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Two Novel Methods for Accurate NLOS Detection Based on Channel Statistics

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ABSTRACT

Time-of-arrival (TOA) estimation is the first step of the most positioning algorithms. However in various environments especially when ultra wideband (UWB) pulses are used, TOA extraction from the received signal is challenging. UWB radio propagation bears multipath phenomenon, therefore correct identification of the first path TOA highly depends on the statistical characteristics of the environment and apprehension that the signal has been passed through the line-of-sight (LOS) channel or the non-line-of-sight (NLOS) one. In this paper, two novel NLOS identification techniques based on the multipath channel statistics are proposed. Simulations show that the first technique using the fitness equations of mean and variance of the received signal is suitable for residential and outdoor environments. The other one that compares the relative energy of two different periods of the received signal is more accurate in office and industrial environments. IEEE 802.15.4a channel models are used and two hypothesis tests are applied to distinguish between LOS and NLOS. The high accuracy identification of channel type is achieved for all mentioned environments.
KEYWORDS*- UWB; channel; TOA; Ranging; optimization; IEEE 802.15.4a*

1. INTRODUCTION

The interest on the UWB technology has been increased since 2002 and it is expected to gain various commercial uses in the near future. UWB radios have relative bandwidths larger than 20% or absolute bandwidths of more than 500 MHz [1]. Such a large bandwidth improves reliability, as the signal contains different frequency components, which increases the probability that at least some of them can go through or around obstacles. Because of its robustness in harsh multipath environments, it has the ability to combine accurate ranging and localization with low data-rate communication [1, 2].

The performance of TOA-based ranging is critically depends on the existence of line-of-sight (LOS) channel between the transmitter and the receiver according to the [3, 4, 5]. In a two-dimensional positioning scenario, three anchors (nodes with known position) are sufficient to localize a target (node with an unknown position) if links between anchors and the target are all in LOS. However such a condition rarely happens especially while the positioning is done in an indoor environment, because the direct path is obstructed by obstacles such as walls. The absence of a direct path results in an extra-delay for the time-of-flight (TOF) and a consequent biased estimation of the real distance [5, 6]. Adding the channel obstruction knowledge to system may improve the accuracy of position estimation. NLOS measurements can be discarded or they can be rectified. As a result, some parameters should be set in the receiver to extract the precise distance between transmitter and receiver. Selection of these parameters highly depends on the fact that the signal has been passed through the LOS channel or the NLOS one.

Several papers have proposed different techniques for NLOS identification. These techniques can be categorized in two main groups [7]. In first group techniques, which are known as parametric techniques, one or more features from the received waveform that varies between different channel conditions are extracted. For example in [8], the identification is based on the relative energy between the first path and the strongest one. In [9, 10], root mean square (RMS) delay spread, mean excess delay and kurtosis parameters are used and in [1], skewness as new statistics information of the multipath channel, has been exploited.

The Second group of identification technique can detect obstacles without observing the received waveform directly, which is the case of the non-parametric approach. In [11], it is assumed that multiple and independent TOA measurements are available. The probability density function (PDF) of distance is compared with the PDF corresponding to LOS propagation. Another recent non-parametric solution based on least-squares support vector machines can be found in [12, 13]. In [14], the combination between the modified biased Kalman filter and a sliding window has been used to identify and mitigate different degree of NLOS errors.

To the best of authors' knowledge, most of the parametric techniques use some assumptions about the received signal statistics that are not available during the range estimation process. In the real situation, the

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receiver has no information about the channel type (LOS/NLOS), therefore it cannot preset its parameters. Our previous practical experiences suggest that optimum receiver parameters for TOA extraction from the received signal are different for LOS and NLOS channel types. As a result, no parameter like threshold and search back window length can be set in the ED receiver. An appropriate channel type detection method should be able to detect both LOS and NLOS channel types. We have practically understood that if for example optimum parameters of LOS channel are set in the receiver, existing channel type detection techniques have a great weakness in finding NLOS channel and vice versa.

Such problems also exist in the non-parametric approaches which decide based on measured distances. Distance calculations depend on correct detection of the channel type so the receiver parameters should not preset before finding the channel type.

In this paper two novel methods are proposed to distinguish that the received signal has been passed through an obstacle or not. The basic idea of these methods is that the received signal is treated in two ways: 1) it is assumed that the signal has been passed through the LOS channel, therefore the receiver parameters (these parameters will be explained in Section 3) are set by contemplating statistics of the LOS channel, 2) hypothesis is that the signal has been passed through an obstacle, so the parameters in the receiver should be set while statistics of the NLOS channel is considered, then a yardstick is enacted to distinguish that the channel was LOS or NLOS . In the first method, mean and variance of the received signal is considered. The second method uses the energy of the received signal. The efficiency of each method in four different environments such as residential, outdoor, office and industrial in the presence of noise is deliberated.

The remainder of this paper is organized as follows: In Section 2, two novel methods are thoroughly explained, results and their discussions are presented in Section 3 and Section 4 concludes the paper.

2. NLOS DETECTION METHODOLOGIES

Due to the extremely large bandwidths of IR-UWB systems, satisfying the Nyquist sampling rate condition is practically unrealizable, therefore, the leading edge detection may have to be achieved at lower-rate samples. This can be realized using energy blocks and processing the signal with a square-law device before sampling it. The signal arriving at the receiver antenna is first passed through a band-pass filter of bandwidth *B*, processed with a square-law device, and finally fed to an integrator and dump device with a sampling duration of t_s. In order to improve the ranging accuracy the resulting samples are further averaged over N_l symbols, thanks to the long preambles dedicated for accurate ranging. The schematic of an ED receiver is illustrated in Fig. 1 [15].

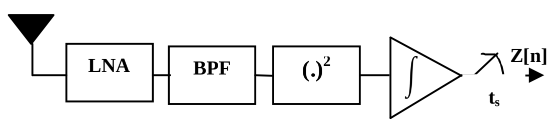

Fig. 1. Sampling the received waveform

The integrator output samples can be expressed as

$$z[n] = \frac{1}{N_l}\sum_{j=1}^{N_t}\int_{(j-1)T_f+(n-1)l_s}^{(j-1)T_f+nl_s}|r(t)|^2 dt \quad (1)$$

Once the received signal is sampled, the leading edge sample can be searched back starting from the strongest sample. In [17], a search back scheme is discussed for finding the leading edge. The algorithm jumps backward to a prior sample, and starts searching for the leading edge in the forward direction. The parameters, such as the search back window length *W*, threshold, etc., for this approach can be optimized based on the statistics of a particular channel model.

3. Two Novel Methodologies for NLOS Detection

In this paper, two novel method for distinguishing LOS and NLOS channels are proposed.The methods are described in the following subsections. It is assumed that the receiver is synchronous to the strongest path. Therefore to consider all the signal rays, distributed around the strongest path, statistical characteristics of two parameters of each channel, peak to lead duration and mean excess delay, are used. A cumulative distribution function (CDF) is defined and used, as follows. The CDF for the peak to lead duration (PLD), denoted as CDF_{PLD}, is used to select the search-back window length. If the PLD which corresponds to the CDF_{PLD} =1 is set for the window length, the first sample will be located in the search back window. But, this increases the probability of the false alarm. Instead, the PLD corresponding to the CDF_{PLD} values less than one, may decrease the TOA estimation error. In this paper, eight standard channel models, proposed in [18], are used and rays are blocked in 1ns intervals. It is practically understood that good accuracy for detection of the first block is obtained if the window length is set to the value corresponding to CDF_{PLD}=0.95. Also, the mean of the peak to lead duration (MPLD) of each channel is used in the second proposed method. The parameter values of the channel models are shown in Table I. Each suggested value is obtained base on 1000 runs of the simulation, in the corresponding channel type.

The mean excess delay (MED), the first moment of the power delay profile, is defined as [18]:

$$\bar{\tau} = \frac{\sum_i a_i^2 \tau_i}{\sum_i a_i^2} = \frac{\sum_i p(\tau_i)\tau_i}{\sum_i p(\tau_i)} \quad (2)$$

The parameter is a measure of multipath spread of the channel and determines the time interval after a peak which yields most of the channel energy. The MED of the standard channel models are presented in Table I. Each suggested value is obtained base on 1000 runs. In the following, two novel techniques for distinguishing NLOS and LOS paths (channel types) are proposed and evaluated.

Table I. MED, MLD and W for eight channel models of the IEEE 802.15.4a

Channel models	MED(ns)≈	MPLD(ns)≈	*W*(ns)
CM1(residential LOS)	17	8	30
CM2(residential NLOS)	20	18	48
CM3(outdoor LOS)	10	4	16
CM4(outdoor NLOS)	18	11	26
CM5(office LOS)	27	12	50
CM6(office NLOS)	80	83	214
CM7(industrial LOS)	2	0	2
CM8(industrial NLOS)	25	12	25

3.1. **Maximum-fitness based method**

In this method, as a contribution of the present paper, the received signal is captured in a period starting from the strongest energy block and going backwards to the energy block, located a window length, *w*, earlier than the strongest block. To normalize the signal level, the energy of each block is divided by the energy of the strongest block. In each environment, the mean and variance of received blocks energies highly depend not only on the channel type (LOS or NLOS), but also, on the distance between the transmitter and receiver. As a result, the mean and the variance of the received signal cannot be used for LOS or NLOS detection, directly.

To demonstrate the dependence of the mean and variance on the distance and channel type, the latter are considered independent variables and the former as dependent ones. An order-3 Gaussian pulse is used for residential and outdoor environments, and an order-2 pulse is used for office and industrial channels. The orders are selected as they lead to suitable TOA estimation, based on our simulation-based observations. In the next step, the signals are transmitted through the standard eight channel models as mentioned earlier, introduced in [17]. The average mean and variance of different channels are calculated by varying the distance between the transmitter and receiver, d, from 1 to 30 meters, in steps of 0.1 meter (30 being the maximum length indicated in the IEEE 802.15.4a model). Using the window lengths shown in Table I. The mean and variance values are calculated by averaging over 1000 iterations. It is observed that the curve introduced by the following formula

$$Ae^{(-B.d)} + C \quad (3)$$

fits well to the calculated mean and variance values, except for the CM7 case. In the above equation, *d* stands for the distance, and *A, B, C* are the fitting parameters, calculated for each channel. In Fig. 2 the mean of CM1 and CM2 vs. *d* is plotted both for the measured data and the fitted curve, and in Fig. 3 the variance of CM1 and CM2 vs. distance is depicted. The *A, B, C* parameter values for channels CM1-CM6 and CM8, and the sum of square errors (SSE) relative to each fitting are listed in Table II.

The mean and variance data for CM7 do fit well to the exponential form (3). The main idea of this method is to use *d* as a parameter, while *A, B, C* are given in Table I, in equation (3), not for distance estimation, but for detecting the channel type. The proposed algorithm is illustrated in Fig. 4. In each environment, after the strongest block is detected, the received signal is treated in two ways: 1) the window length appropriate for LOS is used in ED receiver to process the received signal, 2) appropriate window length for NLOS is used in the ED receiver. The mean and variance of the two signals are measured. Then the mean, variance, and the corresponding distance are applied to (3). After inserting the mean in the corresponding equation, a distance is obtained. The distance is then inserted into equation related to the variances with parameters of the related channel and results a variance. Finally, the absolute value of difference of resulting variance and the measured one in the LOS and NLOS conditions are calculated. By comparing these differences the transmission channel type is assigned to the type which has the smaller difference.

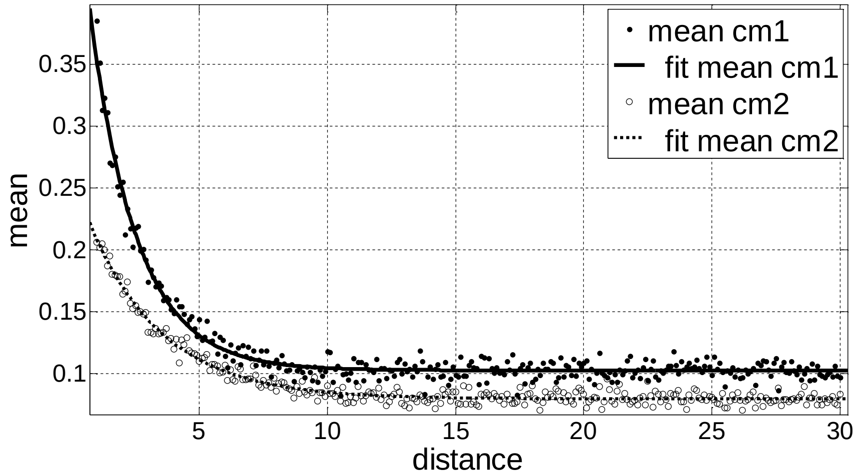

Fig. 2. Measured mean and fitted curve for CM1 and CM2

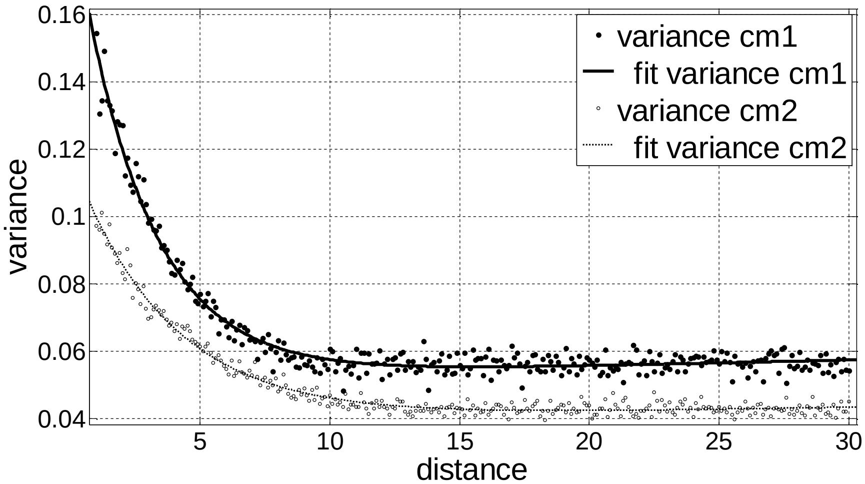

Fig. 3. Measured variance and fitted curve for CM1 and CM2

Table II. Parameters of equation (3) for channel models

Channel models	**Mean**			**SSE**	**Variance**			**SSE**
	A	B	C		A	B	C	
CM1	0.4311	0.5499	0.1043	0.002	0.1416	0.3776	0.0529	0.009
CM2	0.1724	0.3269	0.0781	0.004	0.0752	0.2419	0.0380	0.001
CM3	0.6713	0.9231	0.1466	0.017	0.1903	0.6901	0.0774	0.002
CM4	0.2868	0.6439	0.1402	0.014	0.0785	0.4634	0.0603	0.001
CM5	0.3365	0.4207	0.0660	0.010	0.1252	0.2673	0.0290	0.001
CM6	0.03735	0.3211	0.0519	0.002	0.0169	0.2547	0.0249	0.001
CM8	0.1868	0.6243	0.1577	0.020	0.0618	0.5287	0.0609	0.002

The parameters, used in Fig. 4, are as follows. The measured mean and measured variance, extracted from the received data, denoted by *Mm*, and *Mv*, respectively, also, *Cm* and *Cv*, the calculated mean and variance, respectively, extracted from (3). The *l*os and *nlos* notations, respectively, show whether the measurement or calculation is done with parameters related to the LOS channel or the NLOS one.

3.2 Energy-ratio based method

Tables I and II show that the MPLD and MED, in each environment, are different for LOS and NLOS channels. Consequently, a signal passing through an NLOS channel gets spread, more than that passing through an LOS channel. Therefore, the main goal of the second proposed method is to use the signal spread, to distinguish between LOS and NLOS channels.

In each environment, when the strongest block is detected, the energy is evaluated through two different periods: 1) the energy between MPLD before the arrival of the strongest block and MED after the strongest arrival block relative to the LOS channel, 2) the energy of period which starts from MPLD before the arrival of the strongest path until MED ns after the strongest path arrival relative to the NLOS channel. The ratio of these two calculated energy (2/1) should be compare with a threshold. If it is bigger than the threshold, it will be concluded that the signal has been passed through an NLOS channel, otherwise the channel is concluded to be LOS. In order to clarify the method, the block diagram is presented in Figure 5.

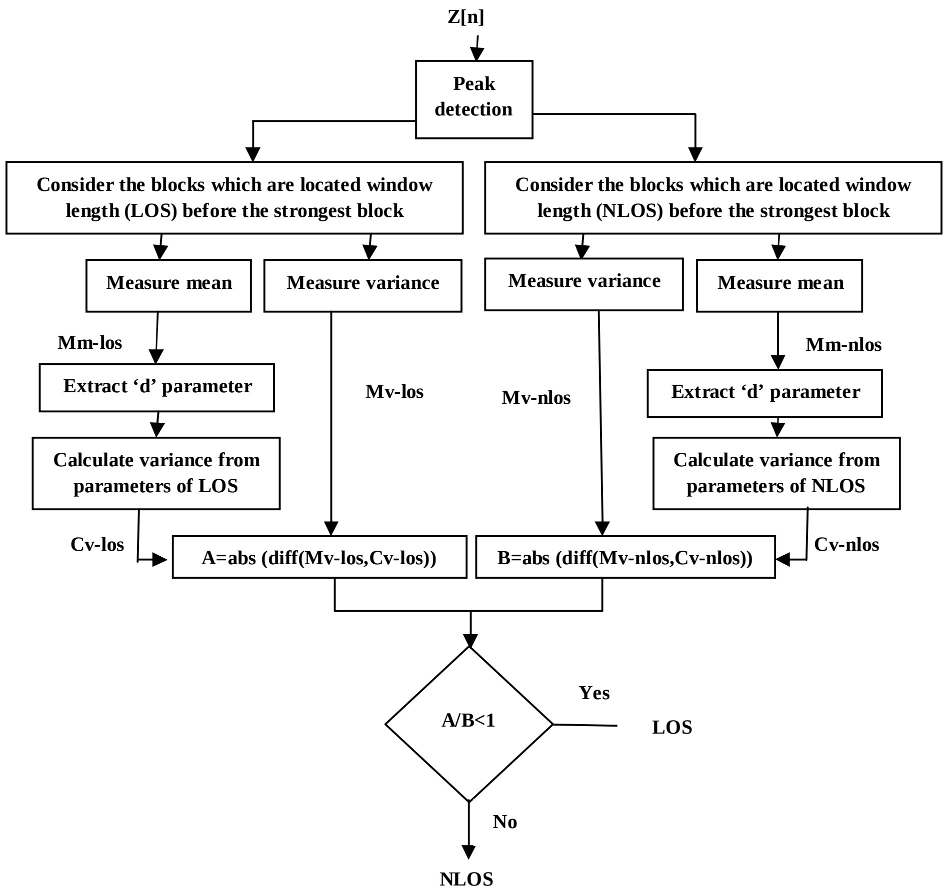

Fig. 4. Block diagram for the Maximum-similarity based method

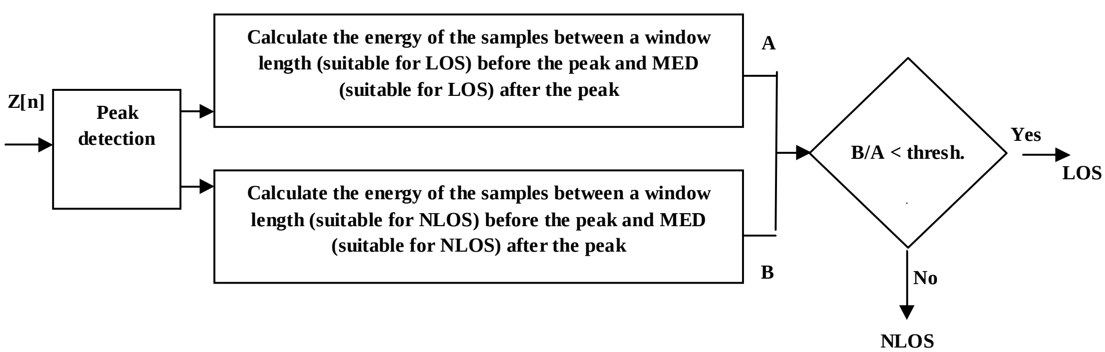

Fig. 5. Block diagram for the Energy-ratio based method

The proper threshold is defined for each environment separately. Therefore, for each channel model the signal is transmitted under the same conditions, as in subsection 3.1. For each channel the distance is changed from 1 to 30 meter by steps of 1 meter, and for each step the signal is transmitted 1000 times. Finally, the average energy of these data is considered as the energy of the two mentioned periods. Figure 6 shows energy ratio of discussed periods for channels CM7 and CM8 versus the distance.

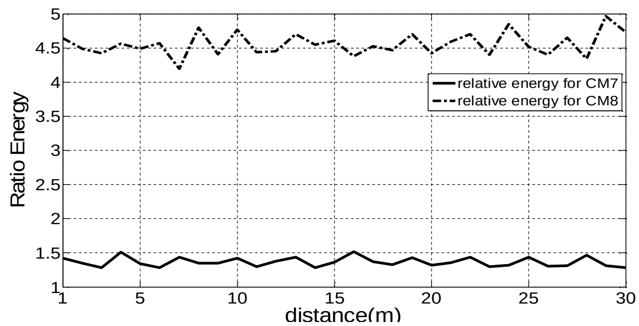

Fig. 6. Ratio energy for CM7 and CM8

As observed in Fig. 6, the energy ratio has no dependency on the distance. Minimum and maximum of the ratio, for each channel, are presented in the Table III. The threshold, for each environment, is evaluated from the following equation and the results are given in the Table III.

$$thereshold = \frac{min(NLOS)+max\ (LOS)}{2} \qquad (4)$$

Table III. Minimum and maximum of relative energy and calculated threshold for each environment

Channel models	Min	Max	Threshold
CM1	1.1154	1.1739	1.1895
CM2	1.1951	1.2707	
CM3	1.3309	1.4299	1.4382
CM4	1.4464	1.5457	
CM5	1.2431	1.4047	1.4043
CM6	1.4038	1.5667	
CM7	1.2814	1.5167	2.8576
CM8	4.1984	4.9681	

Also, an approach is suggested to improve the performance of the proposed methods. Performing the algorithms, over several transmissions of the signals, the channel type (LOS and NLOS) is voted, based on the number of occurrence. The channel type is voted LOS or NLOS, if more than half of the executions come to this conclusion that the channel is LOS/ NLOS.

4 SIMULATION RESULTS AND DISCUSSION

First, the performance of the maximum-fitness based method, presented in 3.1, is discussed. While (3) is not suitable for CM7, simulations are made only for residential, outdoor and office environments. To examine the performance of this method in noisy environments, an additive white Gaussian noise (AWGN) is added to the channel responses. Simulations for 1, 5, 9 and 17 transmissions were done under the SNRs of -10dB, 0dB, 10dB, and 100dB. In each transmission data packets contain 64 preambles, the standard number for ALOHA transmission data packet [19]. For any environment, channel type has been randomly selected as LOS or NLOS, with equal probabilities. In order to extract the percentage of correct channel type predictions, the methods are repeated 1000 times. Simulation results are given in Table IV. Simulation conditions for the energy-ratio based method, proposed in 3.2, are similar to the first one, except that the performance of this method can be evaluated for all environments. Simulation results for the second method are presented in Table V.

Table IV. Efficiency of the Maximum-fitness method relative to SNR and the number of transmissions

Environment	SNR(dB)	Number of transmission to be used for counsellorship			
		1	5	9	17
Residential	100	100%	100%	100%	100%
	10	100%	100%	100%	100%
	0	100%	100%	100%	100%
	-10	89.1%	100%	100%	100%
Outdoor	100	100%	100%	100%	100%
	10	100%	100%	100%	100%
	0	100%	100%	100%	100%
	-10	94.7%	100%	100%	100%
Office	100	47.3%	60.9%	56.3%	43.8%
	10	43.4%	56.3%	50%	43.8%
	0	43%	53.1%	46.9%	35.5%
	-10	42.1%	50%	43.8%	35.5%

Table V. Efficiency of the second method relative to SNR and the number of transmissions

Environment	SNR(dB)	Number of transmission to be used for counsellorship			
		1	5	9	17
Residential	100	92.1%	100%	100%	100%
	10	91.8%	100%	100%	100%
	0	91.4%	100%	100%	100%
	-10	88.7%	100%	100%	100%
Outdoor	100	94.3%	100%	100%	100%
	10	94.%	100%	100%	100%
	0	91.7%	100%	100%	100%
	-10	90.6%	100%	100%	100%
Office	100	62.1%	79.7%	96.9%	100%
	10	60.5%	79.7%	93.8%	100%
	0	59.8%	79.7%	90.6%	100%
	-10	54.7%	68.8%	78.1%	87.5%
Industrial	100	100%	100%	100%	100%
	10	100%	100%	100%	100%
	0	100%	100%	100%	100%
	-10	100%	100%	100%	100%

As observed in Table IV, the maximum-fitness based method is efficient for residential and outdoor environments, even in the case in which the decision is based on one transmission of the signal. Only for very small SNR values, -10dB, the efficiency of the proposed method is not 100%. Such small SNR values are not applicable to real residential and outdoor environments. However, the method cannot be used for official environments because there is not any logical relationship among efficiencies in this channel model.

The performance of the Energy-ratio based method is highly dependent on the difference between the maximum value for the LOS channel and the minimum value for the NLOS channel in each environment. It can be concluded from the measured energy in the Table V that the energy-ratio based method performs better in industrial environments. This is mainly because of the obvious difference in the maximum energy ratio for CM7 and the minimum one for CM8, so by setting the threshold in the middle of these ratios, the correct detection is obtained. While the energy ratio between LOS and NLOS do not differ considerably for the residential and outdoor environments, efficiency of the energy-ratio based method is not as well as it is in the industrial environments. It should be mentioned that in office environments, the energy-ratio based method is acceptable only if the majority decisions are made for 17 transmissions, since the relative energy values for CM5 and CM6 have joint area.

5 Conclusion

The paper presents two novel methods for distinguishing LOS and NLOS channels. The methods assume no previous information about the received signals and the channel type. The first method, maximum-fitness based method, is suitable for residential and outdoor environments which are not multipath rich areas. The second method, energy-ratio based method, works acceptable for multipath rich environments such as office and industrial environments, because the energy of the received signals for such environments is more distributed in the NLOS case, than in the LOS one. Although, in residential, outdoor and industrial environments, one transmission is sufficient, for channel type detection, an office environment requires more transmissions.

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