Non-recognizable error probability in a Terrestrial DAB Single Frequency Network

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Abstract

DAB (Digital Audio Broadcasting) is a the European successor of FM radio and it can broadcast besides audio services also other services such as traffic information. In this paper the probability of non-recognized errors in the system is derived for a 8 kbit/s data subchannel using protection level EEP3-A. This is important as data services rely on error-free transmission. It has been shown that in a live DAB network, this probability is very low. For a realistic user scenario, a user will encounter on average a non-recognized packet each 100000 year.

1 Introduction

DAB (Digital Audio Broadcasting) is standardized in the late nineties [1] and is the European successor of current FM radio broadcasting. The physical layer of DAB, include an OFDM-based transmission with D-QPSK modulated sub-carriers and using RCPC (Rate Compatible Punctured Convolution Codes) for error correction. One DAB channel consists of a *multiplex* of 2304 kbit/s (including error correction). In a typical situation, the multiplex contains about 10 radio stations.

In addition, Terrestrial DAB is designed to operate in a Single Frequency Network which means that all DAB transmitters broadcast on the same frequency. The network is designed in such a way that the delay spread of the received paths of all transmitters are within the cyclic prefix duration, i.e. signals from other transmitters can be considered as extra received paths. For mode I in DAB, the maximum allowable distance between receivers is 100 km [2].

DAB is not only designed for audio services, it can also transmit video or data. Data services include traffic information, electronic programming guide etc. To guarantee error-free reception, DAB uses several techniques to protect the transmitted data bits against errors. However, there will always be a probability that a non-recognizable error will occur. Such an error can cause systems to malfunction, an example being that incorrect traffic jam information is displayed.

This paper identifies the probability of these *non-recognizable errors*. To derive this probability, results from measurements in a live Single Frequency Network (SFN) in Amsterdam are used where the University of Twente conducts a DAB field trial commissioned by the Dutch Ministry of Economic Affairs [3].

The outline of this paper is as follows. First the error detection and correction techniques in DAB are discussed. This is followed by a realistic user scenario and this paper is concluded with a summary.

2 Error detection and correction in DAB

DAB uses several techniques to protect the transmitted data bits against errors:

- Interleaving
- Forward Error Correction (FEC)
- Cyclic Redundancy Codes (CRC)

2.1 Interleaving

The first part is the interleaving function. In wireless communication errors occur often in bursts and the purpose of the interleaver is to convert these burst errors in independent errors. This is required as the FEC decoding function requires independent bit errors. The interleaver consists of two randomize functions, both in frequency and time to meet this goal.

2.2 Forward Error Correction

At the transmitter, extra information (i.e. Forward Error Correction (FEC)), is added to the transmitted data, which allows the receiver to detect and correct errors in the received signal. DAB uses convolutional codes (i.e. Rate Compatible Punctured Convolution Codes) for this purpose. The most common mode used in DAB, is protection level EEP3-A (Equal Error Protection) for data services. EEP3-A has a code rate of $\frac{1}{2}$ which means that for every information bit, two bits are transmitted.

The performance of the FEC system for the different protection levels is discussed in [4]. In figure 1, the Bit-Error Rate (BER) versus the symbol-to-noise ratio ($\frac{E_s}{N_0}$) is depicted for different code rates used in DAB in a slow Rayleigh fading channel that mimics a realistic channel. Protection level EEP3-A uses a code rate of $\frac{8}{16} = \frac{1}{2}$. In addition, the BER curve is shown if no error correction is applied (line *uncoded*). The service area of DAB can be defined as where the BER is lower than 10^{-4} [5],[2]. At the border of the service area, protection level EEP3-A is capable of reducing the raw BER (*uncoded* line) of 10^{-1} to 10^{-4}. So, it reduces the BER with a factor 1000.

In a realistic situation, the user is not always at the border of a service area. For example, figure 2 depicts the measured BER with our measurement vehicle for protection level EEP3-A in Amsterdam. From this figure one can deduce that a realistic scenario would be that the user is only 5 % of the time at the border of the service area. At the border of the service area, the user experiences a BER of 10^{-4}. Within the service area, the $\frac{E_s}{N_0}$ is much higher and therefore the BER is several magnitudes lower (see figure 1). For that reason, this 5 % will determine the probability of non-recognizable errors in the DAB system.

2.3 Cyclic Redundancy Codes

Although the BER is largely reduced by the FEC decoder, still bit errors can occur. To detect these errors, the system uses Cyclic Redundancy Codes (CRC)

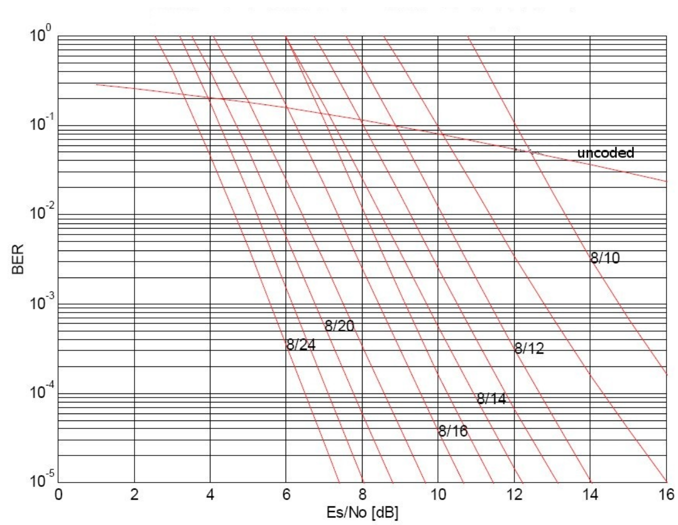

Figure 1: Theoretical BER curves (upper bound) for a slow Rayleigh channel, taken from [4].

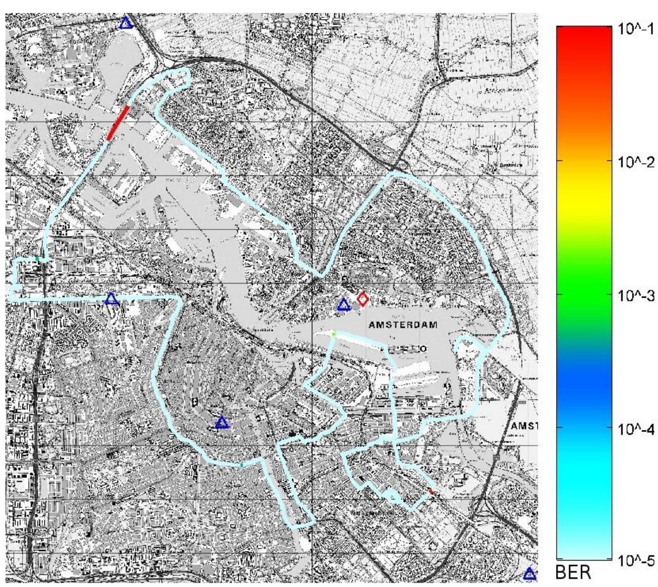

Figure 2: Typical performance for Protection level EEP3-A in Amsterdam (the color is an indication for the BER)

checksums [6] that are added to each packet that is transmitted. In DAB, the CRC-CCTITT code is used: $x^{16} + x^{12} + x^5 + 1$.

To each packet a CRC checksum is added. The CRC checksum is calculated by dividing the packet data by the CRC code i.e. 10001000000100001. The remainder of this division is the CRC checksum. At the receiver side, the division is repeated and both checksums are compared. If they are unequal, the packet contains errors.

The CRC-CCTITT code can detect bit errors as long as the combination of the errors is not a multiple of the CRC code, because in this case the remainder (i.e. checksum) of the division remains the same. The code contains 4-elements, which means that this code can detect any one, two or three bit errors and any unequal number of errors. Most combinations of 4 errors in the packet are detected but not all. The probability of non-recognizable errors is therefore mainly determined by the probability that 4 errors occur in the packet, as the following example will show.

2.3.1 Example

In this example we will derive what the probability is of a non-recognizable packet error, if there are 4 errors in the received packet for a BER of 10^{-4}. This value is compared with the probability when 6 bit errors occur as any combination of 5 errors is detected by the CRC code. Six bit errors are only undetected if it is a combination of two non-recognizable 4-bit errors.

For a 8 kbit/s channel with protection level EEP3-A, each packet contains 192 information bits [1]. To calculate the CRC checksum, the packet is divided by the CRC code. In binary calculations this means that at $192 - 16 = 176$ positions a XOR operation of 17 bits long can be performed. If the bit errors are a multiple of the CRC code they are not detected. So if in one of the stages of the division, errors occur on the positions of the elements of the code, it is undetected. The probability for this to happen is for a single stage in the division is:

$$P_p = \frac{n_e!(L - n_e)!n_e!}{L!} \cdot \frac{L!}{(L - n_e)!n_e!} \cdot P_e^{n_e}(1 - P_e)^{L-n_e} \tag{1}$$

- P_p the packet error probability
- P_e the bit error rate i.e. 10^{-4}
- N the packet length
- n_e the number of errors i.e. 4
- L the length of the CRC code i.e. 17
- ! the factorial function

The last part of the equation is the binomial distribution function [7] i.e. the probability that four bit errors occur in one XOR operation. However, only bit errors at elements of the code are not recognized and there are only 4! combination out of the total number of possibilities that are not recognized (i.e. first part of the equation). So equation 1 reduces to:

$$P_p = n_e! \cdot P_e^{n_e}(1 - P_e)^{L-n_e} \tag{2}$$

For a packet of 192 bits, there are 176 stages, the total packet error probability (non-recognizable errors) if there are four bit errors is: $176 \cdot P_p = 4.2 \cdot 10^{-13}$.

To analyze the probability that six bit errors are not detected by the CRC code is more difficult, but the probability that six errors occur in a packet is $P_e^6(1 - P_e)^{192-6} = 1 \cdot 10^{-24}$. (On the other hand, for four errors this probability is $1 \cdot 10^{-16}$.) As this value is already magnitudes smaller, the non-recognizable packet error probability is determined by the 4-bit errors case. Moreover, six bit errors are only undetected if it is a combination of two non-recognizable 4-bit errors.

In the previous section, it has been derived that it is likely that only 5 % of the time this probability will occur. Therefore the total non-recognizable packet error probability is $2.1 \cdot 10^{-14}$.

3 User scenario

A packet has a duration of 24 ms. So, if the data sub channel of 8 kbit/s is used every day for 8 hours by 10 million users, the probability that in year a packet with non-recognizable errors is received by one of the users is: $365 \cdot 8 \cdot 3600 \cdot 10^7 \cdot \frac{1}{0.024} \cdot P_p \approx 92$. Thus, every year, there are about 100 packets received with non-recognizable errors. Considering 10 million users, this is a very small value. On average, a user will encounter a non-recognizable packet each 100000 year.

4 Summary

In this document the non-recognizable packet error probability has been derived for a 8 kbit/s DAB sub channel for protection level EEP3-A. This probability is $4.2 \cdot 10^{-13}$ which is very small. For a user scenario with 10 million users, it has been shown that on average a user will encounter a non-recognizable packet each 100000 year.

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