Transmit Only UWB Body Area Network for Medical Applications

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Abstract — **This paper investigates methods to enhance the reliability of an Ultra-Wideband Transmit-Only (UWB Tx-only) sensor system. UWB Tx-only system uses asynchronous burst transmission, where each individual sensor transmits periodically without prior knowledge of other users and the channel condition. The application of UWB Tx-only sensor system for Wireless Body Area Network (WBAN) in a single user and multiple user environments is presented. In a single user environment, the main source of interference is from the collision of transmitted signals from individual sensors on the body. In a multiple user scenario, apart from the interference due to collision, there is also another source of interference from transmitting sensors of nearby users. The two major factors affecting the system reliability are the signal to noise ratio and the probability of collisions. The signal to noise ratio can be enhanced with a higher transmission power, which can be achieved through the use of gated systems and by carefully optimizing the pulse repetitive frequency and the gating duty cycle when generating an UWB transmission signal. Meanwhile the collision probability in a Tx-only UWB WBAN system can be reduced by arranging unique transmission intervals. It is shown in this paper that the collision probability for the case of burst transmission can be reduced to less than twice that of a pulse transmission through careful selection of the transmission interval.**

Index Terms — **Ultra Wideband (UWB), Wireless Body Area Network (WBAN), Transmit Only (Tx-Only).**

I. INTRODUCTION

There has been a wide spread use of wireless monitoring systems both in hospital and home environments. Ambulatory Electrocardiogram (ECG) monitoring [1], respiratory rate, blood pressure, Electroencephalogram (EEG) monitoring in emergency departments [2], Oxygen Saturation (SPO2) and blood pressure [3] are now performed wirelessly. Low data rate Ultra Wideband (UWB) is suitable for vital signs monitoring system as its transmission power is lower than WLAN, Bluetooth and Zigbee, which is less likely to affect the human tissue and causes interference to other medical equipments [4]. Furthermore, it is able to transmit at higher data rate which is suitable for real time continuous monitoring of multiple channels. There are numerous advantages for using UWB in a Wireless Body Area Network (WBAN) system, but before UWB can be successfully implemented, there are a few limitations that have to be overcome first.

One of the major challenges faced by UWB currently is that an UWB receiver consumes much more power as compared to an UWB transmitter. To overcome this problem, a UWB transmit-only system (UWB Tx-Only) for WBAN is proposed in [5]. It has been shown that through careful selection of number of pulses per data bit with respect to locations of the sensors and the receiving device, it is possible to improve the overall Bit Error Rate (BER) performance for the UWB Tx-Only system. The key idea of an UWB Tx-Only system is to shift most of the power hungry circuitry and complexity to the receiver nodes, where the power requirement is not as stringent as that of the sensor nodes.

In this paper, in addition to providing a brief overview of the system proposed in [5], we will show how the UWB Tx-Only can be applied to WBAN applications by highlighting the advantages and limitations. BER performance is a good indication for the reliability of a wireless sensor system. In a UWB Tx-Only system, the BER is mainly dependent on the Signal to Noise Ratio (SNR) and the probability of collisions. This paper is organized as follows. First Tx-only multi-access scheme has been described in section II. The effect of gating on the SNR will be covered in section III, and the effect of burst transmission on the probability of collision will be presented in Section IV. Section V concludes the paper.

II. UWB TX-ONLY MULTI-ACCESS SCHEME FOR WBAN

A pulse position modulated (PPM) UWB Tx-Only system can be represented by (1).

$$S_{TX}^{(m,k)}(t) = \sqrt{E_b} \sum_{i=0}^{\infty} \sum_{j=0}^{N_{bit}-1} \sum_{n=0}^{N_s-1} W_{tx} \begin{pmatrix} t - iT_{\text{int}}^{(k)} - jT_b^{(k)} \\ -nT_p^{(m)} - \Delta_j \tau_m - \tau^{(k)} \end{pmatrix} \quad (1)$$

where $W_{tx}(t)$ is the transmitted UWB pulse, E_b is the bit energy, T_{int} is the time interval between successive transmissions for sensor k, T_b is the bit period, which is equal to $N_s T_p$ where N_s is the number of pulses per bit, T_p is the pulse interval for user m, $\Delta_j \in \{0,1\}$ is the information of the bit, τ_m is the time shift for *PPM* modulation, and $\tau^{(k)}$ is the asynchronous random start time of sensor k.

In this system, the burst transmission technique is adopted; each data packet is transmitted at a much higher data rate as compared to its original sampling rate. For example, an ECG signal sampled at 300 Hz using a 12 bit Analog to Digital Converter (ADC) requires a data rate of 3.6 kbps. But instead of transmitting at 3.6 kbps, a much higher data rate in the range of tens of Mbps is used. Figure 1 shows the
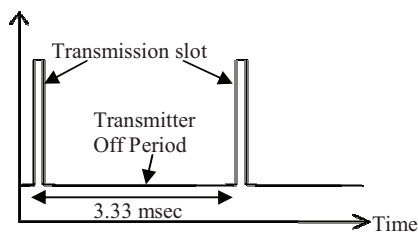
Fig. 1.   Gated ECG signal sampled at 300 Hz

Fig. 2.   Different pulse rate for different users

transmission pattern of an ECG signal using the burst transmission techniques. The signal resembled that of a gated system[1]. The advantages of using burst transmission are firstly low power consumption due to very short "on" time. Secondly, the power overhead for the circuitry to wake up from sleep can be minimized as the whole packet is transmitted in a burst. Thirdly, as this is a Tx-Only system, all sensors transmit asynchronously without prior channel knowledge; therefore the shorter the transmission time, the chances of collision between sensor nodes will be lower.

Two different levels of collision avoidance can be proposed. The first level is to avoid collisions among sensors on the same user while the second level is to avoid collisions from nearby interferers. The first level collision avoidance is achieved by assigning a unique transmission interval for each sensor. The second level collision avoidance is achieved by using a different pulse repetitive frequency (PRF) for different users. In other words, the same pulse rate is used for all the sensors on the same user [5] and a different pulse rate is for a different user [6]. In a typical WBAN system, there are multiple sensor nodes but only one receiver node per user. The receiver should be able to identify whether the signal is from one of sensors of the intended user or it is an interference signal from nearby users. Furthermore, in a Tx-Only system, the transmitter is unable to identify if there is a nearby user and also unable to change its transmission pattern or frequency band to adapt to the environment. Therefore, it is crucial to employ a system such that the receiver can easily differentiate between interfering sources and signals from the intended user. This is the main reason for adopting a different pulse rate for different users. As shown in Fig. 2-(a) and Fig. 2-(b), sensors on the user 1 use the same pulse rate, while user 2 uses a different pulse rate (Fig. 2-(c)). Fig. 2-(d) shows the received signal seen at user 1 receiver, when both sensor 1 from user 1 and user 2 transmit at the same time. As illustrated in Fig. 2-(e), the receiver can easily differentiate signals from another user, as the sampling interval between each pulse is known to the receiver.

Another characteristic of the proposed WBAN system is that different number of pulses is allocated to the different sensors on the same user's body. The assignment of the
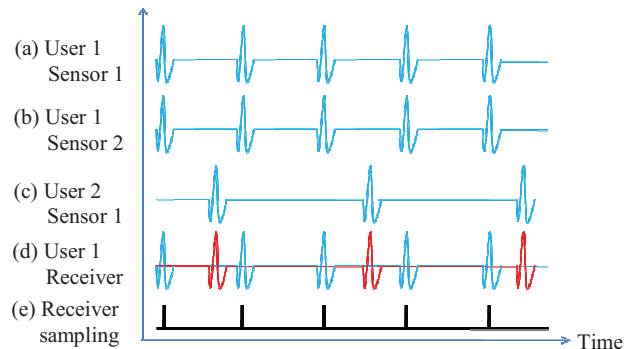
number of pulses is dependent on the distance between the sensors and the receiver. Transmission power management is the main reason for assigning different number of pulses to the sensors; it is to ensure sufficient link budget is achieved. The different number of pulses per data bit can also be used as an identifier for the sensors to help for receiving and monitoring.

Receiver position for this system is selected to be closest to the sensor node that has the highest data rate. This is to ensure that minimal number of pulses can be assigned to the sensor node with the highest data rate. This would reduce the transmission time slot and in turn to minimize the chances of collisions.

The major limitation of Tx-Only system is that the position of the receiver has to be fixed for an optimised performance and it does not allow for reconfiguration to adapt to the changing channel condition. One method to overcome this limitation is by incorporating a simple low-power narrowband feedback to the Tx-Only sensor node, which can allow for synchronization of the sensor nodes and the transmission pattern reconfiguration to suit the changing environment.

III. GATED SIGNAL ANALYSIS FOR TX-ONLY WBAN SYSTEM

The reliability of the system depends mainly on the bit error rate performance. For the proposed Tx-Only system, BER is mainly dependent on the Signal to Noise Ratio (SNR) and the probability of collisions. Key factors affecting the SNR are the transmit power, the channel condition, the propagation distance and the receiver sensitivity. Among all these factors, only transmit power can be determined at the transmitter. Federal Communications Commission (FCC) has placed stringent requirement on UWB transmission, allowing a peak transmission power limit of 0 dBm and an average limit of -41.3 dBm [7]. Therefore, it is important to maximize the transmission power to enhance the system performance.

The measurement of the average and peak power can be calculated easily using a spectrum analyzer in practice. For the average power measurement, the resolution bandwidth is 1 MHz with an integration time of 1 msec. A resolution bandwidth of between 1 to 50 MHz can be used for the

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[1] The concept "gated" is used here to represent a transmission slot that each sensor transmits data during a specified period of time and then sleeps until the next period.

measurement of the peak power. The peak limit is dependent on the resolution bandwidth and varies according to (2).

$$Peak\ Power = 20\log\left(\frac{Resolution\ Bandwidth}{50}\right) dBm \quad (2)$$

FCC has set the limit such that a system with high pulse repetitive frequency (PRF) will be average power limited, while a system with low PRF will be peak power limited [8]. The relationship between the measured peak and average powers with the full bandwidth peak power for PRF much greater than the resolution bandwidth describe in [8] is shown in (3). The equation given in (3) is for the case of continuous transmission and not for a gating system. The measured average power of a gated signal with a PRF much larger than the resolution bandwidth is represented by (4). The measured peak power for a gated signal is similar to that of a non-gated signal, as long as the "on" period is longer than the impulse response duration of the measurement filter.

$$P_{peak}^{m} = P_{ave}^{m} = P_{peak}\tau^2 R^2 \quad for\ R \gg B_R \quad (3)$$

$$P_{ave}^{m} = P_{peak}\tau^2 R^2 \delta \quad for\ R \gg B_R \quad (4)$$

where P_{peak}^{m} is the measured peak power, P_{ave}^{m} is the measured average power, P_{peak} is the full bandwidth peak power (Total transmitted power in a pulse), τ is the pulse width, R is the pulse repetitive (PRF), δ is the duty cycle based on a duration of 1 msec and B_R is the spectrum analyzer's resolution bandwidth.

The relationship for the full bandwidth peak power of a gated signal with PRF $\gg B_R$ shown in (3) and (4) together with FCC peak (1mW) and average limit (75nW) can be represented by (5) and (6).

$$P_{peak} \le 7.5\,x10^{-8}\left(\frac{B_P}{R}\right)^2\left(\frac{1}{\delta}\right)\ Watt \quad for\ R \gg B_R \quad (5)$$

$$P_{peak} \le 0.001\left(\frac{B_R}{50\,x10^6}\right)^2\left(\frac{B_P}{R}\right)^2\ Watt \quad for\ R \gg B_R \quad (6)$$

where B_P is $1/\tau$.

Figure 3 shows the plot of a high PRF continuous transmission system together with a high PRF gated system with 10% duty cycle. It can be observed that the allowable full bandwidth peak power of a gated system is higher than that of a system that transmits continuously. Therefore, a gated system can be used to improve the signal to noise ratio in a WBAN system. Using (5) and (6) full bandwidth peak powers are plotted in Fig. 4 based on 1 msec integration time, a B_R of 1MHz, B_p of 1GHz and PRF of 10 MHz. It is observed that for a duty cycle less than 18.75%, the gated signal is peak power limited, and is average power limited when the duty cycle exceeds 18.75%.
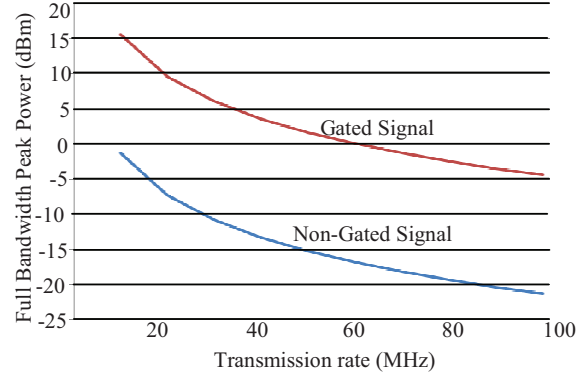

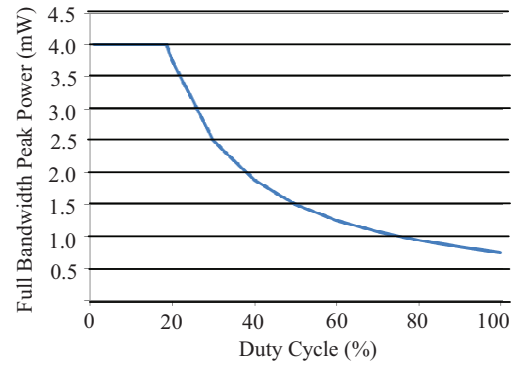Fig. 3.   Transmission power limit for gated and non-gated system

Fig. 4.   Effect of duty cycle on peak power for gated system

As shown in Fig. 3 and 4, the transmitted power is largely dependent on the selection of PRF and the gating duty cycle. As PRF increases, the allowable transmission power per pulse is reduced. The maximum PRF is determined by the minimum transmission power required at the receiver. The minimum transmission power required can be calculated using (7). For example, based on a PPM modulation, a signal bandwidth of 1GHz and distance of 1m, the minimum required transmission power is 45µW, and this translates to a maximum PRF of 94 MHz.

$$P_{peak}^{\min} = N + NF + SNR_{\min} + PL \quad (7)$$

where N is noise (-84dBm for a bandwidth of 1GHz), NF is the noise figure (10dB), SNR_{min} is the minimum required Signal to Noise ratio (10.5dB) and PL is the path loss at 4GHz (50 dB for a distance of 1m)

The minimum PRF to be used depends on the size of the data packet to be transmitted. The transmission slot should be kept below a duty cycle of 18.75% for maximum transmission power. The whole data packet should be transmitted within 187.5 µsec, which is 18.75% duty cycle based on a 1 msec period. The 1 msec period is the integration time based on the FCC for measurement of average power.

IV. Collision Probability for Burst Transmission

Another major factor affecting the reliability of a UWB Tx-Only system is the collision. As discussed in Section II, there are two levels of collisions in the proposed WBAN system. Fig. 5 illustrates these two types of collisions, burst collision and pulse collisions. For the burst collisions, a collision can occur anywhere during the package transmission. Once a collision occurs, all the pulses in the package will be affected and both packets of users are considered lost. The second type of collision is the pulse collision, where only one pulse is affected when a collision occurs. Two key factors affecting burst collision are the Tx-Slot and Tx-Interval. Pulse collision is only affected by the PRF, as the pulse width is constant for all pulses.
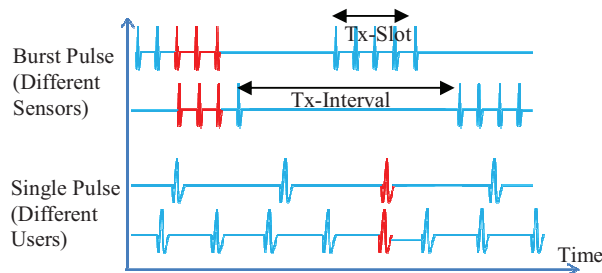

Fig. 5.　Burst pulse and single pulse transmissions.
(Red pulses are the pulses that cause collisions)

In order to design a reliable system, it is important have some prior knowledge of the probability of collisions. The collision probability given by [6] is shown in (8). This equation is valid for pulse collision and not for burst collision, as it is derived based on a one sampling instant per transmission slot. For a burst transmission, there are multiple sampling instants in each transmission slot.

$$P_c(M) = 1 - \prod_{j \in m \setminus \{M\}} \left(1 - \frac{T_{slot}^{(j)}}{T_{int}^{(j)}} \right) \qquad (8)$$

As shown in [5], the calculated peak probability of collisions for burst transmission is much higher than that if a single pulse transmission, as there is equal chances for collision to occur at any sampling instant during the burst transmission. But, it is possible to reduce the collision probability for burst collision to close to that of a pulse collision by selecting the appropriate Tx-Interval. The Tx-Interval should be selected such that all Tx-Intervals used in the system should be relative prime to each other and the minimum time difference between any two Tx-Intervals should be larger than the largest transmission slot. By fulfilling these two criteria, it is possible to keep the burst transmission collision probability to less than twice that of pulse collision. As shown in Table 1, the ratio of the simulated result for burst transmission of 10, 100 and 1000

pulses against the calculated probability using (8) is always less than two regardless of the number of pulses in the burst transmission. The simulation is carried out based on ten users all with a duty cycle of 1%. It is observed that the simulated collision probability matches that of the calculated for pulse collision.

Table 1: Probability of collision for the burst transmission

Pulse	Duty Cycle	Simulated	Calculated	Ratio
1	1%	0.0767	0.0766	1
10	1%	0.1493	0.0821	1.82
100	1%	0.1599	0.0831	1.92
1000	1%	0.1522	0.0828	1.84

V. Conclusion

In this paper, we have discussed how UWB Tx-Only system can be applied to a WBAN application. There are two levels of collision avoidance to cater for both single user and multiuser environments. The reliability of UWB Tx-Only system is mainly affected by the SNR and the collision probability. In this paper, we have highlighted the relationship between the allowable transmission power and its dependency on PRF and gating duty cycle. We have provided the upper and lower limit for selection of PRF and showed that gating duty cycle should be kept below 18.75%. Minimizing the collision is an important aspect for UWB Tx-Only system; we have shown that it is possible to reduce the collision probability for the burst transmission to less than twice that of pulse collision by ensuring that the minimum time difference between any two transmission intervals is larger than the largest transmission slot.

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