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Embedded Throughput Improving of Low-rate EDR Packets for Lower-latency

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***Abstract*—**With increasing utilization of the wireless devices in different fields such as medical devices and industrial fields, the paper presents a method for simplify the Bluetooth packets with throughput enhancing. The paper studies a vital issue in wireless communications, which is the throughput of data over wireless networks**.** In fact, the Bluetooth and ZigBee are a Wireless Personal Area Network (WPAN). With taking these two systems competition consideration, the paper proposes different schemes for improve the throughput of Bluetooth network over a reliable channel. The proposition depends on the Channel Quality Driven Data Rate (CQDDR) rules, which determines the suitable packet in the transmission process according to the channel conditions. The proposed packet is studied over additive White Gaussian Noise (AWGN) and fading channels. The Experimental results reveal the capability of extension of the PL length by 8, 16, 24 bytes for classic and EDR packets, respectively. Also, the proposed method is suitable for the low throughput Bluetooth.

***Keywords*—**Bluetooth, throughput, adaptive packets, EDR packets, CQDDR, low latency. Channel condition

I. INTRODUCTION

WITH increasing utilization of wireless devices especially Bluetooth and Zigbee devices, there are two important factors for all wireless systems power efficiency and efficient throughput. In Bluetooth systems there are many types of packets can be transmitted according to channel conditions and can be detected by Received Signal Strength Indicator (RSSI) at the receiver. For good channel conditions, packets of long sizes are used for transmission and this will increase the throughput of system. On the other hand, in bad channel conditions, packets of small sizes are used in transmission and the throughput of system will be decreased. The paper proposes different packet formats, which can be chosen by CQDDR in between the short and long Bluetooth packets [1-3].

Bluetooth employs variable-size packets. These packets occupy different number of time-slots up to a maximum of five slots; each time-slot length is 625µs. Bluetooth v. 2.1 has brought EDR packets types [4]. These EDR packets support gross air rates of 2 Mbps and 3 Mbps through Л/4-DQPSK and 8DQPSK modulation respectively [5].

The paper is organized as follows. In section II, Related work is discussed. In III section the proposed modifications are presented. In section IV the simulation assumptions are given. The simulation results are introduced in section V. Finally, the paper is concluded in section VI.

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II. RELATED WORK

Several authors have been analyzed the performance of classic Bluetooth packets with the expurgated Hamming (15, 10) code used in the Bluetooth standard [6]. The most appreciable work in the coding of the payload field and EDR was introduced in [7]. In [8] other error control codes for improving Bluetooth performance were proposed. They improved the performance but reduced the PL field length with increasing the complexity. The propositions of FEC bearing data medium (DM) packets for EDR were proposed in [9]. Also, in [10] the author proposes Reed-Solomon (RS) cods for enhance the Bluetooth reliability. In the same manner, all proposed cases improve the performance but reduce the throughput, increase the complexity, and consume the power.

This paper proposes simplification of the packet contents in good channel condition. Also, it enforces the capability of Bluetooth system of employing packets with different sizes through proposition a new adaptive packet format. These proposed formats have been chosen according to CQDDR rules with more flexibility in packet type choosing.

Also, the performance of classic and EDR Bluetooth packets with standard and proposed packets is investigated. In addition we activate the RSSI role for improving the throughput. The proposition is applied to classic and EDR Bluetooth packets [11].

III. THE PROPOSED MODIFICATIONS

In this paper, we study throughput enhancement over Bluetooth system with different types of packet such as EDR packets, classic packets and proposed packets format over AWGN and Rayleigh-flat fading channels. This section proposes the use of different packet size. Our proposition depends on the truth of Bluetooth packet performance which depends on the three fields AC, HD, and PL. over Bluetooth link a packet is discarded if there is an error in the AC, HD, or PL (after decoding), which was not corrected using the error correction scheme. This is the real Bluetooth system operation. From this truth we try to propose new packets. AC and HD fields are encoded by BCH (30, 64) code and repetition (1, 3) code, respectively. These two fields are very important for establishing a Bluetooth link. So these two fields must be protected by FEC [12]. The length of redundant bits in AC and HD is more than 8 bytes. In a good channel conditions this redundant bits can be reserved to extend PL and this leads to enhancement of the system throughput. These proposed packets can exceed the length of PL field to enhance throughput. In this paper we try to increase the number of CQDDR choices by adding new packets [13]. In Bluetooth system, the packet size is determined in CQDDR through RSSI which senses the wireless link and channel condition. Our proposed packets are efficient in good channel conditions. The proposed adaptive packets are applied to classic and EDR Bluetooth packets. In proposed EDR packets we take the three main fields AC, HD, and PL only in our consideration. The proposed adaptive Bluetooth EDR packet format is shown in Figure 1. The proposition is built on two real factors. First, DH packets are chosen by RSSI in the case of good channel. Second, the most discarded packets due two uncoded PL [14]. From this result, if RSSI selects DH packets why not select our proposed packet.

IV. Analytically Analysis

This section studied the analysis of the proposed and standard. Also, the effect of the proposed scheme on the system performance is studied. The throughput performance is affected by the Packet Error Probability (PEP) which is related to packet size as given [7].

$$PEP = 1 - (1 - P_b)^L \tag{1}$$

where P_b is Bit Error Probability (BEP) and L is the number of bits in the packet Equations 2-3 give the P_b over AWGN and Rayleigh fading channels, respectively with BPSK modulation.

$$P_b = \frac{1}{2}\left(1 - \frac{1}{\sqrt{1 + \frac{1}{\sqrt{Eb/No}}}}\right) \tag{2}$$

$$P_b = \frac{1}{2} erfc\left(\sqrt{E_b/N_o}\right) \tag{3}$$

The PEP is decreased when the packet size is going to small. Equation (1) gives PEP of uncoded packets. For encoded packets, the PEP equation is given in [8].

$$PEP_{FEC} = 1 - (1 - P_{CW})^{Nc} \tag{4}$$

PEP_{FEC} is packet error probability of encoded packet, P_{CW} is the codeword error probability, and N_c is the number of codewords in the packet.

The codeword error probability is a function of P_b, the number of correctable error t, and the length of codeword N_b, it can be expressed as

$$P_{CW} = \sum_{n=t+1}^{N_b} \binom{N_b}{n} P^n{}_b (1 - P_b)^{N_b - n} \tag{5}$$

The Bluetooth packet contains three main fields the Access Code (AC), the Header (HD), and the payload (PL). So the PEP of Bluetooth packets in general (encoded and uncoded) is given as follows:

$$PEP_{BT} = 1 - (1 - P_{AC})(1 - P_{HD})(1 - P_{PL}) \tag{6}$$

In Equation 6, the P_{AC} is the AC error probability, the P_{HD} is the HD error probability, and P_{PL} is the PL error probability. The first two fields, AC and HD are encoded by BCH (64, 30) code and repetition (3, 1) code, respectively. P_{AC} and P_{HD} are given as [12].

$$P_{AC} = \sum_{n=7}^{64} P_b (1 - P_b)^{64-n} \tag{7}$$

$$P_{HDW} = \sum_{n=2}^{3} P^n{}_b (1 - P_b)^{3-n} \tag{8}$$

$$P_{HD} = 1 - (1 - P_{HDW})^{18} \tag{9}$$

Classic and encoded Bluetooth packets are encoded by the expurgated Hamming code (15, 10). So the codeword error probability can be expressed as follows:

$$P_{PLW} = \sum_{n=2}^{15} P^n{}_b (1 - P_b)^{15-n} \tag{10}$$

Then the probability of encoded payloads is given as follows

$$P_{PLm} = 1 - (1 - P_{PLW})^m \tag{11}$$

The number of codewords is m, m=16, 100, and183, for the DM1, DM3, and DM5 packets, respectively.

. For 2DMx packets, m=32 for 2-DM1, m=199 for 2-DM3, m=365 for 2-DM1. In case of 3DM1 packets, m=47 for 3-DM1, m=297 for 3-DM3, m=548 for 3-DM5.

$$P_{BT_{coded}} = 1 - (1 - P_{AC})(1 - P_{HD})(1 - P_{PLm}) \quad (12)$$

For uncoded DH packets, the payloads are transmitted without Forward Error Control (FEC). The PEP of these packets is given as follows:

$$P_{PL_{uncoded}} = 1 - (1 - P_b)^L \quad (13)$$

L is the length of the uncoded payloads, L=240, 1500, 2745, for the DH1, DH3, and DH5 packets, respectively. For 2DHx packets, m=464 for 2-DH1, m=2968 for 2-DH3, m=5464 for 2-DH5. The m=696 for 3-DH1, m=4448 for 3-DH1, m=8200 for 3-DH5, In case of 3DHx packets. The uncoded classic Bluetooth packets error probability $P_{BT_{uncoded}}$ can be expressed as:

$$P_{BT_{uncoded}} = 1 - (1 - P_{AC})(1 - P_{HD})(1 - P_{PL_{uncoded}}) \quad (14)$$

The proposed scheme is studied analytically as shown in Figure 2. This figure shows PEP variation for the Bluetooth packets with the standard and the proposed formats over a Rayleigh fading channel for classic and EDR packets. Equation 15 gives the Throughput (T) over Bluetooth network [15].

$$T = \frac{PL(1 - PEP)}{(x + 1)t} \quad (15)$$

PL is the user payload length, x is the number of time slots occupied by the Bluetooth packet, and t is the duration of the Bluetooth time slots. The T is used for evaluate the proposed schemes effectiveness as shown in section V.

V. Simulation Assumption

In this section, the simulation environment is described with the given assumption.

The Monte Carlo simulation method is used in the simulation experiments to compare between the traditional expurgated Hamming (15, 10) code, EDR packets, and the proposed schemes. This method ensures obtaining correct statistical results [16].

A packet is discarded if there is an error in the AC, HD, or PL (after decoding), which was not corrected using the error correction scheme. This is a realistic assumption to simulate the real Bluetooth systems operation.

Hard decision is assumed at the receiver in the decoding process for all channel codes. In the simulation, the interference effects are neglected. In case of EDR simulation, we use AC, HD, and PL fields. The modulation in our simulation is Binary Phase Shift Keying (BPSK) [17].

In some simulation experiments, a block-fading channel is assumed. It is a slow and frequency nonselective channel, where symbols in a block undergo a constant fading effect.

We will concentrate in our experiments on DH1, DM1 (classic Bluetooth packets), 2DH1, and 2DM1 (EDR Bluetooth packets), which are short packets, and 2DM5, 2DH5 as longer Bluetooth packets. MATLAB was used for carrying our simulation experiments of different cases. All simulations results have been gotten by transmission of 10^4 trails over different SNR values.

VI. Simulation Results

Several computer simulations are carried out for the purpose to ensure the capability of our proposed packets. Different classic and EDR packets, DH1, DM1, 2DH1, and 2DM1 are considered in the computer simulation. Four scenarios are applied to these packets, which are standard uncoded packets, standard encoded packets using Hamming code, PR-0 packets format, and PR-1 packet format.

PR-0**:** The AC and HD fields are transmitted without FEC.

PR-1**:** the redundant bit which is reserved in the PR-0 is added to the PL field.

These scenarios are applied to classic and EDR packets. Several experiments are carried out for the purpose of comparison between the standard schemes and the proposed EDR packets. Also, the Number of Lost packets (NLP) and the packet Error Rate (PER) are studied with variant SNR of the channel.

A. The Computer Experiments using Short Classic and EDR Packets

This section is devoted to test measure the NLP and the transmission performance of the proposed schemes using DH1, 2DH1, DM1, and 2DM1 packets with the different scenarios over an AWGN and Rayleigh fading channels. In the first computer experiment, theses packets are transmitted over an AWGN channel with different SNR values using. Table 1 tabulates the NPL variation with the channel SNR using different scenarios for the EDR packets over an AWGN channel.The previous experiment is repeated using short classic packets with the scenarios, DM1, DM1-PR-0, DH1, DH1-PR-0, and DH1- PR1. The results of these experiments are shown in Figure 3. This figure shows the PER of the standard and the proposed classic and EDR packets with channel SNR over AWGN channel. Also, these experiments reveal that with improving the channel condition the proposed packets format can be used for increase the amount of transmitted data over Bluetooth network. Also, the proposed schemes can be as available choice with the standard packets. So, it is can be accepted with a good channel conditions and higher SNR the proposed packets are effective and its performance is better. Also, it enhances the throughput.

The performance of the standard and the proposed classic and EDR packets over a Rayleigh fading channel is shown in Figure 4. This figure shows the PER versus the channel SNR. The NLP of the standard and the proposed EDR packets over a fading channel is tabulated in Table 2. As shown in this results, the proposed packet format can be accepted with the channel condition improvement. This choice can be controlled by the CQDDR.

B. Long Bluetooth Packets Performance over a fading channel

This section is devoted for studying the proposed format effects on the long Bluetooth packets. The computer experiments are carried out using DH5, 2DH5, DM5, and 2DM5 packets with the different scenarios over a Rayleigh fading channels. In the first computer experiment, the long EDR packets are transmitted over a fading channel with different SNR values using. The result of this experiment is shown in Figure 5. This figure gives the PER of the standard and the proposed long classic and EDR packets over Rayleigh fading channel with varying SNR.

Our the simulation results reveal that the PL of EDR and classic Bluetooth packets can be increased by 8, 16, or 24 bytes according to packets types. The proposed packets are efficient for the shorter packets DH1 and 2DH1. Also, the CQDDR can choose the proposed adaptive packets in between the short and long packets according to the channel condition.

C.General Comparison

This section gives a comparison between the standard and the proposed packets for data transmission with different types of packets based on the throuput (T). Figures 6 and 7 show the variation of the throughput with the channel SNR for the data transmission over an AWGN channel for the short classic and the short EDR packets, respectively.. These figures indicate the efficiency of the proposed packet format for the short packets. As shown in these figures the proposed adaptive packets provide higher throughput with the good channel condition. Figure 8 and 9 gives the throughput variation for the data transmission over a fading channel for classic and EDR the standard and the proposed packets.

The obtained results reveal that for SNR>6dB, the proposed packets on PR-1 basis gives a high throughput for short packets over an AWGN channel. The standard packets produce high throughput at SNR<6dB. On other hand, over a fading channel the proposed schemes gives a high throughput at SNR>17dB.

VII. CONCLUSION

We have proposed a group of adaptive packets with different formats depending on the CQDDR concepts for improving and simplify the performance of data transmission over Bluetooth networks. The paper tried to improve the throughput of the data transmission over classic and EDR packets using different proposed schemes. Simulation experiments revealed that the proposed packets are good for the short packets with a good channel condition. The CQDDR is employed for selecting the transmitted packet size by the RSSI according to the channel conditions. The paper proposes a new adaptive BT packet for classic and EDR packets to enhance throughput over the Bluetooth network with respect the CQDDR decisions. The experimental results reveal that the most of discarded packets over BT link due to PL fields, the paper uses this foundation to employ new packets. On the other hand, the experiment results reveal that the proposed packets are inefficient for longer Bluetooth packets. Although, the performance of proposed packets and original packets are much close the increasing in PL is very little proportion to original PL. So, the paper shows a new kind of packets can be available for the CQDDR according to the channel conditions.

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TABLE I
NLP OF EDR PACKETS OVER AN AWGN CHANNEL WITH DIFFERENT SCENARIOS

SNR	**NLP for EDR packets over a fading channel**					
	AC&HD	AC&HD NO FEC	$2DM_1$	, $2DH_1$	$2DH_1$ PR-0	$2DH_1$ PR-1
5 dB	3672	6952	6879	8718	8781	8834
15dB	423	1056	923	1715	1778	1803
25dB	37	109	98	202	201	214
35dB	4	14	12	22	24	26

TABLE II
NLP FOR EDR PACKET OVER A FADING CHANNEL WITH DIFFERENT SCENARIOS

SNR	NLP for EDR packets over AWGN channel					
	AC&HD	AC&HD NO FEC	$2DM_1$	$2DH_1$	$2DH_1$ PR-0	$2DH_1$ PR-1
0 dB	4317	9810	ALL	ALL	ALL	ALL
2 dB	816	8389	9504	ALL	ALL	ALL
4 dB	85	4530	3381	9959	9979	9989
6 dB	2	1106	151	6383	6844	7261
8 dB	0	97	2	790	840	955
10dB	0	1	0	16	23	27

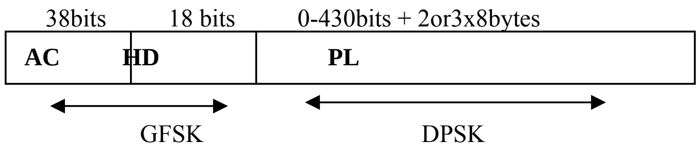
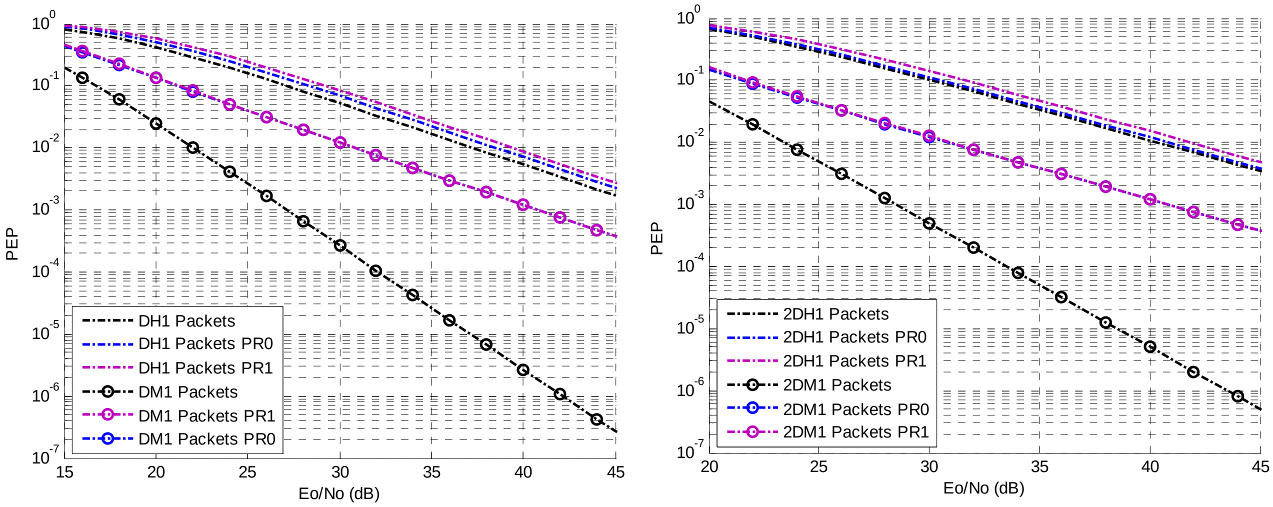


Fig. 1 Adaptive Bluetooth EDR packets format for 2DH1 EDR packets.



(a) (b)

Fig. 2 PEP vs. Eb/No for over a fading channel, a- DM1 and DH1 the standard and the proposed classic packets. b- 2DM1 and 2DH1 the standard and the proposed EDR packets

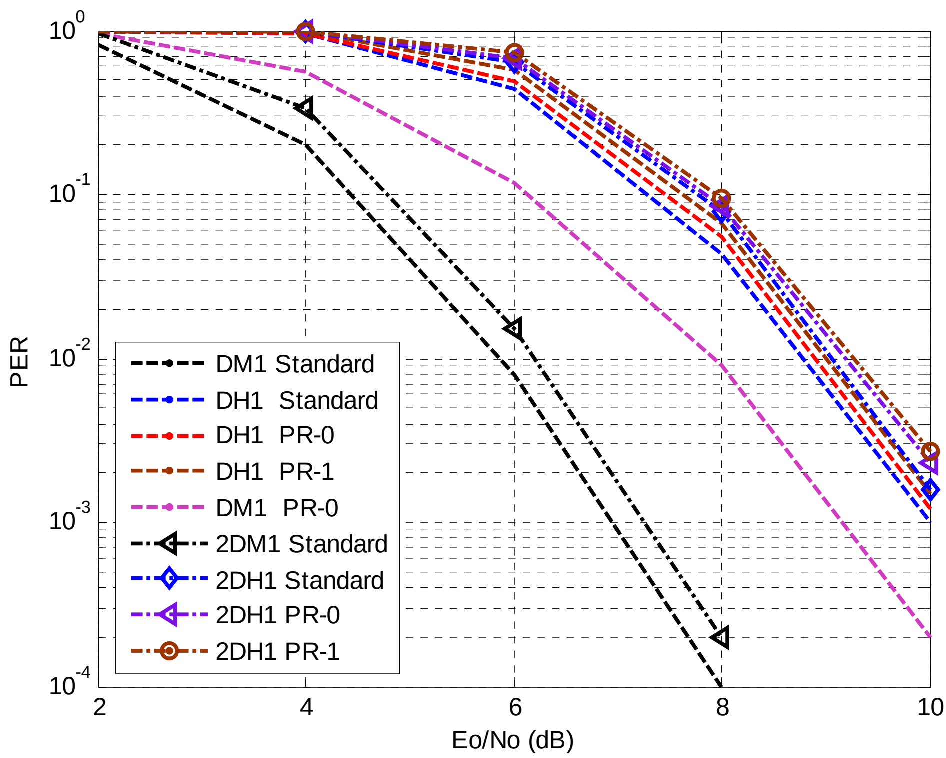


Fig.3 PEP vs. Eb/No over an AWGN channel with different scenarios using DM1, DH1, 2DM1 and 2DH1 the standard and the proposed with classic and EDR packets for data transmission

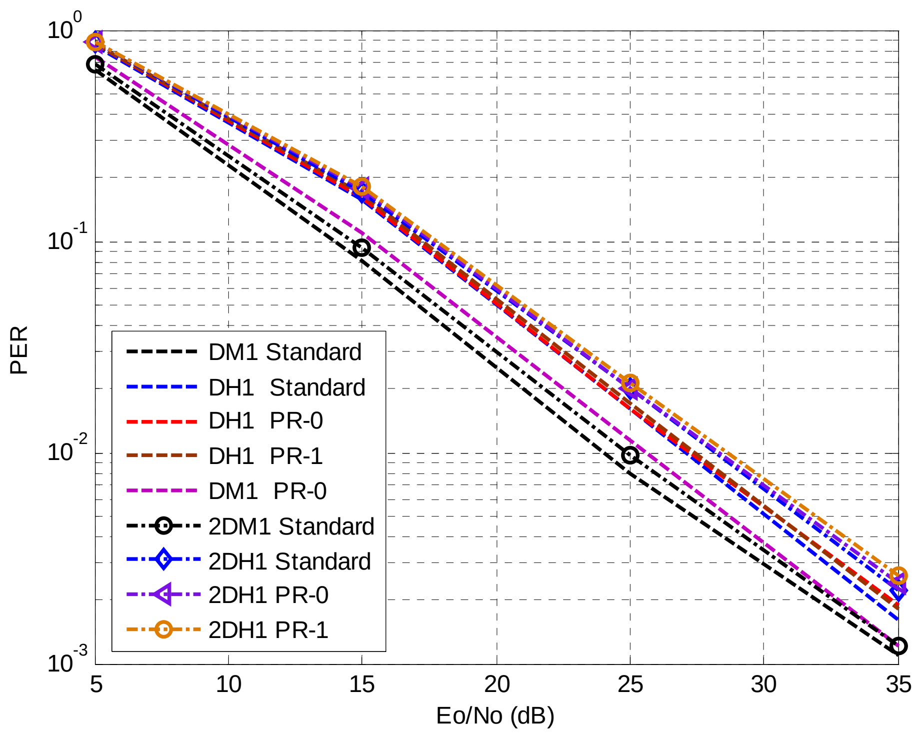


Fig. 4 PEP vs. Eb/No over a fading channel with different scenarios using DM1, DH1, 2DM1 and 2DH1 the standard and the proposed with classic and EDR packets for data transmission

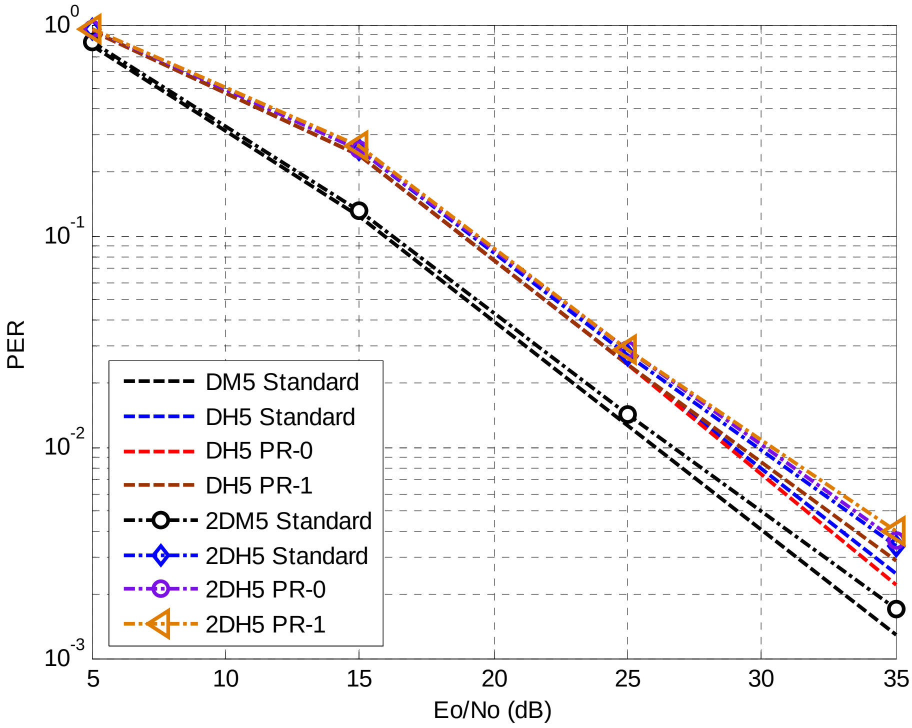


Fig. 5 PEP vs. Eb/No over a fading channel with different scenarios using DM5, DH5, 2DM5, and 2DH5 the standard and the proposed with classic and EDR packets for data transmission

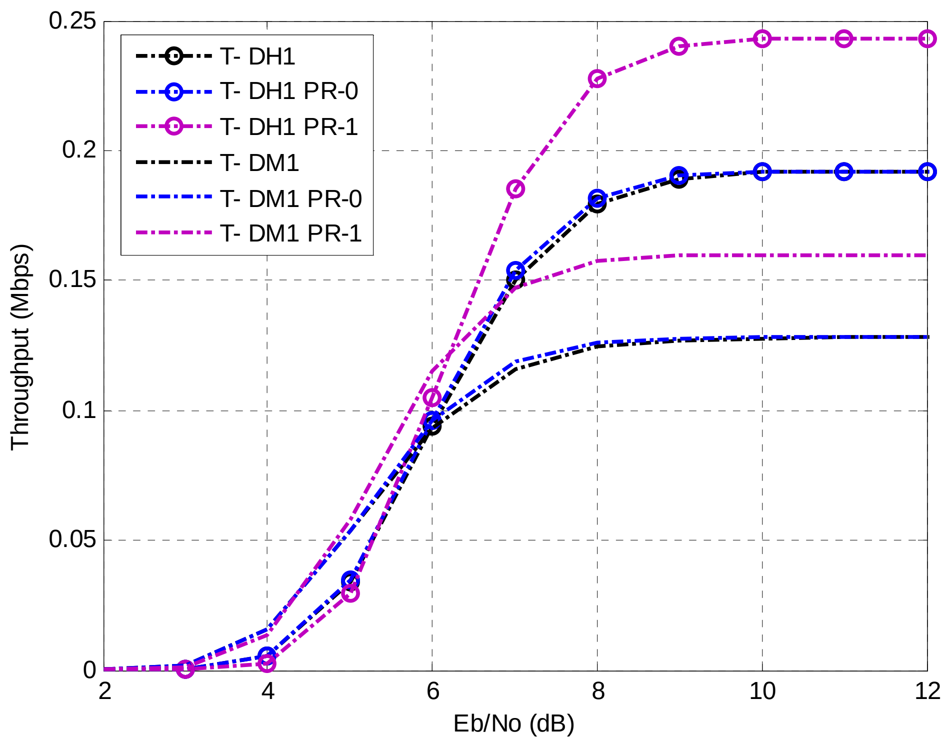


Fig. 6 Throughput vs. Eb/No for the data tarnsmission over an AWGN channel using DM1 and DH1 packets with different proposed scenarios

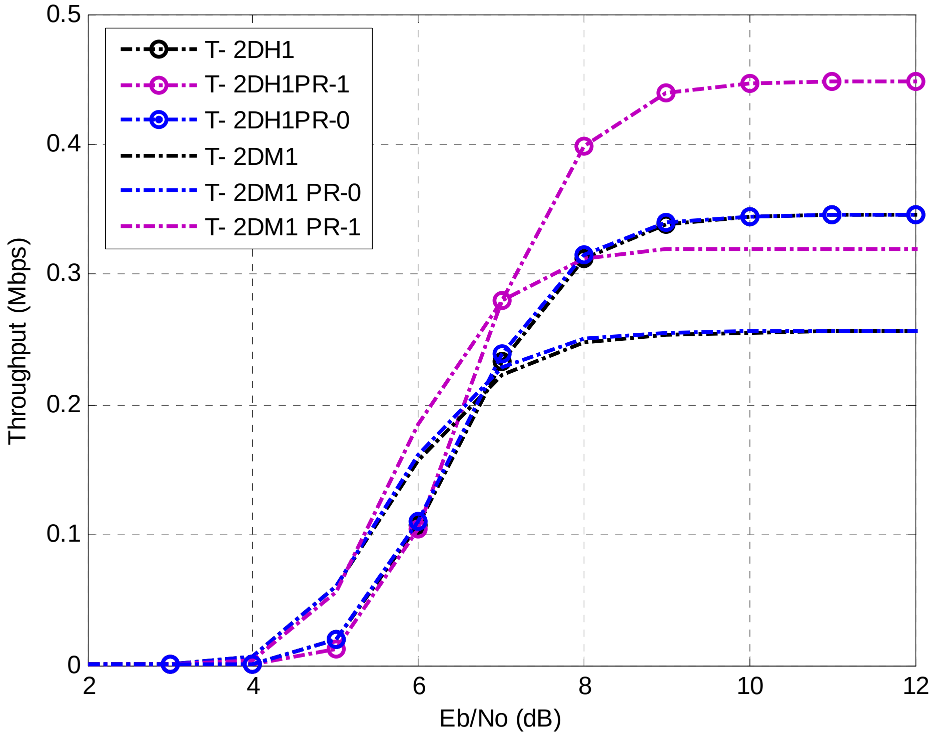


Fig. 7 Throughput vs. Eb/No for the data tarnsmission over an AWGN channel using 2DM1 and 2DH1 EDR packets with different proposed scenarios

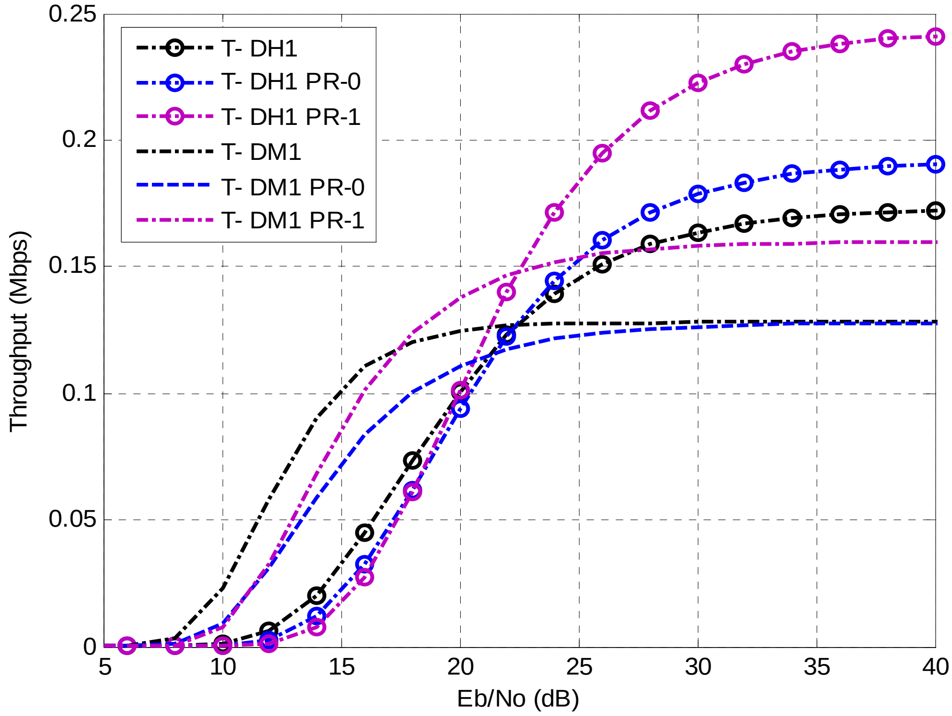


Fig. 8 Throughput vs. Eb/No for the data transmission over a fading channel using DM1 and DH1 classic packets with different proposed scenarios

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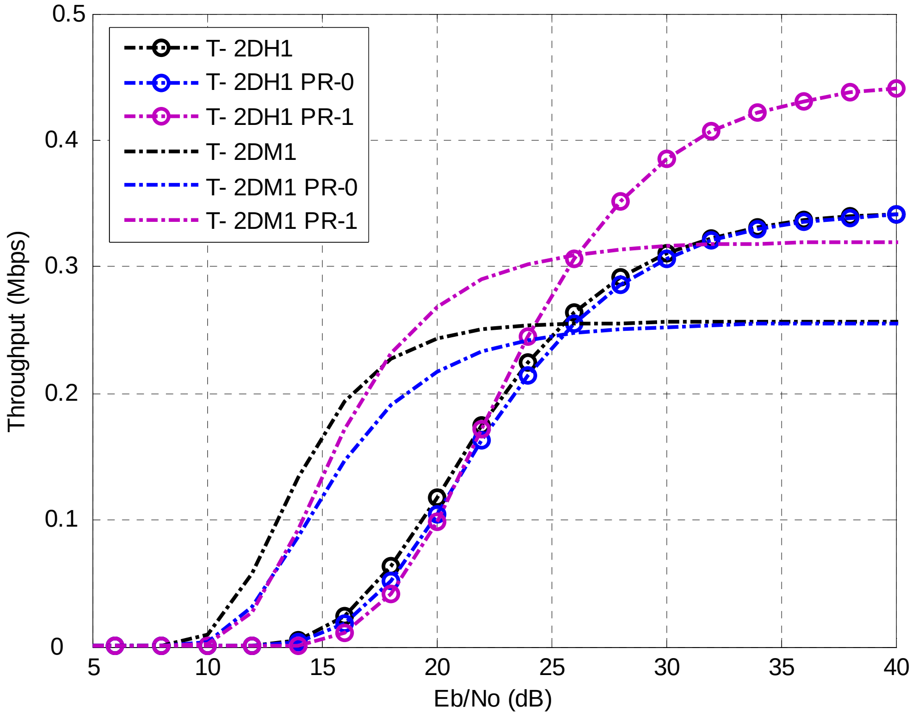

Fig. 9 Throughput vs. Eb/No for the data transmission over a fading channel using 2DM1 and 2DH1 EDR packets with different proposed scenarios