMR codec family has been estimated from a C-code implemented with a fixed point function library in which each operation has been assigned a weight representative for performing the operation on a typical DSP [5]. The figures presented in Table I are average WMOPS values which have been calculated using large amounts of speech material. Since all the codecs are based on the same EFR ACELP technology the program code and the data ROM tables for most parts can be reused for the different codecs.

Table I. Average WMOPS calculations of EFR-based codecs (GSM full rate channel)

| WMOPS | 12.2 kbit/s | 10.4 kbit/s | 7.4 kbit/s | 6.05 kbit/s |
|---|---|---|---|---|
| Speech Encoder | 12.1 | 12.0 | 11.5 | 11.2 |
| Speech Decoder | 1.4 | 1.5 | 1.5 | 1.5 |
| Channel Encoder | 0.4 | 0.4 | 0.4 | 0.4 |
| Channel Decoder | 1.9 | 2.3 | 2.2 | 2.0 |
| **TOTAL** | **15.8** | **16.2** | **15.6** | **15.1** |

# 4. CHANNEL ERROR PERFORMANCE

The channel error performance of the codec family was studied both in the GSM full rate and half rate channels by using ACR (Absolute Category Rating) MOS tests. Both tests were carried out with 12 listeners using 4 speech samples (2 males, 2 females) with modified-IRS weighting and 8 bit A-law compression. Listening was carried out using high quality headphones. Error-free G.726-32 was employed as a high quality reference codec in the tests. The GSM FR and HR codecs were also included in the tests as reference codecs.

In the full rate channel test, the C/I-ratios of 13, 10, 7 and 4 dB were used. These correspond to channel bit error-rates of 2, 5, 8, and 13%. The focus in the half rate channel error test was in the low error-rate conditions where the high quality operation range of the AMR HR channel mode is located. In the half rate channel error test, C/I-ratios of 19, 16, 14, 13, 10, and 7 dB were used. These correspond to channel bit error-rates of 0.4, 0.9, 1.5, 2, 5 and 8%.

## 4.1 Full rate channel

The results of the MOS test for the full rate channel performance are shown in Figure 4. Three codecs were included in the test with source coding bit-rates of 12.2, 10.4 and 7.4 kbit/s. In error-free and low error-rate conditions (C/I $\geq$ 13 dB), the highest bit-rate gives the best performance. At low to medium error-rates (13 dB > C/I $\geq$ 9 dB), the two highest bit-rates perform better than G.726-32, and the performance of the lowest bit-rate is about equal to G.726-32.

The AMR codec family provides improved error robustness over the GSM EFR codec and gives quality improvement at C/I-ratios below about 12 dB. At very high error rates below 7 dB, the quality falls below wireline quality, but it is still substantially better than the one provided by the GSM FR codec. Frame error rates in the full rate channel are shown in Table II. In the lowest source coding bit-rate, the amount of bad frames remains low (below 1%) even at 4 dB.

Table II. Frame error rates in the GSM full rate channel

| | Codec | | | |
|---|---|---|---|---|
| | 12.2 kbit/s | 10.4 kbit/s | 7.40 kbit/s | 6.05 kbit/s |
| C/I = 13 dB | 0.05 % | 0.00 % | 0.00 % | 0.00 % |
| C/I = 10 dB | 0.28 % | 0.28 % | 0.00 % | 0.00 % |
| C/I = 7 dB | 3.42 % | 2.33 % | 0.10 % | 0.03 % |
| C/I = 4 dB | 18.65 % | 15.13 % | 1.48 % | 0.93 % |

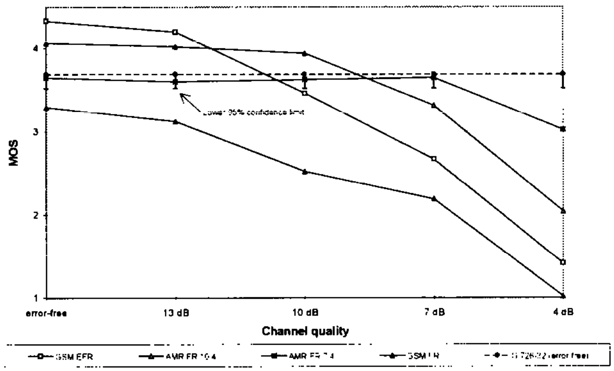


Figure 4. Results of full rate channel error test

## 4.2 Half rate channel

The results of the MOS test for the half rate channel performance are shown in Figure 5. The codec with the highest source coding bit-rate (7.4 kbit/s) performs equally well to G.726-32 above C/I-ratios of 16-19 dB (within the 95% confidence interval). Below C/I=16 dB the quality starts to approach the performance of the GSM FR and HR codecs. At C/I=13 dB it still performs better than the GSM FR and HR codecs. Below C/I=10 dB no improvement over GSM FR or GSM HR codecs is achieved. However, the normal operation range in the half rate channel is in the high quality region at C/I-ratios above 16 dB. Only in cases where channel capacity is not available, the codec temporarily remains in the HR channel at C/I-ratios below 16 dB. Frame error rates in the half rate channel are shown in Table III.

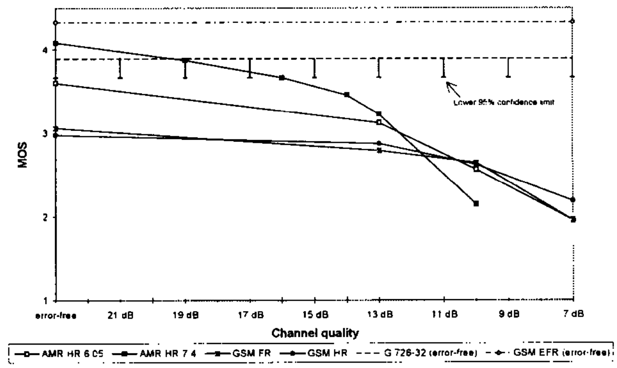


Figure 5. Results of half rate channel error test

Table III. Frame error rates in the GSM half rate channel

| | Codec | |
|---|---|---|
| | 7.4 kbit/s | 6.05 kbit/s |
| C/I = 19 dB | 0.00 % | 0.00 % |
| C/I = 16 dB | 0.02 % | 0.00 % |
| C/I = 14 dB | 0.10 % | 0.00 % |
| C/I = 13 dB | 0.17 % | 0.00 % |
| C/I = 10 dB | 2.53 % | 0.78 % |
| C/I = 7 dB | 9.68 % | 3.45 % |
| C/I = 4 dB | 26.80 % | 12.25 % |

# 5. BACKGROUND NOISE PERFORMANCE

The background noise performance of the codecs was studied with Car noise at S/N=10 dB and Cafe babble noise at S/N=15 dB. The same setup than in the channel error performance test was used, except this test was carried out as a DCR (Difference Category Rating) DMOS test. GSM FR, HR, and G.729 codecs were included as references. No channel errors were included.

The EFR based codecs included in the test have the source coding bit-rates of 12.2 kbit/s, 8.0 kbit/s, 7.4 kbit/s and 6.05 kbit/s. The purpose of the test was to evaluate the quality degradation with the codecs having the lowest rates. Therefore, the 8.0 kbit/s codec was chosen in this test instead of the 10.4 kbit/s codec. Also the G.729 codec (8.0 kbit/s) was included to have a known standard reference at comparable low source coding bit-rates. The test results are shown in Figure 6 for Car noise and in Figure 7 for Cafe babble noise. Confidence intervals (95%) are shown in both figures.

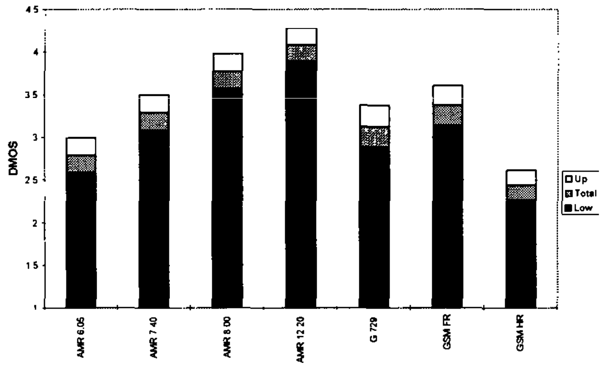


Figure 6. Results of background noise test (Car noise).

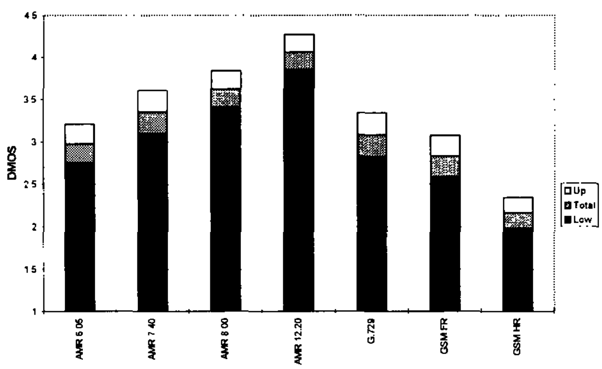


Figure 7. Results of background noise test (Cafe babble noise).

The results for car noise show that the performance of the 7.4 kbit/s source codec is on the same level than the performance of the FR codec but it remains below the 12.2 kbit/s source codec (GSM EFR codec). The 8.0 kbit/s source codec gives improved background noise performance compared to the 7.4 kbit/s codec. The performance of the 6.05 kbit/s codec is better than that of the GSM HR codec. For cafe babble noise, the results show that the 7.4 kbit/s source codec has better performance than the GSM FR codec. The 8.0 kbit/s source codec gives improved performance over the 7.4 kbit/s codec but it remains somewhat below the GSM EFR codec. The performance of the 6.05 kbit/s source codec is equal to the GSM FR codec. Altogether, the results for both tested noise conditions show that the performance of the EFR based codec family correlates well with the source coding bit-rate.

# 6. SWITCHING EFFECTS

In a multi rate codec, transitions from one mode to another may cause quality degradation (such as clicks) due to different contents of state variables. To test this effect two codecs were switched back and forth with different rates. At the fastest switching rate the codec was switched in every frame. The switching was carried out with 12.2 vs. 10.4 kbit/s, 10.4 vs. 7.4 kbit/s and 7.4 vs. 12.2 kbit/s. The effect of switching was evaluated by expert listening and also by using segmental SNRs shown in Table IV. Both evaluations show that no audible effects result in switching between the codecs. Switching without audible quality degradation is one of the advantages of using the same family of codecs in the AMR.

Table IV. Switching effects

| Test case | Codec | | | | |
|---|---|---|---|---|---|
| | 12.2 kbit/s | 10.4 kbit/s | 7.4 kbit/s | 12.2 kbit/s | |
| No switching | 6.69 dB | 6.08 dB | 5.06 dB | 6.69 dB | |
| Switching | - | 6.37 dB | 5.52 dB | 5.81 dB | - |

# 7. SUMMARY

This study presented a GSM EFR based multi rate codec which provides improved error robustness over the GSM Enhanced Full Rate (EFR) codec. When operated in the half rate channel, the codec provides improved channel capacity while still providing for low error-rate channel conditions wireline speech quality.

# 8. REFERENCES

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