Performance Evaluation of the Packet Error Rate of DS-SS physical layer in UWB Networks

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Abstract

The low cost of devices and the possibility of achieving higher data rates without increasing transmitter power make Ultra-Wideband (UWB) radio a viable candidate for short-range multiple access communications in dense multipath environments. This paper analyses the efficiency in terms of PER of Direct Sequence - Spread Spectrum (DS-SS) physical layer standard proposal in an indoor environment with fixed transmitters and receiver positions. The modelling and the performance evaluation of a new channel model, where impulse response is also distance-dependent, are outlined. Simulation results are evaluated in terms PER vs transmitter-receiver distance and number of users.

***Keywords**: UWB, DS-SS, MMSE, IEEE 802.15.3a.*

1. Introduction

In the last years, the Ultra-WideBand (UWB) communication systems have been extensively studied in both the computer and communication communities. Low cost of devices and possibility to achieve higher data rates without the need to increase transmitter power make the UWB technology a viable candidate for short-range multiple access communications in dense multipath environments; due to this recent commercial interest, IEEE founded the 802.15.3a task group, in order to standardize a physical layer for UWB communication systems [6,7].

The goal of this paper is to analyze the efficiency of DS-SS physical layer standard proposal in terms of Packet Error Rate (PER), described in [1], in a indoor environment with and a novel channel modelling and fixed transmitters and receivers positions.

The DS-SS technique provides a wireless PAN with data payload communication capabilities of 28, 55, 110, 220, 500, 660,1000 and 1320 Mbps. 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 and ¾. 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).

Referring to [2], [3] and [5], we have carried out a new channel modelling, in which the dependence on the real distance between transmitter and receiver is explicit. That is to say, the first path delay is, for the LOS scenario, the needed time to cover a fixed distance between transmitter and receiver, while, for the NLOS scenario, we found that this delay is uniformly distributed in an interval proportionally to the length of the straight line, connecting transmitter and receiver, that is computed ignoring possible obstacles. Once the delay of rays has been obtained, following the first path, according to the Saleh-Valenzuela's 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].

Besides, in order to make the signal recovering we employed an adaptive multi-user receiver, using the minimum mean square error (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 intersymbol interference (ISI) due to paths within the observation window.

The paper is organized as follows: section II gives a bried overview of work related to the channel modeling for UWB networks; considered channel model is presented in section III; section IV shows the performance evaluation results and finally the conclusions are summarized in the last section.

2. 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: Direct.Sequence-Spread Spectrum (DS-SS) [1], Orthogonal

Frequency Division Multiplexing (OFDM) [8] and Time Hopping-Pulse Position Modulation (TH-PPM) [9]. We focused on the DS-SS in this paper because it represents a possible candidate to be standardized in the next future.

Some general approaches for the channel modelling of UWB networks, taking into account multipath fading, shadowing and path loss have been considered in [2,3,5]. In particular, in [3], through different simulation campaigns, paths power attenuation was shown to follow a log-normal distribution, that 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 modelled 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 decay 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 modifying the first path time arrival and using, for the paths decay power, log-normal distribution laws obtained in [3].

In [4], instead, a treatment is carried out on the performances in terms of BER of a MMSE receiver. Specifically, the authors analyse 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 performances in term of PER as a function of rate and of the distance. We have taken into account the distance through a channel model characterized by a time-distance dependent impulse response.

3. Channel Model

According to [2] and [5], we used a Saleh-Valenzuela (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 an explicit distance dependence. In fact, for Line Of Sight (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 $T_1 = \frac{d}{c}$, where *c* is the light speed in m/s. For the Non-Line Of Sight (NLOS) scenario, instead, we experimentally found that the time of arrival 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 are 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.

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

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

where the intercept point *PLo* is the path loss at $d_0 = 1$ 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 modelled 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 variates of 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 about the median value. Gaussian distributions for n_1, n_2 and n_3 must be truncated so as to keep γ and c from taking on impractical values. The solution is to confine them to the following ranges:

$$n_1 \in [-1.25, 1.25] \qquad n_2, n_3 \in [-2, 2] \tag{5}$$

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

$$\beta_{k,l} = 10^{-\overline{PL(d_{k,l})}/20} \tag{6}$$

$$\alpha_{k,l}(d_{k,l}) = p_{k,l}\beta_{k,l} \tag{7}$$

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:

$$h(t,d) = \sum_{l=0}^{L}\sum_{k=0}^{K}\alpha_{k,l}(d_{k,l})\delta(t - T_l - \tau_{k,l}) \tag{8}$$

In Fig.1 is plotted the impulse response realization for the NLOS scenario and for a distance between transmitter and receiver of 5m. We can see that distance increase also means a rise of first path delay and more power attenuation of the components.

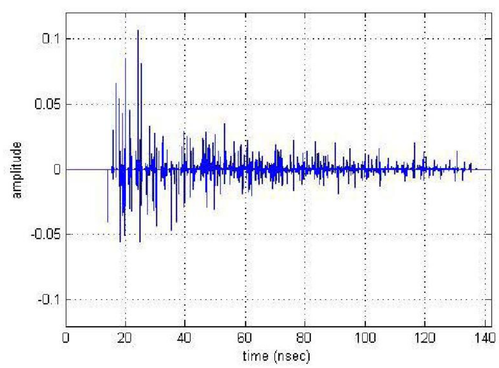

Fig.1. Impulse Response for NLOS scenario with Tx-Rx distance =5m.

4. Performance Evaluation

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

4.1. Simulation Scenario

The transmitted bits sequence is estimated using a MMSE receiver described in [4]. 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 *Normalised Least Minimum Square* (NLMS) to upgrade weights vector W. The equation to calculate the weights is specified below. For more details refer to [4].

$$W(i) = W(i-1) + \mu_m e(i)\frac{u^*(i)}{\varepsilon + u^H(i)u(i)} \tag{9}$$

In (9), is the step size, while 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 PN ternary spreading codes of variable length and FEC of rate ½ and we used fixed dimension packets of 128 bytes.

Parameters adopted in the our channel model are listed in table I.

TABLE I
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

4.2. Simulation Results

For In Fig.2, PER 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.

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 PER curve vs. transmitter-receiver distances for the LOS and NLOS scenarios with 10^{-2} variance is depicted in Fig.3. 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 signal received decreases with the increase in distance and in NLOS conditions).

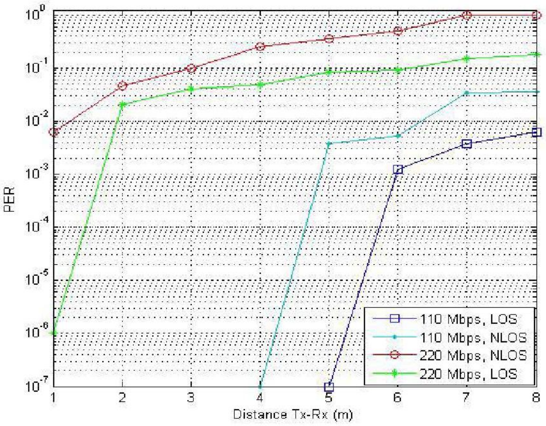

Fig. 2. PER course for LOS-NLOS scenarios and noise variance of 10^{-5}.

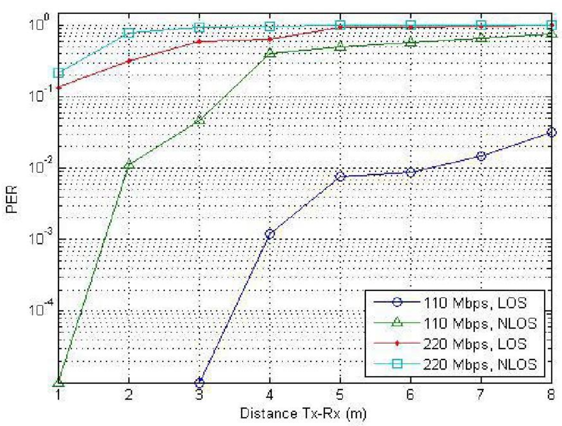

Fig. 3. PER course for LOS-NLOS scenarios and noise variance of 10^{-2}.

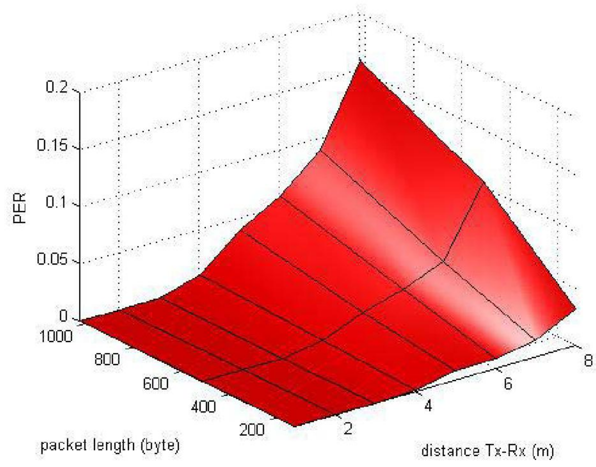

Fig.4. PER vs. packet length and distance for rate 110Mbps in LOS scenario with variance noise 10^{-2}.

Besides, the PER, as demonstrated in [10], is a function of the distribution of the BER and of the size of the packet, 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 (Fig.4).

5. Conclusion

In this paper a more realistic UWB channel model is considered. An explicit multi-path fading distance dependence is considered. The physical layer of the standard DS-SS 802.15.3a has been implemented. Simulation results show how the performance, in terms of PER, of the UWB channel, for high data rate in the case of lower signal-to-noise ratio, degrades for increasing distance (1-10m). Higher data rates are more sensitive to the transmitter-receiver distance and they can be supported for a short distance (<4m) for the LOS scenario and with very low noise power level.

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