DS-SS UWB Wireless Personal Area Network: BER and PER Evaluation under an MMSE Receiver

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Abstract

This paper focuses on the performance evaluation of a Direct Sequence - Spread Spectrum (DS-SS) Ultra Wideband (UWB) network in an indoor environment where receiver and transmitter positions are fixed. In particular, a novel distance and time dependent impulse response has been obtained and considered for our performance evaluation. Moreover, from receiver side, a Minimum Mean Square Error (MMSE) receiver has been considered in order to get the Bit Error Rate (BER) and Packet Error Rate (PER) estimation in many simulation conditions where distance, data rates and noise level are changed. PER analysis has been carried out by using a polynomial regression technique, through the Matlab tool, on simulation results. BER and PER vs. transmitter-receiver distance and number of users performance evaluations have been outlined.

1 INTRODUCTION

Recent work in the area of wireless systems indicates that UWB radio is a viable technology for short-range multiple access communications. The potential strength of the UWB-radio technique lies in its use following desirable capabilities including: accurate position location and ranging, and lack of significant multi-path fading due to fine delay resolution; multiple access due to wide transmission bandwidths; covert communications due to low transmission power operation; possible easier material penetration due to the low frequency components [6-7].

Due to these technical advantages and to the recent commercial interest, IEEE founded the task group 802.15.3a in order to standardize a physical layer for UWB communications systems. However, the UWB technology is not yet fully developed, and an accurate channel model that accurately describes the UWB propagation through distance and time dependent impulse response and a detailed BER and PER evaluation on this channel model needs to be exploited.

The goal of this paper is to analyze the efficiency in terms of PER and BER of the DS-SS physical layer standard proposal, described in [1], in an indoor environment modeled by time and distance dependent impulse response, with fixed transmitters and receiver positions.

The DS-SS technique provides a *Wireless Personal Area Network* (WPAN) with a very high data rate. This UWB system employs direct sequence spreading of *binary phase shift keying* (BPSK) and *quaternary bi-orthogonal keying* (4BOK) UWB pulses. Forward error correction coding (convolutional coding) is used with a coding rate of ½. The proposed UWB system can work in two different bands: the first one on the spectrum from 3.1 to 4.85 GHz (low band) and the second one on the spectrum from 6.2 to 9.7 GHz (high band). As a device is required to implement only support for low band and BPSK modulation, our model works only in these conditions.

Considering references [2-3-5], our contribution is the modeling and the performance evaluation of a new channel model, in which the dependence on distance between transmitter and receiver is explicit. Therefore, in opposition to [2], impulse response is also function of distance and not only of time. That is to say, the first path delay is, for the *Line of Sight* (LOS) scenario, the needed time to cover a fixed distance between transmitter and receiver, while, for the *Non-Line of Sight* (NLOS) scenario, we found that this delay is uniformly distributed in an interval proportional to the length of the straight line, connecting transmitter and receiver, which is computed ignoring possible obstacles. Once the delay of rays, following the first path, has been obtained, according to the Saleh-Valenzuela model [5], we estimate the distances covered by each path, so we can compute the attenuation of impulse response gain coefficients using Ghassemzadeh's model [3].

Moreover, the performance evaluation of UWB channel, in accordance with the standard model IEEE 802.15.3a, is exploited in a wider operative range than the work proposed in [4]. In order to recover the signal we employed an adaptive multi-user receiver, using the MMSE algorithm. As described in [4], the MMSE is more effective than a four or eight fingered RAKE at multipath combining and its complexity is constant. In addition, the MMSE has the

advantage of suppressing *inter-symbol interference* (ISI) due to paths within the observation window.

BER analysis of an ideal MMSE receiver is exploited in terms of distance, noise and data rates dependence giving a lower bound for real MMSE performance. Moreover, PER analysis, has been carried out on simulation results using a polynomial regression technique provided by the Matlab tool.

The paper is organized as follows: section 2 introduces our channel model adopted in the simulation environment; performance evaluation of an ideal MMSE receiver and PER analysis are presented in section 3; a brief overview on other wireless channels modeling and performance evaluation is given in section 4; simulation results and conclusions are respectively given in section 5 and section 6.

2 CHANNEL MODEL

According with [2] and [5], we used an S-V approach for the time-of-arrival statistics: paths arrive in a cluster, so we need to distinguish between the cluster arrival time and ray arrival time. In [2] and [5] it is assumed that the arrival time of first path is zero, while our model provides explicit distance dependence. In fact, for LOS scenarios, we assume that the delay of the first path (direct component) is the necessary time to cover the distance between the transmitter and receiver. If *d* is this distance in meters, then the time of arrival is given by $T_1 = d/c$, where *c* is the light speed in m/s. For the NLOS scenario, instead, we experimentally found that the arrival time of the first path is uniformly distributed in the interval $\left(\frac{d}{c}, \frac{d+1}{c}\right]$.

For both scenarios, as described in [5], the delay of rays that follow the first path is a Poisson process with rate λ, while the clusters arrival is another Poisson process with rate Λ, which is smaller than the ray arrival rate. Therefore, defining:

- T_l, the arrival time of the first path of the *l*-th cluster;
- $\tau_{k,l}$, the delay of the *k*-th path within the *l*-th cluster relative to the first path arrival time,
- Λ, cluster arrival rate;
- λ, ray arrival rate, i.e., the arrival rate of path within each cluster;

the distributions of clusters and rays arrival times are given by:

$$P(T_l / T_{l-1}) = \Lambda\, e^{-\Lambda(T_l - T_{l-1})} \quad l > 0 \tag{1}$$

$$P(\tau_{k,l} / \tau_{k-1,l}) = \lambda\, e^{-\lambda(\tau_{k,l} - \tau_{k-1,l})} \quad k > 0 \tag{2}$$

Once the paths delay is obtained, we can compute the effective distances covered by each path:

$$d_{k,l} = \tau_{k,l} \cdot c \qquad k = 1 \ldots K; l = 1 \ldots L \tag{3}$$

where $d_{k.l}$ is the covered distance of the *k*-th path within the *l*-th cluster, *K* is the number of paths in the *l*-th cluster and *L* is the number of the total cluster.

As described in [3], the power attenuation in decibels, due to distance, is at some distance *d*:

$$\begin{aligned}\overline{PL(d)} = &\left[PLo + 10\mu_\gamma \log d \right] \\ &+ \left[10 n_1 \sigma_\gamma \log d + n_2 \mu_\sigma + n_2 n_3 \sigma_\sigma \right]\end{aligned} \tag{4}$$

where the intercept point *PLo* is the path loss at $d_0 = 1\,\text{m}$, μ_γ and σ_γ are respectively the average value and the standard deviation of the normal distribution of the decaying path loss exponent γ. The shadowing effects, in accordance with [3], are modeled through a zero-mean Gaussian distribution with standard deviation σ, normally distributed and characterized by an average value μ_σ and standard deviation σ_σ. n_1, n_2 and n_3 are zero-mean Gaussian variables with unit standard deviation *N*[0,1]. The first term of eq.4 represents the median path loss, while the second term is the random variation around the median value.

Gaussian distributions for n_1, n_2 and n_3 must be truncated so as to keep γ and σ from taking on impractical values. The solution is to confine them to the following ranges:

$$n_1 \in [-1.25, 1.25] \qquad n_2, n_3 \in [-2, 2]$$

If we denote with $\alpha_{k,l}(d_{k,l})$ the gain coefficient of the *k*-th path relative to the *l*-th cluster, then inserting distance computing in (3) into (4), we can obtain attenuated amplitude of each path, referenced to a unit amplitude, as

$$\beta_{k,l} = 10^{-\overline{PL(d_{k,l})}/20} \tag{5}$$

$$\alpha_{k,l}(d_{k,l}) = p_{k,l}\beta_{k,l} \tag{6}$$

where $p_{k,l}$ is equiprobable +/-1 to account for signal inversion due to reflections.

Therefore, the time-distance dependent channel impulse response is described by:

$$h(t,d) = \sum_{l=0}^{L} \sum_{k=0}^{K} \alpha_{k,l}(d_{k,l}) \delta(t - T_l - \tau_{k,l}) \tag{7}$$

where k=1…K and l=1…L.

In Figure 1 and in Figure 2 are plotted two impulse response realizations for the NLOS scenario and for a distance between transmitter and receiver respectively of 1m and 5m. We can see that distance increase also means a rise of first path delay and more power attenuation of the components.

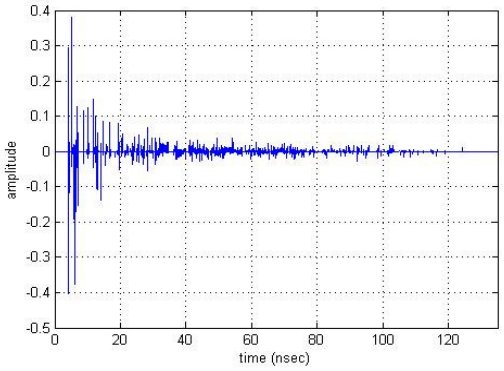

Figure 1. Impulse Response for NLOS scenario with Tx-Rx distance =1m.

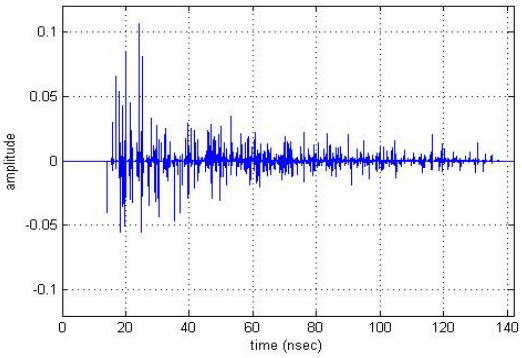

Figure 2. Impulse Response for NLOS scenario with Tx-Rx distance =5m.

3 IDEAL MMSE RECEIVER AND PER REGRESSION ANALYSIS

In DS-SS system, the k-th user's transmitted signal can be expressed as:

$$x_k^{\{v\}}(t) = \sum_{i=1}^{M} b(i) \cdot s_k^{\{v\}}(t) \tag{8}$$

where M is the packet length, the symbol $\{\cdot\}$ means that the signal $x_k(t)$ is also a function of the data rate v while $b(i)$ is the bipolar representation of bits BPSK modulated by a signature waveform $s_k^{\{v\}}(t)$, so -1 or +1 can be assumed depending on the signaling bits. $s_k^{\{v\}}(t)$ consists of a train of pulses, known as Gaussian UWB monocycles, which are modulated by signature spreading sequence of user k, and depends on the data rate v (in fact, spreading sequence length is related to transmission rate and so to the pulses number, composing $s_k^{\{v\}}(t)$, changes on the basis of v).

If k-th user's signal is transmitted through a multipath channel, characterized by an impulse response $h(t,d)$ given by (7), the relative received signal can be expressed as:

$$y_k^{\{v,d\}}(t) = x_k^{\{v\}}(t) \otimes h(t,d) \tag{9}$$

where $\otimes$ is the convolution operator and $\{v,d\}$ denotes that $y_k(t)$ depends also on distance and rate.

The total received signal is then:

$$r^{\{v,d\}}(t) = y_k^{\{v,d\}}(t) + n(t) \tag{10}$$

where $n(t)$ is zero-mean *Additive White Gaussian Noise* (AWGN).

The MMSE receiver is composed of a pass-band filter, for noise and out-of-band interferences suppressions, and an adaptive filter, which acts as a correlator [4].

The observation window of the adaptive filter represents the time in which it "examines" the received signal samples, in order to take a decision on the current bit value. Assuming that T is the duration of observation windows, then the i-th window for the i-th bit decision is:

$$\left(t_0 + (i-1)T_b \ , \ t_0 + (i-1)T_b + T\right)$$

where T_b is the symbol period.

Without loss of generality, we assume that there is only one transmitting user, that we denote with k, and that there is no interference due to a multiple channel access. In addition, we can suppose that T=T_b, because the i-th observation window contains the most of the energy of the i-th bit and the effects on the next incoming bits are negligible.

If user k, placed at some distance d from receiver, transmits with a data rate v a single positive bit through the channel, it is received as:

$$z_k^{\{v,d\}}(t) = s_k^{\{v\}}(t) \otimes h(t,d) \otimes h_b(t) \tag{11}$$

where $h_b(t)$ is the impulse response of the pass-band filter (Figure 3).

The number of signal samples in each observation window is given by:

$$N_b = \frac{T_b}{T_s} = \frac{N \cdot L}{T_s}$$

where T_s is the sampling time, N the number of samples with which each impulse is discretized and L is the length of used spreading sequence (that is to say the number of pulses for each symbol).

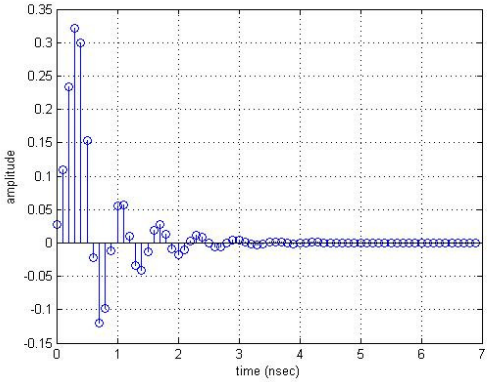

Figure 3. Chebyshev passband filter impulse response.

Referring to [4], we define:

$$j_0 \triangleq \frac{t_0}{T_s}, \quad \tilde{z}_k^{\{v,d\}}(j) \triangleq z_k^{\{v,d\}}(jT_s), \quad \tilde{r}^{\{v,d\}}(j) \triangleq r_b^{\{v,d\}}(jT_s), \quad \tilde{n}(j) \triangleq n_b(jT_s) \qquad j = 1, 2, \ldots \tag{12}$$

where t_0, and therefore j_0, is set so that i-th observation window contains most of the energy from the bit of user k, the symbols with a "tilde" denote the discrete-time version of the continuous-time signals while $r_b(\cdot)$ and $n_b(\cdot)$ are the bandpass filtered versions of $r(\cdot)$ and $n(\cdot)$.

Let us denote the taps vector of the adaptive filter and the received signal in the i-th observation window with:

$$\mathbf{w} \triangleq \left[w(1) \;\; w(2) \;\; \ldots w(N_b) \right]^T \tag{13}$$

$$u^{\{v,d\}}(i) \triangleq \left[\tilde{r}^{\{v,d\}}(j_0 + (i-1)N_b + 1) \;\ldots\; \tilde{r}^{\{v,d\}}(j_0 + (i-1)N_b + N_b) \right]^T \tag{14}$$

From (11) and (12) can be written:

$$u^{\{v,d\}}(i) = b_k(i) \cdot \bar{z}_k^{\{v,d\}}(i) + \bar{n}(i) \tag{15}$$

where

$$\bar{n}(i) \triangleq \left[\tilde{n}(j_0 + (i-1)N_b + 1) \;\ldots\; \tilde{n}(j_0 + (i-1)N_b + N_b) \right]^T \tag{16}$$

$$\bar{z}_k^{\{v,d\}}(i) \triangleq \left[\tilde{z}_k^{\{v,d\}}(j_0 + (i-1)N_b + 1) \;\ldots\; \tilde{z}_k^{\{v,d\}}(j_0 + (i-1)N_b + N_b) \right]^T \tag{17}$$

According with [4], the optimal tap vector to detect user k's i-th bit is:

$$\tilde{\mathbf{w}} = \left[\bar{z}_k^{\{v,d\}}(i) \cdot \bar{z}_k^{\{v,d\}H}(i) + R \right]^{-1} \cdot \bar{z}_k^{\{v,d\}}(i) \tag{18}$$

where H denotes the conjugate transpose and R is the covariance matrix of $\bar{n}(i)$:

$$\mathbf{R} \triangleq E\left\{ \bar{n}(i) \cdot \bar{n}^H(i) \right\} \tag{19}$$

The i-th output of the MMSE filter can be written as:

$$\beta(i) = \tilde{\mathbf{w}}^H u(i) = \tilde{\mathbf{w}}^H \bar{z}_k(i) b_k(i) + e_g(i) \tag{20}$$

where $e_g(i)$ is the residual Gaussian noise after pass-band filtering.

Since the pass-band and MMSE filtering are linear operations and $n(t)$ has zero-mean, therefore $e_g(i)$ is a linear combination of $n(t)$ and it is also a approximately zero-mean Gaussian variable. So, the BER can be written as:

$$Pe(v, d, 2\sigma^2) = Q\left(\sqrt{\frac{\tilde{\mathbf{w}}^H \bar{z}_k^{\{v,d\}}(i)}{\sigma_g^{2\{\sigma^2\}}}} \right) \tag{21}$$

where σ_g^2 is the variance of $e_g(i)$ and is given by:

$$\sigma_g^2 = \sigma^2 \sum_j \left| h_{bw}(j) \right|^2 \tag{22}$$

where $2\sigma^2$ is the *Power Spectral Density* (PSD) of the AWGN while $h_{bw}(j)$ is:

$$h_{bw}(j) \triangleq h_b(j) \otimes \tilde{w}(j) \tag{23}$$

Eq.(21) expresses the BER for a DS-SS system utilizing an ideal MMSE receiver and subject to multipath fading for a given transmission rate, a given distance between transmitter and receiver and a given power level of the background noise. *Forward Error Correction* (FEC) techniques after the MMSE receiver have not been accounted such as in [4]. The expression (21) gives a lower bound for real MMSE performance.

The PER analysis has been carried out by using a polynomial regression technique, by the Matlab tool, on simulation results. The general expression for the PER can be written by a n-th order polynomial regression:

$$PER(d) = \begin{cases} 1 & d > d_{\max} \\ \left[a_0 \;\; a_1 \;\; \ldots \;\; a_n \right] \cdot \begin{bmatrix} 1 \\ d \\ \vdots \\ d^n \end{bmatrix} = \langle a \rangle \cdot \langle d \rangle^T & d_{\min} < d \le d_{\max} \\ 0 & d \le d_{\min} \end{cases} \tag{24}$$

where the polynomial order, coefficients vector $\langle a \rangle$ and the distances d_{min} and d_{max} are related to the considered scenarios (LOS or NLOS), to the data rates and to the background noise level (d_{max} must be intended boundless where it is not specified).

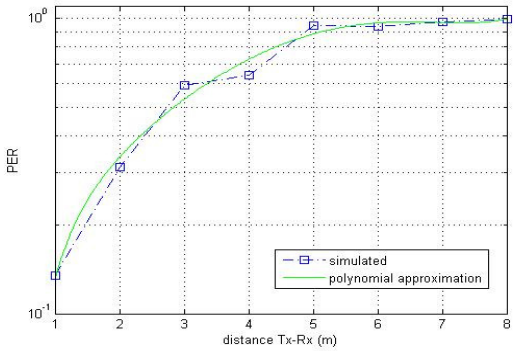

Figure 4. Simulation results and their polynomial approximation for 110Mbps-NLOS scenario, noise variance 10^{-2}.

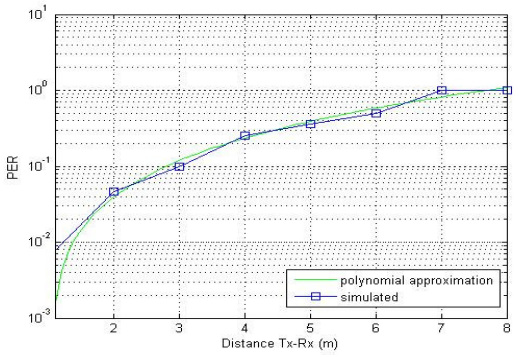

Figure 5. Simulation results and their polynomial approximation for 220Mbps-NLOS scenario, noise variance 10^{-5}.

Specifically, from a regression analysis for the rate 110 Mbps in the LOS scenario with variance noise 10^{-2} the following values were obtained:

$$\langle a \rangle = [-0.2223 \quad 0.50571 \quad -0.20831 \quad 0.06385 \quad -0.0088767 \quad 0.00043242]$$
$$d_{\min} = 1m, \quad d_{\max} = 8m,$$

which, substituted in (24), lead to:

$$\begin{cases} PER(d) = 1 & d > 8 \\ PER(d) = 0.00043242 \cdot d^5 - 0.0088767 \cdot d^4 + 0.06385 \cdot d^3 + \\ \qquad -0.20831 \cdot d^2 - 0.50571 \cdot d - 0.2223 & 1 < d \le 8 \\ PER(d) = 0 & d \le 1 \end{cases}$$

A measure of the goodness of fit is the Euclidean norm of residuals, where the fit residuals are defined as the difference between the ordinate data point and the resulting fit for each abscissa data point. A smaller value of the norm of residuals indicates a better fit than a larger value: therefore the trend to zero of the norm means an almost perfect approximation (see Matlab documentation for further details).

In Figure 4 it can be seen how previous expression approximates very well to the PER above all for sufficiently large values (this is confirmed by norm which assumes quite a small value at 0.12765).

For the rate 220Mbps, in an NLOS scenario with low background noise (variance 10^{-5}), the carried out analysis, instead, produced the following results:

$$\langle a \rangle = [-0.0029504 \quad -0.016999 \quad 0.019117],$$
$$d_{\min} = 1m, \quad d_{\max} = 8m,$$

thus:

$$\begin{cases} PER(d) = 1 & d > 8 \\ PER(d) = 0.019117 \cdot d^2 - 0.016999 \cdot d - 0.0029504 & 1 < d \le 8 \\ PER(d) = 0 & d \le 1 \end{cases}$$

which, as can be seen from Figure 5, supplies an excellent approximation (also in this case a confirmation of the good approximation is given by residuals norm which is at 0.21512).

4 RELATED WORK

In order to develop a unique standard for the physical layer of WPAN networks, owing to increasing interest arising in the international market for UWB technology, the IEEE decided to create the 802.15.3a working group.

Three standards have become the most considered in the academic and industrial environment in the last few years: DS-SS [1], Orthogonal Frequency Division Multiplexing (OFDM) [8] and Time Hopping-Pulse Position Modulation (TH-PPM) [9]. In this paper, we focused on the DS-SS because it represents a possible candidate to be standardized in the next future. The communication system described in [9] is based on a specific model proposed in [10], where an analytical modeling for TH-PPM, in the presence of an ideal channel with multiple access, is considered.

Other more general approaches for the channel modeling of UWB networks, taking into account multipath fading, shadowing and path loss have been considered in [2,3,5,11,12]. In particular, in [3], through different simulation campaigns, paths power attenuation was shown to follow a log-normal distribution, which is a function of the distance between the transmitter and receiver. In [2,5] the arrival of paths on each sampling time interval is not assumed, but they follow a cluster-based arrival rate. These

characteristics are different from the classical IEEE 802.11 wireless networks channel models.

In the Saleh-Valenzuela (S-V) model, the paths arrival times are modeled through two Poisson distributions, where the first one is used to model the arrival time of the first path in each cluster, while the second one describes the arrival time of other paths in each cluster [5]. The path amplitudes follow a Rayleigh distribution law, with a double exponential decaying model.

In [2], contrarily to [5], the authors affirm the inapplicability of the central limit theorem for UWB systems and they propose a log-normal distribution to approximate the amplitudes of the power associated with the path components. However, in [2], the impulse response is not explicitly associated with the transmitter-receiver distance. Thus, following the model presented in [2], it is possible to account for the distance dependence by modifying the first path time arrival and using, for the paths decaying power, log-normal distribution laws obtained in [3].

In [4], instead, an analytical treatment is carried out on the performance in terms of BER of an ideal MMSE. Specifically, the authors analyze the behaviour of the receiver in the presence of a multipath fading channel and as a function of the interferences due to OFDM devices, to the multi-access (that is, in the presence of other DS-UWB devices) and to the background noise. In our treatment, instead, we have focused attention mainly on the performance of the MMSE receiver as a function of rate (in [4] a single data rate with spreading sequence length 15 was considered) and of the distance. We have taken into account the distance through a channel model characterized by a time-distance dependent impulse response (in [4] impulse responses as a function only of time, obtained by measurements carried out in home environments, are considered, therefore distinction is made only between the LOS and NLOS scenarios and distance between the transmitter and receiver is not explicated).

5 PERFORMANCE EVALUATION OF THE DS-SS UWB

Many simulation campaigns have been lead out in order to evaluate the performance of the DS-SS physical layer for the UWB technology. Simulation scenario and simulation results will be presented in the following.

5.1 Simulation Scenario

The transmitted bits sequence is estimated using a MMSE receiver described in [4]. For the Matlab simulation, we use the MMSE model available on the web at [11]. At each bit epoch, a bit decision is made at the output of correlator and it is then fed back to the adaptive filter. This receiver uses an adaptive algorithm called *Normalized Least Minimum Square* (NLMS) to update weights vector *W*. The equation to calculate the weights is specified below. For more details refer to [4].

$$W(i) = W(i-1) + \mu_m \, e(i) \frac{u^*(i)}{\varepsilon + u^H(i)u(i)} \tag{25}$$

In (25), μ_m is the step size, while ε is a small positive constant that has been added (to denominator) to overcome potential numerical instability in the update of the weights; *e(i)* is the error associated with the *i*-th estimated bit; *u(i)* represents the discrete input signal of the adaptive filter. We use a MMSE receiver with 64 taps per observation window size and a step size of 0.5.

We operate in low band piconet channel 1 with a chip rate of 1313 MHz. We also use *Pseudo Noise* (PN) ternary spreading codes of variable length and FEC of rate ½.

Regarding the PER, in our simulations, where not specified, we used fixed dimension packets of 128 bytes.

In the multi-access simulations, we suppose that all users are placed at the same distance from the receiver and that they transmit with the same power. Moreover, we also suppose that the receiver target is recovering information transmitted by user 1.

In Table 1 are listed further simulation parameters: the values of Λ and λ are set in according with [2], while remaining parameters are set in according with [3]. Some simulation results are shown in the following.

TABLE 1
MODEL PARAMETERS

Symbol	LOS	NLOS
Λ [1/nsec] (cluster arrival rate)	0.004~0.0233	0.067~0.4
λ [1/nsec] (path arrival rate)	2.1~10.2	0.5~2.1
PL_0 [dB] (intercept point)	1.4754	1.7502
μ_γ (mean value of paths decay exponent)	1.7	3.5
σ_γ (std. dev. of paths decay exponent)	0.3	0.97
μ_σ [dB] (average value of shadowing standard deviation)	1.6	2.7
σ_σ [dB] (std. dev. of shadowing standard deviation)	0.5	0.98

5.2 Simulation Results

BER vs. distance curves for 110Mbps and 220Mbps in LOS and NLOS scenarios in the presence of low background white Gaussian noise (variance 10^{-5}) are plotted in Figure 6.

We can see how the 110Mbps data rate rejects *Inter-Symbol Interference* (ISI) better than the higher rate because of longer spreading codes. In fact, a longer ternary spread sequence has more zero-valued windows than a shorter sequence in their autocorrelation function, so interference due to multipaths that are within these windows can be eliminated in particular in the LOS scenario where the presence of a stronger direct component makes the impact of the ISI less damaging.

The BER curve vs. transmitter-receiver distances for the LOS and NLOS scenarios with 10^{-2} variance is depicted in Figure 7. In this case the power level of the noise is almost the same as that of the signal, therefore it adds to the negative effects of the ISI further worsening the performance of the system (the impact of the noise is greater for longer distances and in the NLOS scenario because the power level of the received signal decreases with the increase in distance and in NLOS conditions).

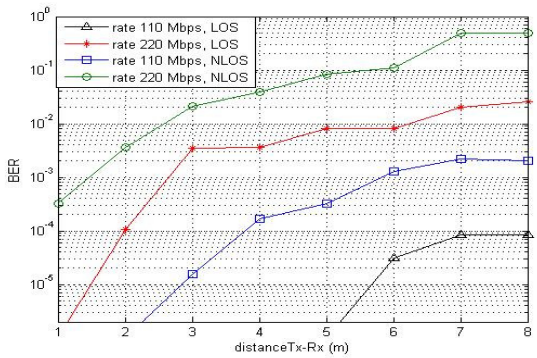

Figure 6. BER vs. distance for LOS-NLOS scenario, noise variance 10^{-5}.

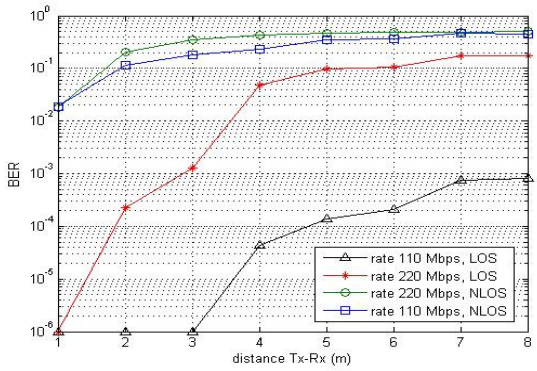

Figure 7. BER vs. distance for LOS-NLOS scenario, noise variance 10^{-2}.

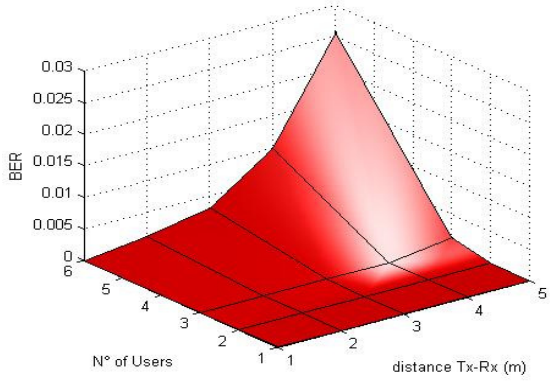

Figure 8. BER vs. distance and number of users for scenario NLOS, rate 28 Mbps and noise variance 10^{-5}.

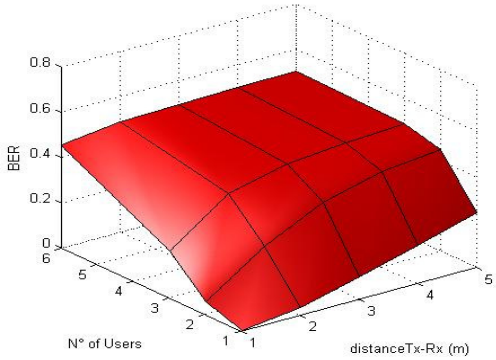

Figure 9. BER vs. distance and number of users for scenario NLOS, rate 220 Mbps and noise variance 10^{-5}.

BER trends vs. transmitter-receiver distance and number of users in the presence of very low background noise (variance 10^{-5}) respectively for 28Mbps data rate in the NLOS scenario and 220Mbps data rate in the LOS scenario are shown in Figure 8 and Figure 9. Also in this case, a greater length of spreading codes means best performance. In fact longer sequences have better cross-correlation properties and so interference between users can be rejected. The 28Mbps rate, thanks to the 24 spreading length is able to avoid interference due to the multiple access of the users and it is able to work in presence of more users, without greatly decreasing system performance. However, in the case of the 220Mbps rate, because the spreading sequences do not present good orthogonal properties, the receiver is not able to correctly separate components coming from different users.

In Figure 10 and in Figure 11 are plotted the PER curves for the rate 110Mbps and rate 220Mbps scenario LOS and NLOS for two distinct noise thresholds (variance 10^{-2} and variance 10^{-5}); also in this case noise can make the estimation of the bits more complicated, therefore there is a

general worsening of the PER with noise increase. If the BER and the PER are compared, it can be seen, instead, how the latter has a worse trend because of the distributed nature of the errors on the bits: in fact, the PER, as demonstrated in [12], is a function of the distribution of the BER and of the packet size; therefore if the packet size is made to go towards one (degenerate case) the PER converges towards the BER, vice versa at increase in the packet size the Packet Error Rate tends to one (Figure 12).

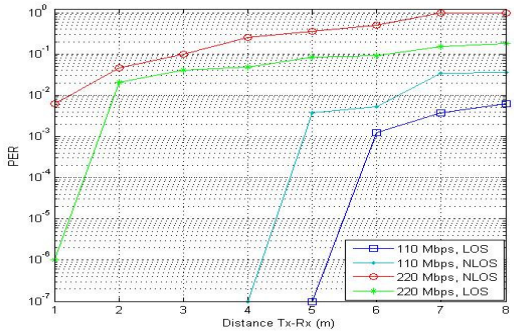

Figure 10. PER course for LOS-NLOS scenarios and noise variance of 10- 5.

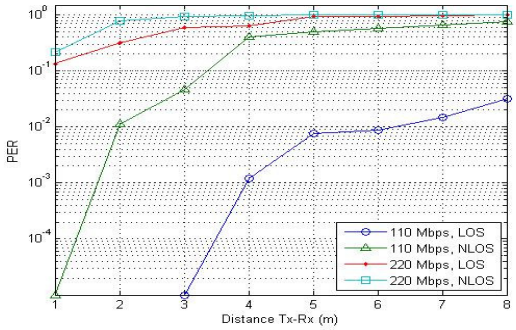

Figure 11. PER course for LOS-NLOS scenarios and noise variance of 10- 2.

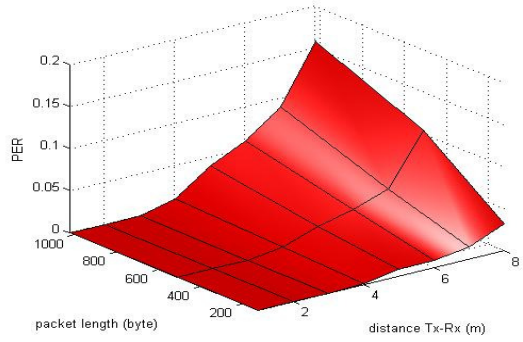

Figure 12. PER vs. packet length and distance for rate 110Mbps in LOS scenario with variance noise 10- 2.

6 CONCLUSION

In this paper a more realistic UWB channel model is considered. An explicit multipath fading distance dependence is considered. PER analysis has been carried out by using a polynomial regression technique, through the Matlab tool, on simulation results. The physical layer of the standard DS-SS 802.15.3a has been implemented. Simulation results show how the performance, in terms of BER and PER, of the UWB channel, for high data rate in the case of lower signal-to-noise ratio and in the presence of interference due to other UWB devices (1-6 users), degrades for increasing distance (1-10m). 28Mbps and 56Mbps rates are slightly influenced by distance, especially for LOS scenario with low noise power level. This is due to the low sensibility to the inter-symbol interference. Instead, higher data rates are more sensitive to the distance and they can be supported for a short distance (<4m) for the LOS scenario and with very low noise power level. Lower data rates are able to correctly work also for a multi-access scenario, while data rates greater than 220Mbps prove to be very sensitive to simultaneous multi-user interference.

REFERENCES

[1] Reed Fisher, Ryuji Kohno, Michael Mc Laughlin, Matt Welborn, "DS-UWB Physical Layer Submission to 802.15 Task Group 3a", *MERGED PROPOSAL #2 802.15.3a* Physical layer.

[2] Molisch, J. Foerster, and M. Pendergrass, "Channel Models for Ultrawideband Personal Area Networks", *IEEE Wireless Communications Magazine*, Dec. 2003.

[3] S. Ghassemzadeh, R. Jana, C. Rice, W. Turin, and V. Tarokh, "Measurement and modeling of an ultra-wide bandwidth indoor channel," *IEEETransaction on Commun.*, pp. 1786–1796, 2004.

[4] Qinghua Li, Member, IEEE, and Leslie A. Rusch, Senior Member, IEEE, "Multiuser Detection for DS-CDMA UWB in the Home Environment", *IEEE Journal on Selected Area in Communications*, VOL. 20, NO. 9, DECEMBER 2002.

[5] Saleh and R. A. Valenzuela, "A statistical model for indoor multipath propagation," *IEEE J. Selected Areas Comm.*, vol. 5, pp. 138–137, Feb. 1987.

[6] David R. McKinstry, "Ultra-wideband small scale channel modelling and its application to receiver design", *Master Thesis*.

[7] Weihua Zhuang, Xuemin (Sherman) Shen, Qi Bi, "Ultra-wideband wireless communications*", Wiley Wireless Communications and Mobile Computing Magazine*, 3 Nov 2003.

[8] A. Batra et al., "Multi-band OFDM physical layer proposal," *Document IEEE P802.15-03/268r3*, march 2004.

[9] A. F. Molisch, et al., "Mitsubishi Electric's Time-Hopping Impulse Radio standards proposal", *document IEEE P802.15-03112*, may 2003.

[10] M. Z. Win, R. A. Scholtz, "Ultra-wide bandwidth time-hopping spread-spectrum impulse radio for wireless multiple-access communications", *IEEE Trans. Communications*, 48, Issue: 4 , pp. 679 –689, april 2000.

[11] http://www.mathworks.com/matlabcentral/fileexchange.

[12] Ramin Khalili, Kavé Salamatian, "Evaluation of Packet Error Rate in Wireless Networks*", MSWIM - Symposium on Modeling, Analysis and Simulation of Wireless and Mobile Systems*,Venice, Italy - October, 2004.