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Bluetooth Performance Improvement Using Convolutional Codes

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Abstract— In this paper, convolutional codes are used as error correcting codes for Bluetooth packets. The traditional coding scheme in standard Bluetooth packets depends on the Hamming (15,10) code in the payload field of each packet. This paper investigates the use of convolutional codes for this purpose. Two different versions of convolutional codes are studied based on the code constraint length. The simulation experiments are performed for the cases of additive white Gaussian noise (AWGN) and Rayleigh flat fading channels. The simulation results reveal the superiority of convolutional codes to the Hamming (15, 10) code used in the standard Bluetooth packets in the cases of AWGN and flat fading channels.

Keywords: Bluetooth, convolutional code, AWGN channel, wireless communications.

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. Stations in Bluetooth systems follow a piconet structure. 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. 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 the Bluetooth range [1, 2].

The frequency range of Bluetooth operation is the unlicensed 2.4 GHz Industrial-Scientific-Medical (ISM) 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 Bluetooth systems has low levels, where there are three classes of power levels. Class 1 refers to 1mw (0dBm), class 2 refers to 2.4mw (4dBm), and class 3 refers to100 mw (20dBm). This leads to the occurrence of many errors. So, error correction codes are required in Bluetooth packets [5, 6].

Standard Bluetooth systems use the Hamming (15,10) code for error correction in the payload field of the Bluetooth packet because of its simplicity. Several researchers have investigated the performance of this simple coding scheme [7]. Most of them have come to the conclusion that this scheme is not powerful for fading channels [8].

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This paper proposes the use of convolutional codes for error correction instead of the Hamming (15,10) code. Better performance is achieved due to the ability of convolutional codes to correct more errors than their Hamming counterparts. The study in this paper is performed on both AWGN and Rayleigh flat fading channels.

2. BLUETOOTH PACKET FORMAT

The standard Bluetooth packet has three portions as shown in Fig. 1; a 72-bits Access code (AC), a 54-bits packet header (HD), and a payload of 0-2745 bits. The function of the access code is to identify the packets exchanged within a piconet, where each piconet has a unique access code. It is also 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 systems have several types of packets.

We focus in our study on a certain type called ACL packets which refers to asynchronous connectionless packets. ACL packets have two types; DM_x and DH_x packets. The M refers to medium data rate packets, while the 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 values of 1, 3 or 5 referring to the number of time slots between consecutive frequency hops. Always, DM_x packets are coded and DH_x packets are uncoded [11].

(AC)	**(HD)**	**(PL)**
72 bits	54 bits	0 – 2745 bits

Fig. 1. Standard Bluetooth Packet Format

3. CHANNEL CODING CONSIDERATIONS

Channel coding is required in wireless communications to protect data from errors which may result from noise and interference. In Bluetooth systems, there are several channel coding schemes that are implemented in the different fields of Bluetooth packets. These schemes succeed in reducing retransmission times due to channel errors [12, 13]. Researchers have agreed to the standardization of both the AC and the HD fields in Bluetooth packets. They concentrate on varying the method of coding in the payload field. The most appreciable work in coding the payload field was introduced by Galli et al. [7]. This work adopts the shortened Hamming (15, 10) code with a rate of 2/3 for coding the payload. Our study aims at investigating convolutional codes to obtain a better performance.

4. PROPOSED PACKET FORMAT

In this section, convolutional coding schemes are proposed for encoding the payload field in Bluetooth packets. Convolutional codes differ from block codes in the method of generation. In block codes, a block of n bits is generated by the encoder for an input block of k bits.

In convolutional codes, on the other hand, an output block of n bits generated by the encoder depends not only on an input block of k bits but also on the block of (k-1) bits within a previous span of N-1 time units. In convolutional codes, k and n are small values.

A convolutional code converts the entire data stream (input of encoder) into one single code word (output of encoder). The convolutional encoder operates on the input bits of an information sequence in a serial manner as shown in Fig. 2. A convolutional code will be referred to as convolutional code (k, n, K), where k is the number of input bits of the encoder, n is the number of output bits of the encoder at one time interval, and K is the constraint length. It is defined as the number of shifts over a single input bit that can influence the encoder output and it is used to define the convolutional encoder characteristics. [6].

The length of the convolutional encoder output equals n(L+M), where M is the memory length of the encoder and L is the length of information bit stream at the encoder input. So, for a convolutional code (1,2,K), the maximum length of the payload field of a DM_x packet equals $2(L_{Mx} + 2)$ bits. For DM_5 packets, L_{M5}=1372 bits. So, the payload length after encoding = 2(1372+2) =2748 bits. This length will be shortened to 2745 bits to accommodate for the maximum length of the payload field in DM_x packets.

5. SIMULATION ASSUMPTIONS

In our simulations, we consider BPSK modulation. Also, the Monte Carlo simulation method is used to evaluate the performance of Bluetooth systems when DM_x or DH_x packets are transmitted. In the simulation experiments, a Bluetooth packet is dropped if there is at least one error after decoding the three portions of the packet. In the case of uncoded Bluetooth DH_x packets, the packet is discarded if there is a single error after decoding the first two portions.

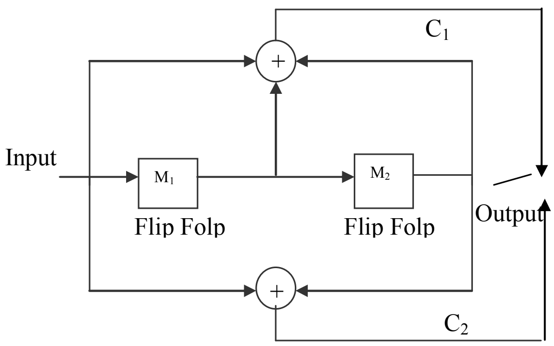

Fig. 2. Encoder of the convolutional code (1,2,3).

For the simulation of frequency hopping, each sequence of packets is transmitted within consecutive hops (1, 3, or 5). The simulation channel is considered time-invariant. This means that Δf = zero (Doppler spread equals zero).

In all simulations, a hard decision process is performed at the receiver in the decoding step for all channel codes. The errors occurring in the simulations are assumed independent and the interference effect is neglected.

6. SIMULATION RESULTS

This section investigates the performances of Bluetooth systems if the standard Bluetooth packets (DH_x and DM_x packets) are transmitted over AWGN and fading channels. Also, the proposed coding schemes of the payload fields in DM_x packets using convolutional codes are studied. A comparison study between the standard Bluetooth case and the case implementing the proposed coding schemes is made. Several cases are considered in the simulation experiments.

The performances of standard Bluetooth systems employing DH_x and DM_x packets are simulated in the case on an AWGN channel. The simulation results are shown in Figs. 3 and 4, respectively. These figures reveal that DM_x packets are preferred to DH_x packets due to the coding effect. It is also clear from these figures that the decrease in x leads to a better performance. This is attributed to the small size of the DH_1 and DM_1 packets as compared to the other types of packets. So, the smaller the packet length, the lower the probability of error in this packet. The packet error probability or packet error rate (PER) considers one or more bit errors in the packet as a single packet error.

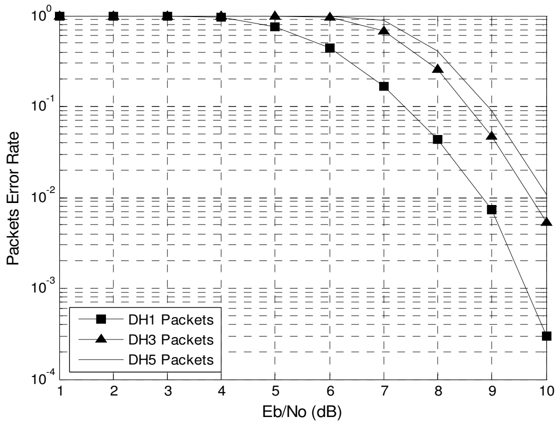

Fig. 3. Simulation of the performance of standard Bluetooth systems employing DH_x packets over an AWGN channel.

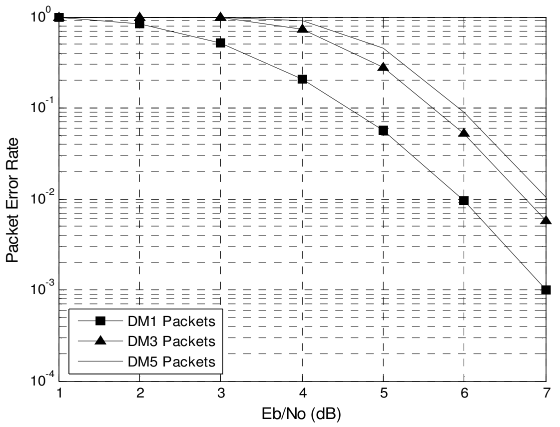

Fig. 4. Simulation of the performance of standard Bluetooth systems employing DM_x packets over an AWGN channel.

The performances of Bluetooth systems employing the convolutional code (1,2,3) in the payloads of DM_x packets are simulated. Figure 5 shows the simulation results in the case of an AWGN channel. This figure reveals the superiority of convolutional codes to the shortened Hamming (15, 10) code employed in the standard Bluetooth systems simulated in Fig. 4.

The Simulation results shown in Fig. 6 are for DM_x packets using the convolutional code (1, 2,3) for the both the AC, the HD and the payload in the case of an AWGN channel. The results shown in Figs. 5 and 6 are very close. This means that the use of convolutional codes in the AC and the HD fields is ineffective. These results justify the trend taken by researchers to study the effect of error control coding schemes on the payload fields only.

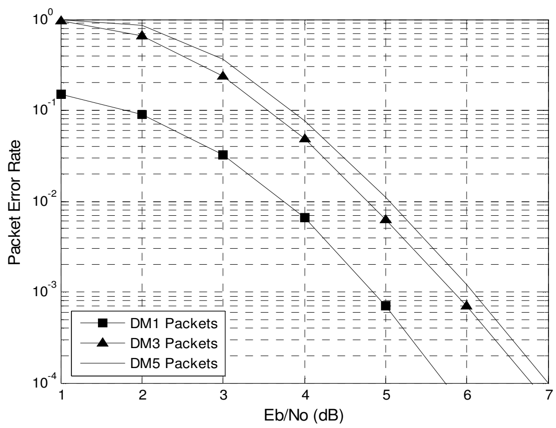

Fig. 5. PER vs. SNR for DM_x packets transmitted over an AWGN and employing the convolutional code (1, 2, 3) for the payload field only over an AWGN channel.

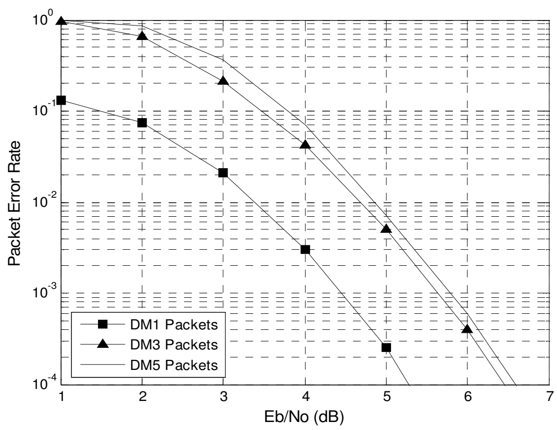

Fig. 6. PER vs. SNR for DM_x packets transmitted over an AWGN and employing the convolutional code (1, 2, 3) for both the AC, the HD and the payload fields over an AWGN channel.

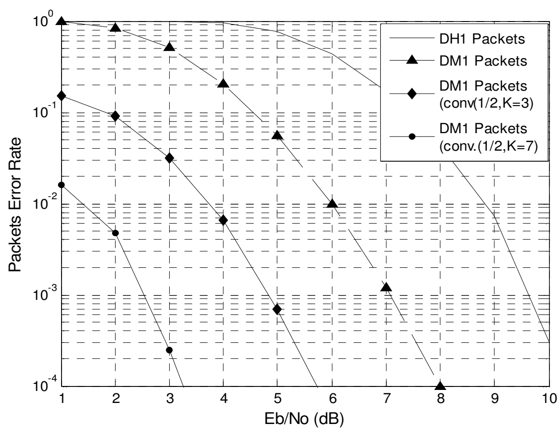

Fig. 7. Performance Comparison between standard Bluetooth systems employing DH_1 and DM_1 packets and the Bluetooth systems employing the convolutional codes (1,2,3) and (1,2,7), respectively over an AWGN channel .

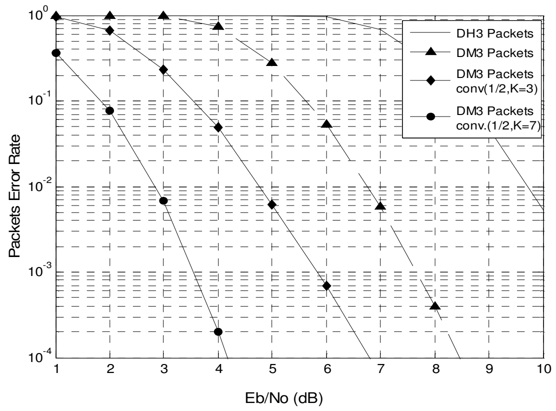

Fig. 8. Performance Comparison between standard Bluetooth systems employing DH_3 and DM_3 packets and the Bluetooth systems employing the convolutional codes (1,2,3) and (1,2,7), respectively over an AWGN channel .

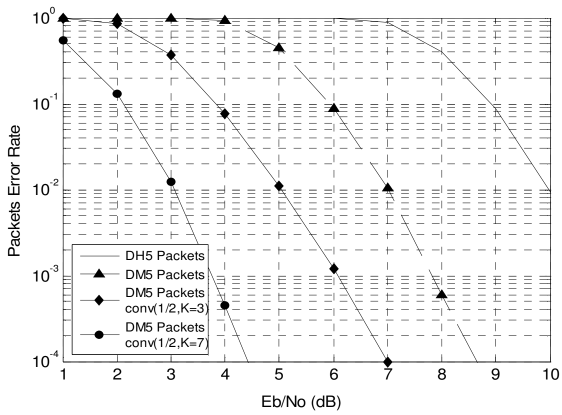

Fig. 9. Performance Comparison between standard Bluetooth systems employing DH_5 and DM_5 packets and the Bluetooth systems employing the convolutional codes (1,2,3) and (1,2,7), respectively over an AWGN channel .

Figures 7, 8 and 9 are devoted to compare between the performances of the standard Bluetooth systems and the systems employing the proposed convolutional coding schemes in the payload fields of all types of Bluetooth packets in the case of an AWGN channel. Another factor which is studied in these simulation experiments is the constraint length K of the convolutional code used. It is clear that the convolutional code with K=7 gives better performance than that with K=3.

At this point, there is a need to transfer to the case of Rayleigh flat fading channels. All the simulation experiments performed above are repeated for Rayleigh flat fading channels and the results are given in Figs. 10 to 16. From all figures, it is clear that the situation in flat fading channels is more complex than that in AWGN channels.

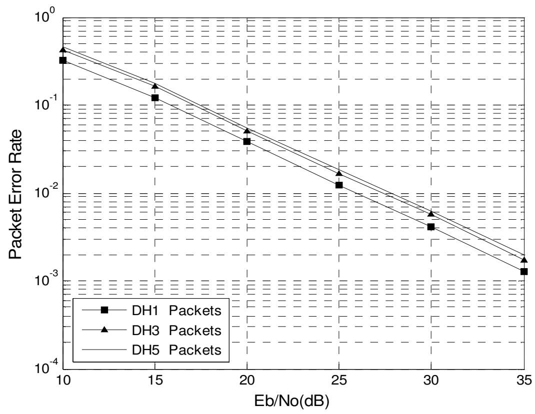

Fig. 10. Simulation of the performance of standard Bluetooth systems employing DH_x packets over a Rayleigh flat fading channel.

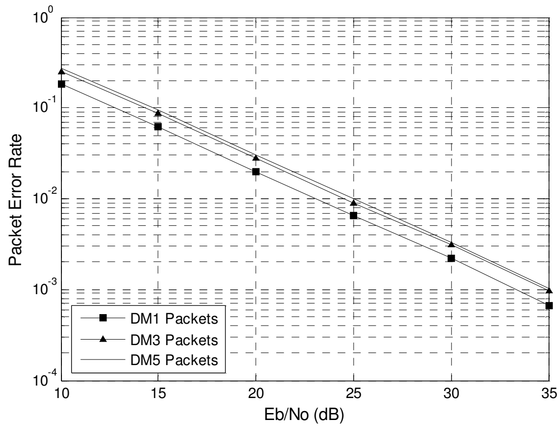

Fig. 11. Simulation of the performance of standard Bluetooth systems employing DM_x packets over a Rayleigh flat fading channel.

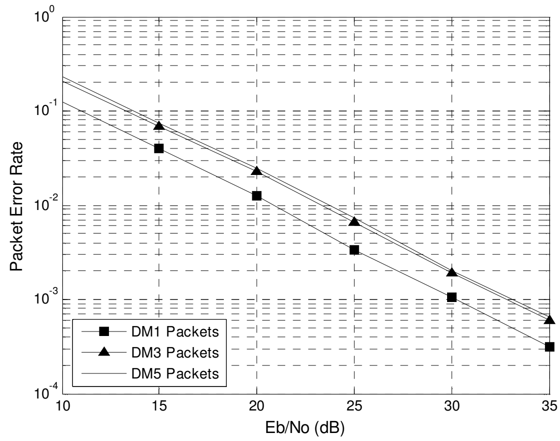

Fig. 12. PER vs. SNR for DM_x packets transmitted over an AWGN and employing the convolutional code (1, 2, 3) for the payload field only over a Rayleigh flat fading channel.

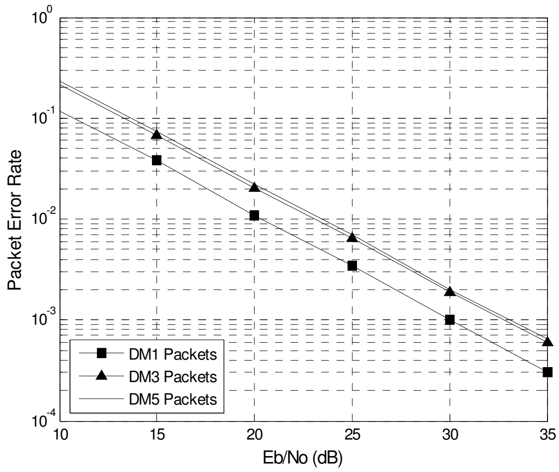

Fig. 13. PER vs. SNR for DM_x packets transmitted over an AWGN and employing the convolutional code (1, 2, 3) for both the AC, the HD and the payload fields over a Rayleigh flat fading channel.

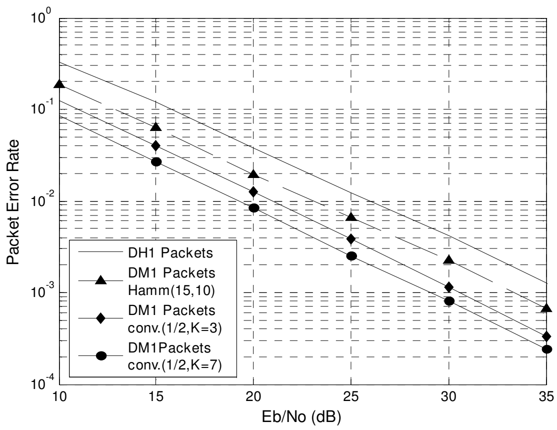

Fig. 14. Performance Comparison between standard Bluetooth systems employing DH_1 and DM_1 packets and the Bluetooth systems employing the convolutional codes (1,2,3) and (1,2,7), respectively over a Rayleigh flat fading channel.

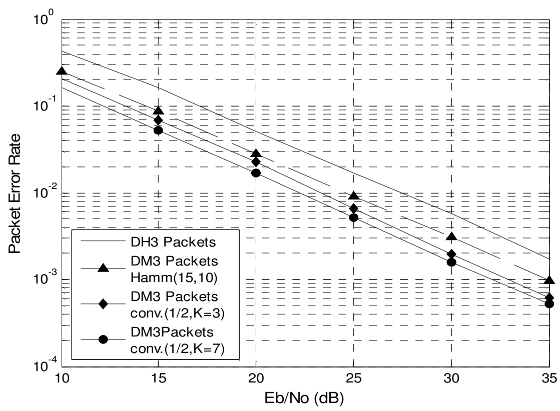

Fig. 15. Performance Comparison between standard Bluetooth systems employing DH_3 and DM_3 packets and the Bluetooth systems employing the convolutional codes (1,2,3) and (1,2,7), respectively over a Rayleigh flat fading channel.

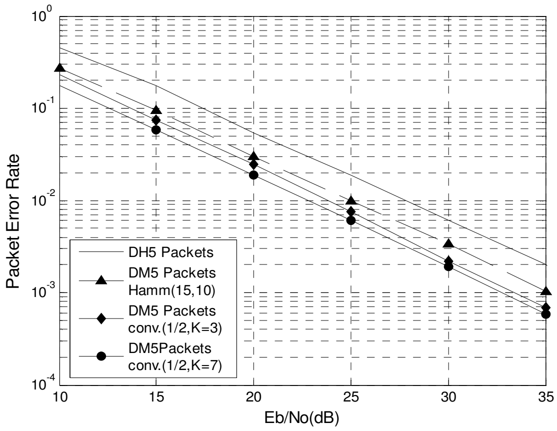

Fig. 16. Performance Comparison between standard Bluetooth systems employing DH_5 and DM_5 packets and the Bluetooth systems employing the convolutional codes (1,2,3) and (1,2,7), respectively over a Rayleigh flat fading channel.

It can be observed from Figs. 14 to 16 that convolutional codes with larger constraint lengths are the best option for coding in Bluetooth systems in the case of Rayleigh flat fading channels. Although the improvement due to convolutional codes is small in this case, we can go to a conclusion that convolutional codes are preferred if a lower PER is required in both the AWGN channel and the Rayleigh flat fading channel cases.

7. CONCLUSIONS

The paper studies the performances of standard Bluetooth systems employing the Hamming (15,10) code in payload coding. Enhancements in the performance are proposed in the paper by using convolutional codes in coding the payload fields. A comparison study is held between the standard case and a proposed case based on using the convolutional codes. Both AWGN and Rayleigh flat fading channels are considered in this study. The results of the study are in the favor convolutional codes for all channel cases.

Acknowledgment

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