Distance-Dependent BER Evaluation of DS-SS IEEE 802.15.3a Physical Layer under Multiple User Data-Rates and Multi-User Interference

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***Abstract*—The Federal Communications Commissions (FCC) defines Ultra Wideband (UWB) radio as a transmission system, whose relative bandwidth is larger than 20%.The UWB system characteristics include high data rates, low power operation, multi-path fading immunity and low cost of devices In this work we propose a new multipath fading indoor channel model for UWB network in which impulse response is time-distance dependent. Using our channel model, we have evaluated the performances of Direct Sequence-Spread Spectrum (DS-SS) Wireless Personal Area Network (WPAN) proposed standard. In particular, we evaluate the Bit Error Rate (BER) as function of transmitter-receiver distance, noise power level and number of simultaneous users.**

***Index Terms*—UWB, DS-SS, MMSE, IEEE 802.15.3a.**

I. INTRODUCTION

Ultra-wideband (UWB) communication techniques have attracted a great interest in both academia and commercial area in the past few years for applications in short-range wireless mobile systems. This is due to the potential advantages of UWB transmissions such as low power, high rate, immunity to multipath propagation, less complex transceiver hardware, and low interference. Due to this recent commercial interest, IEEE founded the task group 802.15.3a in order to standardise a physical layer for UWB communication systems.

The goal of this paper is to analyse the efficiency of *Direct Sequence - Spread Spectrum* (DS-SS) physical layer standard proposal, described in [1], in an indoor environment modelled by time and distance dependent impulse response, with fixed transmitter and receiver positions.

The DS-SS technique provides a wireless PAN with a very high data payload communication capabilities. 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 nominally occupying the spectrum from 3.1 to 4.85 GHz (low band), and the second one nominally occupying 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] and [5], our contribution is the modelling and the performance evaluation of a new channel model, in which the dependence on distance is explicit. Therefore, in opposition to [2], impulse response is also function of distance, and not only of time. Moreover, the performance evaluation of UWB channel, according 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 *minimum mean square error* (MMSE) algorithm [4].

In the following a brief synthesis of the related works, channel model and performance evaluation are respectively given in section II, section III and section IV. Conclusions are summarised in section V.

II. RELATED WORK

The IEEE 802.15.3a working group has mainly considered three standards: *Direct .Sequence-Spread Spectrum* (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 viable candidate to be standardised in the next future.

Many works are developed on the channel model evaluation of UWB technology in the recent years. Channel modelling of UWB networks, accounting multipath fading, shadowing and path loss have been considered in [2,3,5,10,11]. In particular, in [3], through different simulation campaigns, paths power attenuation has been shown to follow a log-normal distribution that is function of the distance between transmitter and receiver. In [2],[5] the arrival of paths on each sampling time interval is not assumed, but a cluster based arrival rate is followed. These characteristics are different by classical IEEE 802.11 wireless networks channel models.

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

In [2], contrarily to [5], authors affirm the inapplicability of the central limit theorem for UWB systems and they propose a log-normal distribution to approximate amplitudes of the power associated to path components. However in [2], impulse response in not explicitly associated to the transmitter-receiver distance. Thus, following the model presented in [2], our proposal is to account the transmitter-receiver distance dependence modifying the first path arrival time and using a log-normal distribution in [5] of the paths power decaying. More details about our approach will be given in the next section.

III. CHANNEL MODEL

For the time-of-arrival statistics, the model uses a Saleh-Valenzuela (S-V) approach [2,5]. As the channel measurements showed multipaths arriving in clusters, so we need to distinguish between cluster arrival time and ray arrival time. In [2] and [5] it is assumed that 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 first path (direct component) is the necessary time to cover the distance between transmitter and receiver. If *d* is such distance in meters, then the time of arrival is given by $T_1 = \frac{d}{c}$, where *c* is light speed in m/s. For the Non-Line Of Sight (NLOS) scenario, instead, we experimentally found that the time of arrival of first path is uniformly distributed in the interval $\left(\frac{d}{c}\ ;\ \frac{d+1(meters)}{c}\right]$.

The distributions of clusters and rays delays, that follow the first path, follow the two Poisson models defined in [2]. Once the paths delay are obtained, we can compute the effective distances covered by each path:

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

where $\tau_{k,l}$ and $d_{k.l}$ are respectively the delay and the covered distance of the *k-th* path within the *l-th* cluster, relative to the first path arrival time, while *K* and *L* are respectively the paths number in each cluster and the total number of cluster. As described in [3], the power attenuation in decibel, due to distance, is at some distance *d*:

$$\begin{aligned}\overline{PL(d)} = &\left[PLo + 10\mu_\gamma \log d\right] \\ &+ \left[10 n_1 \sigma_\gamma \log d + n_2 \mu_\sigma + n_2 n_3 \sigma_\sigma\right]\end{aligned} \tag{2}$$

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, according 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 variables of unit standard deviation N[0,1]. The first term of the eq.2 represents the median path loss, while the second term is the random variation about average value.

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

$$n_1 \in \left[-1.25, 1.25\right] \qquad n_2, n_3 \in \left[-2, 2\right] \tag{3}$$

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 (1) into (2), we can obtain attenuated amplitude of each path, referred to a unit amplitude, as

$$\beta_{k,l} = 10^{-\overline{PL(d_{k,l})}/20} \tag{4}$$

$$\alpha_{k,l}(d_{k,l}) = p_{k,l}\beta_{k,l} \tag{5}$$

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

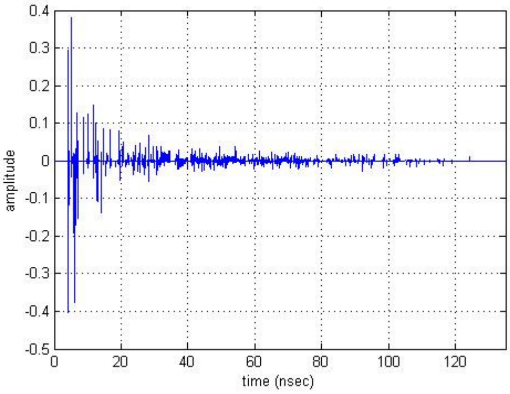

Fig.1. Impulse Response for NLOS scenario with Tx-Rx distance =1m.

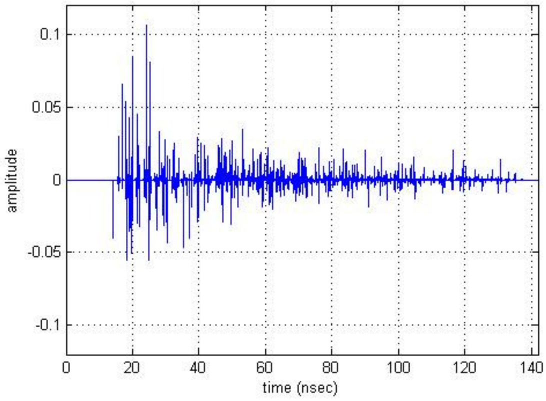

Fig.2. Impulse Response for NLOS scenario with Tx-Rx distance =5m.

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

$$h(t,d)=\sum_{l=0}^{L}\sum_{k=0}^{K}\alpha_{k,l}(d_{k,l})\delta(t-T_l-\tau_{k,l}) \tag{6}$$
$$k=1...K\ ;\ l=1...L$$

Two impulse responses for NLOS scenario and for a distance of 1m and 5m between transmitter and receiver are respectively depicted in Fig.1 e in Fig.2. It is possible to observe the increase of the first path delay for higher transmitter-receiver distance value.

IV. PERFORMANCE EVALUATION

SIMULINK simulator tool of MATLAB has been applied to assess the UWB channel evaluation. In the following, simulation scenario and simulation results will be presented.

A. *SIMULATION SCENARIO*

In our simulation we used a MMSE receiver because, as described in [4], it is more effective than a four or eight fingered RAKE receiver 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. MMSE receiver consists of a bandpass filter and an adaptive filter. At each bit epoch, a bit decision is made at the output of correlator and it is then fed back to the adaptive filter. The observation window of the filter is typically longer than 1 bit interval and, therefore, windows overlap in time. 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].

$$W(i)=W(i-1)+\mu_m\, e(i)\frac{u^*(i)}{\varepsilon+u^H(i)u(i)} \tag{7}$$

In (7), 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 to 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 .

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

Channel model parameters adopted in our simulation campaigns 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

B. *SIMULATION RESULTS*

In Fig.3, BER vs. distance curves for different bit rates and LOS scenario in presence of high background white Gaussian noise (variance 10^{-1}) are plotted.

We can see as low bit rates (28 and 55 Mbps) reject inter-symbol interference better than higher rate because of longer spreading codes. In fact, a longer ternary spread sequence have more zero valued windows than a shorter sequence in their autocorrelation function, so interferences due to multipath that are within these windows can be eliminated.

The BER curve vs. transmitter-receiver distances for the NLOS scenario with 10^{-2} variance is depicted in Fig.4. Since there is no line of sight between transmitter and receiver, multipath components are more dense and they are also more attenuated in comparison with the LOS scenario. Thus, a greater sensibility to the inter-symbol interference are verified. A performance decrease is observed also for lower power noise level.

In Fig.5 and Fig.6 BER trends vs transmitter-receiver distance and number of users in presence of very low background noise (variance 10^{-5}), respectively for 28Mbps data rate in NLOS scenario and 220Mbps data rate in LOS scenario, are shown. Also in this case, a greater length of spreading codes means best performances, in fact longer sequences have best cross-correlation properties and 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 too much decreasing system performances. However, in the case of the 220Mbps rate, because of the spreading sequences do not present good orthogonal properties, the receiver is not able to correctly separate components coming from different users.

V. CONCLUSION

In this paper a more realistic UWB channel model is considered. An explicit multi-path fading distance dependence is obtained. The physical layer of the standard DS-SS 802.15.3a has been implemented. Simulation results show as only low data rates support transmission on long distance (28 and 55 Mbps are able to operate also in presence of high background noise and in NLOS scenario) while high date rate can operate only on distance less of 4 m. Regarding multi-access scenario, we noted as high data rates transmission (e.g. 220 Mbps) is impracticable because only longer spreading sequences are able to suppress simultaneous multi-user interferences.

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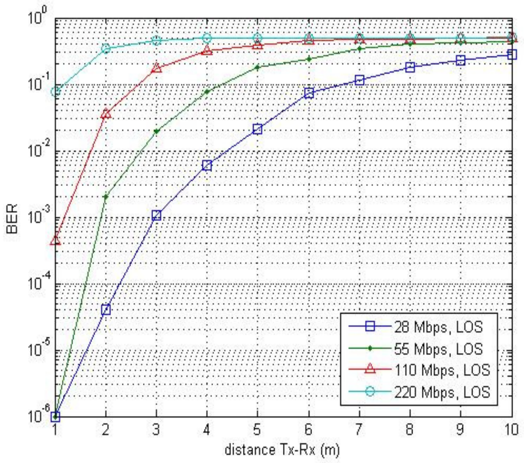

Fig.3. BER vs. distance for LOS scenario, noise variance 10^{-1}.

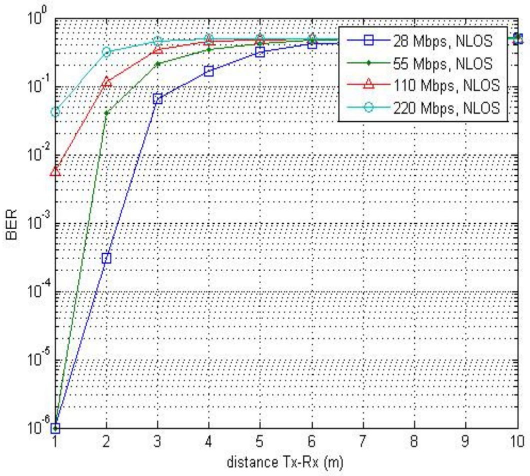

Fig.4. BER vs. distance for NLOS scenario, noise variance 10^{-2}.

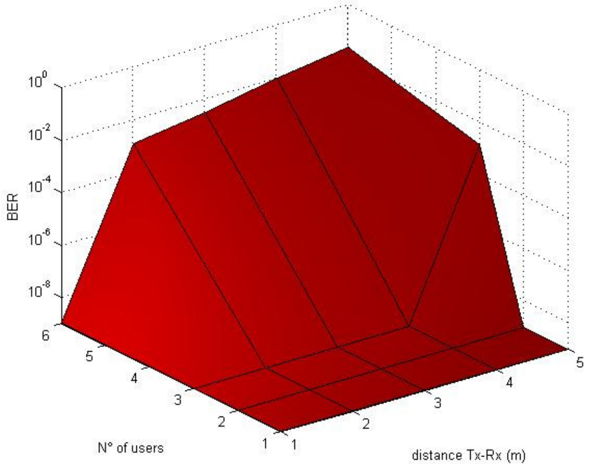

Fig.5. BER vs. distance and number of users for scenario NLOS, rate 28 Mbps and noise variance 10^{-5}.

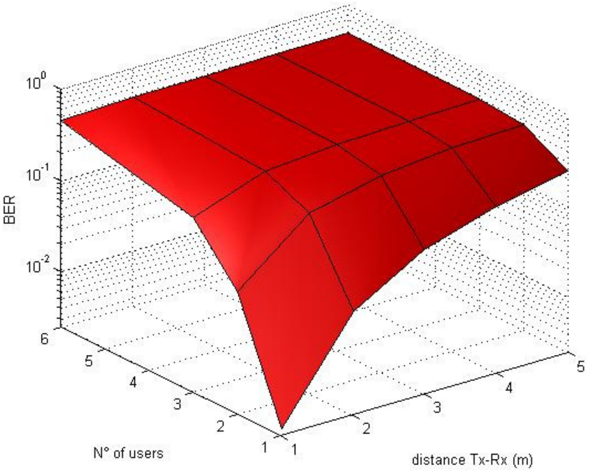

Fig.6. BER vs. distance and number of users for scenario NLOS, rate 220 Mbps, noise variance 10^{-5}.