On-Body Evaluation of UWB Receiver position for Wireless Body Area Network

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Abstract—In a wireless body area network, the position of the sensor nodes are fixed, while the receiver position can be changed. In this paper, we evaluate three popular receiver positions based on the bit error rate obtained from an ultra wideband sensor nodes and receiver hardware. The three receiver positions evaluated are waist, chest and arm. It is shown that by selecting the optimum receiver position, it is possible to transmit up to 20 dB less power, while maintaining the required bit error rate of $10^{-3}$. Evaluation of different combination of sensor nodes shows that chest position is preferred location for the receiver.

I. INTRODUCTION

In recent years, there has been vast interest in using Ultra Wideband (UWB) wireless technology for Wireless Body Area Network (WBAN) application. Numerous WBAN applications such as ECG [1], neural recording [2] and endoscope [3] using UWB are proposed. In a WBAN system, very stringent requirements have been placed on the sensor node. The sensor nodes has to be small, consume extremely low power and reliable. Therefore, it is very important to minimise the power consumption of a sensor node. One method of minimizing power and ensure reliability is to select an optimum receiver position. A typical WBAN system consists of multiple sensor nodes and a single receiver node attached on each user. The location of the sensor nodes are fixed, depending on the physiological signals to be measured. The receiver position is not fixed, it is normally placed at location identified by the system designer or at location that enhances the user comfort level. In [4], it has been shown through simulation that by selecting the appropriate receiver position, it is possible to enhance the overall performance of an UWB WBAN system comprising of multiple sensor nodes.

In this paper, evaluation of three popular receiver positions, namely the waist, arm and chest is performed using bit error rate (BER) obtained from an UWB WBAN hardware setup.

II. UWB WBAN HARDWARE CONFIGURATION

Figure 1a shows the measurement setup used for evaluating the performance of UWB sensor nodes and receiver for various locations on a human body. The measurement setup consist of UWB transmit and receive antenna, UWB sensor node, UWB receiver frontend, high speed analog to digital converter (ADC), high speed FPGA and a laptop.

A. UWB Sensor node

The sensor nodes are assembled on a four layers printed circuit board with dimensions of 2.5cm by 2.5cm (Figure 1b), which is sufficiently compact for use in a WBAN application. The block diagram of the sensor node is shown in Figure 2. The narrow pulse generator is formed using a variable Voltage Controlled Oscillator (VCO), delay circuitry and a XOR gate. It is able to produce narrow pulse ranging from 0.5 ns to 2 ns, with a variable pulse repetitive frequency of between 17 MHz to 170 MHz. The generated narrow pulse passes through a pulse shaping filter, which
shapes the pulse spectrum to conform to the UWB requirement. After passing through the filter, the UWB pulse is amplified using wideband low noise amplifier (LNA) to meet the -41.3 dBm transmission power level. Time domain and frequency domain plot of the UWB pulse is shown in Figure 3. The microcontroller performs the analog to digital conversion, determine the transmission format, modulation scheme and set the data rate. The UWB pulse rate is independent of the data rate, therefore enabling the system to vary the number of UWB pulses per data bit. The logic gates combined the data with the generated UWB pulse before transmitting the information using a wideband UWB antenna. The system is designed to operate in the 3.1 GHz to 5 GHz frequency band; using direct modulation technique (i.e. no carrier is used).

B. UWB receiver circuitry

The receiver circuitry is assembled using off-the-shelves modules. The receiver antenna is placed on-body as shown in Figure 1a, the receiver circuitry is placed off-body. Block diagram of the receiver circuit is shown in Figure 4. The signal entering the receiver passes through a 3 to 5 GHz bandpass filter to eliminate away the unwanted interfering signal. The filtered signal is amplified by 48 dBm using three wideband LNA before down converting to baseband signal using a mixer and a 4 GHz VCO. The baseband signal passes through a low pass filter with 100 MHz bandwidth before going through the baseband amplification stage. Figure 5 shows the recovered UWB pulse after passing through the receiver front end circuitry.

The recovered UWB pulse is digitalized using a high speed ADC and processed by the FPGA before transferring the data to the laptop using serial cable. The role of the FPGA is to process the received multiple UWB pulses and determine whether it is bit “1” or bit “0” before sending to the laptop and set the appropriate baud rate for data transfer to the laptop. Preprocessing is necessary as the data transfer rate via the serial cable is much lower than the data rate the sensor nodes is sending to the UWB receiver using the gating method. After FPGA processing, the data is transfer to the laptop based on the baseband data rate. The BER is computed in the laptop using Matlab based on a known pseudorandom data sequence that the transmitter is sending.

III. EXPERIMENTAL SETUP

Bit error rate in this paper are obtained based on the experimental settings shown in Table 1. The UWB pulse rate is selected to be much higher than the actual data rate, to allow for processing gain and ease the synchronising process [4]. The sensor nodes are designed to perform gating operation, which allows the transmitter to transmit at a maximum peak power of -24.4 dBm [5] based on a 3 MHz resolution bandwidth on the spectrum analyser.
Table 1: Experimental Parameter

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values</th>
</tr>
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<tbody>
<tr>
<td>UWB pulse rate</td>
<td>25 MHz</td>
</tr>
<tr>
<td>UWB pulse width</td>
<td>2 ns</td>
</tr>
<tr>
<td>UWB frequency band</td>
<td>3.9 – 4.5 GHz</td>
</tr>
<tr>
<td>Data rate</td>
<td>1 Mbps</td>
</tr>
<tr>
<td>Modulation</td>
<td>OOK</td>
</tr>
<tr>
<td>Maximum transmission</td>
<td>-24.4 dBm</td>
</tr>
</tbody>
</table>

Four locations commonly used for physiological signal monitoring are chosen to evaluate the performance of UWB WBAN at different receiver position. Figure 6 shows the sensors and receiver position evaluated in this paper. Sensor 1 is at the ECG position, sensor 2 at EEG position, sensor 3 on the wrist and sensor 4 on the waist. All the readings are taken in a controlled environment where the subject under test remains static throughout each measurement. For each sensor and receiver pairs, 5 sets of reading are taken. Each set of reading consists of 10000 data bits. All the readings are taken using antenna orientation that gives the strongest signal strength.

IV. RESULT AND DISCUSSION

Figure 7 to 10 shows the BER plots obtained from four sensor positions across the body. Most of the commonly monitored physiological signals are located on the front upper half of the body. Therefore, we have selected four commonly used sensor locations that are well spread throughout the upper body to perform this evaluation. All the sensor nodes and receiver are placed 10 mm away from the body in order to reduce the effect of the body on the antenna.
For ECG sensor, receiver placed at the chest requires 14dB less power as compared to the receiver placed on the waist. Receiver placed at the arm has the worst performance, requiring 18 dB more power as compared to receiver placed at the chest.

For EEG sensor, the best receiver position is on the chest, and the worst receiver position is on the waist. For a BER of $10^{-3}$, there are only 8 dB differences between the best receiver and worst receiver position.

For sensor on the wrist, receiver placed at the arm performs much better than the receiver placed at the waist and chest. For a BER of $10^{-3}$, receiver placed at the arm requires 20 dB less power as compared to the receiver placed at waist. The receiver on the waist is partially blocked by the body; therefore the performance is affected.

For sensor on the waist, the best receiver position is on the waist, followed by the arm, then the chest. The differences in the required transmit power for the best and worst receiver position is only 7 dB.

Table 2 shows the various sensor nodes configuration and the optimum receiver position for each combination. The optimum receiver position is selected based on the minimum total transmit power required to attain a bit error rate of $10^{-3}$ for the all the sensor nodes in the particular configuration.

From the result obtained, we can conclude that chest receiver position is the most optimum receiver position whenever an ECG sensor is used. If ECG sensor is not used and a wrist sensor is used, the most optimum receiver position in this case will be the arm. Receiver located at the waist is only preferred when there is only one waist sensor in use.

V. CONCLUSION

Minimizing the power consumption and ensuring reliability are two major considerations for a WBAN system. By selecting an appropriate position for the receiver, it can ensure that the reliable transmission can take place with lower transmission power. Lower transmission power enhances the battery lifespan of the sensor nodes. In this paper, we have evaluated three popular receiver positions; waist, chest and arm. It is shown that by carefully selecting the receiver position, it is possible to reduce the amount of transmission power to up to 20 dB. There are numerous configurations for the sensor nodes in a WBAN system; therefore there is no one receiver position that is optimised for all configurations. Receiver position at the centre of the chest is the preferred choice for most of the configuration especially when ECG monitoring is used.

REFERENCES