CHAPTER 6

IMPROVED SUCCESSIVE INTERFERENCE CANCELLATION FOR MIMO/UWB BASED WIRELESS BODY AREA NETWORK USING m-ZCZ SEQUENCES

6.1 INTRODUCTION

Remote monitoring of the physiological conditions of a patient is possible nowadays with the help of wireless medical telemetry (Pattichis et al 2002, Tachakra et al 2001, Veerapal Kaur & Jyoteesh Malhotra 2011). This enhances the quality of patient care and the efficiency of hospital administration capabilities. It also helps to reduce healthcare costs because it permits simultaneously remote monitoring of several patients. The development of this technology leads to the evolution of WBAN (Bernhard et al 2003) in which smart wireless medical sensors measuring ECG, non-invasive blood pressure and blood oxygen saturation placed in and around the body can communicate with the outside world through wireless media. The information can be forwarded to a physician in real-time.

UWB communication has strong advantages that are promising for WBAN applications (Porcino & Hirt 2003). It offers a low-power, high data rate technology with large bandwidth signals that provide robustness to jamming and has low probability of interception (Win & Scholtz 2002). UWB low transmit power requirements, which are mainly used in low data
rate networks with low duty cycles, allow longer battery life for body worn units (Bernhard et al 2003). Moreover, UWB can be used to monitor vital parameters such as respiration and heart-rate (Bernhard et al 2003). In addition, UWB gives good penetrating properties that could be implemented in medical imaging applications (Jung Nam Bae et al 2011).

UWB system with the help MIMO scheme employs features such as spatial diversity and spatial multiplexing, leading to higher system throughput. However, in UWB/MIMO systems, the performance degradation may be caused by the effects of MAI and multi-path fading.

Due to the rising interest in WBANs, a number of investigations on the UWB BAN channel have been recently published. Porcino & Hirt (2003) have suggested that UWB is a promising technology for the next generation body sensor networks due to its potential for both low power and large bandwidth, and less complex hardware and currently unavailable using conventional narrowband systems.

Yuce et al (2007); Yu et al (2010) mentioned that traditional narrowband wireless protocols, such as medical implant communication service (MICS), Zigbee, ISM, and Bluetooth standards suffer from large power consumption and low data rate.

Lingli Xia et al (2011) clearly stated that unlike these traditional narrowband systems, UWB wireless sensors operate with a large bandwidth (3.1 - 10.6 GHz) and a low maximum transmission spectral density (-41.3 dBm/ MHz). According to Shannon-Hartley theorem, with an ultra-wide bandwidth, high data rate can be achieved with low transmitted power in UWB.
Jung Nam Bae et al (2011) proposed an efficient interference cancellation scheme for WBAN and described that SIC scheme proved to work well for interference cancellation of outdoor communication and other multimedia transmission systems. In their work, they presented that the interference due to MAI has been mitigated by introducing optimal SIC for UWB/MIMO using ZCD code as spreading code for UWB system in a multi-device environment. The system had utilized conventional ZCZ codes in which the length of conventional ZCZ code is restricted to $2^k$ where $k$ is an integer. Due to this reason, number of codes is limited and hence the system capacity is reduced.

Jayasheela & Rajeswari (2009) had analyzed the BER performance of CDMA system using m-ZCZ. These sequences have both autocorrelation side lobes, the cross correlation function is zero and the sequence length is flexible.

In this chapter, an improved interference cancellation schemes for UWB/MIMO based WBAN using m-ZCZ sequences is proposed. BER performance of the improved SIC scheme in MIMO/UWB based BAN using m-ZCZ sequences is obtained under various BAN channel models.

### 6.2 WBAN ARCHITECTURE

Figure 6.1 shows the architecture of a wireless medical communication network. This wireless medical communication network is composed of different set of radio protocols (Hamalainen et al 2008; Hamalainen et al 2009). One part utilizes short range communication standards, such as UWB, Zigbee or WLAN. The other part creates connections between limited range network to backbone network, dedicated medical networks and data bases. These long haul connections
are implemented using the existing cellular phone networks, WiMAX, fixed Internet connection or satellite. There are also dedicated radio standards for vehicular networks, such as IEEE802.11p or mobile WiMAX IEEE802.16e.

![Figure 6.1 Architecture of a wireless medical communication network](image)

An UWB BAN applied in a medical application consists of less than dozen of the nodes in the same network. This can be handled by proper system and user specific spreading code design. In this Chapter, improved successive interference cancellation for MIMO/UWB based wireless BAN using m-ZCZ spreading code is proposed.

### 6.2.1 WBAN Application

BANs are used for continuous health monitoring of a patient (Milanesi et al 2006; Yuce et al 2007; Nakagawa et al 2009; Miranda et al 2010; Yu et al 2010; Khaleghi et al 2010). In real time, a single or multiple
wearable sensor node with a wireless transmitter is attached to a patient and the receiver is fixed to a nearby location such as walls and ceiling (Lingli Xia 2011).

6.2.2 WBAN Channel Model

In WBAN, radio propagation from devices that are very near to or inside the human body are complex and distinctive, compared to the other environments as the human body has a complex shape consisting of different tissues with their own permittivity and conductivity.

Figure 6.2 Possible communication links for WBAN

Figure 6.2 shows possible communication links for WBAN. WBAN channel is classified into two categories according to the field of applications (Jung Nam Bae et al 2011). The first category is a non-medical application where the user is using the wireless connection between his
MP3 player and headset. The other category is medical application related with patient health care domain.

According to the location of the equipment there are three types: in-body, on-body and off-body. Moreover, speed is categorized as low, moderate and high. Table 6.1 gives the classification of the WBAN systems for various criteria (Jung Nam Bae et al 2011).

**Table 6.1 Classification of WBAN channel (Jung Nam Bae et al 2011)**

<table>
<thead>
<tr>
<th>Criterion</th>
<th>WBAN Channel Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field of application</td>
<td>Non medical</td>
</tr>
<tr>
<td>Location</td>
<td>In-body</td>
</tr>
<tr>
<td>Speed</td>
<td>Low</td>
</tr>
</tbody>
</table>

The distance between the external devices is typically considered to be a maximum of 5 meters. Table 6.2 shows the parameters of WBAN Channels for different directions of the body (Jung Nam Bae et al 2011).

**Table 6.2 Parameters of WBAN channel for different directions of body (Jung Nam Bae et al 2011)**

<table>
<thead>
<tr>
<th>Direction of body in degrees</th>
<th>Exponential decay factor: $\Gamma$ in ns</th>
<th>$K$ factor in NLOS: $F_k$</th>
<th>Variance: $\sigma$[dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>44.6346</td>
<td>5.111</td>
<td>7.3</td>
</tr>
<tr>
<td>90</td>
<td>54.2868</td>
<td>4.348</td>
<td>7.08</td>
</tr>
<tr>
<td>180</td>
<td>53.4186</td>
<td>3.638</td>
<td>7.03</td>
</tr>
<tr>
<td>270</td>
<td>83.9635</td>
<td>3.983</td>
<td>7.19</td>
</tr>
</tbody>
</table>
In WBAN channel, the complex impulse response $h_i(t)$ for the $i$th device is given by Jung Nam Bae et al (2011).

$$h_i(t) = \sum_{m=0}^{M-1} \alpha_m^i \delta(t - \tau_m^i)$$

where $M$ is the number of total arrival paths and modeled as passion random variables with mean value of 400, $m$ is the $m$th arrival path of the signal and $\alpha_m^i$ is the magnitude of $m$th path (Jung Nam Bae et al 2011).

$$|\alpha_m^i|^2 = L_0 \exp \left( -\frac{\tau_m^i}{\tau} - F_k [1 - \delta(m)] \right) \beta$$

where $L_0$ is a path Loss, $\tau$ is an exponential decay factor, $\beta$ is a log random variable, $\tau_m^i$ is described as path arrival time, $d$ is the distance between $m$th device and the receiver and $F_k$ is an effect of the $k$-factor in non line sight which can calculated as,

$$F_k = \frac{4k\ln10}{10}$$

6.3 PROPOSED UWB/MIMO SYSTEM MODEL USING m-ZCZ

Figure 6.3 shows the block diagram of the proposed UWB/MIMO TH PPM system using m-ZCZ codes. The UWB/MIMO system with $N$ transmit and $M$ receive antennas are considered in the WBAN environment. The transmitted signal TH PPM UWB signal $s(t)$
spread by a m-ZCZ sequence from the n\textsuperscript{th} transmit antenna is expressed as follows,

\begin{equation}
    s(t) = \sum_{i=1}^{\infty} a_i \sum_{m=1}^{\infty} \sum_{j=0}^{\infty} p(t - mT_s - jT_f - C_j^{(m)}T_s - b_j^{(m)}\delta)
\end{equation} \tag{6.4}

Notation \( a_i \) represents the \( i \textsuperscript{th} \) information symbol from the \( n \textsuperscript{th} \) transmit antenna given by \( a_i = b_j^{(m)} \), \( b_j \) is the data sequence of \( n \textsuperscript{th} \) transmit antenna and \( C_j^{(m)} \) is the m-ZCZ sequence of the \( n \textsuperscript{th} \) transmit antenna. In order to allow all the devices to share the same channel and to nullify the extremely harmful collision, each device is assigned with a time
shift pattern $c_j^m$ is known as m-ZCZ sequences which takes values from 0 to $N_h - 1$.

Based on the literature, Ganlin Ye et al (2007) has analyzed for given $L = 64$, $W_{\text{min}} = 30$ a set of m-ZCZ codes are denoted by $(64, 2, 30)$ containing $j = \left\lceil \frac{63}{30} \right\rceil = 2$ codes are obtained as,

$$(z_{01}, z_{02}) = \begin{pmatrix}
-1 & 1 & 1 & 1 & 1 & 1 & -1 & -1 \\
-1 & -1 & 1 & 1 & -1 & 1 & 1 & -1 \\
1 & -1 & 1 & -1 & 1 & -1 & -1 & 1 \\
-1 & 1 & 1 & -1 & -1 & 1 & 1 & -1 \\
1 & 1 & 1 & -1 & 1 & 1 & 1 & -1 \\
1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 \\
-1 & -1 & 1 & 1 & 1 & 1 & -1 & 1 \\
1 & 1 & 1 & -1 & 1 & -1 & -1 & 1 \\
-1 & -1 & -1 & 1 & -1 & 1 & -1 & 1 \\
1 & -1 & -1 & -1 & 1 & -1 & -1 & 1 \\
-1 & -1 & 1 & 1 & -1 & 1 & -1 & 1 \\
1 & -1 & -1 & 1 & -1 & 1 & -1 & 1 \\
1 & 1 & 1 & -1 & 1 & -1 & -1 & 1 \\
1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\
1 & 1 & -1 & 1 & -1 & 1 & -1 & 1 \\
1 & 1 & -1 & 1 & -1 & 1 & -1 & 1 \\
1 & 1 & -1 & 1 & -1 & 1 & -1 & 1 \\
1 & 1 & -1 & 1 & -1 & 1 & -1 & 1]
\end{pmatrix} \quad (6.5)$$
In the proposed UWB/MIMO TH PPM system using m-ZCZ codes, the data from the devices are transmitted by using TH PPM UWB modulator. As a spread code of TH PPM UWB systems, the ZCZ code with robust MAI is employed for random hopping. The signal is then fed into UWB MIMO (2×2) encoder and it is fed through WBAN channel with the channel parameters shown in the Table 6.2. At the receiver side, the incoming data is processed by MMSE equalizer and is followed by SIC scheme with optimal ordering to mitigate the interference.

The received signal \( Y_p(t) \) at the \( p^{th} \) receive antenna is given as,

\[
Y_p(t) = \sum_{n=1}^{N} \sum_{k=0}^{L} h_{p,n}(k) x_n(t-kT_p) + n_m(t) \tag{6.7}
\]

where \( h_{p,n}(k) \) represents a fading coefficient of \( m^{th} \) path for the signal from \( n^{th} \) transmit antenna to the \( p^{th} \) receive antenna. \( L \) is total number of multipath components and \( n_k(t) \) is the AWGN noise.
6.3.1 MMSE Equalizer for 2 × 2 MIMO Channel

The received signal in the first receive antenna is,

\[ y_1 = h_{1,1} x_1 + h_{1,2} x_2 + n_1 = \begin{bmatrix} h_{1,1} & h_{1,2} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_1 \]  

(6.8)

The received signal in the second receive antenna is,

\[ y_2 = h_{2,1} x_1 + h_{2,2} x_2 + n_2 = \begin{bmatrix} h_{2,1} & h_{2,2} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + n_2 \]  

(6.9)

where, \( y_1, y_2 \), are the received symbols on the first and second antenna respectively,

\( h_{1,1} \) is the channel from 1\(^{st}\) transmit antenna to 1\(^{st}\) receive antenna,

\( h_{1,2} \) is the channel from 2\(^{nd}\) transmit antenna to 1\(^{st}\) receive antenna,

\( h_{2,1} \) is the channel from 1\(^{st}\) transmit antenna to 2\(^{nd}\) receive antenna,

\( h_{2,2} \) is the channel from 2\(^{nd}\) transmit antenna to 2\(^{nd}\) receive antenna,

\( x_1, x_2 \), are the transmitted symbols and \( n_1, n_2 \) is the noise on 1\(^{st}\), 2\(^{nd}\) receive antennas.
Assuming the receiver knows \( h_{11}, h_{12}, h_{21}, h_{22} \) and \( y_1, y_2 \), the matrix representation of above equation is,

\[
\begin{bmatrix}
  y_1 \\
  y_2
\end{bmatrix} =
\begin{bmatrix}
  h_{11} & h_{12} \\
  h_{21} & h_{22}
\end{bmatrix}
\begin{bmatrix}
  x_1 \\
  x_2
\end{bmatrix} +
\begin{bmatrix}
  n_1 \\
  n_2
\end{bmatrix}
\]

(6.10)

Equivalently,

\[
y = Hx + n
\]

(6.11)

The MMSE algorithm is used to find a coefficient \( W \) which minimizes the error criterion. The decoding matrix is given by (Jung Nam Bae et al 2011),

\[
W = \left( H^H H + N_0 I \right)^{-1} H^H
\]

(6.12)

where, \( W \) - equalization matrix and \( H \) - channel matrix. This matrix is known as the pseudo inverse for a general \( m \times n \) matrix and \( N_0 I \) is the noise term, where

\[
H^H H =
\begin{bmatrix}
  h_{11}^* & h_{12}^* \\
  h_{21}^* & h_{22}^*
\end{bmatrix}
\begin{bmatrix}
  h_{11} & h_{12} \\
  h_{21} & h_{22}
\end{bmatrix} =
\begin{bmatrix}
  \|h_{11}\|^2 + \|h_{12}\|^2 & h_{11} h_{12} + h_{12} h_{11} \\
  h_{21} h_{11} + h_{22} h_{12} & \|h_{21}\|^2 + \|h_{22}\|^2
\end{bmatrix}
\]

(6.13)

The MMSE algorithm is used to manage MAI interference by varying the decoding matrix according to SNR.

### 6.3.2 SIC with Optimal Ordering

The interference cancellation technique SIC is used after MMSE equalization to mitigate the effect of MAI. In the conventional SIC, the
receiver arbitrarily takes one of the estimated symbols (e.g., $x_2$) and subtract its effect from the received symbol $y_1$ and $y_2$. If the previous decision is incorrect and error occurs, the next decision could also be incorrect (Jung Nam Bae et al 2011).

To eliminate the error propagation, SIC with optimal ordering is adopted. SIC with optimal ordering has more intelligence in choosing the effect of $x_1$ first or $x_2$ first and then subtracts the corresponding $x_1$ or $x_2$ from the received signal. In this scheme, the strongest signal is cancelled out first followed by the second strongest, and so forth.

The power received at both the antennas corresponding to the transmitted symbol $x_1$ is,

$$P_{x_1} = |h_{1,1}|^2 + |h_{2,1}|^2$$ (6.14)

The power received at both the antennas corresponding to the transmitted symbol $x_2$ is,

$$P_{x_2} = |h_{1,2}|^2 + |h_{2,2}|^2$$ (6.15)

If $P_{x_1} > P_{x_2}$ the receiver then decides to remove the effect of $x_1$ from the received vector $y_1$ and $y_2$. $x_2$ is then re-estimated as,

$$r_2 = Hx_2 + n$$ (6.16)

The transmitted signal can be reestimated by combining the information from the multiple copies of the received signal. In this
proposed application, Maximal Ratio Combining (MRC) scheme is adopted. The final result for $x_2$ is then given as,

$$\hat{x}_{2_{\text{final}}} = \frac{H^H r_2}{H^H H} \hspace{1cm} (6.17)$$

Else if $P_{x_2} \leq P_{x_2}$ the receiver decides to subtract the effect of $\hat{x}_2$ from the received vector $y_1$ and $y_2$. $\hat{x}_1$ is then re-estimated as,

$$r_1 = H\hat{x}_1 + n \hspace{1cm} (6.18)$$

Reestimation of the transmitted signal is done by combining the information from the multiple copies of the received signal. Hence, the final result for $x_1$ is given as,

$$\hat{x}_{1_{\text{final}}} = \frac{H^H r_1}{H^H H} \hspace{1cm} (6.19)$$

The SIC with optimal ordering guarantees the reliability of the signal decoded first so that the signal has minimum error probability.

6.3.3 Pseudo Code for the Proposed System

**Step 1:** Random binary sequence of +1’s and -1’s is generated.

**Step 2:** Binary sequence is spread using m-ZCZ sequences and groups them into symbols.
Step 3: The spread symbols are converted into UWB pulses. It is modulated using TH PPM modulation [TH PPM m-ZCZ].

Step 4: The symbols are transmitted through BAN channel.

Step 5: Received symbols are equalized using MMSE criterion.

Step 6: SIC by optimal ordering approach is applied.

Step 7: MRC is performed for equalizing the new received symbol.

Step 8: Hard decision decoding is performed and calculated BER.

Step 9: BER performance of proposed TH PPM m-ZCZ has been compared with PPM-TH, PAM DS-PN and PAM-DS-ZCD (Jung Nam Bae et al 2011).

6.4 RESULTS AND DISCUSSION

The performance of the proposed UWB/MIMO system using m-ZCZ sequences combined with SIC scheme in the WBAN environment has been obtained and the performance of the proposed system for various modulation schemes using ZCZ codes is simulated using Monte Carlo simulation. BER performances have been compared for UWB/MIMO (2×2) system employing SIC with optimal ordering for different codes. Table 6.3 gives the simulation parameters.
Table 6.3  Simulation parameters for UWB/ MIMO (2×2) system

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power level of users</td>
<td>Constant power level ( P_1 )</td>
</tr>
<tr>
<td></td>
<td>Random power level ( P_2 )</td>
</tr>
<tr>
<td>Type of spreading sequences</td>
<td>( m )-sequences/( m )-ZCZ sequences</td>
</tr>
<tr>
<td>Frame length</td>
<td>10000</td>
</tr>
<tr>
<td>Type of the channel</td>
<td>WBAN channel (CM4)</td>
</tr>
<tr>
<td>( \frac{E_b}{N_0} )</td>
<td>2-12 dB for WBAN Channel</td>
</tr>
<tr>
<td>MIMO scheme</td>
<td>2×2</td>
</tr>
<tr>
<td>Equalizer</td>
<td>MMSE</td>
</tr>
<tr>
<td>Multiuser Detector</td>
<td>SIC with optimal ordering</td>
</tr>
</tbody>
</table>

Figure 6.4  Performance of auto correlation of \( m \)-ZCZ in TH PPM UWB system under WBAN channel
Figure 6.5 Performance of cross correlation of m-ZCZ in TH PPM UWB system under WBAN channel

Figures 6.4 and 6.5 show the performance of the correlation function of ZCD and m-ZCZ code. It is seen that performance is evaluated in terms of correlation peak value. The energy of the side lobes is higher in case of ZCD for the auto correlation function almost approaches zero in case of m-ZCZ code and ZCD has comparatively high peak values. Owing to good auto correlation and cross correlation properties, m-ZCZ code shows better performance than that of ZCD code.
6.4.1 BER Performance of Proposed UWB/MIMO (2×2) TH PPM System with SIC Under Constant Power Level $P_i$ in WBAN Channel

Figure 6.6 Performance of UWB/MIMO (2×2) TH PPM system with SIC optimal ordering using m-ZCZ sequences for different sequence length with constant power level $P_i$.

Figure 6.6 shows the BER Performance of UWB/MIMO (2×2) TH PPM system with SIC optimal ordering using m-ZCZ sequences for different sequence lengths with constant power level $P_i$. The performance of PN, ZCD and the proposed m-ZCZ code with different code length for SIC optimal ordering is compared. Since m-ZCZ has robust MAI characteristics, it shows better performance than that of the existing PN and conventional ZCD codes. When $\frac{E_b}{N_0} = 8$ dB, BER of m-ZCZ code is 0.0007 and for ZCD code BER value is increased to $\sim 10^{-3}$ and $\sim 10^{-2}$ for PN code.
From Figure 6.6, it is seen that as $\frac{E_b}{N_0}$ increases, BER of UWB/MIMO system decreases.

6.4.2 BER Performance of the Proposed UWB/MIMO (2×2) TH PPM System With SIC Under Random Power Level $P_2$ in WBAN Channel (Near Far Effect)

![Graph showing BER performance](image)

**Figure 6.7** Performance of UWB/MIMO (2×2) TH PPM system with SIC optimal ordering using m-ZCZ sequences for different sequence length with random power level $P_2$

Figure 6.7 shows the BER performance of UWB/MIMO (2×2) TH PPM system employing SIC with optimal ordering using m-ZCZ sequences for different sequence length with random power level $P_2$. The performance of PN, ZCD and the proposed m-ZCZ code with different
code length for SIC optimal ordering is compared with different power levels. Since m-ZCZ has robust MAI characteristics, it shows better performance than that of the existing PN and conventional ZCD codes. For \( \frac{E_b}{N_0} = 8 \) dB, BER of m-ZCZ code is 0.0012 and for ZCD code BER value is increased to 0.01 and 0.045 for PN code. From Figure 6.7, it is seen that when compared with Figure 6.6 the proposed UWB/MIMO (2x2) TH PPM system has poor BER performance since MAI is dominating due to random power levels.

![Performance of UWB System for varying modulation types](image)

**Figure 6.8** BER performance of UWB system employing for varying modulation types in WBAN channel

Figure 6.8 shows the comparison of BER performance of UWB system in WBAN for PPM TH (Jung Nam Bae et al 2011), PPM TH m-ZCZ [proposed], PAM DS-PN (Jung Nam Bae et al 2011) and PAM DS-ZCD (Jung Nam Bae et al 2011) system. It shows that the proposed
system with PPM TH-ZCZ is better than the other three. In Figure 6.8, for $\frac{E_b}{N_0} = 8$ dB, BER value of PPM TH ZCZ code is $\sim 10^{-5}$. PAM-DS-ZCD system, the BER is increased to $\sim 10^{-4}$. In PPM TH system without ZCZ code BER value is increased to $\sim 10^{-2}$. It can be seen that PPM TH-ZCZ shows 88% improvement of BER than PAM DS-ZCD (Jung Nam Bae et al 2011) for $\frac{E_b}{N_0} = 8$ dB.

In order to validate the performance of the proposed improved SIC for MIMO based WBAN, several devices are considered in WBAN channel for body surface to external [CM4]. BER results have been obtained with multiple biological functions as the input to the various devices in the system model shown in Figure 6.9. Samples of biological functions such as ECG, blood pressure are given below. The samples are taken from http://www.physionet.org/physiobank/database/mimicdb.
BIOLOGICAL FUNCTIONS

Figure 6.9  Transmission / reception of sample biological functions of patients through PPM TH m-ZCZ UWB/MIMO (2×2) system under WBAN channel CM4
Figure 6.9 (a) to (c) shows that ECG signal of a patient is passed through TH-PPM UWB MIMO system under WBAN environment [CM4]. At the receiver side, the signal is demodulated based on TH code of each patient, despread and then decoded to get back the transmitted ECG signal. Similarly, Figure 6.9 (d) to (f) shows that the blood pressure signal of a patient is passed through TH-PPM UWB MIMO system under WBAN environment [CM4].

Performance of Proposed system using WBAN Channel for multi-device Environments

Figure 6.10 Performance of PPM TH UWB/MIMO (2×2) system using m-ZCZ codes for multi-device environments in WBAN channel

Figure 6.10 shows the performance of PPM TH-ZCZ UWB/MIMO (2×2) system with 10, 5 and 1 devices in WBAN channel CM4 with inputs such as ECG, blood pressure. From Figure 6.10, it can be seen that when one device is used, BER value is $\sim 10^{-3}$ at $\frac{E_b}{N_0} = 10$ dB and
for the same \( \frac{E_b}{N_0} \), BER is increased to \( \sim 10^{-2} \) when the number devices are increased to five. Thus, increase in the number of devices cause an increase of MAI which leads to increase of BER. Thus, it has been validated that the increase in the number of devices induces the performance degradation of PPM TH-ZCZ UWB/MIMO system in WBAN environment.

### 6.5 APPLICATION OF THE PROPOSED SYSTEM WITH BIOMEDICAL IMAGES AS INPUT

In this section, the performance of the proposed PPM TH-ZCZ UWB/MIMO (2×2) system with m-ZCZ sequences by applying biomedical sample images is obtained. Figure 6.11 (a) shows the input of biomedical image which are given to the proposed system. Figure 6.11 (b) shows noisy images obtained after passing through WBAN channel. Figure 6.11 (c) shows the detected images using improved SIC for MIMO UWB based BAN with m-ZCZ codes.
(a): Input

(b): After passing through WBAN Channel [CM4] in UWB/MIMO System

*CM4-body surface to External [ON BODY]

(c): Detected Image

<table>
<thead>
<tr>
<th>PSNR</th>
<th>PSNR</th>
<th>PSNR</th>
<th>PSNR</th>
</tr>
</thead>
<tbody>
<tr>
<td>30.2471</td>
<td>30.2346</td>
<td>30.6569</td>
<td>30.3023</td>
</tr>
</tbody>
</table>

Figure 6.11 PSNR values of sample biomedical images sample biological images through PPM TH m-ZCZ UWB/MIMO (2×2) system
6.6 CONCLUSION

In this chapter, an improved SIC scheme for MIMO UWB based WBAN is proposed. The proposed system utilizes ZCZ sequences as a spreading sequence. To mitigate inter device interference in BAN, SIC with optimal ordering is used. TH PPM modulation followed by MMSE equalization is employed. From the results of the simulation, it can be seen that TH PPM m-ZCZ UWB system gives 91% BER improvement than that of the existing PAM-DS-ZCD and 98% BER improvement than that of the existing PAM-DS-PN, under WBAN channel CM4 because of good cross correlation properties. Also, ZCZ codes have been compared with various other codes such as PN, ZCD codes for UWB MIMO (2×2) system for different code length. Finally, the results are validated using sample biological functions as an input for the proposed TH PPM m-ZCZ UWB/MIMO (2×2) system in WBAN environment with multiple devices. Proposed TH PPM-ZCZ UWB/MIMO (2×2) system in WBAN environment with multiple devices have been tested with biomedical images as input.