Pilot-Assisted Channel Estimation for Coexisting Heterogeneous Wireless Personal Area Networks

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***Abstract*—Wireless personal area networks (WPANs) are drawing more and more attention recently, specially with the proposal of high rate technologies for its physical (PHY) layer. Multiband orthogonal frequency division multiplexing (MB-OFDM) ultra wideband (UWB) and direct-sequence (DS) UWB are the two technologies proposed for the PHY-layer in WPANs. Coexistence issue of the two aforementioned technologies while operating simultaneously in collocated WPANs, is a matter of concern, as they may induce mutual interference. In this paper, we address the channel estimation issue for DS-UWB receiver DEVs, in the presence of multi-user interference (MUI) and MB-OFDM interference. In fact, we use the minimum mean square error estimation (MMSE) to estimate the channel based on a pilot transmission scheme. Later, we employ the maximum likelihood (ML) criteria to detect the data symbols.**

***Index Terms*—Multiband orthogonal frequency division multiplexing (MB-OFDM), direct-sequence ultra wideband (DS-UWB), multi-user interference (MUI), channel estimation.**

I. INTRODUCTION

There are several proposals for the physical (PHY) layer of wireless personal area networks (WPANs). Ultra wideband (UWB) is one of these proposals which provides high rate and short range applications, such as home multimedia. Currently, there are two UWB standards available, multiband orthogonal frequency division multiplexing (MB-OFDM) UWB [1] and direct-sequence (DS) UWB [2]. These two standards may concurrently operate in the same coverage area within a framework of heterogeneous WPANs, because they are both available in the future market.

In the literature there is an extensive amount of research work which address the UWB systems alone, e.g., the system performance evaluation [3]–[7] or the coexistence problem between UWB and narrowband wireless communication systems. However the coexistence of heterogeneous UWB-based WPANs (UPANs) which employ the two aforementioned UWB standards in PHY-layer is not adequately investigated and there are several issues such as the mutual interference and the channel estimation which need further research. Among the works more related to the subject we can mention the ones in [8]–[11]. In [8], the authors have derived the channel parameter estimates using a maximum-likelihood (ML) approach. They have considered two different techniques for the channel estimation, i.e., data-aided and nondata-aided. This work solely focuses on channel estimation for one pulse position modulation (PPM) time-hopping (TH) UWB transceiver and does not take into account the effects of multi-user interference (MUI) and other external sources of interference. The work in [9] proposes a compressed sensing maximum likelihood (CSML) channel estimator in order to reduce the Nyquist sampling rate, which renders the implementation of UWB systems easier. The authors have shown that while retaining the noise statistics formulation of ML to achieve a reliable performance, the sampling rate is reduced significantly. However, similar to the previous work this work also focuses on single-user communications without considering different sources of interference. In the work reported in [10], the authors simulated the MB-OFDM UWB and DS-UWB standards to study the effect of the mutual interference between both systems, and proposed to reduce the interference by means of power control. The research work in [11] presents an analysis of the effect of the DS-UWB and TH-UWB systems on the performance of the MB-OFDM standard in terms of BER.

In this paper, we present a channel estimation for the DS-UWB receiver within the novel framework of heterogeneous UPANs, then we use this estimation to evaluate the performance of the system in terms of bit error rate (BER). Specifically, we use a pilot-data transmission phase similar to the approach in [12] in order to estimate the UWB channel based on minimum mean square error estimation (MMSE). Later, in the detection phase this estimation is employed to detect the received bits using a ML criteria. We consider the effect of internal interference or MUI caused by different transmitting DS-UWB systems and also the external interference caused by MB-OFDM transmitters. Our estimation and detection process indirectly contributes to mitigate the effects of different sources of interference. Numerical results are provided to compare the system's performance for different number of interferers. We have also compared our method with the ideal channel state information (CSI) case.

The remainder of this paper is organized as follows. In Section II, the signals and the network models are discussed. Section III addresses the interference analysis at the DS-UWB system. Section IV presents our channel estimation method and Section V discusses the numerical results and comparisons

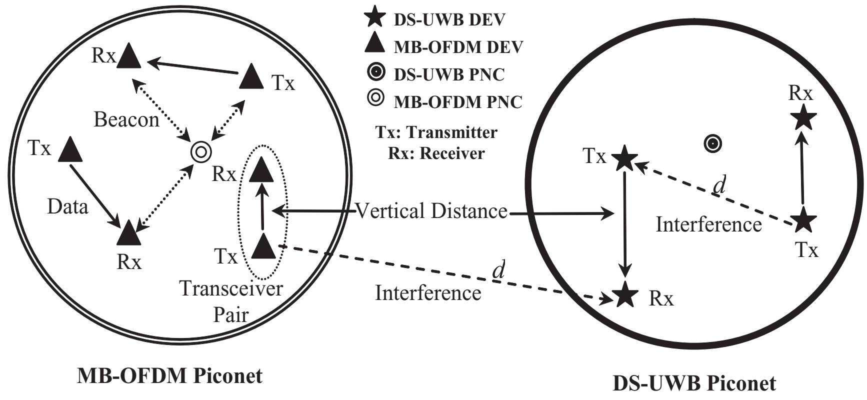

Fig. 1. A typical heterogeneous WPAN topology.

illustrating the BER performance of the DS-UWB system in the presence of multiple MB-OFDM interferers and the MUI. Finally, concluding remarks are given in Section VI.

II. Signals and the Network Models

In this section we present the models for the DS-UWB system and MB-OFDM interfering signal along with the network topology.

A. Network Topology

In the heterogeneous coexistence environment, a number of nodes with different UWB technologies share the UWB spectrum. We consider the WPAN as network topology. Fig. 1 shows a typical heterogeneous WPAN topology consisting of two piconets. In the WPAN standard terminology, a piconet is a collection of nodes which form a network with the same technology. Each *node* is technically called a device (DEV). The piconet controller (PNC) is chosen by other DEVs and is responsible for coordinating and synchronizing the DEVs within the piconet. For this purpose PNC broadcasts *beacons* to the DEVs at regular superframe intervals. After coordination, the communication is performed directly between the transmitter and receiver, forming a *transceiver pair*. The first piconet in Fig. 1 consists of $N_{\rm DS}$ number of DS-UWB transceiver pairs and the other piconet consists of $N_{\rm MB}$ number of MB-OFDM UWB transceiver pairs. Each receiver in a pair is subject to interference from other simultaneously transmitting nodes, whether located in the same piconet or in other piconets.

B. Signals

The transmitted signal symbol of the kth DS-UWB DEV can be expressed as:

$$P_{\rm DS}^{(k)}(t) = \sqrt{U_{\rm p}} \sum_{i=-\infty}^{+\infty} \sum_{n=0}^{N_c-1} d_{i,k} c_{n,k} q(t - nT_c - iT_f), \quad (1)$$

where t is the time index and $q(t)$ is the pulse waveform with fourier transform $\mathrm{Q}(\omega)$ and normalized such that $\int_{-\infty}^{+\infty} q^2(t)dt = 1$. $U_{\rm p}$ denotes the pulse energy, N_c indicates the number of chips per information bit (hence, the bit energy is given by $U_{\rm b} = N_c U_{\rm p}$), the sequence $\{c_{n,k}\}$ represents the spreading signature, T_c denotes the hop width, $T_f = N_c T_c$ is defined as frame width and $d_{i,k}$ represents the binary data transmitted. Throughout the analysis, we do not consider the self interference pertaining to DS-UWB reference signal and we assume all the transmitting DS-UWB systems have the same pulse energy.

As for the kth MB-OFDM transmitter DEV, the set of symbols $\{b_{n,s}^{(k)}, 0 \leq s \leq N-1\}$ are grouped into blocks which are modulated by an N-point IDFT (implemented with FFT) onto N subcarriers in the nth block interval. After a guard interval is inserted, the purpose of which is to reduce interference between blocks, the general formula for the transmitted sequence of the nth MB-OFDM symbol of the kth MB-OFDM transmitter DEV is expressed as:

$$B_{n,m}^{(k)} = \sqrt{U_{\rm T}^{(k)}} \sum_{s=0}^{N-1} b_{n,s}^{(k)} e^{\frac{j2\pi sm}{N}}, -N_G \leq m \leq N-1, \quad (2)$$

where the first N_G elements are the guard samples which are the summation of the cyclic prefix and the guard interval, $U_{\rm T}^{(k)}$ is the transmit energy of the kth MB-OFDM transmitter DEV, and $B_{n,m}^{(k)}$ is assumed to be zero for $m < -N_G$ and $m \geq N$. In particular, we consider high data rates for the MB-OFDM system (320 and 480 Mb/s) where the data symbols are assumed independent and identically distributed (i.i.d.). In the high data rate mode, the time spreading factor is considered to be one and the data bits are i.i.d. with respect to different data subcarriers and different data blocks. At the RF block, a carrier is inserted and the signal is taken to the specified carrier frequency with respect to the frequency-hopping pattern of the MB-OFDM system [13]:

$$P_{\rm MB}(t) = \mathbf{Re}\left\{ \sum_{n=-\infty}^{+\infty} B_{n,m}^{(k)}(m - n(N+N_G)) e^{-j2\pi(f_c + f_{\rm MB}[n])t} \right\}, \quad (3)$$

where f_c is a constant frequency offset and $f_{\rm MB}[n] \in \{(n_b - 1)N\Delta_F : n_b \in \{1, 2, ..., N_B\}\}$ is the additive periodic value used to hop between the N_B MB-OFDM frequency bands, with Δ_F denoting the subcarrier's bandwidth. Moreover, the frequency hops are chosen based on a deterministic hopping pattern as defined in the MB-OFDM proposed standard [1].

III. Signal Processing at the DS-UWB Receiver

In this section we present the interference analysis for the multi-user DS-UWB system and the MB-OFDM interfering signals.

A. Multi-User Interference (MUI) Analysis

The signal at the input of the DS-UWB receiver DEV is given by:

$$\begin{aligned} y(t) = \sqrt{U_{\mathrm{p}}} \sum_{k=1}^{N_{\mathrm{DS}}} \sum_{l=0}^{L-1} h_{k,l}(t) e^{j\tau_{k,l}(t)} \sum_{i=-\infty}^{+\infty} \sum_{n=0}^{N_c-1} \\ \times d_{i,k} c_{(n-l),k} q(t - nT_c - lT_c - iT_f) + y_{\mathrm{MB}}(t) + n(t), \end{aligned} \tag{4}$$

where L is the number of resolvable path, N_{DS} is the number of DS-UWB transmitters, $h_{l,k}$ is the kth user channel amplitude of the lth path, $\tau_{k,l}$ is the kth user channel phase of the lth path, $y_{\mathrm{MB}}(t)$ is the interference resulting from the MB-OFDM transmissions, and $n(t)$ is the thermal noise with double-sided power spectral density $N_0/2$. A perfect synchronization between the transmitter and the receiver is assumed. We also consider a slowly fading channel so the time dependency of $h_{l,k}$ and $\tau_{k,l}$ will be dropped. After passing through the correlation receiver, the output y_p corresponding to the pth path of the 0-th bit of the first DS-UWB receiver is written as:

$$\begin{aligned} y_p &= \sum_{m=p}^{p+N_c-1} \int_0^{T_f} y(t) c_{(m-p),1} q(t - mT_c) dt \\ &= \sqrt{U_b N_c} d_{0,1} h e^{j\tau} + I_{\mathrm{DS}}^p + I_{int}^p + n_{\mathrm{DS}}^p, \end{aligned} \tag{5}$$

where I_{DS}^p is the MUI, I_{int}^p is the contribution of the MB-OFDM interference and n_{DS}^p is the Gaussian noise with the variance $\sigma_{n_{\mathrm{DS}}}^2 = N_0 N_c/2$. Here we ignore the self-interference effect. The MUI can be written as:

$$\begin{aligned} I_{\mathrm{DS}}^p = \sum_{l=0}^{L-1} \sum_{k=2}^{N_{\mathrm{DS}}} h_{k,l} e^{\tau_{k,l}} \\ \times \sum_{m=p}^{p+N_c-1} \int_0^{T_f} P_{\mathrm{DS}}^{(k)}(t - lT_c) c_{(m-p),1} q(t - mT_c) dt. \end{aligned} \tag{6}$$

I_{DS}^p in (6) can be further simplified according to [14]:

$$\begin{aligned} I_{\mathrm{DS}}^p = \sqrt{U_p} \\ \times \sum_{k=2}^{N_{\mathrm{DS}}} \sum_{l=0}^{L-1} h_{k,l} e^{\tau_{k,l}} \left(d_{-1}^{(k)} \bar{R}^{(k)}(l,p) + d_0^{(k)} R^{(k)}(l,p) \right), \end{aligned} \tag{7}$$

where $\bar{R}$ and R are the partial cross-correlation functions and are defined as [14]:

$$R^{(k)}(l,p) = \int_0^{lT_c} C^{(k)}(t - lT_c) C^{(1)} q(t) dt. \tag{8}$$

$$\bar{R}^{(k)}(l,p) = \int_{lT_c}^{T_f} C^{(k)}(t - lT_c) C^{(1)}(t) dt. \tag{9}$$

In (8) and (9), $C^{(k)}(t)$ and $C^{(1)}(t)$ are given by

$$C^{(k)}(t) = \sum_{n=-\infty}^{\infty} c_{(n-l)}^{(k)} q(t - nT_c). \tag{10}$$

$$C^{(k)}(t) = \sum_{n=-\infty}^{\infty} c_{(n-p)}^{(1)} q(t - nT_c). \tag{11}$$

The mean value of the real part of MUI is given by

$$\begin{aligned} \mathbf{E}[\mathbf{Re}[I_{\mathrm{DS}}^p]] = \sum_{l=0}^{L-1} \sum_{k=2}^{N_{\mathrm{DS}}} \mathbf{E}\left[\mathbf{Re}[h_{k,l} e^{\tau_{k,l}}]\right] \\ \times \sum_{m=p}^{p+N_c-1} \int_0^{T_f} P_{\mathrm{DS}}^{(k)}(t - lT_c) c_{(m-p),1} q(t - mT_c) dt. \end{aligned} \tag{12}$$

$\mathbf{E}[\mathbf{Im}[I_{\mathrm{DS}}^p]]$ is calculated similar to $\mathbf{E}[\mathbf{Re}[I_{\mathrm{DS}}^p]]$. The covariance of I_{DS}^p is calculated according to

$$\begin{aligned} Cov[\mathbf{Re}[I_{\mathrm{DS}}^{p_1}], \mathbf{Re}[I_{\mathrm{DS}}^{p_2}]] = U_p \sum_{k=2}^{N_{\mathrm{DS}}} \sum_{\substack{l_1 = 0 \\ l_1 \neq p_1}}^{L-1} \sum_{\substack{l_2 = 0 \\ l_2 \neq p_2}}^{L-1} \\ Cov[\mathbf{Re}[h_{k,l_1} e^{\tau_{k,l_1}}], \mathbf{Re}[h_{k,l_2} e^{\tau_{k,l_2}}]] \\ \times \left(d_{-1}^{(k)} \bar{R}^{(k)}(l_1,p_1) + d_0^{(k)} R^{(k)}(l_1,p_1) \right) \\ \times \left(d_{-1}^{(k)} \bar{R}^{(k)}(l_2,p_2) + d_0^{(k)} R^{(k)}(l_2,p_2) \right). \end{aligned} \tag{13}$$

Assuming independent multipath components for different transmitters, the term $Cov[\mathbf{Re}[h_{k,l_1} e^{\tau_{k,l_1}}], \mathbf{Re}[h_{k,l_2} e^{\tau_{k,l_2}}]]$ in (13) is given by

$$\begin{aligned} Cov[\mathbf{Re}[h_{k,l_1} e^{\tau_{k,l_1}}], \mathbf{Re}[h_{k,l_2} e^{\tau_{k,l_2}}]] = \\ Cov[\mathbf{Im}[h_{k,l_1} e^{\tau_{k,l_1}}], \mathbf{Im}[h_{k,l_2} e^{\tau_{k,l_2}}]] = \\ \begin{cases} \sigma_{k,l}^2, \ For \ l_1 = l_2 = l \\ 0, For \ l_1 \neq l_2 \end{cases} \end{aligned} \tag{14}$$

B. MB-OFDM Interference Analysis

By replacing (2) and (3) in (5) and applying some slight changes (considering only one block of data, removing s and replacing it with n in $b_{n,s}^{(k)}$), the resulting interference term, I_{int}^p, is written as [15]:

$$\begin{aligned} I_{int}^p &= \sum_{k=1}^{N_{\mathrm{MB}}} \sum_{m=p}^{p+N_c-1} c_{(m-p),1} \sqrt{U_{\mathrm{T}}^{(k)}} \\ &\times \sum_{n=0}^{N-1} \mathbf{Re}\{b_n^{(k)} e^{j2\pi(n\Delta_F + f_c + f_{\mathrm{MB}})mT_c} \\ &\times \int_0^{T_c} e^{j2\pi(n\Delta_F + f_c + f_{\mathrm{MB}})x} q(x) dx\} \\ &= \sum_{k=1}^{N_{\mathrm{MB}}} \sum_{m=p}^{p+N_c-1} c_{(m-p),1} \sqrt{U_{\mathrm{T}}^{(k)}} \\ &\times \sum_{n=0}^{N-1} \mathbf{Re}\left\{ b_n^{(k)} e^{js_n(mT_c + \frac{T_p}{2})} Q(s_n) \right\}, \end{aligned} \tag{15}$$

where we can define $Q(s_n) = \int_{-T_p/2}^{T_p/2} e^{js_n x} q(x)dx$ as the fourier transform of the left-shifted version of pulse $q(t)$ which gives us a symmetric pulse and the limits of the integral have been changed to the pulse width of the signal, T_p. Equation (15) can be simplified further as:

$$I_{int}^{p} = \sum_{k=1}^{N_{\text{MB}}} \sum_{m=p}^{p+N_c-1} \sum_{n=0}^{N-1} I_{m,n,k}, \tag{16}$$

where

$$\begin{aligned} &I_{m,n,k} = \\ &b_n^{(k)} c_{(m-p),1} \sqrt{U_{\text{T}}^{(k)}} Q(s_n) \cos\left[s_n (mT_c + \frac{T_p}{2}) \right]. \end{aligned} \tag{17}$$

It is important to mention that (16) calculates the interference assuming all transmitters are transmitting at the same time. However, the total interference might be less depending on the network activity factor.

Finally, n_{DS}^{p} is calculated as

$$n_{\text{DS}}^{p} = \sum_{m=p}^{p+N_c-1} \int_0^{T_f} n(t) c_{(m-p),1} q(t - mT_c) dt. \tag{18}$$

IV. Channel Estimation

In order to estimate the UWB channel, we use a well know model similar to the one described in [12]. In this model, the fading amplitudes, $h_{k,l}$ are modelled as Rice variables and $h_{k,l}e^{j\tau_{k,l}}$ are complex Gaussian variables with independent quadrature components. Before the detection, channel estimation is performed by employing pilot signal. During the pilot transmission a number of N_p identical bits are transmitted from the DS-UWB transmitter to the receiver and the correlators' output pertaining to $l = 0, ..., L-1$ paths is give by

$$\begin{aligned} \mathbf{T} =& \begin{bmatrix} \mathbf{Re}[T_0] \ \mathbf{Im}[T_0] & ..... & \mathbf{Re}[T_{L-1}] \ \mathbf{Im}[T_{L-1}] \end{bmatrix} \\ =& \sqrt{U_b N_p N_c}\mathbf{h} + \mathbf{I}_{\text{DS}}^{p} + \mathbf{I}_{int}^{p} + \mathbf{n}_{\text{DS}}^{p}, \end{aligned} \tag{19}$$

where $\mathbf{h} = he^{\tau}$ and $\mathbf{I}_{\text{DS}}^{p}$ is the MUI vector defined as

$$\mathbf{I}_{\text{DS}}^{p} = \begin{bmatrix} \mathbf{Re}[I_{\text{DS}}^{0}] \ \mathbf{Im}[I_{\text{DS}}^{0}] & ..... & \mathbf{Re}[I_{\text{DS}}^{L-1}] \ \mathbf{Im}[I_{\text{DS}}^{L-1}] \end{bmatrix} \tag{20}$$

and the terms, $\mathbf{I}_{int}^{p}$ and $\mathbf{n}_{\text{DS}}^{p}$ are respectively, the MB-OFDM interference vector and thermal noise vector, which are defined similar to $\mathbf{I}_{\text{DS}}^{p}$. The mean value vector and the covariance matrix of $\mathbf{T}$ is given by

$$\mathbf{E}[\mathbf{T}] = \sqrt{U_b N_p N_c}\mathbf{E}[\mathbf{h}] + \mathbf{E}[\mathbf{I}_{\text{DS}}^{p}]. \tag{21}$$

$$\begin{aligned} &Cov[\mathbf{T}] = U_b N_p N_c Cov[\mathbf{h}] + Cov[\mathbf{I}_{int}^{p}] + Cov[\mathbf{n}_{\text{DS}}^{p}] \\ &+ \sqrt{U_b N_p N_c} Cov[\mathbf{h}, \mathbf{I}_{\text{DS}}^{p}] + \sqrt{U_b N_p N_c} Cov[\mathbf{I}_{\text{DS}}^{p}, \mathbf{h}] \\ &+ Cov[\mathbf{I}_{\text{DS}}^{p}]. \end{aligned} \tag{22}$$

In (22), $Cov[\mathbf{I}_{\text{DS}}^{p}]$ and $Cov[\mathbf{h}]$ are calculated based on (13) and (14). The other terms can be derived easily with similar procedures. We use MMSE to estimate $\mathbf{h}$ in (20) based on the observation of the pilot vector $\mathbf{T}$.

$$\begin{aligned} \hat{\mathbf{h}} = \mathbf{E}[\mathbf{h}|\mathbf{T}] = \left(Cov[\mathbf{h}, \mathbf{T}] Cov^{-1}[\mathbf{T}] \right) \mathbf{T} \\ + \mathbf{E}[\mathbf{h}] - Cov[\mathbf{h}, \mathbf{T}] Cov^{-1}[\mathbf{T}] \mathbf{E}[\mathbf{T}] \end{aligned} \tag{23}$$

It can be shown that

$$Cov[\mathbf{h}, \mathbf{T}] = \sqrt{U_b N_p N_c} Cov[\mathbf{h}] + Cov[\mathbf{h}, \mathbf{I}_{\text{DS}}^{p}] \tag{24}$$

After the channel estimation, the detection starts based on a ML test criteria conditioned on the channel estimate. ML test for the 0th detected bit of the $(k = 1)$th DS=UWB receiver DEV is given by [12]

$$\begin{aligned} \Delta = ln \left(\frac{p(\mathbf{S}|\hat{\mathbf{h}}, d_{0,1} = 1)}{p(\mathbf{S}|\hat{\mathbf{h}}, d_{0,1} = -1)} \right) = \\ \mathbf{E}[\mathbf{S}|\hat{\mathbf{h}}, d_{0,1} = 1]^T Cov[\mathbf{S}|\hat{\mathbf{h}}, d_{0,1}]^{-1} \mathbf{S}, \end{aligned} \tag{25}$$

where $\mathbf{S}$ is a vector composed of real and imaginary parts of L correlator outputs which correspond to 0th transmitted bit. $\mathbf{S}$ is defined similar to $\mathbf{T}$ as

$$\begin{aligned} \mathbf{S} =& \begin{bmatrix} \mathbf{Re}[S_0] \ \mathbf{Im}[S_0] & ..... & \mathbf{Re}[S_{L-1}] \ \mathbf{Im}[S_{L-1}] \end{bmatrix} \\ =& \sqrt{U_b N_c} d_{0,1}\mathbf{h} + \mathbf{I}_{\text{DS}}^{p} + \mathbf{I}_{int}^{p} + \mathbf{n}_{\text{DS}}^{p}, \end{aligned} \tag{26}$$

V. Numerical Results

In this section we present the numerical results for the BER performance of the DS-UWB system in the presence of MB-OFDM interferers and MUI. The numerical value considered for the DS-UWB system time slot is $T_c = 0.9\ ns$. We consider a MB-OFDM system with 128 subcarriers, each with a spacing of 4.125 MHz. Three bands of operation are defined for a mode-1 device, with center frequencies at 3432 MHz, 3960 MHz and 4488 MHz. The MB-OFDM system hops between these three bands based on a uniform sequential hopping sequence [1]. A fixed-point platform is considered for the simulations. For simplicity, the bandwidth of the DS-UWB receiver and MB-OFDM interferers are considered identical. However, through some modifications in the analysis parameters such as the activity factor, the effect of systems' bandwidth difference can be compensated. Second order Gaussian monocycle pulse is assume as the waveform model for the DS-UWB:

$$q(x) = \frac{2}{T_M^2} \left(1 - \frac{2x^2}{T_M^2} \right) exp \left(-\frac{x}{T_M} \right)^2, \tag{27}$$

where T_M is the time normalization factor with the numerical value given as $T_M = 0.16\ ns$. In this study we have considered 20 multipath components.

Fig. 2 shows the average BER versus E_{b}/N_0 of the DS-UWB system for ideal CSI in the presence of $N_{\text{MB}} = 5$ MB-OFDM interferers and different number of multiuser interferers, N_{DS}, and different number of chips, N_c. As we can see, the system performance improves as the number of chips increases. This improvement can be interpreted as a kind of coding gain achieved by increase in the number of chips

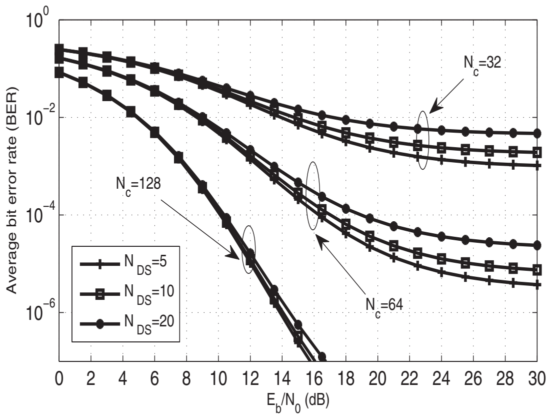

Fig. 2. Average BER versus E_b/N_0 of the DS-UWB system for ideal CSI in the presence of different number of multiuser interferers and number of chips, assuming $N_{\rm MB} = 5$.

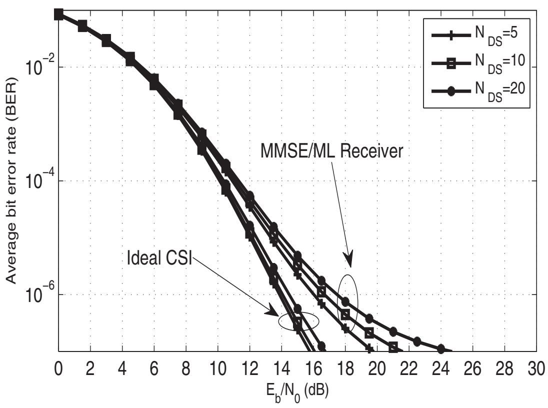

Fig. 3. Average BER versus E_b/N_0 of the DS-UWB system for ideal CSI and MMSE/ML in the presence of different number of multiuser interferers, assuming $N_c = 128$ and $N_{\rm MB} = 5$.

in the spreading signature. In fact this sequence is multiplied to the signal and the system robustness increases as the chips increase. The increase in the number of chips is less desirable at a fixed frame width, in a reverse interference scenario when the DS-UWB is the source of interference onto a MB-OFDM receiver. It is also observed that DS-UWB is more sensitive to MUI in lower number of chips per information bit.

Fig. 3 shows the average BER versus E_b/N_0 of the DS-UWB system for ideal CSI and MMSE/ML in the presence of different number of multiuser interferers, assuming $N_c = 128$ and $N_{\rm MB} = 5$. In this plot we notice that the performance of MMSE/ML receiver is quite acceptable, comparing with the ideal CSI case. However, the performance is more remarkable in lower E_b/N_0.

VI. Conclusion

In this paper, we proposed a UWB channel estimation for DS-UWB receivers while impaired by multi-user interference and MB-OFDM interference. Heterogeneous UWB-based WPANs was considered for the network topology. As for the channel estimation, we employed a pilot sequence transmission phase and the minimum mean square error estimation technique. In the data transmission phase, a maximum-likelihood criteria was used to detect the data bits using the channel estimation information which was obtained during the pilot transmission. It was realized that increase in the number of chips in the DS-UWB system can improve the performance significantly, while at the same time it can reduce the system degradation due to an increase in the number of multi-user interferers. The performance of our proposed channel estimation and data detection technique was also compared to the ideal channel state information case and it was observed that its performance is quite acceptable, especially in lower values of E_b/N_0.

References

[1] A. Batra, J. Balakrishnan, A. Dabakand, and al, "Multi-band OFDM physical layer proposal for IEEE 802.15 task group 3a," *IEEE P802.15-03/268r3*, Mar. 2004.

[2] R. Fisher, R. Kohno, M. Mclaughlin, and al, "DS-UWB physical layer submission to 802.15 task group 3a," *IEEE P802.15- 04/0137r4*, Jan. 2005.

[3] J. Bellorado, S. S. Ghassemzadeh, L. J. Greenstein, T. Sveinsson, and V. Tarokh, "Coexistence of ultra-wideband systems with IEEE-802.1la wireless LANs," in *Proc. IEEE Global Telecommunications Conference (Globecom'03)*, vol. 1, Dec. 2003, pp. 410–414.

[4] M. Hamalainen, J. Saloranta, J.-P. Makela, I. Oppermann, and T. Patana, "Ultra-wideband signal impact on the performances of IEEE 802.11b and bluetooth networks," *International Journal of Wireless Information Networks*, vol. 10, no. 4, pp. 201–210, Oct. 2003.

[5] A. Giorgetti, M. Chiani, and M. Z. Win, "The effect of narrowband interference on wideband wireless communication systems," *IEEE Trans. Commun.*, vol. 53, no. 12, pp. 2139–2149, Dec. 2005.

[6] R. Giuliano and F. Mazzenga, "On the coexistence of power-controlled ultrawide-band systems with UMTS, GPS, DCS1800 and fixed wireless systems," *IEEE Trans. Veh. Tech.*, vol. 54, no. 1, pp. 62–81, Jan. 2005.

[7] K. B. Letaief and N. Boubaker, "MMSE multipath diversity combining for multi-access TH-UWB in the presence of NBI," *IEEE Trans. on Wireless Commun.*, vol. 5, no. 4, pp. 712–719, Apr. 2006.

[8] V. Lottici, A. D'fAndrea, and U. Mengali, "Channel estimation for ultra-wideband communications," *IEEE J. Sel. Areas Commun.*, vol. 20, no. 9, pp. 1638–1645, Dec. 2002.

[9] T.-K. Liu, X. Dong, and W. Lu, "Compressed sensing maximum likelihood channel estimation for ultra-wideband impulse radio," in *Proc. IEEE International Conference on Communications (ICC'09))*, vol. 1, 2009, pp. 1–5.

[10] Y. Zhang, H. Wu, Q. Zhang, and P. Zhang, "Interference mitigation for coexistence of heterogeneous ultra-wideband systems," *EURASIP J. on Wireless Commun. and Netw.*, vol. 2006, pp. 1–13.

[11] A. Mehbodniya and S. Aissa, "Coexistence between DS-UWB and MB-OFDM: analysis and interference mitigation," in *Proc. IEEE Global Telecommunications Conference (Globecom'07)*, vol. 1, Washington, DC, USA, Nov. 2007, pp. 5200–5204.

[12] C. R. C. M. da Silva and L. B. Milstein, "The effects of narrow-band interference on uwb communication systems with imperfect channel estimation," *IEEE J. Sel. Areas Commun.*, vol. 24, no. 4, pp. 717–723, Apr. 2006.

[13] A. Nasri, R. Schober, and L. Lampe, "Analysis of narrowband communication systems impaired by MB-OFDM UWB interference," *IEEE Trans. on Wireless Commun.*, vol. 6, no. 11, pp. 4090–4100, November 2007.

[14] J. Lehnert and M. Pursley, "Error probabilities for binary direct-sequence spread-spectrum communications with random signature sequences," *IEEE Trans. on Commun.*, vol. 35, no. 1, pp. 87–98, Jan 1987.

[15] A. Mehbodniya and S. Aissa, "Performance of DS-UWB in MB-OFDM and multi-user interference over nakagami-m fading channels," *Wiley Wireless communications and Mobile Computing, First published online 18 Jan 2011.*