Packet collision based Multiuser Interference (MUI) analysis for TH-PAM and TH-PPM Ultra wideband (UWB) system

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Abstract—In our previous work [1], we have analysed Multiuser Interference (MUI) by considering synchronous and asynchronous transmission under multiuser case for DS-CDMA based OFDM system. In [1] we have considered MUI at receiver from N-chronous transmission under multiuser case for DS-CDMA based packet based transmission with Impulse radio. In this situation MUI is generated due to collision of UWB pulses, which are used to define single bit under UWB transmission. This type of interference will take place in UWB based network due to organization of information bits into packets by higher layers. Here we have considered the TH-PAM and TH-PPM based Impulse radio systems for evaluating MUI.

I. INTRODUCTION

In April 2002, Federal Communication Commission (FCC) has released a new spectrum of 3.1 GHz to 10.6 GHz for UWB applications. Signal, which occupies fractional bandwidth of 20% in this frequency range is considered as UWB signal. Where the fractional bandwidth is defined as a ratio of signal bandwidth to its centre frequency. In IEEE 802.15.3a and IEEE 802.15.4a UWB is a possible radio technique at physical layer. Because of wideband nature of UWB signal it provides the high data rate in Wireless Personal Area Networks (WPANs) for multimedia traffic. UWB is also known as wireless USB, as it is seen as a replacement of USB cable. In UWB, there are two approaches for multiple accesses. One is based on time hopping (TH), which is known as an Impulse radio [2], [3] and second is based on Multi band OFDM [4], [5]. In second approach, signal is defined as a UWB signal, if it occupies band of at least 500MHz in assigned frequency range.

Here we have considered Impulse based UWB system for analysing the MUI in packet based communication. For multiple access in Impulse radio based UWB system, literatures [3], [6] suggest method based on Time Hopping (TH) technique. This access technique can be used with Pulse Position Modulation (PPM) or Pulse Amplitude Modulation (PAM) schemes. Depending upon modulation scheme TH UWB signal is known as TH-PAM UWB [3] or TH-PPM UWB [3], [6]. Also Direct Sequence UWB (DS-UWB) approach proposed in [7] which is same as TH-PAM UWB except minor difference.

In all TH-UWB method single bit duration ($T_b$) is divided into $N_f$ number of frames, each with equal duration of ($T_f$) such that, $T_b = N_f T_f$. Further each frame duration ($T_f$) is divided into $N_c$ number of chips of duration ($T_c$). During each chip period ($T_c$) UWB radio signal is transmitted. This UWB pulse is Gaussian pulse or its derivative, which is transmitted depending upon TH code. UWB radio signal comprised of a sequence of sub-nano second duration pulses. In TH-PAM, antipodal signal is used for representing data bit ‘1’ and ‘0’. In TH-PPM, UWB pulse will take additional delay of $\delta$ at the beginning of chip duration when data bit ‘1’ is transmitted.

Here we have analysed MUI by considering packet based transmission. In this situation MUI is generated due to collision of UWB pulses, which are used to define single bit under UWB transmission. This type of interference will take place in UWB based network due to organization of information bits into packets by higher layers (like MAC layer). Here we have considered the TH-PAM and TH-PPM based Impulse radio technique and we evaluated performance of the UWB system.

Paper is organized as, In Section II, we discuss the system model for TH-PAM and TH-PPM based UWB system. In section III we describe the simulation results with asynchronous transmission. Also effect of selection of different UWB pulse shape is discussed. Finally in Section IV, we conclude our work and future scope discussed in Section V.

II. SYSTEM MODEL FOR IMPULSE RADIO

Figure 1 shows the multimedia transmission scenario with UWB system. UWB device collects date from different high speed multimedia sources and transmit UWB signal to different devices. In this situation UWB device transmit signal with TH-PAM or TH-PPM schemes. We have considered downlink transmission. Here we studied MUI based on collision of UWB pulses, which will take place due to packet collision.

A. TH-PAM system model

In literature [10] TH-PAM UWB system is considered for Ultra wideband communication. In TH-PAM UWB single bit duration ($T_b$) is divided into $N_f$ number of frames each with equal duration ($T_f$), so $T_b = N_f T_f$. Further each frame is divided into $N_c$ chips with chip duration of $T_c$ such that $N_c T_c \leq T_f$. During each frame UWB pulse is transmitted which is Gaussian monocycle or Scholtz Monocycle. UWB pulse occupy one chip slot depending on time hopping code $c_j$ which take value such that $0 \leq c_j \leq N_c - 1$. During
each bit duration \( N_f \) UWB pulses are transmitted by TH-PAM transmitter. For modulation antipodal pulses are used. TH-PAM UWB signal is represented as

\[
s^{(k)}(t) = \sum_{i=-\infty}^{\infty} \sum_{j=0}^{N_f-1} d^{(k)}_j w(t - jT_f - c^{(k)}_j T_c)
\]

Where\( S^{(k)}(.) \) is \( k^{th} \) user signal, \( d^{(k)}_j \) is \( k^{th} \) user bipolar data, \( N_f \) is number of frames per bit and \( w(.) \) is UWB pulse.

**B. TH-PPM system model**

In literature [6], [8], [9] TH-PPM UWB system is proposed for Ultra wideband communication. In which single bit duration \( T_b \) is divided into \( N_f \) frames each with equal duration \( T_f \) so \( T_b = N_f T_f \). Further each frame is divided in to \( N_c \) chips with chip duration of \( T_c \) such that \( N_c T_c \leq T_f \). During each frame UWB pulse is transmitted which is Gaussian monocyte or Scholtz Monocycle. This UWB pulse is transmitted during chip duration depending up on time hopping code \( c_j \) which has value such that \( 0 \leq c_j \leq N_c - 1 \). During each bit duration \( N_f \) UWB pulses are transmitted by TH-PPM transmitter. Additional delay of \( \delta \) is provided to UWB pulse at the beginning of chip duration when data bit ‘1’ is transmitted. Here TH-PPM signal is represented as

\[
S^{(k)}(t) = \sum_{i=-\infty}^{\infty} \sum_{j=0}^{N_f-1} w(t - jT_f - c^{(k)}_j T_c - d^{(k)}_j \delta)
\]

Where \( S^{(k)}(.) \) is \( k^{th} \) user signal, \( d^{(k)}_j \) is \( k^{th} \) user data, \( N_f \) is number of frames per bit, \( w(.) \) is UWB pulse.

**C. Receiver configuration for Impulse radio**

Receiver for multi-pulse signals like, TH-PAM or TH-PPM can be based on soft decision or hard decision based. In soft decision the all \( N_f \) pulses is considered as a signal and received signal is correlated with correlation mask generated at receiver. While in hard decision detection all \( N_f \) pulses are considered as independent pulse and all are detected. And decision is based on majority rule. In this case error occurs if more than half pulses are detected wrong. In this paper we have analysed MUI based on packet collision, so we have considered hard decision decoding of TH-PAM and TH-PPM signal. Here we have considered asynchronous transmission between different devices. In asynchronous transmission packet arrival can be modelled by Poisson process. In impulse radio, single bit is represented by \( N_f \) UWB pulses. So we can consider inter pulse arrival process as Poisson distributed. In this situation probability of pulse collide with useful user signal can be expressed as,

\[
P_c = 1 - e^{-2(N-1)T_b}
\]

In hard decision decoding bit decision will be wrong if half of the pulses from \( N_f \) pulses are detected wrong. So bit error probability is,

\[
P_b = \sum_{j=N_f}^{N_f} \binom{N_f}{j} (0.5P_c)^j (1 - 0.5P_c)^{N_f-j-1}
\]

probability of correct transmission is given as,

\[
P_c = 1 - P_b,
\]

which is,

\[
P_c = 1 - \sum_{j=N_f}^{N_f} \binom{N_f}{j} (0.5P_c)^j (1 - 0.5P_c)^{N_f-j-1}
\]

When information bits are transmitted in packet form, If single bit in entire packet will get corrupted is considered as a packet is corrupted. If a packet is of length \( L \). Probability that packet is transmitted unsuccessfully is given as,

\[
P_{un} = 1 - (1 - P_b)^L
\]

so packet success rate depends on packet length and data rate. figure 2 shows the how time hopping based UWB signal is transmitted for one data bit by UWB device shown in figure 1.
III. SIMULATION RESULTS

Here we have evaluated probability of error by considering the overlapping of UWB pulses. Also in simulation we have considered the different pulse shapes, which defines the UWB signal. We carried out simulation for Gaussian pulse and its second derivative (scholtz monocycle). Also we have compared results with BER evaluated in [9], [10], [11] by considering soft decision decoding. In this analysis two pulse will collide if portion of waveform will overlap, we have considered the collision of pulse with different overlap. For this we have considered different effective pulse duration by taking energy parameter into consideration. We have considered 60%, 70%, 80%, 100% of total energy of UWB pulse for taking overlap into consideration.

The event of pulse collision is independent of pulse shape if pulse duration will remain same. So we expect that performance of system (in terms of BER) will remain same for different pulse shape, which we have considered here. If pulse is broader or narrower then effective pulse duration is different which affects the BER performance. Simulation parameters for TH-PAM and TH-PPM are shown in Table-1

<table>
<thead>
<tr>
<th>TABLE 1</th>
<th>SIMULATION PARAMETERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>TH-PAM Parameters</td>
<td></td>
</tr>
<tr>
<td>Data Rate</td>
<td>55.55Mbps</td>
</tr>
<tr>
<td>Number of frames (N_f)</td>
<td>6</td>
</tr>
<tr>
<td>Frame duration (T_f)</td>
<td>3 nsec</td>
</tr>
<tr>
<td>Number of chips (N_c)</td>
<td>3</td>
</tr>
<tr>
<td>Chip duration (T_c)</td>
<td>1 nsec</td>
</tr>
<tr>
<td>Pulse shape</td>
<td>Gaussian and its 2(^{nd}) derivative</td>
</tr>
<tr>
<td>Pulse shape factor (\tau)</td>
<td>0.25 nsec</td>
</tr>
<tr>
<td>Effective pulse duration</td>
<td>for 60%, 70%, 80%, and 100% of total energy</td>
</tr>
<tr>
<td>UWB pulse duration (T_p)</td>
<td>0.15 nsec</td>
</tr>
</tbody>
</table>

| TH-PPM Parameters | |
| Data Rate | 55.55Mbps |
| Number of frames \(N_f\) | 6 |
| Frame duration \(T_f\) | 3 nsec |
| Number of chips \(N_c\) | 3 |
| Chip duration \(T_c\) | 1 nsec |
| PPM Shift \(\delta\) | 0.5 nsec |
| Pulse shape | Gaussian and its 2\(^{nd}\) derivative |
| Effective pulse duration | for 60%, 70%, 80%, and 100% of total energy |
| UWB pulse duration \(T_p\) | 0.15 nsec |

Figure 3 shows the performance of TH-PAM and TH-PPM under pulse collision based MUI model. Here we have considered Gaussian UWB pulse shape for simulation. It can be seen that as pulse collision area is more interference effect is more. So performance of system in terms of BER is reduced. In figure 3, it can be seen that that when pulse collision is 100% BER is almost constant for different number of multimedia devices. Figure 4 shows the performance of TH system by considering Scholtz mono cycle as UWB pulse. Actually performance under pulse collision depends only on duration of pulse. So for different pulse shape with same duration we expect same performance. Here performance under Scholtz monocyce is poorer compared to Gaussian pulse, as this pulse is broader in time. Also from figure 4 it can be seen that performance of system is poorer with higher amount of collision.

In N multimedia devices, for one multimedia device, \(N - 1\) devices are interfering devices. For analysis we can consider MUI as a Gaussian noise. Which is known as standard Gaussian Approximation (SGA) hypothesis. This hypothesis is appropriate if number of interfering devices are more. Figure 5 and Figure 6 shows the performance comparison between pulse collision based model and SGA for TH-PAM and TH-PPM. It can be seen from this result that as number of interfering devices are more then difference between results with SGA and pulse collision based model less. While with lesser number of devices this difference is high. Also it can be seen that in TH-PAM performance is better compared to TH-PPM.

In TH-PAM received signal is,
where $r(t)$ is received signal, $r_1(t)$ is intended multimedia device data, $r_{MU1}(t)$ is MUI.

and

$$r_1(t) = \sum_{i=-\infty}^{\infty} \sum_{j=0}^{N_f-1} d^{(k)}_{i}(t) w(t - jT_f - C_j^{(k)} T_c)$$

$$r_{MU1}(t) = \sum_{K=2}^{N} \sum_{i=-\infty}^{\infty} \sum_{j=0}^{N_f-1} d^{(k)}_{i}(t) w(t - jT_f - C_j^{(k)} T_c - d_i^{(k)} \delta)$$

For TH-PPM, received signal is,

$$r(t) = r_1(t) + r_{MU1}(t)$$

where $r(t)$ is received signal, $r_1(t)$ is intended multimedia device data, $r_{MU1}(t)$ is MUI.

and

$$r_1(t) = \sum_{i=-\infty}^{\infty} \sum_{j=0}^{N_f-1} w(t - jT_f - C_j^{(k)} T_c - d_i^{(k)} \delta)$$

$$r_{MU1}(t) = \sum_{K=2}^{N} \sum_{i=-\infty}^{\infty} \sum_{j=0}^{N_f-1} w(t - jT_f - C_j^{(k)} T_c - d_i^{(k)} \delta)$$

Also we have compared results of pulse collision based model with TH based system discussed in [9], [10], [11]. Here we have considered performance of multiuser scenario with soft decision decoding. In this decoding technique, decision for data bit is taken after considering $N_f$ UWB pulses as one signal. From figure 7, it can be seen that, soft decision decoding performs better compared to hard decision decoding in TH based system.

**IV. Conclusion**

Here we have evaluated MUI effect by considering packet based collision schemes. For performance evaluation we have considered TH based UWB system. We have considered different pulse shape for evaluating the performance. It can be seen from results that, when Scholtz monocycle is selected as UWB pulse performance of system is degraded compared to Gaussian pulse shape. If both the pulses are of same duration then we would expect same performance. Also it can be concluded that under SGA, performance difference between packet collision based system is less if more number of interfering devices are available. Also it can be seen that, TH-PAM UWB system performs better compared to TH-PPM UWB system.

**V. Future work**

Here we have considered TH based system for evaluating performance under MUI. We will consider DS-UWB system proposed in [7] and evaluate performance under packet collision based system.
REFERENCES