ULTRA-WIDEBAND (UWB) FOR MULTIMEDIA APPLICATIONS

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Abstract— **UWB communication refers to impulse radio technology, in which wireless data is transferred using time domain modulation of data and extremely narrow radio impulses (i.e. nanosecond duration) that occupy typically several GHz of bandwidth. In this paper, we simulate an indoor environment whereby the channel characteristics model of UWB is observed - Saleh-Valenzuela-4 channel model is adopted-, and tested for the feasibility of UWB system in transmitting real time multimedia as incorporating a wireless link, which UWB is the first candidate to transfer these types of data due to its features, i.e. very high data rate (up to 500Mbps), multipath immunity, LPI. Certain aspects were emphasized such as multiple user and channel effects. Designing a wireless link for a streaming video and audio with a wire-like quality was the main objective of this paper.**

Index Terms—**Impulse Radio Ultra-wideband, Multimedia, home-network**

I.INTRODUCTION

UWB is considered to be the next "big thing" in the wireless space, which it allows high data throughput with low power consumption for short-to-medium distances, which is very applicable to the digital home requirements [1][2]. The fastest data rate publicly shown over UWB is now an impressive 252 Mbps, and a rate of 480 Mbps is expected to be shown in the not-too-distant future [2].

Requirements for the digital home include high-speed data transfer for multimedia content, short-range connectivity for transfer to other devices, low power consumption due to limited battery capacity, and low complexity and cost due to market pricing pressures and alternative wired connectivity options. Transfer of video from a camcorder to an entertainment PC is one scenario. Another model is the ability to view photos from the user's digital still camera on a larger display. Removing all the wires to the printer, scanner, mass storage devices, and video cameras located in the home office is another possible scenario.

Closely related is wireless connectivity for consumer electronics (CE) devices. Portable CE audio/video (A/V) devices such as DV camcorders, digital still cameras, portable MP3 audio players, HDTV displays, personal video recorders (PVRs), Entertainment PCs and emerging personal video players are likely candidates for the early UWB mainstream market. Table 1 shows the effective bit-rate requirements for different services that can be found in a home environment [3][4].

Table 1: Effective Bit Rate Requirements for home network

Data Stream	Bit Rate
HDTV	19Mbps
DVD player	10Mbps
MPEG-2	1-8Mbps
MPEG-1	1.5Mbps
Broadband access	1-10Mbps
Video conference	1-2Mbps
TV as a terminal	2-5Mbps
CD player (stereo)	1.4Mbps
Computer network	1-10Mbps
Telephone	8-64kbps

Network architecture designed for home and WPAN can take many topologies infrastructure, which it is not suitable for WPAN and wire replacement in-home network, and non-infrastructure (ad-hoc) devices distributed randomly in clusters or piconets. This network should be robust, easily deployed, and easily installed, where users have complete control over where and how many devices are located about the home. In addition, a variety of such devices operating under variable and random circumstances will present different demands on the network.

In this paper we employ the indoor channel characteristics and environment to simulate the robustness and reliability of UWB for multimedia. The received power at the receiver, probability of error and the signal propagation distance are examined as the function of the transmitter and receiver separation distance, data rate, signal to noise ratio and multi-user interference.

The remainder of the paper is organized as follows. Section II defines the system structure used during simulation. Signal to Interference and Noise Ratio (SINR) is discussed in Section III. Then, UWB multi-user performance is derived in Section IV, which is followed by simulation results in Section V. Finally, some concluding remarks are made in Section VI.

II.UWB INDOOR SYSTEM MODEL

The transmitted UWB signal consists of a train of short pulses, which dithered by a time-hoping (TH) sequence to facilitate multiple accesses and reduce spectral lines. The polarities of the transmitted pulses also are randomized by using a direct sequence (DS) spreading code [5], [6].

a) Pulse Model

The generalized UWB signal transmitted during the acquisition process for a single user can be expressed as a series of 2^{nd} derivatives of Gaussian pulse [7].

$$\psi(t)=\sqrt{\frac{4}{3t_n\sqrt{\pi}}}\left(1-\left(\frac{t}{t_n}\right)^2\right)\exp\left(-\frac{1}{2}\left(\frac{t}{t_n}\right)^2\right) \quad (1)$$

The parameter t_n determines the effective time width of the pulse T_p and, hence, it's bandwidth (shown in Figure 1).

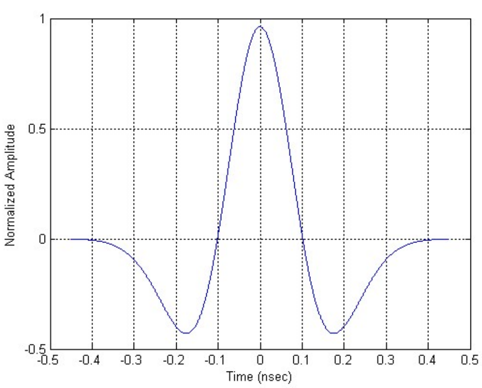

Figure 1: second derivative of Gaussian pulse

b) Signal model

Then the transmitted signal is given by

$$x(t)_{Tx}^{(n)} = \sum_{j=-\infty}^{\infty}\sqrt{E_{Tx}^{(n)}}\,p(t-jT_s-c_j^{(n)}T_c-a_j^{(n)}\varepsilon) \quad (2)$$

Where $P(t)$ is the energy-normalized pulse waveform, $E_{Tx}^{(n)}$ is the energy transmitted over each single pulse, $c_j^{(n)}$ is the j-th co-efficient of the TH sequence used by user n; and T_c is the chip duration; ε is the PPM shift, and $a_j^{(n)}$ is the binary value (0,1) conveyed by pulse j of user n; T_s is the pulse repetition period (PRP).

UWB systems employ long spreading sequences of a pseudorandom (PN) spanning multiple symbol intervals in order to remove and smoothing spectral lines resulting from the pulse repetition period (PRP) - which makes appear energy spikes in the spectrum- present in the transmitted signal, this problem shown in Figure 2. In the absence of any side information regarding the timing of the received signal, the receiver needs to search through a large number of phases at the acquisition stage, which results in a large acquisition time [8].

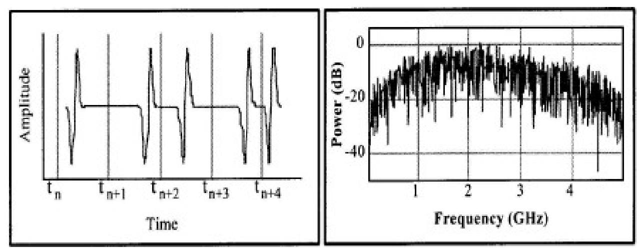

Figure 2: Monocycle dithering and associated spectrum

c) Channel model

The UWB indoor propagation channel can be modeled by a stochastic tapped delay line [9], which can generally be expressed in terms of its impulse response

$$h(t)=\sum_{k=0}^{N_{tap}-1} h_k f_k(t-\tau_k), \quad (3)$$

Where N_{tap} is the number of taps in the channel response, h_k is the path gain at excess delay τ_k corresponding to the *k*-th path. Due to the frequency sensitivity of the UWB channel, the pulse shapes received at different excess delays are path-dependent [10]. The function $f_k(t)$ models the combined effects of transmitting and receiving antennas and propagation channel corresponding to the *k*-th path of the transmitted pulse.

The receiver signal can also be written as follows:

$$r(t)=r_u(t)+r_{mui}(t)+n(t) \quad (4)$$

Where $r_u(t)$ and $r_{mui}(t)$ are the useful signal and multi-user interference (MUI) received by the receiver, MUI signal can be removed if all codes were orthogonal at the receiver under the hypothesis of perfect synchronization between all users in the system. $r_u(t)$ for a single user can then expressed as

$$r_u(t) = \sum_{j=0}^{N_s-1} \sqrt{E_{Rx}^{(1)}}\, p(t - jT_s - c_j^{(1)}T_c - a_j^{(1)}\varepsilon) \qquad (5)$$

$t \in [0, T_b]$, where T_b bit time interval;

$$r_{mui}(t) = \sum_{n=2}^{N_u} \sum_{j=-\infty}^{\infty} \sqrt{E_{Rx}^{(n)}}\, p(t - jT_s - c_j^{(n)}T_c - a_j^{(n)}\varepsilon - \tau^{(n)}) \qquad (6)$$

where

$$p(t) = \sum_{k=0}^{N_{tap}-1} h_k \psi_k (t - \tau_d), \qquad (7)$$

is the received waveform corresponding to a single pulse. Here $\psi_k(t) = f_k(t) * p(t)$ is the received UWB pulse from the *k*-th path. The duration of the received pulse is assumed to be less than the chip duration T_c. The propagation delay is denoted by t_d and $n(t)$ is a zero mean noise process. Given the received signal, the acquisition system attempts to retrieve the timing offset t_d.

III. Signal to Interference and Noise Ratio (SINR)

To determine the appropriate transmitted power value the transmitting node needs to know at least the Signal to Interference and Noise Ratio (SINR) at receiving node. The SINR is estimated at the receiving node and then sent back to the transmitting node in feedback channel. If wideband feedback channel is used then the transmitted power of user i can be calculated as

$$P_i(t+1) = \frac{\delta_{ij}^T(t)}{\delta_{ij}(t)} P_i(t) \qquad (8)$$

Where $P_i(t)$ is the transmitted power of user i at iteration t, $\delta_{ij}^T(t)$ is the target SINR to send data from user i to user j at iteration t, and $\delta_{ij}(t)$ is the actual SINR of user i at the receiver j at iteration t. Note that the target SINR can change from slot to slot, it depends on the data rate and the target BER for a given packet. The SINR formula depends on the modulation technique. In CDMA the SINR can be represented as

$$\delta_{ij}(t) = PG_i(t) \frac{P_i(t) G_{ij}(t)}{\sum_{\substack{k=1 \\ k\neq i \\ k\neq j}}^{Q} P_k G_{kj}(t) + N_j}, \quad t = 1,2,.. \qquad (9)$$

Where $PG_i(t)$ is the processing gain, N_j is the additive white noise at the receiving node. $G_{ij}(t)$ the channel gain between users user i to user j, this is modeled as a combination path loss (α) and Rayleigh fading (multipath) channel (r_{ij}) where

$$G_{ij}(t) = \frac{1}{\left|x_i - x_j\right|^{\alpha}} r_{ij} \qquad (10)$$

IV. UWB Multi-User Performance

The average symbol error rate coincides with the average bit rate $\Pr_b$ since modulation is binary and corresponds to the probability of misdetecting a reference bit b transmitted by user 1. The soft decision correlation receiver output can be expressed as follows:

$$Z = \int_0^{T_b} r(t) m(t) dt \qquad (11)$$

Where $m(t)$ is the template signal and is defined as follows:

$$m(t) = \sum_{j=0}^{N_s-1} v(t - jT_s - c_j^{(1)}T_s) \qquad (12)$$

with

$$v(t) = p(t) - p(t - \varepsilon) \qquad (13)$$

The probability of bit error for a PPM modulation with TH-UWB multiple access technique can be calculated as follows:

$$\Pr_b = 0.5 erfc\left(\sqrt{\frac{1}{2(1/SNR_n + 1/SIR)}}\right) \qquad (14)$$

Where SNR_n and SIR are the signal to thermal noise and signal to MUI ratios, respectively. SNR_n can be expressed as:

$$SNR_n = E_b / \sigma_n^2 = \frac{E_b}{N_0}(1 - R_0(\varepsilon)) \qquad (15)$$

where E_b the useful signal energy, σ_n^2 is the variance of thermal noise, and $R_0(\varepsilon)$ is the autocorrelation function of the pulse waveform $p(t)$; and the SIR in the case of orthogonal pulse can be expressed as:

$$SIR = E_b \Big/ \sigma_{mui}^2 = \frac{(1-R_0(\varepsilon))^2}{\sigma_M^2} \frac{1}{R_b^2 \sum_{n=2}^{N_u} \frac{E_{Rx}^{(n)}}{E_{Rx}^1}} \quad (16)$$

Where σ_{mui}^2 variance of MUI noise, $R_b = 1/T_b$ is the bit rate of the Tx, and the term σ_M can be written as follows:

$$\sigma_M^2 = \int_{-T_M}^{2T_M} (R_0(t) - R_0(t+T_M))^2 dt \quad (17)$$

Where T_M is the time duration of $p(t)$. Under perfect power control

$$\sum_{n=2}^{N_u} \frac{E_{Rx}^{(n)}}{E_{Rx}^1} = N_u - 1 \quad (18)$$

Equation (18) shows that global system performance depends on the amount of multi-user interference, which in turn is determined by the correlation properties of the time-hopping codes. Most often, pseudo-random codes are used, due to their good cross-correlation properties.

V. Numerical Results and Discussions

In this section, we study the behavior of the distributed protocol through Matlab simulations. We have simulated an area of 15m×15m with 20 users randomly distributed. The traffic flows (QoS or BE flows) are generated based on a Poisson process (with rate of λ arrivals/s). During simulations, perfect synchronization and perfect power control are considered. The default parameter settings are shown in Table 1.

Table 2: Parameters settings

Parameters	Values
Pulse repetition time: T_f	10 ns
Dimensional parameter pulse: σ^2	$1.99x10^{-3}$
Noise PSD	-174dBm/Hz
Signal PSD	41dBm/MHz
Signal noise ratio threshold: λ	6dB
Path gain constant: α	4
Path loss at 15 m	45dB
Processing gain	20

a. Effect of Additive White Gaussian Noise (AWGN) on the transmitted signal

Figure 3 compares the received signal at different E_b/N_o . It can be observed clearly that higher E_b/N_o provide a more reliable transmission where the received signal is less corrupted by the noise. This will eventually degrade the signal quality. Moreover, due to the wide spectrum or wide bandwidth characteristics of UWB, more noise is admitted to the system as the wider the bandwidth, the more noise affects the received signal. Thus, consideration must be taken to avoid the effect of noise to the transmitted signal by increasing the E_b/N_o . From this simulation, it can be concluded E_b/N_o must be equal or more than 15 dB in order to reliably transmit multimedia contents between CE devices while meeting the required video or audio quality constraints.

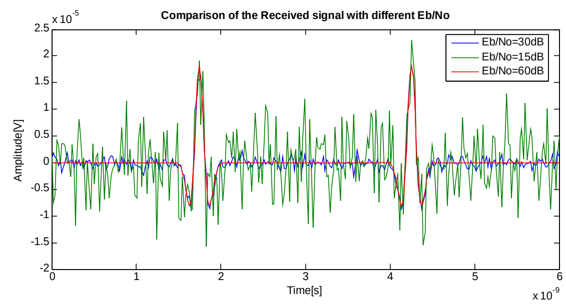

Figure 3: Comparison of received signal at different E_b/N_o

There are four scenarios that are considered for this simulation. The first (Case A) is characterized by the presence of only one user, the second (Case B) by the presence of five interfering users, the third (Case C) by 10 users and the fourth (Case D) is by 20 users. In each case, the reference user generates a stream of bits, leading to three R_b of 20Mbps, 100Mbps and 300Mbps. Each bit period is organized into three frames and three pulses are transmitted for each bit. Each frame is further subdivided into six slots, that is the TH code can assign one out of six possible positions to the single pulse within each pulse repetition period. This simulation assumes that all users transmit with the same signal format.

Figure 4 shows Pr_b versus E_b/N_o when only one user is present (Case A) without any MUI interference. This means that there is only one transmitter sending bit to a receiver without having any other users sending bit at the same time. Figure 4 depicts three curves, which each represents the Pr_b for different R_b , specifically 20 Mbps, 100 Mbps and 300 Mbps. At R_b of 20 Mbps, the only contribution that affects the system performance is the presence of thermal noise at the receiver. MUI seems to have no effect on the system performance. At 10 dB, the probability drops to $7x10^{-4}$ and further decrease to 10^{-36} when E_b/N_o is at 30 dB. However, when the R_b increases to 100 Mbps, the probability of error tends asymptotically to a constant value, leading to the conclusion that system performance in the presence of high E_b/N_o values is determined by only MUI. From At R_b of 300 Mbps, the probability or error is nearly constant with the increase of E_b/N_o. This shows that the probability of error reaches a value that cannot be further decreased. This value is called Pr_b floor, where the performance is limited by MUI.

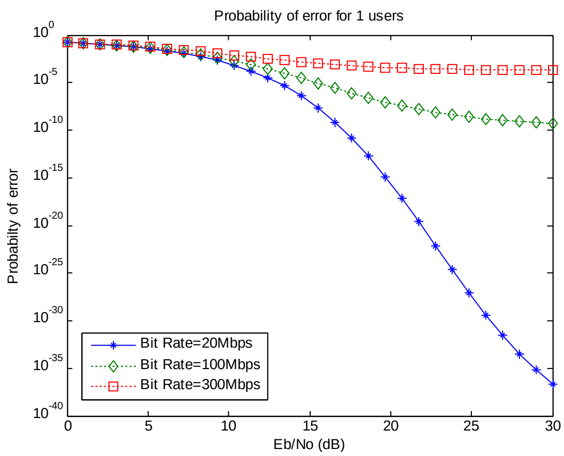

Figure 4: Probability of error with 1 user interference (Case A)

From Case A, it can be concluded that for a reliable multimedia transmission at 20 Mbps, the minimum value of E_b/N_o is 10 dB. For 100 Mbps and 300 Mbps, the minimum E_b/N_o for guaranteed transmission is at 15 dB.

Figure 5 shows Pr_b versus E_b/N_o when five interfering users are present (Case B). It can be observed that at R_b of 20 Mbps, MUI seems to have no effect on the system performance, since the probability of error decreases with E_b/N_o with the same trend. In other words, the only contribution that seems to affect system performance is the presence of thermal noise at the receiver. This is similar to Case A except for the higher value of probability of error. For instance, at 15 dB, the probability of error for Case A is 10^{-7} and 10^{-5} for Case B. At 100 Mbps, the probability or error is nearly constant at 3×10^{-3} with the increase of E_b/N_o. This shows that the probability of error reaches a value that cannot be further decreased. This value is called Pr_b floor, where the performance is limited by MUI. This goes the same for R_b of 300 Mbps with the Pr_b floor at 2.5×10^{-2}.

For a reliable multimedia transmission at 20 Mbps, the minimum value of E_b/N_o is 15 dB. For 100 Mbps and 300 Mbps, the minimum E_b/N_o for guaranteed transmission must be more than 30 dB. Below 30 dB, the probability of error is quite high for a wireless transmission. The bit send by the transmitter might be corrupted or deceptive.

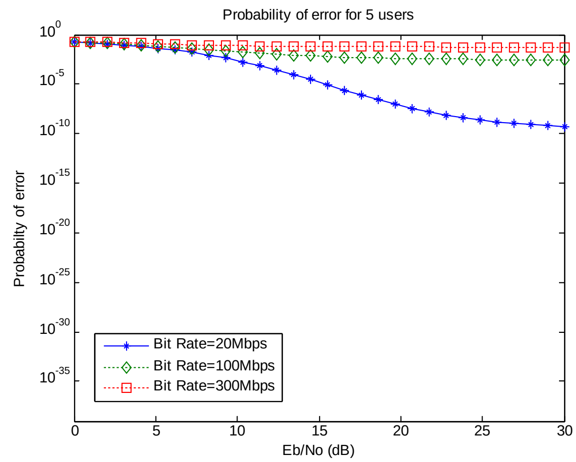

Figure 5: Probability of error with 5 user interference (Case B)

Figure 6 shows Pr_b versus E_b/N_o when 10 interfering users are present (Case C). It can be observed that at R_b of 20 Mbps, MUI seems to be the dominant effect on the system performance, since the probability of error tends asymptotically to a constant value of 2×10^{-4}, leading to the conclusion that system performance in the presence of high E_b/N_o values is determined by only MUI. When the R_b increases to 100 Mbps, the probability or error is nearly constant at 5.49×10^{-2} with the increase of E_b/N_o, this is the Pr_b floor. This goes the same for R_b of 300Mbps with the Pr_b floor at 1.296×10^{-1}.

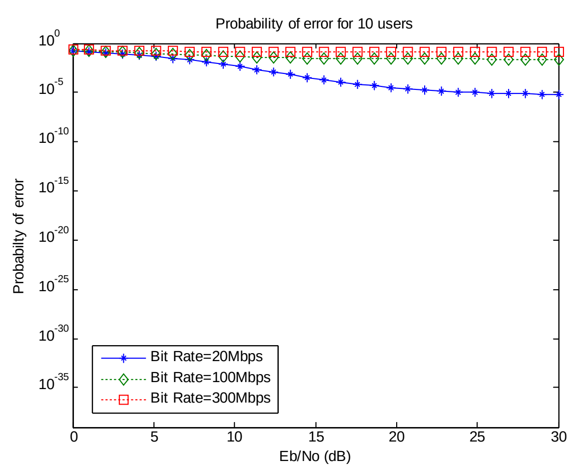

Figure 6: Probability of error with 10 user interference (Case C)

Figure 7 shows the probability of error versus E_b/N_o when 20 interfering users are present (Case D). Case D is almost similar to Case C except the curve at 20 Mbps.

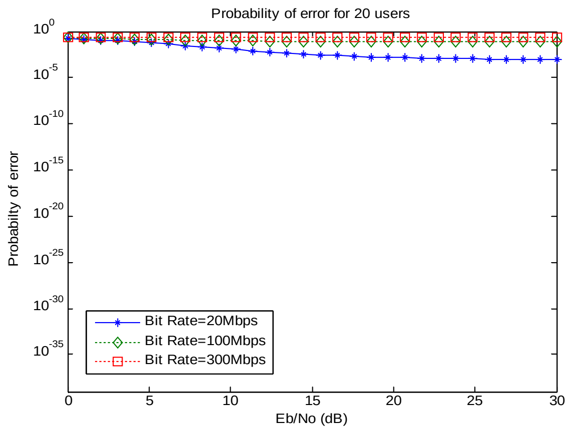

Figure 7: Probability of error with 20 user interference (Case D)

VI. CONCLUSIONS

From this simulation, there are primarily two states of operation for all systems that affect the transmission link which are thermal noise and MUI. The first state; the thermal noise corresponds to the situation where E_b/N_o is low, and the probability of error is mainly determined by the thermal noise. The presence of noise can corrupt one or more bits. If the data rate is increased, then the bits become shorter so that more bits are affected by a given pattern of noise. Thus at a given noise level, the higher the data rate, the higher the Pr_b. In such a situation, the performance can be improved by allowing all devices to increase the transmitted energy per pulse, or increase the transmitted power. When the transmitter power, increases, the ratio E_b/N_o at the receiver also increases, with a corresponding decrease in the Pr_b value.

Each code has the effect of modifying the transmitted signal in such a way that a reference receiver is capable of isolating the useful signal from other users' signals, which are seen by the reference receiver as interfering signals.

In a realistic scenario, however, where devices do not achieve ideal synchronization, and codes lose orthogonality because of different propagation delays on different paths, the receiver may not be capable of removing completely the presence of the undesired signals, and as a consequence system performance is affected by MUI.

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