CHOICE OF FORWARD ERROR CORRECTION FOR DIGITAL WIRELESS COMMUNICATION

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Abstract. *When digital data is sent over a wireless channel, transmission errors may occur. These errors are for instance caused by interferences in the channel. To improve the performance of the communication link, error detection and correction codes are used. Before starting implementing this link, a well-considered choice of forward error correction (FEC) is very important. In this article instructions are given to help finding the right error correction code for a specific application.*
After an introduction on channel models, the typical errors introduced by these channels are given. The efficiency of error correction codes, like Reed Solomon and convolutional codes, is tested by means of simulations. First we look at the performance of forward error correction codes for different channels. Based on the properties of both, the channel and the error correction code, we explain the simulation results.. In this way, a guideline for the choice of a FEC code is presented.
Keywords: *wireless, forward error correction, channel model.*

Introduction

To achieve high performance in digital wireless communication systems, forward error correction (FEC) is a common used technique. In spite of the fact that there are a lot of good mathematical books on these techniques, small companies experience difficulties with the practical implementation of error correction. A cooperation between KaHo St-Lieven and a few of these companies is set up to make the FEC more accessible.
To achieve the goal of this project an analysis on FEC codes and the properties of wireless channels is done. Practical implementations of wireless systems in addition with FEC codes are planned.
This paper gives an introduction on the behaviour of different channels and the properties of forward error correction. The main part of the paper handles about selecting an error correction technique depending on the channels behaviour.

Background

To start, a short introduction about two types of FEC codes will be given. Afterwards the properties of channel models are handled.
Block codes and convolutional codes are two types of forward error correction that are often used. A (n,k) block encoder divides the bit stream in blocks of k symbols [4]. With these k symbols the encoder calculates n new symbols, with n larger than k. The factor n/k is called the redundancy factor.
In a (n,k,m) convolutional code the factor n/k defines also the redundancy factor. Here the input stream is not divided into blocks. Each output bit of the encoder is calculated using the (m+1)k last input bits of the encoder [1].
Block codes can correct burst errors, i.e. errors that occur one after the other. Convolutional codes, on the other hand, are not able to correct burst errors [2]. These codes are typically used to correct uncorrelated errors. Block codes are also able to correct these uncorrelated errors, but not as efficiently as convolutional codes.

The behaviour of the FEC codes will be evaluated using two different channel models. The first model is the additive white gaussian noise (AWGN) channel model [5]. This channel introduces uncorrelated errors.

The second one is the multipath Rayleigh fading channel model. Signals sent over this channel arrive at the receiver with different delays. The gain of the different paths varies with time. This time-dependant gain leads to periods where lots of transmission errors occur and others where there are no errors at all. Hence, the errors introduced by a Rayleigh channel are correlated.

FEC over AWGN channels

In this paragraph the performance of convolutional and block codes over an AWGN channel are simulated and compared. All simulations are done using 4-differential phase shift keying (4DPSK). At the transmitter and receiver a squared raised cosine filter [3] is used to avoid inter symbol interference. The used roloff factor of this filter is 0.5.

For the convolutional decoder the viterbi decoding algorithm is implemented. As block code Reed Solomon (RS) codes are used. The redundancy factor of all used codes is 3/1. Figure 1.a shows the configurations with only one FEC code.

Figure 2 shows that the (3,1,5) convolutional code gives better results compared to the (15,5) RS code. The errors introduces by the AWGN channel are not correlated. As mentioned before, the convolutional code reacts better when errors are not correlated. Hence the convolutional decoder gives better results than the RS decoder.

Figure 2 also shows that the (15,5) RS and the (31,11) RS code give the same performance. A larger Reed Solomon code can correct larger burst errors. But when the errors are not correlated this does not lead to a better performance.

To further reduce the probability of a bit error, two FEC codes can be used (Figure 1.b). The first decoder is called the inner decoder.

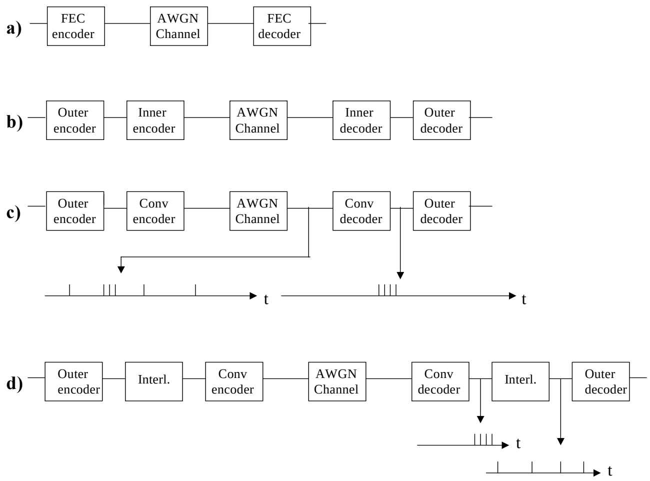

Figure 1. Configurations of FEC codes in combinations with an AWGN channel

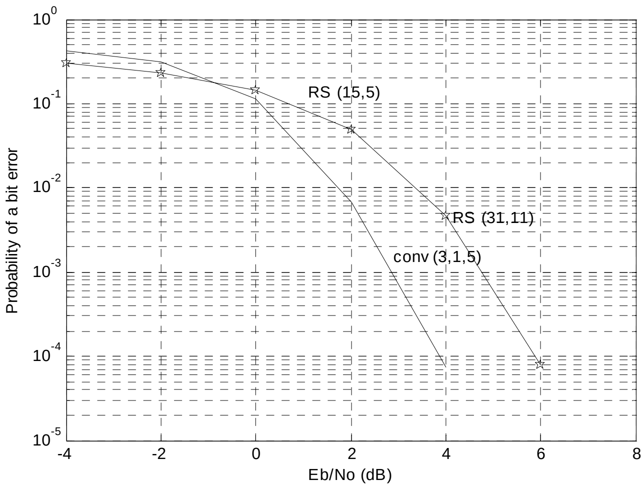

Figure 2. Performance of convolutional vs. RS code for an AWGN channel

The errors that are not corrected by the inner code can be further reduced by the outer code. As inner code a convolutional code is used (Figure 1.c). This because the transmission errors after the AWGN channel are uncorrelated. The convolutional code is able to correct most single bit errors. But when there are too many errors one after the other, this inner decoder will not be able to correct them. The errors, the convolutional code cannot correct, will typically occur in bursts. Keeping this in mind a RS code as outer code will give better results. This can be seen in Figure 3.

Another method to increase the performance of a wireless link is by using an interleaver. An interleaver changes the order of the symbols transmitted over the channel.

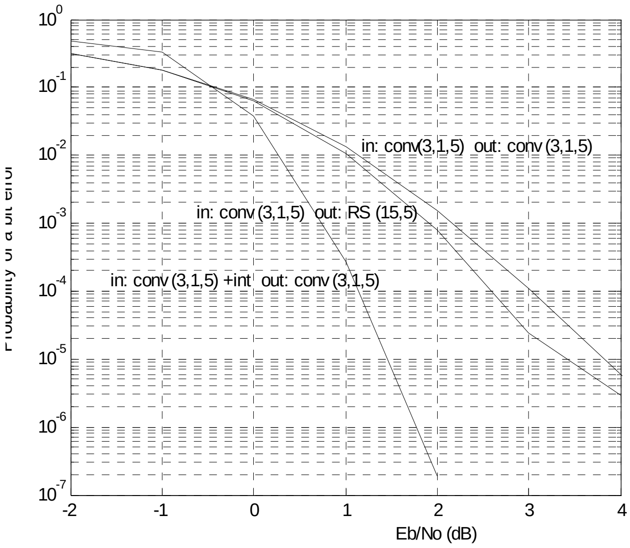

Figure 3. Performance of an outer RS vs. outer convolutional code for an AWGN channel

When an interleaver is placed after the convolutional decoder, it is able to spread the burst errors with time (Figure 1.d). So after the interleaver, the correlation between the errors will be decreased. In this case a convolutional outer code leads to the best results. Figure 3 shows that an inner convolutional code in combination with an interleaver and an outer convolutional code give a better result than when a RS outer code is used.

FEC over Rayleigh channels

The same comparison as above can be made using a Rayleigh channel. The used Rayleigh model has 5 delay lines (
Table 1). The Doppler frequency is 100 Hz [3,5]. Simulations are done for a transmission speed of 20 kbps.

Table 1. JTC Rayleigh channel model for indoor commercial areas [6]

Gain (dB)	Delay (µs)
0	0.0
-2.9	0.05
-5.8	0.10
-8.7	0.15
-11.6	0.20

The main difference between this channel and an AWGN channel is that a Rayleigh channel introduces correlated errors. This influences the choice of the FEC code. The Performance of one FEC code will be discussed first (Figure 4.a).

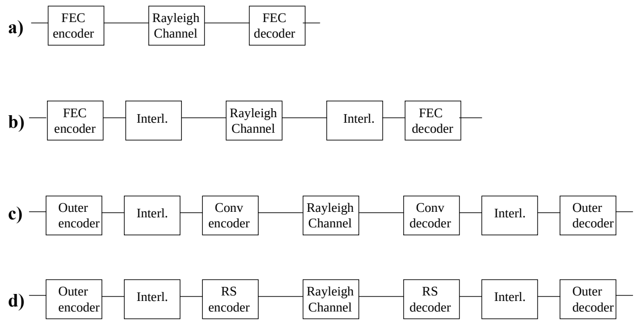

Figure 4. Configurations of FEC codes in combination with a Rayleigh fading channel

When RS codes with different sizes are compared, the largest RS code gives the best results. Figure 5 shows for example that using a (63,21) RS code leads to a better performance than a (31,11) RS code. This because larger RS codes can correct larger burst errors. Larger codes need of course more decoding time.

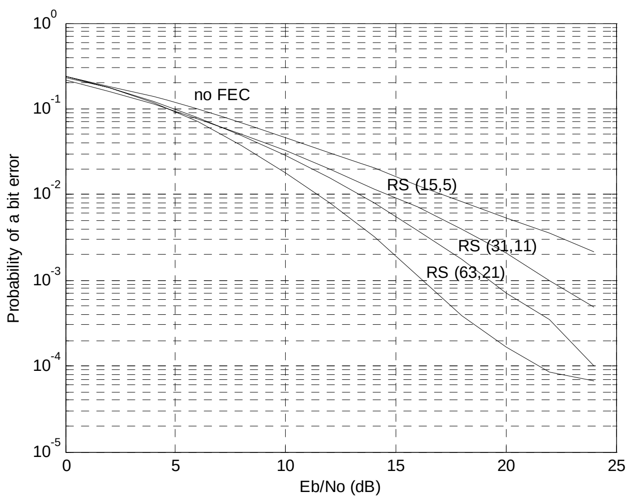

Figure 5. Performance of different RS codes

When the burst errors are larger than the error correcting capacity of the RS code, the performance of a convolutional code can get even better than the performance of this RS code. This can be seen in Figure 6. The (3,1,5) convolutional code does better than the (15,5) RS.

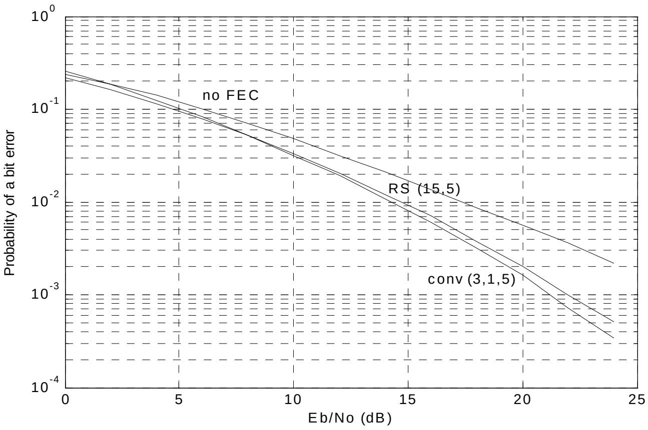

Figure 6. Performance of different FEC codes

To spread the burst errors with time, an interleaver can again be included (Figure 4.b). When the burst errors are interleaved a convolutional code can correct the single errors. The larger the interleaver the better the bit error probability (Figure 7). The disadvantage of a larger interleaver is on the other hand that it introduces larger delays.

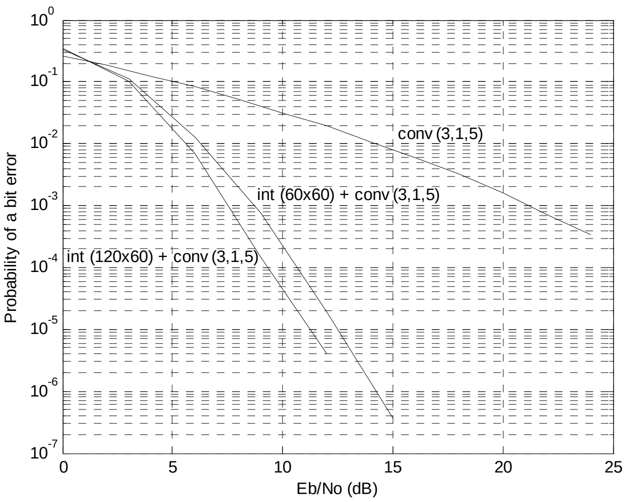

Figure 7. Performance of a convolutional code with different interleavers

Again it is possible to use two FEC codes. First the performance of convolutional code as inner code is analysed (Figure 4.c). This convolutional code will be able to correct single transmission faults. But it will not be able to correct the burst errors introduced by the channel. Thus the errors after the inner convolutional decoder are correlated. Including a RS code after this convolutional code will give a further decrease of the BER. Figure 8 shows that a larger RS code will give better results.

When using a convolutional code as outer code, this gives no satisfying results. This outer code is not able to correct correlated errors. To decrease this correlation again an interleaver can be used. Figure 8 shows that the introduction of a convolutional outer code in combination with an interleaver can give even better results than a small RS outer code.

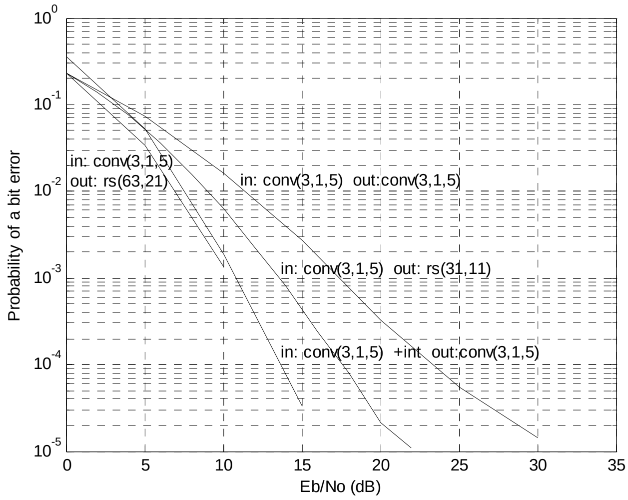

Figure 8. Performance of two FEC's, inner convolutional code

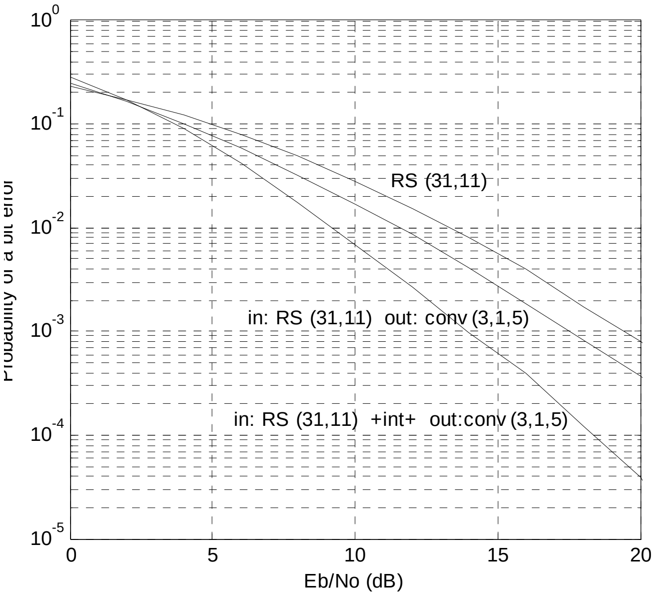

Figure 9. Performance of two FEC's, inner RS code

In Figure 9 a RS code is used as inner code to correct the burst errors (Figure 4.d). Burst errors that are too large will not be corrected by this inner code. So when a convolutional code is used as outer code, the improvement of the performance is not very large. The comparison of a single RS and a RS in combination with a convolutional outer code is shown in Figure 9.

The correlation of the errors before the outer decoder can again be reduced using an interleaver. This is also shown in Figure 9.

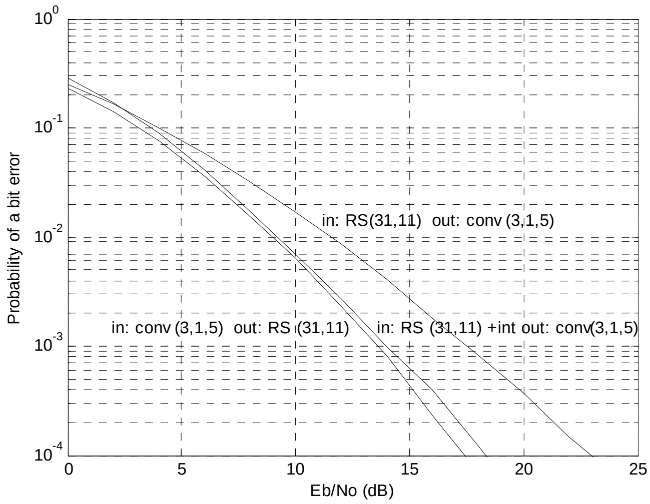

Figure 10. Comparison of the performance of two FEC's

Looking at Figure 10, which is a compilation of Figure 8 and Figure 9, best results occur when using a convolutional code as inner code. Comparing e.g. the inner (31,11) RS combined with the outer (3,1,5) convolutional and the reverse configuration, the second case gives the best results. For a signal to noise ratio (SNR) of 10 dB the first configuration gives a BER of $1.8x10^{-2}$, the second one gives only a BER of $6x10^{-3}$. To achieve the same probability of a bit error, when using a Reed Solomon as inner code and a convolutional code as outer code, an interleaver is needed.

Conclusion

In this article the performance of FEC codes over different channels is simulated. This results in a guideline for the choice of a forward error correction technique over an AWGN and a Rayleigh channel. Single FEC codes as well as a combination of two FEC codes are discussed. The influence of an interleaver is also included.

If the behaviour of the wireless link is similar to an AWGN channel, it' is best to use a convolutional code. If the BER not satisfy your specifications, you can use a larger convolutional code. Another possibility is the use of a convolutional code as inner code in combination with a RS as outer code. The combination convolutional code interleaver convolutional code gives the best results, but keep in mind that the interleaver will introduce an extra delay. If the behaviour of the wireless link is similar to a multipath Rayleigh fading channel, correlated errors will occur. When using a single code, a RS code is the best choice. Here it is also possible to combine two FEC codes. Combining a RS as inner and a convolutional code as outer code does not give good results without an interleaver. When using a convolutional code as inner code the outer code must be able to correct burst errors. There are two options.

It is possible to use a RS code. The other possibility is the combination of an interleaver and a convolutional code an outer code.

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