A Low-Complexity Bio-Medical Signal Receiver for Wireless Body Area Network

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***Abstract*—In accordance with the tendency towards an aging society, the wireless communication technology has been gradually used in medical monitoring. Such devices are all with characteristics of low power consumption, low cost, and low complexity. Thus, we want to construct a smart bio-sensing system, which is wireless, tiny, and can be provided for more than one person to use simultaneously. The sensing bio-signal will be sent to the smart analyzing system by wireless transmission. Once the abnormal signal is detected, the smart analyzing system will send out a warning signal. The system can save a lot of medical human resources. This paper accomplished the baseband receiver for the wireless bio-medical signal transmission. The receiver can sustain ten users within one meter. The PER is less than 1 % given SNR=7dB. The total power consumption is 304 µW at 5MHz system clock.**

I. Introduction

Facing an aging society, we have to think over how to provide a safe and comfortable environment for the elderly. The aging population has been increasing rapidly in recent years; medical human sources will soon become a serious social problem. Therefore, if we can detect and receive abnormal signals immediately, through a personal home monitoring system, and then transmitting them to the medical staffs for estimation and maybe even first aid care, a large amount of human sources can be saved. Most of the present physiology signals measuring apparatuses transmit signals to a server by wired transmission. This limits not only the measurement space, but also the movement of the users, especially for long time measurements. Therefore, wireless physiology signals transmitting becomes one of the important developments [1].

Many literatures have been published on present personal wireless physiology signal home monitoring system [2][3], but those on group wireless biomedical signal monitoring are relatively few. Environments that may need group wireless biomedical signal monitoring are hospitals or nursing homes. Under the effect of aging population and declining birthrate, the need for nursing homes will be increased. Therefore, we expected that the system can not only be used for personal home monitoring, but also in crowded hospitals and nursing homes. The error rate will not therefore increase and signals would not be affected between users.

Fig. 1 shows the diagram of a wireless physiology signal monitoring system with smart detectors. When the Wireless Sensor Node (WSN) is modulated, it will be transmitted to the Central Processing Node (CPN) on the human body surface, which can be integrated with watches, necklaces or rings, etc. CPN has a built-in intelligent detection system; hence, it can send out warnings due to abnormal signals. The distance between WSN and CPN is about 0.5m.

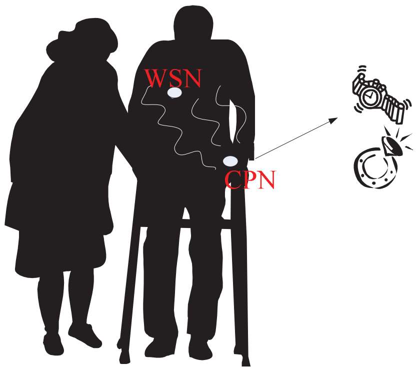

Figure 1. The architecture of wireless smart bio-medical signal receiver.

This paper is organized as follows. The system block diagram of the baseband receiver is described in Section II. Simulation results are shown in Section III. Implementation results are given in Section IV. Finally, Section V concludes this investigation.

II. System Block Diagram

Electrocardiogram (ECG) signals are regarded as the hugest data among the physiology signals, which varies instantaneously and once abnormal signals appear, it may cause death. Therefore, it needs long time monitoring. Moreover, an intelligent determination system is also needed to detect abnormal signals. For other physiology signals, such as body temperature or blood sugar, since they would not change instantaneously, they don't need long time monitoring.

In order to design an intelligent wireless physiology signals determination system, it would be better to make the external disturbances as small as possible. Therefore, this paper set the Wireless Medical Telemetry Service (WMTS) bandwidth as the transmitting bandwidth, 608MHz ~ 614MHz [4]. ECG signals are the main transmitting signals, together with the intelligent ECG features detection technique, hoping that abnormal ECG signals can be detected instantly, saving lots of first aid time.

Fig. 2 shows the architecture of the baseband transmitting end. The data that need to be transmitted will be added a preamble and then pass through a 31-bit Gold code spread, producing 31 times longer data. Then the data will be modulated by the binary phase shift keying (BPSK) which uses two different phase, 180° difference, carriers to represent the input bit, 0 or 1. The reason for choosing BPSK modulation is that the system does not need high speed transmitting and because of its simple modulation, error rate can be minimized, meeting the system needs. The modulated signals will finally pass the D/A converter and then given out through the antenna. This paper has taken the packet format of Zigbee as the reference packet length, in which the length of PHY payload is variable, maximum 127 bytes. Therefore, the proposed system sets the maximum raw data that each packet can contain are 30 bits [5]-[7].

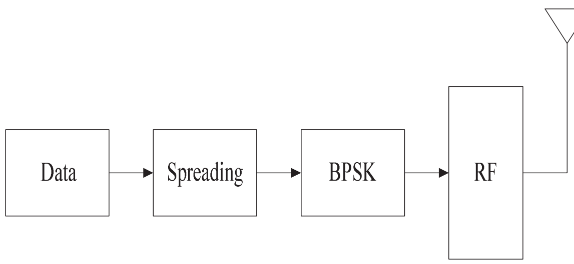

Figure 2. Block diagram of the transmitter.

Fig. 3 shows the architecture of the baseband receiving end. The data received from the antenna will first pass through the A/D converter and then enter the packet detector which is used to set a threshold level to the total energy of a sampling in a period of time. Once the energy is higher than the threshold level, this means that a preamble is detected and the following samplings are used to estimate the first carrier frequency offset (CFO), then followed by energy detection and synchronous symbol boundary detection. The correct starting point can only be confirmed after synchronization. The synchronous symbol boundary detection uses the characteristics of 31-bit per period, after the given preamble spread, to carry out cross correlation. With a row of correlators, the coefficients are regarded as the spread codes, producing different time offsets to the input preamble. If a peak value is produced when the preamble and the spread code correspond to each other, this means a symbol boundary is detected and with the same preamble, after bit spread, the second symbol CFO can be estimated. Then compensating the CFO to the data and with de-spreading and de-modulation, the original data can be achieved.

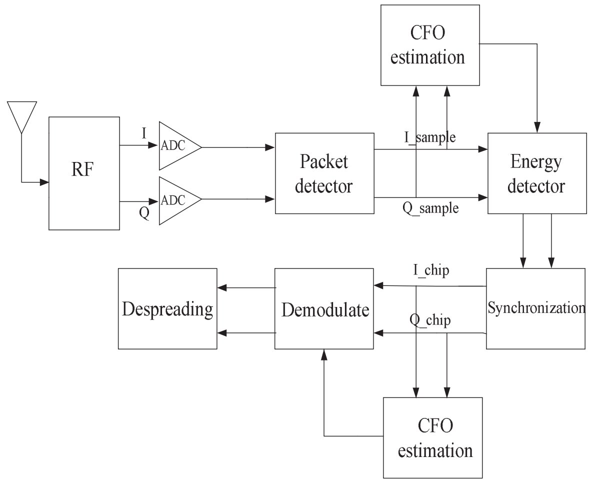

Figure 3. The Receiver block diagram.

III. Simulation Results

Considering Additive white Gaussian noise (AWGN), phase noise and CFO into the channel module and then run the bit numbers simulation, floating-point converting to fixed-point, and finally implement the designed architecture with hardware.

A. Carrier Frequency Offset

This paper adopted WMTS bandwidth, but the transmitting specification has not been decided yet. Therefore, in order to meet different operating frequencies or the regulated CFO of the bandwidth, this paper has simulated the compensation range of the CFO of the system under different signal-to-noise ratio (SNR) environments, which is 20ppm ~ 80ppm. Figure 4 shows that when the offset range is within 80ppm, there is not much changes on packet error rate (PER). However, when offset is above 80ppm, the packet loss rate increases, about 2.5%, and also the error rate. The actual efficiency starts to decrease; therefore, knowing that the offset correction range of this system is about 60ppm.

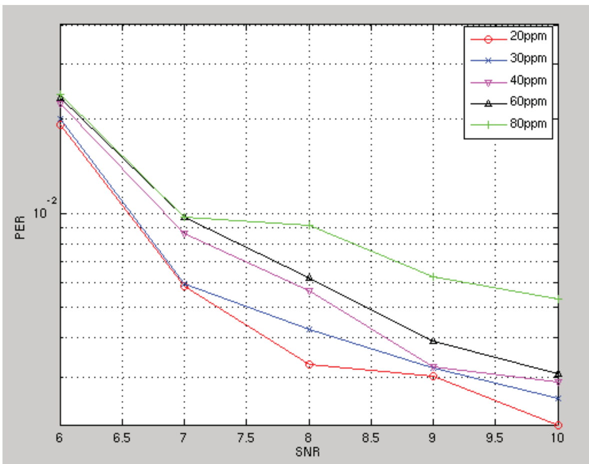

Figure 4. The simulation result of CFO compensation range.

B. Fixed Point

To implement hardware, we must first know the required bytes needed by the whole system, which can be obtained by fixed-point simulation. For biomedical signal, its PER is strictly limited below 1%, preventing serious mistakes in judging of diseases.

In Fig. 5, it shows the 6-bit fixed-point error rate is higher than the others. This may be caused by the high packet loss rate, almost 30%, meaning that packet detection, frequency offset compensation and symbol boundary detection can not demodulate the correct data. Hence, both the packet loss rate and the error rate become high. When SNR = 7dB, the error rates decrease and after 7dB, the error rate difference between 7-bit fixed-point and floating-point is about 0.25% and the overall error rate is below 1%, under specification. The simulation result of the 8-bit fixed-point is close to that of the floating-point. But in order to let the hardware operate with as small bit as possible, this paper has decided to adopt the 7-bit fixed-point. For integers, we have discovered that the real value may be greater than ±2. Therefore, the integer needs at least 3 bits to be expressed, that means using 10 input bits for hardware design.

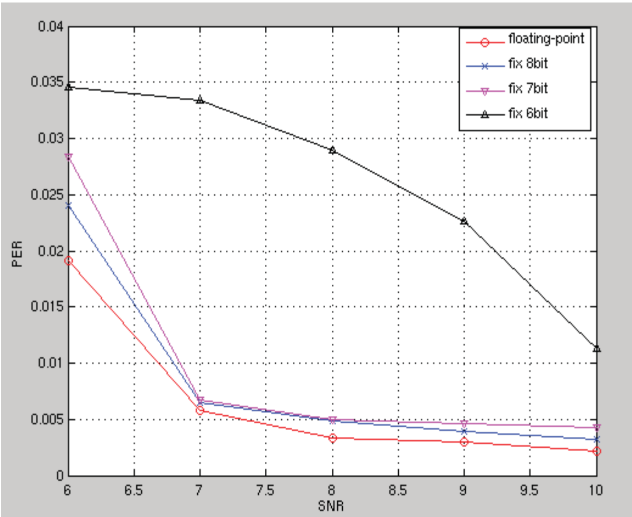

Figure 5. The simulation result of fixed point.

C. Quantity of users

For wireless network, the signal transmitting range will be faded to different levels, according to the effects of the landforms. Since the receiving end of the system is set on human body surface, the transmitting end and the receiving end will be regarded as line-of-sight when there are no abnormalities; hence, no need to consider multipath. Assuming the transmitting ends of other interferers and the receiving ends of the users are line-of-sight, a free space signal loss model will be used for power fading.

Free space fading is the basic signal fading mode. The signal intensity of the receiving end is in square relationship with distance. When the antenna is ideal, the relationship between the transmitted signal under free space fading and the received signal is shown in eq. (1).

$$\frac{P_t}{P_r} = \frac{(4\pi d)^2}{\lambda^2} \quad (1)$$

where P_r represents the received power, P_t represents the signal power, d is the distance between transmitting end and receiving end, and λ is the wavelength. Put $\lambda = c/f$ into eq. (1), where f is the signal transmitting frequency. Then eq. (1) can be rewritten as:

$$\frac{P_t}{P_r} = \frac{(4\pi df)^2}{c^2} \quad (2)$$

In Figure 6, we assumed the distance between the transmitting end and the receiving end of the system to be 0.5m; the actual effects from the interferers to the users are simulated, for every 0.1m. The simulation shows that when there less than four users using the biomedical signal transmitting simultaneously and the interferers are away from 60cm, PER can still be maintained below 1%. That means, in a two- or four-person ward of a hospital, patients don't need to worry that their signals between will affect each other. However, with increasing patients, the distance between each patient needs to be increased too. When there are seven users, the distance must be lengthened, at least to 0.8m, to make the system demodulate the physiology signals properly, preventing interferences. When the patient number is increased to ten persons, the distance must be lengthened above 1m, about one-step long, so that the system can demodulate signals properly. Under the environment of a nursing home, without any special conditions, many old people can move around to any public facilities and do social activities, without keeping a distant between each other since misreading of the physiology signals would not happen in this occasion.

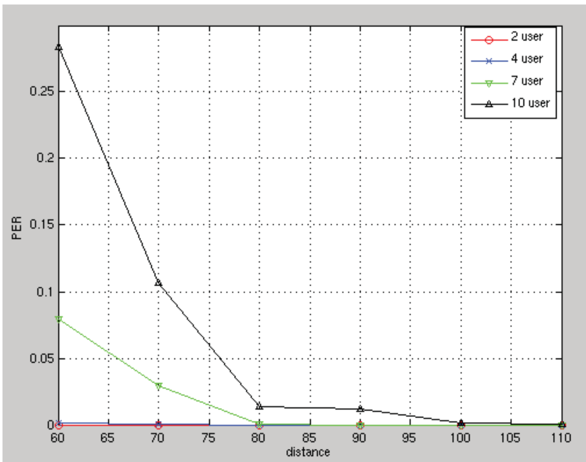

Figure 6. The simulation result of different number of users.

IV. Implementation Results

The receiving end in this paper is mainly concentrated on low power and low complexity features [8]; therefore, in designing the block functions of the whole architecture, only most of the basic functions are retained and so algorithms can become simpler. For the hardware, the more complex circuits are cancelled and the multiplication and division operations are prevented, which need large amount of computations. Therefore, simple addition and subtraction operations are used instead. With these improvements, the hardware power can be minimized. The required SNR value is simulated with MATALB, together with the proposed system power dissipation from the cell-based, is compared with those of the other systems, as shown in Table I.

Different voltage ranges is available in different processes and increasing the operation frequency will also cause higher power dissipation. Therefore, a system's good and bad can not be easily judged by just considering its power dissipation. For this reason, we have to decide a normalized parameter, making the same standpoint, so that comparisons become possible. The normalized parameter:

$$\alpha = \frac{P}{fv^2} \qquad (3)$$

where P is the hardware power dissipation, f is the operation frequency, and v is the voltage of the process.

In Table I, the normalized parameter in [9] is extremely high. However, when comparing with other systems, we discover that [9] has adopted orthogonal frequency division multiplexing (OFDM) and multi-tone code division multiple access (MT-CDMA) for higher WSN, making the transmitting quantity higher than a common direct sequence spread spectrum (DSSS) system. The architecture is therefore larger and also the power dissipation, but wider operation range. The design in [10] is a DSSS system. Its spread code is the Zigbee 15-bit PN code. Though it has the smallest normalized parameter, its spread code can not be used in multi-user system. Hence, it is only suitable for personal biomedical home monitoring. Furthermore, the proposed system in this paper will first process users' ECG signals, before wireless transmitting, and then transmit them through WSN to CPN to determine abnormal signals. This can reduce transmitting quantity and therefore decrease the power dissipation. There is not much difference between the normalized parameter of this paper and that in [10], but our proposed system can be used under multi-user environment, having great superiority.

TABLE I. COMPARISON RESULT

	This Work	**Yu's [9]**	**Wang's [10]**
CMOS Process	180 nm	90 nm	180 nm
Power supply	1.8 V	0.5 V	1.8 V
Modulation Type	BPSK	MT-CDMA, OFDM	BPSK
Operating Frequency	5 MHz	5 MHz	2.4 MHz
Power	304.1μW	UL:520μW MT:490μW	144μW
SNR	7 dB	N/A	5 dB
Normalized parameter (α)	18.76	404	18.518

V. CONCLUSION

Biomedical signal receiver must equip with characteristics of low power, low complexity, and high accuracy, so we could reduce the hardware computing data and complexity to fulfill the overall system operating in the best condition. Our spread spectrum system using Gold code could prevent the interference between users while they are transmitting signals. The overall operating frequency is 5 MHz; moreover, the power consumption is 304 μW, and the error rate is less than 1% in one meter within ten users. The SNR of system requires 7dB. Because the simple packet detection algorithm can not operate in a complicated environment, decreasing the SNR that the system requires will be our target in the future. The transmitter can also combine with pulse shaping filter to reduce the signal interference and avoid distortion. Therefore, the error rate will be improved.

ACKNOWLEDGMENT

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