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Raptor Code for Energy-Efficient Wireless Body Area Network Data Transmission

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Abstract

Wireless Body Area Network (WBAN) is a device developed mainly for the purpose of monitoring the medical condition of a human. WBAN is worn on the surface or in the human body, and it contains a wireless communication device. A WBAN device is required to be small-sized, with limited power and high data reliability. The data reliability can be obtained by using a carefully designed channel coding scheme so that the energy consumed can be maintained at a low level. In this paper, data transmission in Rayleigh, Rician, and Nakagami-m fading channels using Raptor and BCH codes is simulated. Simulation results show that Raptor-coded data transmission consumes lower energy compared to BCH-coded transmission for various fading channels if the transmission distance exceeds 10 meters. Therefore, Raptor code is a good candidate for the channel coding scheme for WBAN.

Keywords: *wireless body area network, raptor code, data transmission, rayleigh, fading channel*

1. Introduction

Wireless Body Area Network (WBAN) is a cluster of wireless sensors worn by humans mainly for the purpose of medical condition monitoring. The human physiological data such as blood pressure or body temperature are monitored by the sensors and sent to a data processor regardless of the location or the activity of the subject [1]. WBAN is a structure which contains a short-range communication system based on IEEE 802.15.6. The standard allows for low-power and small-sized devices and includes characterization of electromagnetic wave propagation transmitted by a device located on or in the human body.

Aside from being able to send information using a small-sized antenna and limited power, a WBAN device must also be able to send information reliably over a long term. Reliability and durability can be achieved through appropriate modulation and coding schemes. The modulation scheme choice will affect the transmitter and receiver power required by WBAN device, which will subsequently affect the device lifetime. However to achieve high reliability, the coding scheme will play the more important part compared to that of the modulation scheme. An ideal coding scheme for WBAN is one that ensures reliable transmission of information in a rapidly changing wireless channel.

Raptor codes, an extension of Luby-Transform (LT) codes with linear time encoding and decoding have been shown to attain good upper-bound on overall error probability when used in binary erasure channel [2]. Several channel model for WBAN has been proposed based on numerical simulations and/or measurements. A mathematical model using dyadic Green function to model the human body as a simplified cylinder has been proposed and used to show the receive signal variations around the human body [3]. Another research proposes the use of pathloss channel model based on measurement [4]-[5]. The pathloss channel is stated as a function of distance and frequency, and the fluctuating power is shown to match lognormal distribution. As the wearer of a WBAN device moves around, the wireless channel is subject to fading. Objects around the human body will also reflect and scatter the signal, contributing to a multipath fading of a Rice distribution [6]. A more general fading model form WBAN is Rayleigh-distributed. Another possibility that can be taken into consideration is the Nakagami-m distributed fading channel, as this is the model which provides indoor-mobile multipath propagation in addition to ionospheric radio link [6]. Various researches have shown that Raptor codes provide a robust data transmission even in noisy channels. The performance of an optimized Raptor code in quasi-static Rayleigh fading channel has been analyzed and shown to

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be close to the theoretical limits on varied delay requirements [7]. For Rician fading channel, the Raptor code performance is shown to also have near-Shannon capacity performance when used with fixed rates [8]. Another research shows that Raptor code combined with turbo codes can yield good performance in soft-blockage and hard-blockage channel models, where the soft-blockage channel uses Nakagami-m distribution [9].

In this paper, the performance of Raptor codes in Nakagami-m, Rician, and Rayleigh distributed fading channel based on the total energy consumed is considered. The energy consumed when data is transmitted under various fading conditions using Raptor code and BCH code is also simulated. Simulations show that Raptor coded data in BFSK modulation scheme consumes comparable energy in Nakagami-*m*, Rayleigh and Rician fading channels. The consumed energy for Raptor coded data is as low as 0.3 Joule for a transmission distance of 50 meters. Compared to BCH coded data, the Raptor coded data shows lower energy consumption when the transmission distance exceeds 10 meters.

The rest of the paper is organized as follows. Section 2 provides the description of the system model, while in Section 4 the simulation results are presented. The conclusion is given in Section 5.

2. System Model

The WBAN considered in this paper follows the model proposed in [1] that consists of a wearable body sensor equipped with a transmitter, and a central processing unit as the receiver. The WBAN works in cycles consisting of active mode, transient mode, and sleep mode periods. During active mode period, T_{ac}, the data obtained by the wearable sensor is amplified, filtered, digitized and coded. An L-bit binary message is generated in the digitization process. The encoder in turn will split the bit stream into blocks with equal length B_j, j = 1, …, L/k where k is the block length. The encoder will then generate a coded bit stream C_j, j = 1,…, L/k with a random block length depending on the channel condition [1]. The coded bit are FSK modulated and transmitted to the central processing unit, and the wearable body sensor returns to the sleep mode which lasts for T_{sl}. The period between the active mode and the sleep mode is denoted as the transient mode T_{tr}. The Raptor code parameters used in this paper are taken from [1].

The total energy consumed by the WBAN to transmit L-bit message considering the power consumed by the power synthesizer (P_{sy}), the power amplifier (P_{Amp}) and the circuit (P_c) can be stated as [1]

$$E_L = 2(1+\alpha)\frac{\ell_d N_0}{G_c}\frac{L}{\bar{R}_c \cdot^2 \log M}\ln\frac{M}{4P_b} + \left(P_c - P_{Amp}\right)\frac{ML}{2R_c \cdot B \cdot^2 \log M} + 1.75 P_{sy} T_{tr} + L\frac{E_{enc}+E_{dec}}{\bar{R}_c} \tag{1}$$

where α is power amplification factor based on the type of the power amplifier, ℓ_d is the ratio between the transmitted and received signal powers for the wearable body sensor and the central processing unit separated by distance d, M is the modulation order, P_b is the bit error rate, $\bar{R}_c$ is the average Raptor code rate, and the computation energy of the encoder and decoder is denoted as E_{enc} and E_{dec}, respectively.

For BCH-coded data transmission, the energy consumed is

$$E_{BCH} = \frac{1}{1-P_b} E_{trans} \tag{2}$$

where P_b is the bit error probability given in (9) and E_{trans} is the total energy required by the transmitter and receiver which can be stated as

$$E_{trans} = L\left(P_t + P_r\right) \tag{3}$$

where P_t and P_r are the transmitter and receiver power, respectively. The total required power can be stated as

$$P = P_t + P_r = e_{tc} + e_{rc} + e_{TA} \quad (4)$$

where e_{tc} and e_{rc} are the energy consumed by the transmitter and receiver circuitry, respectively, and e_{TA} is the energy required for the transmitter amplifier. The parameter e_{TA} can be stated as [10]

$$e_{TA} = \frac{\gamma_s (NF_r)(N_0)(4\pi/\lambda)^\beta}{(G_{ant})(\eta_{amp})} \quad (5)$$

where γ_s is the SNR, NF_r is the noise figure of the receiver, β is the path loss exponent, λ is the wavelength in meters, G_{ant} is the antenna gain and η_{amp} is the transmitter power efficiency.

To analyze P_b, several formulations are used according to fading channels involved. The symbol error probability for orthogonal *M*-FSK Nakagami-*m* fading is [11]-[12]

$$P_s(E) = \sum_{l=1}^{M} (-1)^{l-1} \binom{M-1}{l} \frac{(l+1)^{m-1}}{[1 + l(1+\bar{\gamma}_s / m)]^m} \quad (6)$$

where *m* is the shape parameter and $\bar{\gamma}$ denotes the average SNR. For Rayleigh fading, the symbol error probability is [10]

$$P_s(E) = \sum_{m=1}^{M-1} (-1)^{m+1} \binom{M-1}{m} \frac{1}{1 + m(1+\bar{\gamma}_s / m)} \quad (7)$$

For Rice fading, the symbol error probability is stated as [11]

$$P_s(E) = \sum_{m=1}^{M-1} (-1)^{m+1} \binom{M-1}{m} \frac{1+K}{1+K+m(1+K+\bar{\gamma}_s)} \times \exp\left(- \frac{K \cdot m \cdot \bar{\gamma}_s}{1+K+m(1+K+\bar{\gamma}_s)} \right) \quad (8)$$

The relation between the symbol error and the bit error rate probability is [11]

$$P_b(E) = \frac{1}{2}\left(\frac{M}{M-1}\right) P_s(E) \quad (9)$$

4. Simulation Results

In the first simulation, a Raptor coded data which length is 8192 bits is transmitted in a Nakagami-m fading channel. Figure 1 shows the simulation of Raptor coded data transmission performance in Nakagami-m channels with *m* = 2, 3, and 4. It is shown that for transmission distance below 15 m, the Raptor coded data will have similar energy consumption. The energy gap for channel conditions where *m* = 2, 3 and 4 with distance above 15 m, however, is negligible. This means when the fading condition worsens (*m* = 2), the Raptor coded transmission consumes approximately the same energy as when the fading condition is not too severe (*m* = 4). However it should be noted that the bit error probability for the simulated Nakagami-*m* channels varies between 10^{-2} to 4×10^{-2}.

Figure 2 shows the simulation results of the total energy consumed by transmitting Raptor coded data transmitted in Rice and Rayleigh fading channels. It is shown that the energy consumed for transmission in a Rice fading channel slightly exceeds that in Rayleigh fading channel. However the probability of error resulting from the simulated transmission in a Rice fading channel is less than that in a Rayleigh fading channel. This agrees with the fact that in a Rice fading channel, there exists a strong Line-of-Sight component. Both figures show that the Raptor coded data will consumed 0.1 Joule of energy when the transmission distance is at least 80 meters.

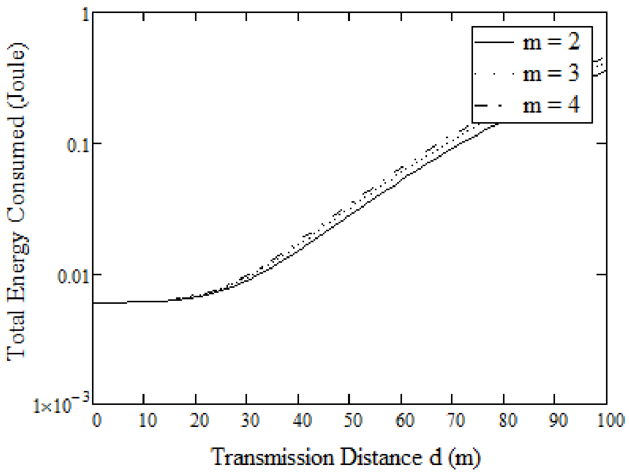

Figure 1. Raptor coded data transmission in Nakagami-m channel

Figure 3 shows the comparison of total energy consumed when data is sent under Rayleigh fading condition, using Raptor code and BCH code. It is shown that for transmission distance below 20m, the energy required by BCH-coded data is considerably lower than that of Raptor-coded data. The rate of the BCH code used is 157/511, meaning the number of bits in each codeword sent is lower than the Raptor-coded bits, where the codeword block length is varied indicating the rateless behavior of the Raptor code [1]. The small codeword size of BCH-coded data results in lower energy consumption compared to the Raptor-coded data. The energy requirement of data transmission using Raptor code will be the same with that of BCH code when the transmission distance is 13 meters and beyond. The energy consumed by both BCH-coded and Raptor-coded data will increase with respect to transmission distance. However, the increase of energy requirement for Raptor-coded data is not as steep as that of a BCH-coded data due to the code rate of Raptor code. This makes the implementation of Raptor code in WBAN more favorable than BCH code.

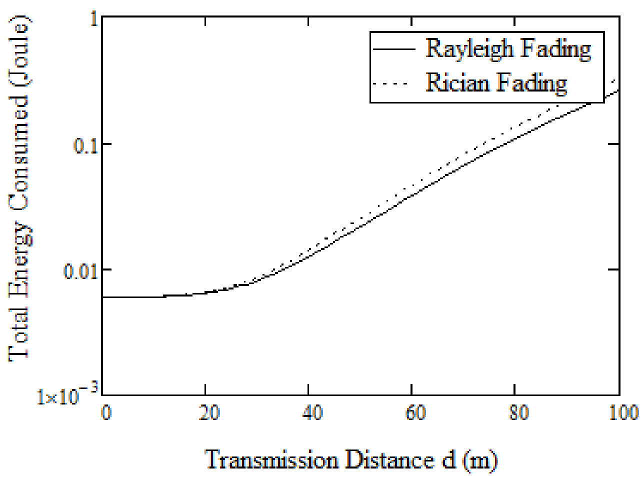

Figure 2. Raptor coded data transmission in Rayleigh and Rician fading channels

Figure 4 shows the simulation result for Raptor-coded data and BCH-coded data transmitted under Nakagami-*m* fading channel, where *m* = 4. The result is similar to that of Raptor-coded and BCH-coded data transmission under Rayleigh fading condition, with the BCH-coded data requiring less energy for short transmission distance. In the case of Nakagami-*m* fading channel, the BCH-coded data transmission will consume the same energy as the Raptor-coded data transmission when the transmission distance reaches 10.3m. For transmission distance greater than 10.3m, the BCH-coded data transmission will require considerably greater energy than Raptor-coded data. Again, the increase of energy requirement for Raptor-coded data is not as steep as that of a BCH-coded data.

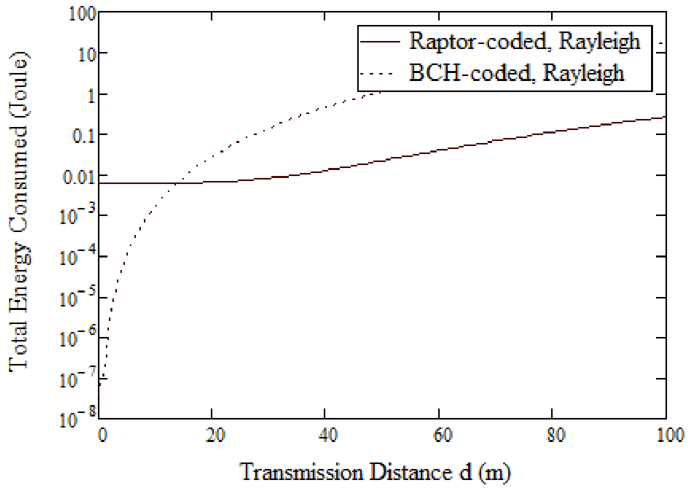

Figure 3. Raptor-coded vs BCH-coded data transmitted under Rayleigh fading condition

A similar result is shown in Figure 5, where Raptor-coded data and BCH-coded data is transmitted under Rician fading. Under Rician fading, the transmission Raptor-coded data will require the same amount of BCH-coded data when the transmission distance reaches 11 meters. From Figure 3 – 5 it is apparent that for all simulated fading channels, the use of Raptor code is favorable for transmission distance of more than 10 meters.

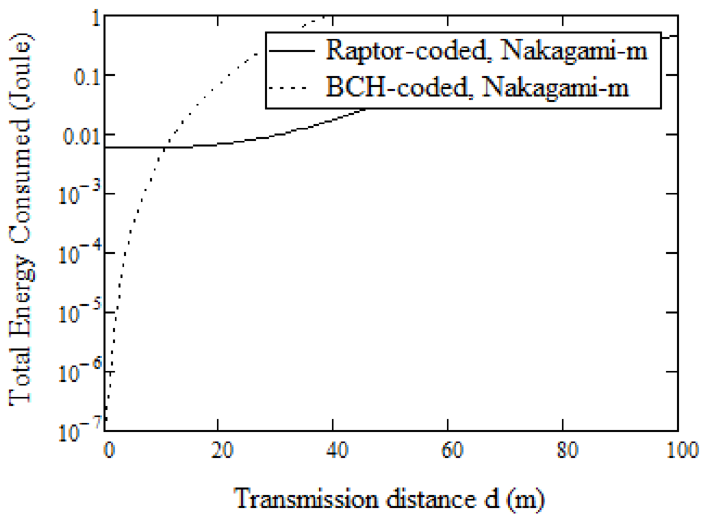

Figure 4. Raptor-coded vs BCH-coded data transmitted under Nakagami-*m* fading, *m* = 4

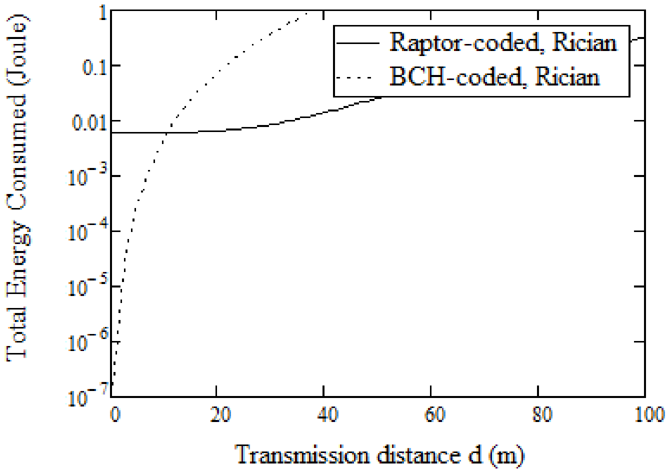

Figure 5. Raptor-coded vs BCH-coded data transmitted under Rician fading

4. Conclusion

Simulations of Raptor coded data transmission in different fading channels have been done. It is shown that in various fading conditions, the total energy consumed by Raptor coded data is low, namely 0,1 Joule for a transmission distance of 80 m. In severe fading condition, namely Nakagami-*m* fading channel with m = 2, the total energy consumed by Raptor coded data is comparable to that in better fading conditions, namely Nakagami-*m* fading channels with m = 3 and 4. For Rayleigh and Rice fading channels, the total energy consumed is less than that in Nakagami-*m* channels.

Simulations are also done to compare the energy requirements for the transmission of Raptor-coded and BCH-coded data in Rayleigh, Nakagami-*m* (m = 4) and Rician fading channels. It is shown that for short transmission distance (d < 10 meters), the BCH-coded data transmission will require lower energy compared to Raptor-coded data, due to the large value of BCH code rate. However as the transmission distance increases, the energy requirement of the BCH code will be greater than that of the Raptor-coded data. It is also shown that although the energy requirement increases for both Raptor-coded and BCH-coded data transmission with respect to the transmission distance, for Raptor-coded data the increase is gradual as opposed to the very steep energy requirement increase for BCH-coded data.

These simulations show that Raptor code is a good candidate as a channel coding scheme for WBAN devices, especially ones that require a transmission distance between 10 – 100 meters, based on the total energy consumed. However further researches are required to improve the bit error probability of the proposed system.

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