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Recursive Systematic vs. Non-systematic Encoding for 8-PSK HR Optimized Voice Bearer

1 Introduction

Using the existing AMR Narrow-band speech codec, GERAN will introduce a new 8-PSK half rate optimized voice bearer. For the channel codec of this voice bearer, contributions using recursive systematic encoders (RSC) and non-recursive, non-systematic encoders (NSC), respectively, for convolutional encoding—without comparing these two encoding schemes—have been presented. In two contributions, [1] and [2], Nortel Networks presented performance results for 8-PSK AMR (FS) on a half rate channel and they compared NSC and RSC. They concluded that non-systematic encoding performed according to their proposal is superior to recursive systematic encoding. Since the results shown raised some questions (considering past evaluations of RSC vs. NSC, [3], [4] and the sometimes stated opinion, that using RSC results in a lower BER than NSC—at least for low SNR, [5], [6, p. 576]) we tried to reproduce the presented results and to improve the performance of the RSC.

2 Setup

We considered three parameters of major influence: RSC or NSC, position of systematic bit in the encoded bit stream (i.e., arrangement of the feed forward polynomials in the encoder), and the interleaver used. For the interleaver, we implemented two schemes, outlined in Section 2.4 The combination of these three parameters resulted in eight different encoding schemes.

Since we did not strive for proposing an optimized complete channel coding scheme at this time, we limited our scope to the AMR NB mode MR122. The simulations were run for 25000 speech frames each.

2.1 AMR Full Rate Speech

Bit classification and CRC computation were performed as defined in [2, Annex A]. The bit classification is identical to GSM 05.03, Section 3.9.4.2.

2.2 Convolutional Encoder

The following three polynomials, as defined in GSM 05.03 [7], were used,

$$
\begin{aligned}
G4 &= D^6 + D^5 + D^3 + D^2 + 1, \\
G5 &= D^6 + D^4 + D + 1, \\
G6 &= D^6 + D^4 + D^3 + D^2 + D + 1.
\end{aligned}
$$

In the respective encoders, we implemented the following combinations of these polynomials,

Feed forward	Feed back
G4 G5 G6	—
G4 G5 G6	G6
G6 G4 G5	—
G6 G4 G5	G6

2.3 Puncturing

The convolutionally coded bits were punctured according to [2, sec. 4.1.3].

2.4 Interleaving

Two different interleaver were implemented and tested. The one (called *Intlv 1* in the figures) used the same interleaving scheme as proposed in [2, sec. 5]. For the other (*Intlv 2*) we used the same type of diagonal interleaving as defined for TCH/AHS.

2.5 Symbol Mapping

The interleaved bit streams are re-arranged to always keep the class 1a bits (I1) in the first two bit positions of the 8-PSK symbol. The third bit ("weak bit") always carries class 1b bits (I2).

$$\begin{aligned}
S1(B,3j) &= I1(B,2j) \\
S1(B,3j+1) &= I1(B,2j+1) \\
S1(B,3j+2) &= I2(B,j) \qquad \text{for } j=0,1,\ldots,42 \\
\\
S2(B,j) &= I2(B,j+43) \qquad \text{for } j=0,1,\ldots,38.
\end{aligned}$$

The resulting bit streams are combined in the following way:

$$\begin{aligned}
S(B,j) &= S2(B,j) \qquad \text{for } j=0,1,\ldots,20 \\
S(B,3*(j+7)) &= S1(B,j) \qquad \text{for } j=0,1,\ldots,42 \\
S(B,j+150) &= S2(B,j+21) \qquad \text{for } j=0,1,\ldots,17.
\end{aligned}$$

The resulting bit stream S is mapped to 8-PSK symbols by grouping 3 bits at a time,

$$Sm(B,j) = [S(B,3*j), S(B,3*j+1), S*B,3*j+2)], \qquad \text{for } j=0,1,\ldots,55.$$

2.6 Mapping on a Burst

As stated in [2, sec. 7], the result of the interleaving and symbol mapping is a distribution of the reordered 244 symbols of a given data block, $n=N$, over 4 blocks using the even numbered symbols of the first 2 blocks ($B=B0+2N+0,1$) and the odd numbered symbols of the last 2 blocks ($B=B0+2N+2,3$). The reordered symbols of the following data block, $n=N+1$, use the even numbered symbols of the blocks $B=B0+2N+2,3$, ($B=B0+2(N+1)+0,1$) and the odd numbered symbols of the blocks $B=B0+2(N+1)+2,3$. Continuing with the next data blocks, one block always carries 56 symbols of data from one data block ($n=N$) and 57 symbols from the next block ($n=N+1$). The symbols from the data block with the higher number are always the even numbered data symbols; those of the data block with the lower number are the odd numbered symbols.

3 Simulation Results

The simulation results are for TU3 with ideal frequency hopping. We used 25000 speech frames in the simulation. Figure (1a) shows the Class 1a FER performance and Figure (1b) shows the Class 1b RBER performance for all eight encoder configurations (c. f. Table 1) using the AMR mode MR122.

Interleaver	Feed forward polynomials	Feed back polynomial
Intlv 1	G4 G5 G6	—
Intlv 1	G4 G5 G6	G6
Intlv 1	G6 G4 G5	—
Intlv 1	G6 G4 G5	G6
Intlv 2	G4 G5 G6	—
Intlv 2	G4 G5 G6	G6
Intlv 2	G6 G4 G5	—
Intlv 2	G6 G4 G5	G6

Table 1 Encoder combinations tested.

4 Discussion

Looking at the results for class 1a FER (Figure 1(a)), we see a correspondence with [2, Figure 1(a)] for RSC at $FER = 1\%$. In both cases the C/I value is close to 12dB (for interleaver *Intlv 1*). The Interleaver *Intlv 2* shows a worse performance. The curves in general, however, do not look alike at all; they even show a different shape. While the curves obtained from our simulations are convex and tend to $FER = 0$ for high C/I show the curves in [2, Figure 1(a)] an almost concave behavior.

Another remarkable difference is the performance gap between RSC and NSC in [2, Figure 1(a)]: NSC seems to outperform RSC by up to 3dB (at 1% FER). We could not find such a superior performance of the NSC. Our results show an identical behavior of NSC and RSC in the case of FER. If one considers the FER related to the burst error probability, these results are supported by theory [5]:

> "The free distance of a convolutional code is the principle determiner of the burst error probability for high signal-to-noise ratios when maximum likelihood decoding or nearly so is used. Since the free distance is a code parameter, the burst error probability will be the same whether the convolutional code is encoded by a non-systematic feed forward encoder or by its systematic feedback encoder. Bit error probability, however, depends on the encoder used."

If we compare the class 1b RBER performance shown in Figure 1(a) and [2, Figure 1(a)] we can see a similarity in the general trend of the results. If one looks close enough, it is even possible to identify the pair of curves in 1(a) where the NSC "outperforms" the RSC (Intlv 1, {G4/5/6}/G6 vs. Intlv 1, {G4/5/6}) as stated in [2] as a general result. However, the only conclusion which can be drawn from looking at this particular pair of curves is, that one has to choose the arrangement of the feed forward polynomials for a given puncturing scheme very carefully. By simply re-arranging {G4/5/6} to {G6/4/5}, we gain a considerable decrease in RBER for RSC, especially in the case of low C/I values; NSC performance, however, remains the same. This might be due to the fact that by using {G4/5/6}/G6 and the puncturing scheme as proposed in [2], not all systematic bits are transmitted.

5 Summary and Conclusion

We tried to reproduce the performance of NSC vs. RSC as shown in [2]. In general, we were not able to duplicate the results. In particular, we did not come to the conclusion that NSC is superior to RSC, but quite the contrary. It can be seen from our results that choosing a not-so-optimal arrangement of the feed forward polynomials can degrade the performance of an otherwise superior encoding scheme (RSC) significantly. Thus, it is necessary to select interleaving, polynomials (including their sequence in the encoder), and puncturing very carefully for a given encoder.

Based on our results we propose to select recursive systematic encoding of convolutional codes for the 8-PSK AMR optimized voice bearers; of course with optimized interleaving, polynomial selection, and puncturing.

References

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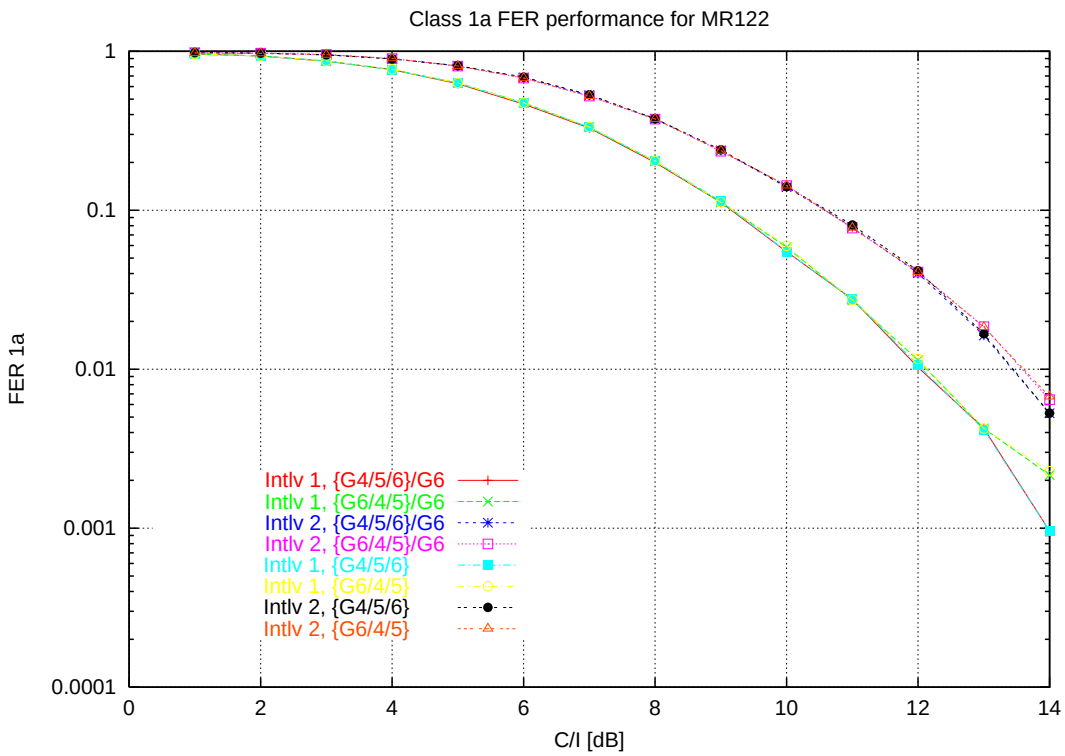
[3] Ericsson/Nokia/Siemens, Tdoc SMG11 329/98, "Objective test results for alternative AMR channel coding schemes."

[4] Ericsson/Nokia/Siemens, Tdoc SMG11 330/98, "AMR channel coding schemes."

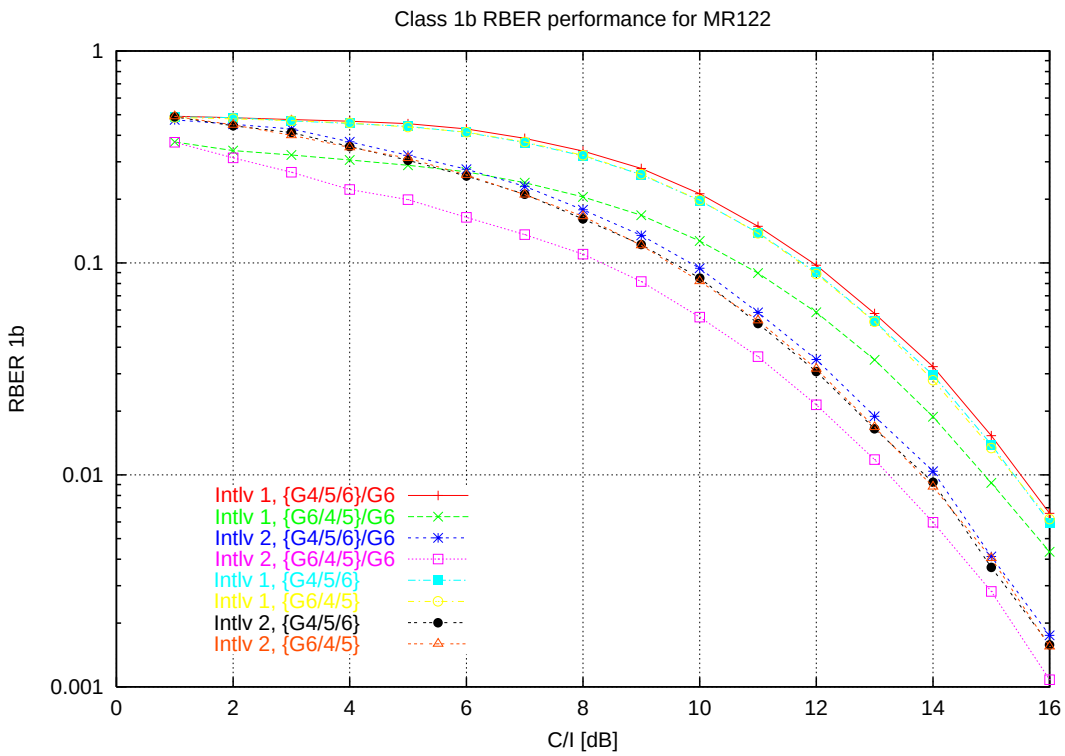
[5] R. Johannesson, L. L. Massey, and P. Stahl, "Systematic bits are better and no buts about it." http://www.it.lth.se/it/projects/codingtheory/svnce.html. To appear in a book to be published in honor of G. David Forney, Jr. on the occasion of his 60th birthday.

[6] S. Benedetto and E. Biglieri, *Principles of Digital transmission. With Wireless Applications.* Kluwer, 1999.

[7] ETSI, GSM 05.03, "Digital cellular telecommunications system channel coding."



(a)



(b)

Figure 1 Class 1a FER (a) and Class 1b RBER (b) performance for MR122.