Performance Analysis of Fountain Codes in Wireless Body Area Networks

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Abstract: Wireless Body area network (WBAN) has emerged in recent years as a special case of wireless sensor network (WSN) targeted at monitoring physiological human beings. One of the major challenges in this network is to prolong the network and node lifetime. The data transmitted from the sensors are vulnerable to corruption by noisy channels, reflections and distortions. This paper investigates the reliability of transmissions within WBAN and compares the performance provide by Automatic Repeat reQuest (ARQ) scheme and Luby Transform code (LT). The Theoretical and practical results presented in this paper show that the use of LT codes in WBAN has a better performance not only in BER, but also in resources and energy consumption.

1 INTRODUCTION

The increase of life expectancy in most countries of the world is one of the major challenges in recent decades. In Morocco, life expectancy has increased significantly from 47 years in 1960 to 71 years in 2014. This fact implies an overload on the health care system. In this context and with the appearance of physiological intelligent micro-components, which can be integrated into the human body; new solutions are being considered to allow remote medical monitoring. Imagine a set of small electronic devices, autonomous, placed on the patient's bodies and make them able to communicate with each other wirelessly. Together they form a network named wireless body area network (WBAN)(Movassaghi and Abolhasan, 2014).

Furthermore, in such applications, the network must deliver reports and patient health alerts in a perfect manner, in which delay or loss is not tolerated. The application of these micro-components in a medical context requires:

- A sensor network where the majority of nodes are always active.
- A particular attention to errors made in the transmission channel, which is not-reliable.
- A sensor has only limited energy resources.

This causes loss of information and energy, to deal with these two problems of instability of the radio channel and energy consumption, several solutions have been proposed in the literature, and that they can be grouped into two major error control modes: ARQ (Automatic Repeat reQuest) and FEC (Forward Error correction).

This work investigates the reliability of transmissions and energy consumption within WBAN. We indeed focus on ARQ (Roshanzadeh and Saqaeeyan, 2012)(Automatic Repeat reQuest) and FEC(Oskar, 2009) (Forward Error correction), especialy on the fountain codes that derives from the FEC.

The rest of the paper is divided into 5 sections. In Section 2, we provide an introduction of WBAN. In section 3 we review the two most widely used error correction techniques, ARQ and FEC, in particular the LT process. Section 4 discusses a simulation results using IEEE 802.15.6 standard. We finally state our conclusion and future work in Section 5.

2 WBAN

Wireless Body Area Network (WBAN) is a special case of wireless sensor networks (WSNs) that is a collection of small and intelligent wireless medical sensors which are attached to or implanted into a human body(see figure 1). These sensors have wireless sense capability and transmission biological informations;

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such as electrocardiogram (ECG), photoplethysmogram (PPG), electroencephalography (EEG), pulse rate, blood flow, pressure and temperature; to one or more collection points. These information will be transmitted wirelessly to an external processing unit. This device will instantly transmit all information in real time to the doctors throughout the world.

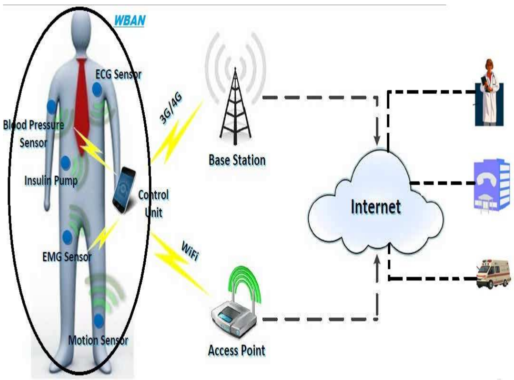

Figure 1: WBAN : Wireless Body Area Networks.

For the realization of the international standardization for WBAN, a study group of IEEE called IEEE 802.15.6, has been launched in November 2007 to work on the WBAN standardization. This last established the first draft of the communication standard of WBANs in April 2010, optimized for low power devices and operation on, in or around the human body (Ullah and Ullah, 2010). The approved version of the IEEE 802.15.6 standard was ratified in February 2012. The purpose of this group is to establish a communication standard optimized for low power, high reliability.

3 ERROR CONTROL CODING (ECC)

In general, the error control mechanisms can be categorized into two main approaches:

- **Automatic Repeat reQuest (ARQ):** The main idea is that the transmitter after sending the packet waits for a specific time (time out) to receive an acknowledgment. If it receives positive acknowledgment (ACK), it sends the next packet, while if it receives negative acknowledgment (NAC) or timed out before receiving any acknowledgment, then it retransmits the same packet. The process keeps repeating until the transmitter receives an ACK, or a specific number of retransmission is reached.
- **Forward Error Correction (FEC):** In FEC source node encodes data using some error correcting code which lets the receiver node to correct errors in data packet if it existed. Thus, making retransmission outdated. Error control coding also provides coding gain, which lowers required transmitting power for specific bit error rate (BER). Several codes have been investigated for error correction in WSN, including fountain codes, turbo codes, BCH codes and LDPC codes.

In our study, we considered FEC schemes employing fountain codes due to its low encoding/decoding complexity, and its adaptation with all channels, contrast to other families (such as LDPC which is dedicated just for erasure channels).

3.1 Fountain Code

The main idea of a Digital Fountain (DF) is analogous to the case of a water fountain. To fill a drink at the fountain (Figure 2) we focus only on the amount of water needed to fill the glass without considering the scheduling water drops or those that fall outside of the glass. This idea leads to the achievement of codes with that characteristic.

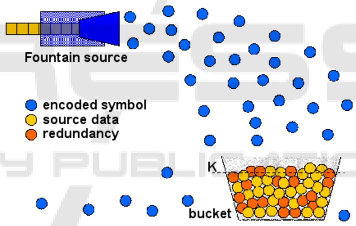

Figure 2: Analogy code fountain with filling a glass with a water fountain.

Fountain codes (Mitzenmacher and Rege, 1998) are universal i.e they are simultaneously near optimal for every erasure channel. Regardless of the statistics of the erasure events on the channel, we can send as many encoded packets as are needed in order for the decoder to recover the source data. It follows that such codes are optimal for any channel because it is only necessary to receive enough symbols to decode with high probability the source information. There are three main category of fountain codes: Random Linear Fountain (RLF)(MacKay and David, 2005), Luby Transform (LT), and Raptor codes(Shokrollahi, 2006). In this work, we consider an LT code because of its lower decoding complexity.

3.2 Luby Transform (LT)

LT codes proposed by Luby (Luby, 2002) in 1998, they are the first practical realization of Fountain codes. LT codes are rateless, i.e., the number of generated encoded packets are potentially limitless, and encoded symbols are generated on the fly. This means that the encoder is capable of producing as many symbols as needed by the decoder to recover the original k input symbols, no matter where the channel exists.

3.2.1 Encoding

The encoding LT principle is :

1. Divide the information transmitted in K fragments of the same size,
2. To select randomly a degree $d_m \in \{1,\ldots,k\}$ according to the distribution $\Omega(x)$,
3. To select uniformly at random d_m distinct information symbols and set e_m equal to their bitwise modulo 2 sum.

3.2.2 Decoding

The decoding process uses the method Belief Propagation (see Algorithm 2) that is based on the fact that the degree of packet 1 may be considered decoded. Thus, using the previously decoded packet, the decoder iteratively reduces the amount of encoded packets, until all of the fragments are decoded. The amount of packets needed to decode without errors is in the order of $K' = K + \varepsilon$, where ε is the coding redundancy rate.

4 SIMULATION

In this section, we investigate the reliability of transmission and energy efficient, of LT code and ARQ scheme, within wireless body area network (WBAN). The simulation is carried out for a two system peer-to-peer, the first one with LT code the other is uncoded channel (using ARQ). The transmission chain to implement is shown in figure 3 :

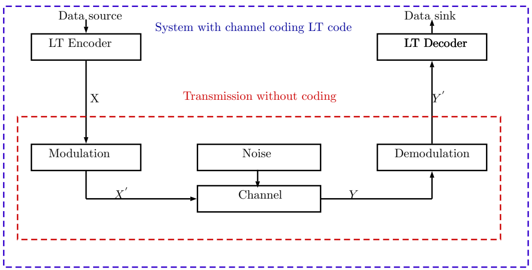

Figure 3: Transmissions with and without coding.

The performance evaluation holds in terms of energy consumption and channel bit error rate (BER) via extensive simulations using IEEE 802.15.6 standard with 7 medical sensor nodes implanted in the human body. The transmission is over an additive white Gaussian noise (AWGN) channel, with variance N0/2 and zero mean, using BPSK modulation for all encoded bits. The following simulation parameters were considered.

Table 1: Simulation parameters.

Parameter	Type or Value
P_t Transmit power	10 dBm
N_0 white noise	-111 dBm/Hz
R Transmission rate	20Kbit/s
F Frequency carrier	868 MHz
N_b number of bits per packet	100octets (uncoded channel) 105 octets (with LT coding)
E_{Ele}	50 nJ
E_{amp}	0.013 pJ

4.1 Results and Analysis

4.1.1 BER Test

This section discuss the BER performance versus SNR for a transmission with LT code, compared to uncoded channel (ARQ).

Fig. 4 and fig. 5 show the relationship between the SNR and BER, as we increase the SNR, BER decreases respectively.

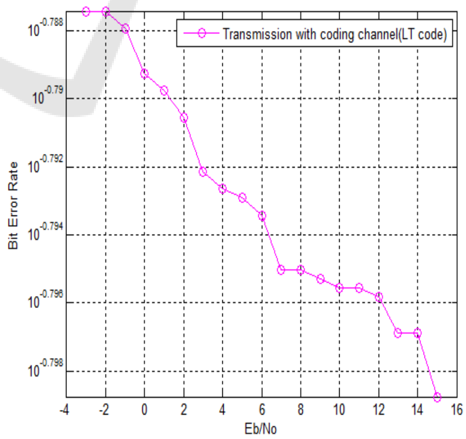

Figure 4: Performance in terms of BER versus SNR for coding channel with LT code.

From this figures, it can be observed that the coding channel of the LT codes (between $10^{-0.79}$ and $10^{-0.788}$) have a less BER than that uncoded channel (between 10^{-6} and 10^{0}).

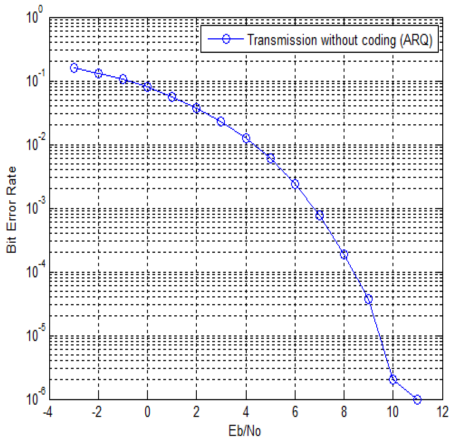

Figure 5: Performance in terms of BER versus SNR for coding channel with LT code.

4.1.2 Energy Consumption

Initially we presented a theoretical comparison of energy consumed in a transmission with fountain code and without coding. According to (Marie and Katia, 2008), the energy consumed for the transmission of one packet can be decomposed as:

$$E_p = E_T(s,d) + E_R(s) + E_{ack} \qquad (1)$$

Where :

- E_T is the energy consumed in transmission :

$$\begin{aligned} E_T(s,d) &= E_{Telec}(s) + E_{Tamp}(s,d) \\ &= (E_{elec} * s) + (E_{amp} * s * d^2) \end{aligned}$$

- E_R is the energy consumed in receiver :

$$E_R = E_{Rele}(s) = E_{elec} * s$$

- E_{ack} is the energy consumed in acknowledgement.

E_{elec} and E_{amp} represent the energy of electronic transmission and amplification respectively.

The total energy used to transmit K fragments of information for the case without coding (ARQ mechanism) can be expressed, in the form:

$$E_{T_{ARQ}} = K.\frac{1}{\gamma_{ack}}.\left(\left(\frac{1}{\gamma_{data}}.(E_T + E_R)\right) + E_{ack}\right)$$

The energy consumption of LT codes is given by:

$$\begin{aligned} E_{LT} = &\ (K + \varepsilon - 1).\frac{1}{\gamma_{data}}.(E_T + E_{enc} + E_R + E_{dec}) + \\ &\ \frac{1}{\gamma_{ack}}.\left(\frac{1}{\gamma_{data}}.(E_T + E_{enc} + E_R + E_{dec}) + E_{ack}\right) \end{aligned}$$

Where E_{enc} and E_{dec} represent the energy used to encode and decode LT respectively.

Fig. 6 show the energy consumption for two different schemes : the LT codes and ARQ as a function of the distance with K=100 packets. It can be observed from the results that the uncoded channel (ARQ) scheme has energy consumption higher than the LT code.

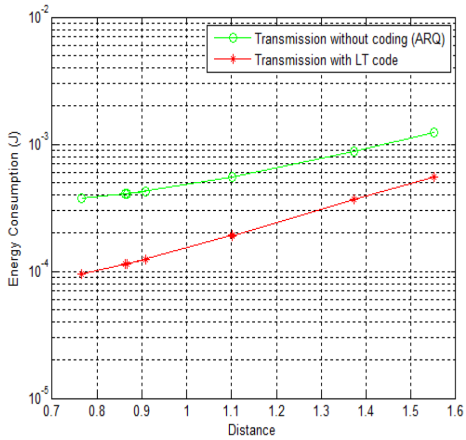

Figure 6: Energy consumption as a function of the distance.

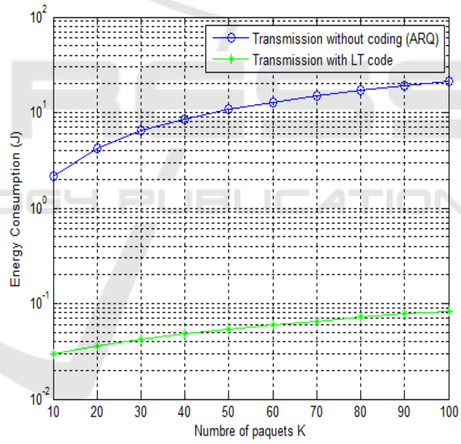

Figure 7: Energy consumption as a function of the packets sent.

In fig 7 the energy consumption for the LT codes and ARQ is plotted as function of the number of packets sent. We can be inferred also that transmission using LT coding is more energy efficient than using ARQ.

However, the LT code have lower energy consumption, as can be seen in Fig. 6 and fig. 7. The advantage of LT code is to increase the reliability of packets without a significant increase in the energy consumption.

Despite the number of data packets transmitted in the case with coding (LT), amounts, it may be noted that the energy consumption is lower than in the case with ARQ, because the sends of acknowledgment packets can occur for each packet, while for LT, it is just for the last packet which can be transmitted. In addition the encoding process introduces mathematical operations XOR type, which generates a sequence encoding complexity $O(log(\frac{K}{\delta}))$. Consumption to the calculation process is small and can be neglected compared to the energy consumption required for the transmission radio.

5 CONCLUSIONS

In WBAN the network must deliver reports and patient health alerts in a perfect manner, in which delay or loss is not tolerated. This paper has presented two solutions for the problem of instability of the radio channel and sensor lifetime: ARQ and LT code that derives from the FEC. We simulated and verified that LT code has a better performance not only in BER, but also in resources and energy consumption.

In our future work, it should be compared the performance provided by LT codes with the other famille of FEC sush as LDPC code and BCH in wireless body area Networks (WBAN).

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