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OPTIMIZATION OF BLUETOOTH FRAME FORMAT FOR EFFICIENT PERFORMANCE

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Abstract—This paper presents a modification for Bluetooth frame structure to improve its performance over both Additive White Gaussian Noise (AWGN) and fading channels. The paper investigates the effect of using different block codes on the performance of the Bluetooth system. Both Hamming and BCH codes with different lengths are studied as error control codes for the Bluetooth frame. Experimental results reveal that shorter Hamming codes have a better performance in AWGN channels. Also, the BCH (15, 7) code has a better performance for interleaved channels. All this work is devoted to Bluetooth 1.1 version.

1. INTRODUCTION

Bluetooth has emerged as a wireless communication technology aiming at achieving the interconnection between computer peripherals in an efficient manner. It is a short range communication system. It operates within a distance of 10–100 meters. The structure of stations in the Bluetooth network follows a piconet structure as shown in Fig. 1. Each piconet comprises up to seven Bluetooth devices working as slaves (S) and only one as a master (M) station. The limited number of slaves leads to an address field of no more than three bits. As shown in Fig. 1, a slave can be a member in more than one piconet. A master of any piconet may be a slave in another one. Up to 10 piconets can exist within Bluetooth range [1, 2].

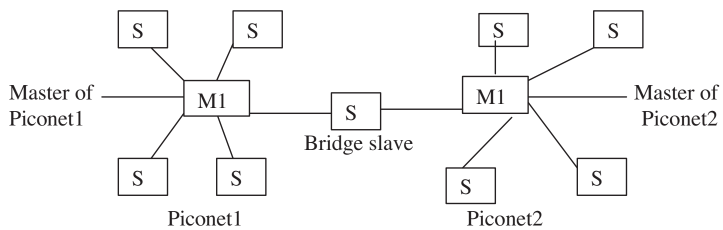

Figure 1. Bluetooth network structure.

The frequency range of Bluetooth operation is the unlicensed 2.4 GHz ISM (Industrial-Scientific-Medical) frequency band, which is also utilized by various wireless and radio technologies. It suffers from interference with other wireless services such as IEEE 802.11b, cordless telephones, and even microwave ovens [3, 4]. Also, the power used in this system has low levels, where there are three classes of power levels as follows. Class 1 refers to 1 mw (0 dBm), class 2 refers to 2.4 mw (4 dBm), and class 3 refers to 100 mw (20 dBm). This leads to much more errors, so error correction is required in Bluetooth systems. This has led to the usage of error correcting codes in the frame format for Bluetooth systems [5, 6]. Several researchers have investigated the issue of error control code design for Bluetooth systems [7]. Most of them have come to the conclusion that error control codes implemented for this task are not powerful for fading channels [8].

This paper tries to vary the concept of weakness of all block codes in Bluetooth systems. It investigates the performance of different versions of Hamming and BCH codes in error correction over AWGN, interleaved and bursty fading channels. It presents an optimization of the Bluetooth frame format for error detection and correction.

The rest of the paper is organized as follows. Section 2 surveys the standard Bluetooth frame format. Section 3 discusses the considerations of channel coding in the Bluetooth system. Section 4 presents the proposed formats for Bluetooth frames and gives an analytical study of the proposed formats. Section 5 gives a comparison study between the standard Bluetooth frame format and the proposed frame formats. Finally, the concluding remarks are given in Section 6.

2. BLUETOOTH FRAME FORMAT

The standard frame format for Bluetooth systems is illustrated in Fig. 2. This figure shows the packet contents of the Bluetooth frame. The function of the access code is to identify the packets exchanged within a piconet, where each piconet has a unique access code. The access code is used to synchronize the slaves in a piconet to its master [9]. The main function of the header of the Bluetooth packet is to determine an individual slave address in the piconet by the Logical Transport-Address (LT_ADDR). The last part of the Bluetooth frame is the payload. Bluetooth has several types of packets. We focus in our study on a certain type called ACL packets which refers to Asynchronous Connectionless Communications. Packets of the ACL payload may be one of two types; DM_x and DH_x. M refers to medium

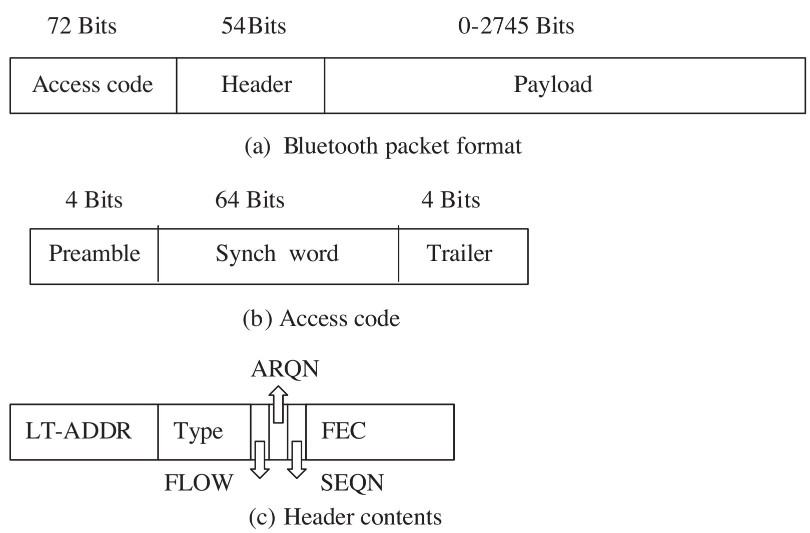

Figure 2. Bluetooth frame format.

data rate packets, while H refers to high data rate packets. The symbol x denotes the number of time slots between two hops in the frequency hopping system used [10]. It takes the values of 1, 3, or 5 referring to 1, 3, or 5 time slots between consecutive frequency hops. Always DM_x packets are coded packets and DH_x packets are uncoded packets [11].

3. CHANNEL CODING CONSIDERATIONS

Channel coding is required for wireless communications to protect data from the errors which may result from noise and interference. In the Bluetooth system, there are several channel coding schemes that are implemented. The purpose of the channel coding scheme on the data payload is to reduce the retransmission times which are due to channel errors [12, 13].

There are three types of error control coding which are used in Bluetooth systems, 1/3 rate error control code, 2/3 rate error control code, and ARQ (Automatic Repeat Request). Researchers have agreed to the standardization of both access and header fields in Bluetooth frames. They concentrates on varying the method of coding the payload which means dividing the payload between data and checksum.

The most appreciable work in the coding of the payload field was introduced by Galli et al. [7]. This work adopts the Hamming (15, 10) code with rate 2/3 for coding the payload. This type of Hamming codes is used as an error control code for the DM_x packets. Our study aims at investigating other coding schemes to obtain a better performance.

4. THE PROPOSED FRAME FORMAT

In this section, different coding schemes are proposed to code the payload field in the Bluetooth frame. First the Hamming (7,4) code is proposed. This is accomplished by dividing the payload into four bit segments which are then encoded to 7 bit codewords with the Hamming (7,4) code. This coding structure can be used for both AWGN and fading channels. An alternative to the Hamming code is the BCH (15,7) code for the same channels.

To find the relation between the packet error probability (PEP) and the SNR, we must take into consideration the different error control codes which are adopted in the different packet fields; access code, header, and payload.

This PEP is given by [7, 8]:

$$PEP = 1 - \left(1 - p^{AC}\right)\left(1 - p^{HD}\right)\left(1 - p^{PLx}\right) \tag{1}$$

where P^{AC} is the access code error probability, P^{HD} is the header error probability and P^{PLx} is the payload error probability.

The codeword error probability is a function of t which is the number of errors that can be corrected by the code, n which is the codeword length, and m which is the number of codewords. To find the error probability over the whole frame, we use the following equation [7, 8]:

$$P_{ew} = \sum_{i=t+1}^{n} \begin{pmatrix} n \\ i \end{pmatrix} P_b^i (1 - P_b)^{n-i} \tag{2}$$

P_{ew} is the error probability of the codeword.

The probability of packet error after decoding is given by [7, 8]:

$$P_{BadPkt} = 1 - P_{GoodPkt} = 1 - (1 - p_{ew})^m \tag{3}$$

P_b Pb is the bit error probability of uncoded BPSK over a Rayleigh flat fading channel and is given by:

$$P_b = \frac{1}{2}\left(1 - \sqrt{\frac{E_b/N_o}{1 + E_b/N_o}}\right) \cong \frac{1}{4E_b/N_o} \tag{4}$$

The previous equations would be modified for the following cases:

For the BCH (15, 7) code, the length of the payload will be reduced to keep the Bluetooth frame with the same standard length. This modification makes.

DM_1 payload $= 112$ bits $\rightarrow m = 16$.

DM_3 payload $= 700$ bits $\rightarrow m = 100$.

DM_5 payload $= 1281$ bits $\rightarrow m = 183$.

Before writing the new equations, we note that the number of codewords is the same in this case and in the case of Hamming (15, 10) code. The main difference is that the length of the payload is reduced by 30 percent, and $t = 2$. Then P_{ew} will be given by:

$$P_{ew} = \sum_{i=2+1}^{15} \begin{pmatrix} 15 \\ i \end{pmatrix} P_b^i (1 - P_b)^{15-i} \tag{5}$$

By this equation we get the codeword error probability.

From Eq. (3), we get the probability of error in DM_1, DM_3, and DM_5 packets as follows

For DM_1

$$P_{BadPKt}^{PL1} = 1 - \left(1 - p_{ew}^{PL1}\right)^{16} \tag{6}$$

For DM_3

$$P_{BadPKt}^{PL3} = 1 - \left(1 - p_{ew}^{PL3}\right)^{100} \tag{7}$$

For DM_5

$$P^{PL5}_{BadPKt} = 1 - \left(1 - p^{PL5}_{ew}\right)^{183} \quad (8)$$

For BCH (15, 7) code, the PEP will be given by:

$$PEP = 1 - \left(1 - p^{AC}\right)\left(1 - p^{HD}\right)\left(1 - p^{PLx}_{BADPKt}\right) \quad (9)$$

From the last equation, we conclude that the PEP is a function of the SNR as all terms are functions of SNR.

For the Hamming (7,4) code, with the same concepts, we propose the modification of the payload length to be as follows:

DM_1 payload $= 136\,\text{bits} \rightarrow m = 34$.

DM_3 payload $= 856\,\text{bits} \rightarrow m = 214$.

DM_5 payload $= 1568\,\text{bits} \rightarrow m = 392$.

We note that the number of codewords has been changed as compared to the BCH (15, 7) code. The length of the payload is decreased by 15 percent, and $t = 1$.

For the Hamming (7,4) code:

$$P_{ew} = \sum_{i=2}^{7} \binom{7}{i} P_b^i \left(1 - P_b\right)^{7-i} \quad (10)$$

For DM_1

$$P^{PL1}_{BadPKt} = 1 - \left(1 - p^{PL1}_{ew}\right)^{34} \quad (11)$$

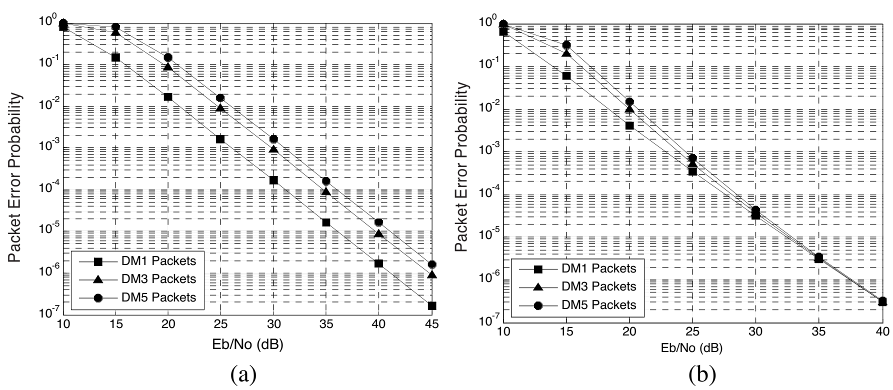

Figure 3. (a) Analytical Packet Error Probability (PEP) for DM_x packets using a Hamming (7,4) code over an interleaved channel. (b) Analytical PEP for DM_x using a BCH (15,7) code over an interleaved channel.

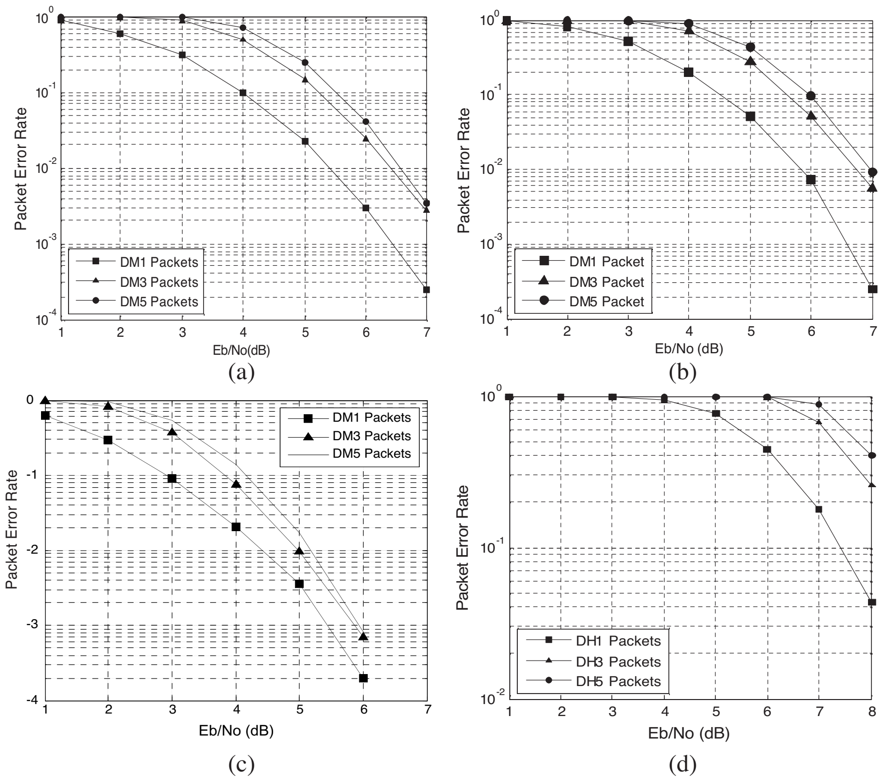

Figure 4. (a) Simulated performance of DM_x packets using a Hamming (7,4) code over an AWGN channel. (b) Simulated performance of DM_x packets using a Hamming (15,10) code over an AWGN channel. (c) Simulated performance of DM_x packets using a BCH (15,7) code over an AWGN channel. (d) Simulated performance of DH_x uncoded Packets over an AWGN channel.

For DM_3

$$P_{BadPKt}^{PL3} = 1 - \left(1 - p_{ew}^{PL3}\right)^{214} \tag{12}$$

For DM_5

$$P_{BadPKt}^{PL5} = 1 - \left(1 - p_{ew}^{PL5}\right)^{392} \tag{13}$$

The experimental results will be given the following section.

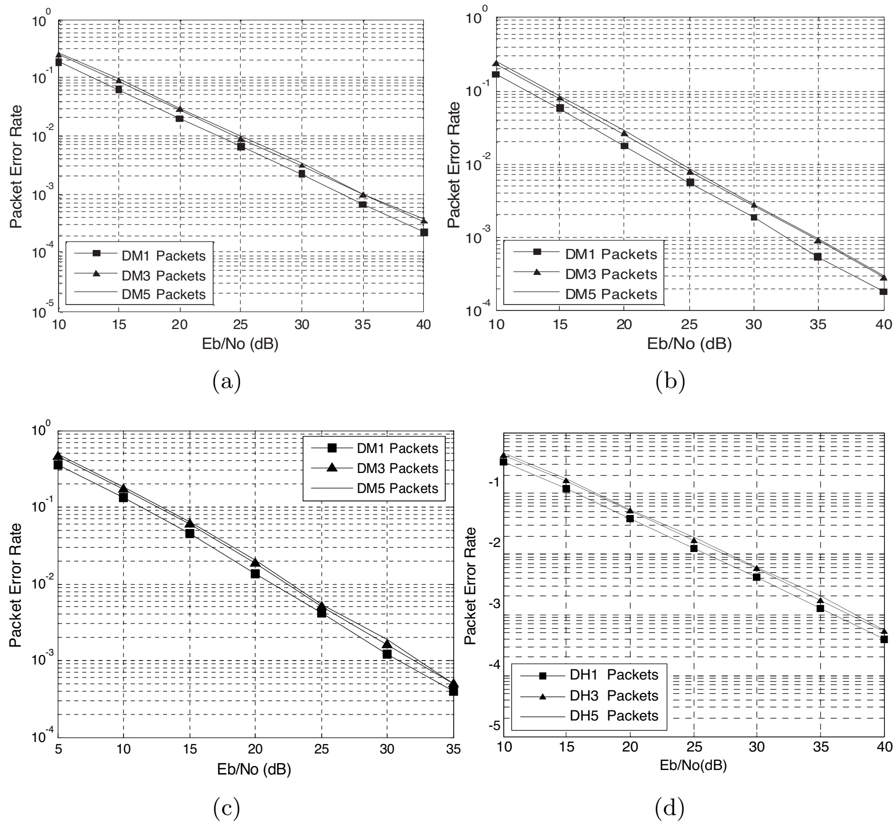

Figure 5. (a) Simulated performance of DM_x packets using a Hamming (15,10) code over a block fading channel. (b) Simulated performance of DM_x packets using a Hamming (7,4) code over a block fading channel. (c) Simulated performance of DM_x packets using a BCH (15,7) code over a block fading channel. (d) Simulated performance of uncoded packets over a block fading channel.

5. SIMULATION RESULTS

In this section the performance of the suggested coding schemes for Bluetooth frames is investigated. Simulation Experiments are carried out to evaluate the performance of these coding schemes and compare it to the analytical models for these schemes. First the analytical models are used to evaluate the performance of the Hamming (7,4) and the BCH (15,7) codes when they are used as error correcting codes for Bluetooth frames over an interleaved channel. This is clear in Fig. 3.

Then, several simulation experiments are carried out to investigate the performance of DM_x and DH_x packets over AWGN and Rayleigh fading channels using the proposed coding schemes. A comparison with the previously published coding schemes in Bluetooth systems is carried out.

In the first experiment, the performance of the Hamming (7,4), the Hamming (15,10) and the BCH (15,7) coding schemes is studied and compared to the performance of uncoded DH_x packets over an AWGN channel. The results of this comparison are given in Fig. 4. These figures reveal the superiority of the BCH (15,7) code for the AWGN channel. It is also clear that the Hamming (7,4) code has a better performance than the Hamming (15,10) code. This means that if Hamming codes are intended to be used for error correction in Bluetooth frames, shorter codes are preferred to longer ones.

The same experiment is repeated but with a block fading channel. The results are given in Fig. 5. The results of the Hamming codes are very close, which means that the Hamming (15,10) is better due to its low redundancy bits. It is also clear from the figure that the BCH code has the best performance for Bluetooth frames if the redundancy length is tolerated.

6. CONCLUSION

The paper investigates some possible frame formats for Bluetooth systems depending on the distribution of the payload field between data and checksum. Hamming and BCH codes are investigated for both AWGN and Rayleigh fading channels. Results reveal the superiority of short Hamming codes in noisy channels and BCH codes in fading channels.

Over interleaved fading channels, it is preferable to use DM_x packets for transmission if BCH codes are used. Over AWGN channels, at low SNRs , BCH codes improve the performance of DM_x coded packets, more than Hamming codes. At high SNRs the best throughput is achieved by DH_x uncoded packets, but at low SNRs the coded packets are preferable.

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