Performance of Multi-User UWB Systems Based on Receive Diversity

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Abstract — In this paper, multiple receive antennas are applied to multi-user binary pulse amplitude modulation (PAM) ultra-wideband (UWB) systems to achieve high data rate communications. The effects of spatial diversity on the performance of PAM UWB systems are analytically investigated. We observe the link reliability at different distance and evaluate the distance between the transmitter and receiver (T-R separation distance) performance. Numerical results show that the transmission and receive distance performance can be enhanced by spatial diversity combining. Moreover, the pulse shapes are presented that satisfies the FCC spectral mask. The simulation was carried out depending on communication distance under noisy and Multi-User Interference (MUI) environment. We can know that multiple receive antennas has the reliability of the transmission at the more than double distance.

Keywords — pulse amplitude modulation (PAM), multi-path, multiple accesses, ultra-wideband (UWB), receive diversity.

1. Introduction

Since its ability to provide wireless communication channels was first discovered, the adoption of radio technology in the form of communication methods and services has been vastly implemented on a global scale [1]. From mobile phones to satellite links, especially wireless power supplies, everything around us has become wireless. And yet the potential in the development of wireless technology remains boundless. As an example that demonstrates the technological advancement wireless implementations have provided is its applications in the biomedical measurement ECG sensor system. In most cases, it would have a note that reads, “The use of mobile phones – prohibited”, as it is a common practice to prohibit any use of electrical equipment that emits high radiation, for instance a mobile phone, for they may cause interference to critical medical equipment. The principle of ultra-wideband (UWB) radio technology has been around since the invention of radio communication methods and has been in development since the 1970’s [2]. It is that a sudden surge of interest has fallen upon Impulse radio. Impulse radio was first utilized in radar applications in an era when only low data rates were practiced. Now with limited bandwidth and increased demand for higher data rates, current and more advanced UWB technology has surfaced to breakthrough the restrictions of conventional Impulse radio applications.

In this paper, multiple receive antennas are applied to multi-user binary pulse amplitude modulation (PAM) UWB systems to achieve high data rate communications. The effects of spatial diversity on the performance of PAM UWB systems are analytically investigated. Moreover, the pulse shapes are presented that satisfies the FCC spectral mask. The simulation was carried out depending on communication distance under noisy and Multi-User Interference (MUI) environment. We can know that multiple receive antennas has the reliability of the transmission at the more than double distance.

2. System Design using S-Function Builder

Figure 1 is a system configuration using in this paper.

2.1 Basic Transmitter

The construction of the basic transmitter is headed by the creation of a pulse generator; a customized Block is created for this purpose. The pulse Generator Block takes the role of generating the monopulse resembles the Gaussian functions, the Gaussian distribution formula [3] stands as follows:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \tag{1}$$

This distribution was used to generate a data array representing the monopulse waveform. The Block is designed to output monopulses with a pulse width of 0.2 nanoseconds, resulting in a center frequency of 5GHZ. This complys with the FCC ruling for the operating frequency [4]. Therefore by using the PAM, binary coded data can be reproduced with opposite polarity monopulses, each representing either a ‘1’ or ‘0’. The generated output of the monopulse from this design, representing ‘0’ is displayed in Figure 2.
2.2 Receiver

The construction of Basic Transmitter leads to the design of the receiver. Within the receiver, it includes the emulation of the Pulse Correlator, as well as a symbol recognition device. A template to match the monopulse is also created within the Correlator (with synchronization already present in the Simulink environment), making it sensitive towards the placement of the monopulse in time. Figure 3 is representing Receiver.

2.3 Multiple Accesses

Multiple Accesses is achieved in impulse radio through time channeling [5]. According to Robert A. Scholtz [6], time hopping sequences must have a distinct time shift pattern assigned to each user in order to eliminate catastrophic collisions. This application looks at the change in the construction of the pulse generator, as well as the coding sequence for channel coding in the time domain, described as the timing sequence for the propagation of the monopulse.

The structure of the Multiple Access system is based on a single Transmitter sending signal to three remote Receivers. This new Transmitter is redesign to make possible three data streams simultaneously sending data to the Pulse Generator Block, with each data stream dedicated to one of the Receivers.

Having three receivers, three channels are required. But with duplexing and multipath effects, the more closely impulses are situated, the greater the effect of multipath fading. As a result, 10 channel spaces are allocated before the next pulse repetition is sent from each user. Amplitude and bandwidth of the signals are observed on a Spectrum Analyzer to ensure that the emitted power and spectral bandwidth complies with FCC’s regulatory standards. Emitted power is set at a maximum of -42dBm with most of the spectral power spread to 10GHz. A generated signal from the Transmitter is shown in Figure 4, with the code number of the channel sequence.

2.4 Free Space Environment

This stage is dedicated to the development of a realistic environment where UWB signals are propagated in free space.

The first consideration is the path loss varied by the distance between the transmitter and the receiver (T-R separation). This element allows the distance between the links to be variable, accommodating to the amount of path loss by distance. The Log-distance Path Loss model [7] is use in this analysis:

$$PL(d) \propto (d / d_0)^n$$  \hspace{1cm} (2)

Where, $d_0$ is assumed at 1m with a Path Loss $-PL(d_0) = 3dB$ and path loss exponent $n$ of 2.4. The value of $n$ was assumed for an indoor UWB channel.

The second consideration is the external interference ($I_u$) noise floor, where a large number of narrow band radiators are located within the UWB receiving bandwidth. Estimations [8] based on the antenna design of the UWB receiver were considered. Assuming that the front-end receiving antenna compensates the band limiting loss with the amplification application, $I_u = -60dBm$ is taken as the average noise floor in an indoor environment, in order to achieve a comfortable signal-to-noise ratio (SNR), in accordance with the FCC part 15 ruling, the maximum emission EIRP is at -41.3dBm.

Another consideration is the multipath effect. It is essential, due to the high-resolution properties of UWB signaling, the multipath effect is added to verify the positive impact of implementing Receive Diversity. Multipath effects can contribute positively to the received energy, when the delayed paths are placed correctly. As this system tests the limitations of UWB radio, the worst-case scenario is implemented for a negative effect. The elements of multipaths for each receiving bin consider two multipath components. The first being a quarter of a pulse width delayed replicate of the direct path, while the second component registers an inverted version of a pulse previously sent, which is placed randomly into the receiving bins of each user channel. The scenario at the receiving end width the addition of two multipath components is shown in Figure 5.
2.5 Design of Transceivers in Remote Sensors

This stage tailors to a system of one Master Node to three Slave Nodes, catering the Wireless ECG system. Designing starts with the Slave Nodes Transmitter, where the information is sent to the Receiver unit of the Master Node. As more blocks are added into the system model, the time taken for simulation is lengthened in relation to the processing speed. With this constraint taken into account, one Pulse Generator Block is used for the three Slave Nodes. The Model of the Slave Nodes is shown on Figure 6.

![Figure 6. Slave Node Block](image)

What happens next is the retrieve of data from the Slave Nodes to the Master Node. The Master Node’s Receiver Module takes shape as three receivers are assigned with a Channel Code Sequence, each to read the data from each Slave Node. With the addition of a noise floor from the Indoor Environment Module, the Receiver must be sensitive to the noise power to prevent bit errors.

With design of the data link of the system completed, control of the system is now the main focus. The responsibility of system control falls on the Master Node, with the role of turning ‘on’ and ‘off’ the Slave Nodes, and at same time retrieving data from the Slave Nodes. Three channels are allocated for the control of the Slave Node, with an channel for each individual Slave Node. In order for the Slave Nodes to receive the control command, a receiver at each Node ‘tunes’ into the signal according to the allocated channel code. Channel Allocation is shown in Table 1 below.

<table>
<thead>
<tr>
<th>Table 1. Channel Allocation</th>
<th>For Transmission</th>
<th>For Reception</th>
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<tbody>
<tr>
<td>Slave Node 1 Channel</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Slave Node 2 Channel</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Slave Node 3 Channel</td>
<td>7</td>
<td>8</td>
</tr>
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</table>

3. Diversity

A popular method to mitigate the effects of multipath fading is diversity, a process of obtaining multiple independent signal branches through many dimensions including space, polarization, frequency, and time [9]. The collection of independently fading signal branches can then be combined in a variety of ways to improve the received SNR.

The three most prevalent space diversity combining techniques are Selection Combining (SC), Equal Gain Combining (EGC), and Maximal Ratio Combining (MRC). MRC co-phases the signal branches, weights them according to their respective SNRs, and then takes their sum. MRC is the most complex combining technique, but also yields the highest SNR [10]. For space diversity combining, one key assumption is that the antennas are spaced far apart enough such that the received signal branch at each antenna will experience independent channel fading [11].

3.1 Equal Gain Combining (EGC) Diversity

In Equal Gain Combining (EGC), all the received signals are co-phased at the receiver and added together without any weighting. The performance of EGC is only marginally inferior to the optimal maximal ratio combiner. In case of a two-fold diversity scheme, the combining equation is given by:

\[ Z_k = Z_{1k} + Z_{2k} \]  

3.2 Retrieving Signal Using Receive Diversity

Following the completion of the Model Design using Single Template receivers, Receive Diversity technique is tried as a method to improve the gains of the signal, when multipath components ‘distort’ the monopulses sent. The Receive Diversity methods are used to ‘capture’ the signal based on the EGC diversity technique. The System configuration with the Receive Diversity is shown on Figure 7.

![Figure 7. System Configuration with the Receive Diversity](image)

4. Simulation

4.1 Simulation 1 for evaluation Bit Error Performance at different T-R separation distance with multipath components \( I_u = -60dBm \).

The purpose of this experiment is to observe the link reliability at different distances, where the noise level is suppressed to a comfortable SNR, and with the introduction of multipath elements.

Test environment specification:

- Noise floor, \( I_u \) set at -60dBm
- Maximum Emitted power = -42dBm
- Two Multipath Components introduced
- Log-Distance Path Loss Model considered where Path Loss assumed as 3dB at a distance of 1m \( (d_0) \)
- Data Rate – 100Mbits/s
• Multipath environment – present with 2 components
• Maximum Emitted power = Dive

FCC. The Simulation was carried out depending on accordance with the restrictions and regulations governed by designed on the basis of transceivers capable of motile on one-Master-to-three-Slave design node, where each node is perspectives of a UWB system. The Simulink model is based in this paper, this simulation provides visual and analytical techniques in the propagation of monopulses in time to minimize multipath fading. A practical application of this could lead to, for instance, the invention of ‘undetectable Bugging’ devices.

5. Conclusion

In this paper, this simulation provides visual and analytical perspectives of a UWB system. The Simulink model is based on one-Master-to-three-Slave design node, where each node is designed on the basis of transceivers capable of motile accessing. The design procedures have been carried out in accordance with the restrictions and regulations governed by FCC. The Simulation was carried out depending on communication distance under noisy and Multi-User Interference (MUI) environment. Multiple receive antennas are applied to multi-user PAM modulation UWB systems to achieve high data rate communications. The effects of spatial diversity on the performance of PAM UWB systems are analytically investigated. We observe the link reliability at different distance and evaluate the distance between the T-R Separation distance performances, and obtain the same SNR. Numerical results show that the T-R Separation distance performance can be enhanced by spatial diversity combining. We can know that multiple receive antennas has the reliability of the transmission at the more than double distance. Finally, having compared the simulation results with the requirements of ECG sensors, it can be concluded that UWB radio-link technology is a suitable and reliable mode of application in the development of wireless ECG sensors.

From now on, various aspects of the hardware are not incorporated in the simulation, due to scarce resources available. While these aspects do provide valuable contributions to the research, existing simulations proves to be sufficient for the purposes of this paper. One example of these potential developments is in the receiving antenna. Though the assumption has been to adopt band-limiting filter at front-end antenna of the receiver so as to suppress the noise floor, improvements of this operation can be speculated in the areas where the suppression of noise bandwidths can be maximized. Another aspect for potential future studies is the use of coding techniques in the propagation of monopulses in time to minimize multipath fading. A practical application of this could lead to, for instance, the invention of ‘undetectable Bugging’ devices.

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REFERENCES