

Reliability of LT Codes under Dynamic Channel Conditions in Wearable Body Area Network

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ABSTRACT

Body Area Network (BAN) is considered as a promising technology for numerous applications, such as healthcare services. BAN is in high requirement for reliable information transmission especially for vital physiological signs. As the external environments and human body motions make the channel characteristics vary frequently, which results in high package error probability and low reliability, the codes with fixed code rate are not suitable. In this paper, we use LT codes to automatically adapt to the time-varying channel condition. LT codes were firstly proposed to provide reliability for erasure channel, followed by fading channel. The efficiency of LT codes in BAN had been analyzed by simulation, only considering the medical implant communications service. Hence, we conduct a large number of experiments to analyze and verify the adaptability of LT codes to dynamic channel especially in wearable BAN. In order to carry on a comprehensive analysis, the reliability of LT codes are tested under different scenarios, such as indoor and outdoor scenes. The influence of human motion and transmission distance are also taken into account. The results demonstrate that LT codes have a good performance of reliability over on-body communication channel.

Categories and Subject Descriptors

E.4 [Coding and Information Theory]: Error Control Codes

General Terms

Measurement, Reliability, Verification

Keywords

LT codes, Dynamic network, Code rate, Body area network, Shimmer

1. INTRODUCTION

Recently, advances in wireless communication technologies and the design of human physiological sensors have promot-

ed the development of Body Area Network (BAN). BAN is defined as a body-centric system which consists of a number of sensors attached on or implanted in the body with a central control unit (CCU). In BAN, sensors can continuously monitor human's motion states and vital signs such as blood pressure, ECG and EEG [7]. Then the sensors send the data to a remote medical service center where doctors can analyze the patient's physical conditions and response timely. With BAN, patients can overcome the constraints of locations and activities, thus the healthcare quality is improved.

Since BAN transmits important health information, the sensors must be robust enough to provide long-time service and the reliability of wireless signal transmission must be guaranteed. Unfortunately, in wearable BAN, the movement of human body makes the network dynamical, therefore the channel characteristics vary frequently. The shadowing effect of human body, as well as the geometry of local environment and the location of sensors also influence the propagation path loss which produces effects on the received signal strength [7]. All above factors increase the package error probability in the receiver and decrease the communication reliability. Accordingly, there are crucial design challenges for physical layer. Several methods have been proposed to overcome the problem, including automatic repeat request (ARQ) and error correction coding. The ARQ requires many retransmissions in the case of poor channel conditions. Consequently, this brings about high latency which is contrast to the demand of BAN of transmitting the patient's real-time physiological signals. Nevertheless, error correction coding, adding redundant bits in data packets, is a significant approach to enhance the communication dependability and service flexibility in the design of physical layer.

More recently, fountain codes, which also can be called rateless codes, has attracted a lot of attention from researchers for being capable of generating any number of output symbols from a given finite set of input information bits [4]. Due to this characteristic, the code rate of fountain codes can adapt to the time-varying channel condition automatically. LT codes [8], optimal for erasure channels, are the first practical realization of rateless codes, followed by Raptor codes [9]. [5] presented a rateless-coding framework for communication over fading channels, demonstrating the advantage in reliability and robust over conventional fixed-rate codes only through simulation. [2] proposed an augmentation protocol using the rateless code with the frequency-shift keying (FSK) modulation scheme to enhance the energy-

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BODYNETS 2013, September 30-October 02, Boston, United States

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DOI 10.4108/icst.bodynets.2013.253653

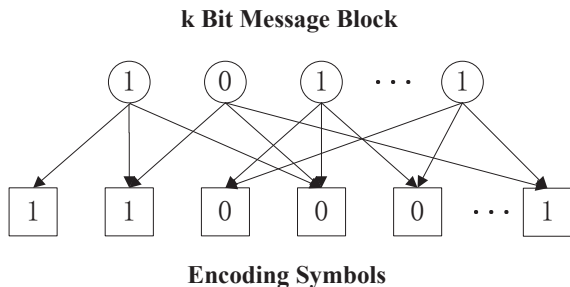


Figure 1: Tanner graph of LT code

efficiency and reliability. However, the protocol only takes implantable BAN into consideration. In this paper, we focus on wearable BAN, considering on-body channel characteristics change constantly under the effects of human movements and environmental elements. The main outcome of this paper is to perform plenty of experiments about the performance of LT codes in a real BAN, which is organized by Shimmer sensors [1]. For purpose of verifying the impacts of dynamic network condition, our experiments have been conducted under different human body motions and sensor locations. And the experiments scenes are divided into indoor and outdoor environments. The data processing results show that LT codes can well adapt to the time-varying channel condition, therefore the service reliability is improved.

The rest of the paper is organized as follows. In Section 2, the design of LT codes and the on-body channel model are described. Then, the experimental design, measurement results and discussions are presented in Section 3. Finally, in Section 4, an overview of the results and conclusions are presented.

2. PRELIMINARY

In this section, the encoding process of LT codes and the fading channel model of wearable BAN are introduced.

2.1 Principle of LT Codes

Traditional error correction codes are typically block codes with a fixed code rate. The n encoding bits are made up of k information bits and $n - k$ check bits, and as a result the code rate is k/n . In contrast, LT codes are rateless due to the encoding bits are generated on the fly, as few or as many as needed [8]. In other words, the number of encoding bits is limitless. LT codes can adapt to different channel conditions flexibly via changing the code rate.

The tanner graph of LT codes is illustrated in Figure 1, and the process of generating an encoding symbol can be described as following steps:

- (1) Choose the degree d from a degree distribution randomly for the encoding symbol.
- (2) Choose d distinct information bits, the exclusive-or result of which is regarded as the value of encoding symbol.

In order to recover the original input data, the degree and

Table 1: Parameters of Path Loss Model

	Hospital Room	Anechoic Chamber
a	6.6	29.3
b	36.1	-16.8
σ_N	3.80	6.89

a list of information bits indices should be given to the decoder for each encoding symbol. In theory, after receiving any set of encoding symbols whose total number is slightly bigger than n , the decoder can recover the source data successfully. Obviously, a reasonable degree distribution plays a key role in the performance of LT codes. The popular robust degree distribution $\mu(d)$ is described by following equations:

$$\mu(d) = \frac{\rho(d) + \tau(d)}{\sum_d \rho(d) + \tau(d)} \quad (1)$$

where $\rho(d)$ and $\tau(d)$ are given by

$$\rho(d) = \begin{cases} \frac{1}{k} & d = 1 \\ \frac{1}{d(d-1)} & d = 2, 3, \dots, k \end{cases} \quad (2)$$

$$\tau(d) = \begin{cases} \frac{s}{kd} & d = 1, 2, \dots, (\frac{k}{s} - 1) \\ \frac{s}{k} \log(\frac{s}{\delta}) & d = \frac{k}{s} \\ 0 & d > \frac{k}{s} \end{cases} \quad (3)$$

In equation 3, parameter s is determined by

$$s = c \ln\left(\frac{k}{\delta}\right) \sqrt{k} \quad (4)$$

where δ is the permitted probability that the decoder fails to recover the original data with K encoding symbols and c is a suitable constant. The further discussion on how degree distribution effects the performance of LT codes, according to the measurement results, will be presented in Section 3.

2.2 The On-Body Channel Model

In BAN, for the sake of characterizing the channel model, attention should be paid to the shadowing effects generated by human body or obstacles near the human body. At the same time, human motion should also be carefully taken into account. IEEE 802.15.6 group [3] has defined several scenarios according to the location of sensors (i.e. implant, body surface and external). In this paper, we only consider CM3 (Body Surface to Body Surface) as the experiment condition is wearable BAN.

The path loss model is described as below [6]:

$$PL(d) [dB] = a \cdot \log(d) + b + N \quad (5)$$

where a and b are coefficients of linear fitting, d is the distance in mm between sender and receiver, and N is a normally distributed variable with standard deviation σ_N .

As the operating frequency is 2.4GHz, Table 1 summarizes the corresponding parameters.

3. EXPERIMENTS

In this section, the experiment setup and measurement design are presented, as well as the discussion based on measurement results.

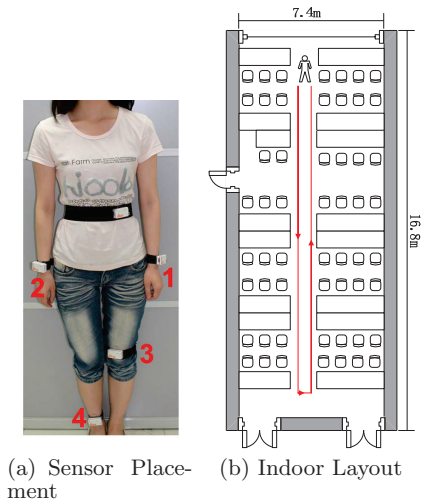


Figure 2: On-Body Sensor Placement and Indoor Layout

3.1 Setup

The experiment is set up to measure on-body BAN communication links while the volunteer performed everyday activities such as walking and running. We use code rate as the measurement parameter, in order to analyze what factors impact the reliability of BAN.

Our experiments use two Shimmer [1] sensors running TinyOS platform. The core elements of the sensor are the low-power MSP430 microprocessor and the TI Chipon CC2420 radio transceiver which can work at 2.4GHz. The sensor node, measuring $52 \times 30 \times 12$ mm with a weight of only 15 grams, contains three-axial accelerometer which can monitor human body motion status. Consequently, Shimmer is an ideal platform for confirming the performance of LT codes.

For each experiment, the receiver is fixed on left waist. However, considering the impact of sensor location, the sender is placed to one of the four positions, namely, right wrist, left wrist, right ankle and left knee. The sensors can be attached to the body surface by flexible attachment straps, as shown in Figure 2(a). We consider different scenarios, such as indoor scene and outdoor scene. The layout of our indoor environment is depicted in Figure 2(b). The room size is $16.8\text{m}(\text{length}) \times 7.4\text{m}(\text{width}) \times 2.4\text{m}(\text{height})$. And the female volunteer is 24 years old, with a withers height of 170cm and a body weight of 60kg.

Our experiments are divided into three plans. Plan 1 and Plan 2 are to confirm the impacts of sensor location, human motion and external environment on BAN. Plan 3 is to demonstrate the influence of degree distribution on the performance of LT codes.

Plan 1: The experiments are conducted in the office described in Figure 2(b), in which the red line represents the route that the volunteer is asked to go along. The block length of original information is set to be 50, 100, 150, 200 bytes separately.

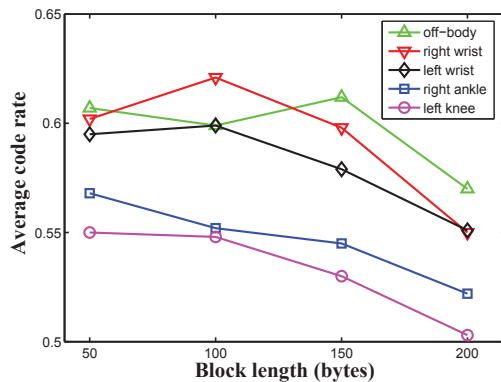


Figure 3: Measurement results of indoor environment

Plan 2: We do experiments on the playground which is a standard semicircular track field. The volunteer performs walking and running motions. The block length is set to be 50 and 100 bytes.

Plan 3: Because the flash memory of Shimmer is limited, the max degree is 5 in our experiments. With the purpose of testing the influence of degree selection, the max degree is set to be 5 and 10 respectively. In order to eliminate the human factors, the sender and receiver are both placed on desk with a distance of 50cm.

3.2 Results

For each test case, the experiments are conducted twenty times, we evaluate the performance of LT codes through the average code rate. The results of Plan 1 are demonstrated in Figure 3, we can find that as the block length increases, the average code rate decreases. This is due to the max degree is fixed. Since the difference between max degree and block number increases, the decoding ability of LT codes weakens. Figure 3 also indicates that when the sender is placed on left knee or right ankle, the average code rate is lower than that when the position of sender is left wrist or left wrist. The reason is that as the distance between sender and receiver raises, the fading path loss becomes larger according to equation (5), so the decoder needs to receive more packets to decode the original information successfully.

The results of Plan 2 are shown in Figure 4 and Figure 5. Figure 4 illustrates the BAN behavior in the office and open environment. As we can see, the average code rate of outdoors is higher than that of indoors. The obstacles shown in Figure 2(a) influences the parameters of equation (5), which results in higher path loss.

Figure 5 shows the measurement results under different human motions. We can see the average code rate of running motion is lower than that of walking. When the volunteer performs strenuous exercises, the channel condition varies frequently, and the packet loss probability is higher. Therefore, the sender needs to generate more packets to ensure reliable transmission.

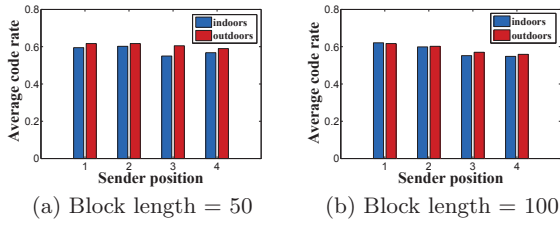


Figure 4: Measurement results under different environments(the sender is placed on 1: left wrist, 2: right wrist, 3: left knee, 4: right ankle)

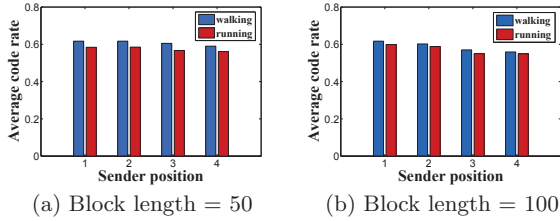


Figure 5: Measurement results under different human motions(the sender is placed on 1: left wrist, 2: right wrist, 3: left knee, 4: right ankle)

The results of Plan 3 is described in Figure 6. The degree selection of each encoding symbol follows the robust degree distribution, and the max degree is set to be 5 and 10 separately. As shown in Figure 6, we discover that the average code rate is about 0.58 when the max degree is 5. On the other hand, the value is 0.66 in the case that the max degree is 10. In conclusion to above results, the average code rate decreases with the max degree increasing. Although the measured results of code rate are different from the theory, the trend also can reflect the influences of different conditions.

4. CONCLUSIONS

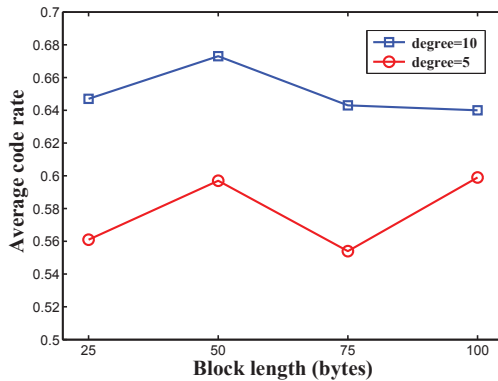


Figure 6: Measurement results under different degrees

In this paper, we conduct plenty of experiments to analyze the reliability of LT codes in real wearable BAN composed by Shimmer sensors. We considered factors that may effect channel condition, including sender position, external environment and human body motion. The statistical results show that when the sender is attached to left wrist or right wrist, the code rate is about 9 percent higher than that of other positions. It also turns out the code rate decreases in poor channel condition. From the above discussion, the conclusion can be reached that the code rate of LT codes can adapt to the flexible communication channel automatically, in this way, the reliability is guaranteed. In future works, similar measurements with more samples need to be done in order to improve the accuracy. Moreover, in order to get a more comprehensive view of LT codes, measurements under the condition of multi-sensor network are necessary.

Acknowledgments

This research was supported by National Basic Research Program of China (973 Program) under Grant No.2011CB302702.

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