ToA Node Distance Estimation Enhancement in MANET Localization Algorithm Based on Cooperative Trilateration

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Abstract. *This paper provides a brief survey of the Time of Arrival (ToA) ranging method often used in the Range-based localization for node distance estimation. It is focused especially on the Non Line-of-Sight (NLoS) channel identification – one of the dominant factors that negative affect the location accuracy. It deals with the improvement of the received signal arrival time determination in the case of NLoS communication with undetected direct path. The low complexity NLoS mitigation method is proposed in this paper that estimates the time of arrival of the missing direct path as a mean of the time delays of reflected paths. This method is implemented in the cooperative positioning algorithm based on the circular trilateration. The IEEE 802.15.4a statistical channel model is used to simulate the mobile node communication.*

Keywords

LoS/NLoS identification, NLoS mitigation, positioning, ToA, trilateration.

1. Introduction

In the field of mobile communications, the wireless nodes location problem has gained increasing interest. Location estimation is a complex problem. It has been investigated extensively in the literature in the last few years, where authors solved various problems. It is generally true that the position determination problem consists of two steps. At first, localization parameters must be estimated. In accord with this fact positioning systems are differentiated to the Range-based and Range-free [13]. Finaly, obtained parameters are used for position calculation via one of the localization algorithms, which are classified as Anchor-based or Anchor-free [12]. In this paper, we concentrate on Range-based localization. A variety of methods, which are based on *Received Signal Strenght* (RSS), *Time of Arrival* (ToA) or *Angle of Arrival* (AoA), [2], are available to perform the range measurements. We prefer the ToA ranging technique in combination with Ultra Wide-Band (UWB) communication technology, which is one of the most promising approaches of the mobile localization and has a great potential for accurate ranging especially in the indoor environment. Due to a very wide bandwidth of the UWB systems, these are capable to resolve individual multipath components in the received channel impulse response and to determine the time of their arrival very precisely. Kaveh Pahlavan and his team of researchers engage in the area of ToA estimation. The problem of ToA estimation in the case of undetected direct path and its identification can be found in [6], [14]. The impact on the node distance estimation accuracy using a different system bandwidth is also analyzed. More related works which deal with ToA can be found in section 2. We have proposed the low complexity method for ToA node distance estimation improvement and utilized it in the proposed cooperative positioning algorithm based on circular trilateration.

2. ToA Node Distance Estimation and LoS/NLoS Identification

Time of Arrival is the technique where the node distance can be estimated as the product of the measured signal propagation delay and the speed of light [1]:

$$d = c \cdot t, \tag{1}$$

where d represents the node distance, c the speed of light and t the estimated time of arrival of the received signal.

Let the Channel Impulse Response (CIR) of the received signal be represented as [5]:

$$h(t) = \sum_{l=1}^{L} A_l \delta(t - \tau_l), \tag{2}$$

where L represents the number of multipath components, A_l and τ_l are the signal amplitude and the time delay of the l-th multipath component, respectively. In general, the time of arrival of the first arriving path, the first CIR component, is considered as the time of arrival of the received signal. The problem occurs when the direct path is missing in the channel impulse response because it is blocked or attenuated under the detection threshold of the receiver. Wireless communication channel profile can be classified to [6]:

- Line-of-Sight (LoS) with Dominant-Direct-Path (DDP). In this case, the direct path is the strongest and the first detected path in the channel profile and it can be detected by the receiver. There are no considerable obstacles between the transmitter and the receiver.
- Non Line-of-Sight (NLoS) with Non Dominant-Direct-Path (NDDP). Line-of-Sight communication between a transmitter and a receiver does not exist. In NDDP channel profile, the direct path is not the strongest path of the CIR, however, it is still detectable because it is received above the detection threshold of the receiver.
- Non Line-of-Sight (NLoS) with Undetected-Direct-Path (UDP). In UDP channels, the direct path goes below the detection threshold of the receiver while other paths are still detectable. The receiver assumes the first detected peak as a direct path which causes considerable distance estimation errors.

The performance of the Range-based localization systems based on ToA node distance estimation techniques mainly depends on the presence of Line-of-Sight communication between the transmitter-receiver pairs. NLoS radio propagation is one of the most dominant factors that affect the positioning accuracy [3]. The absence of a direct path in the received signal results in an extra-delay for the ToA because the signal travels an extra distance that leads to the incorrect location [1]. Several LoS/NLoS identification methods have been proposed [3], [5]. One of the most basic LoS/NLoS identification methods are based on the prior knowledge of statistics of the signal received in LoS conditions. During the real-time localization, measurements are taken and the statistics of these measurements are calculated. When the calculated statistics are significantly different from the reference statistics, the received signal is assumed to be corrupted by NLoS communication. That can be expressed with simple binary detection scheme, where the detection is performed by extracting a certain number of received signal features such as *Kurtosis*, *Mean Excess Delay* or *RMS Delay Spread* of the Multipath Channel and applying the classical decision theory [1], [5]:

$$\frac{p(\gamma \mid \mathrm{LoS})}{p(\gamma \mid \mathrm{NLoS})} \overset{H_0}{>} \frac{p(NLoS)}{p(LoS)}, \tag{3}$$

$$\frac{p(\gamma \mid \mathrm{LoS})}{p(\gamma \mid \mathrm{NLoS})} \overset{H_1}{<} \frac{p(NLoS)}{p(LoS)}, \tag{4}$$

where $p(\gamma|LoS)$ and $p(\gamma|NLoS)$ represent, the PDFs of the set of measured received signal features $\gamma = \{\gamma_1, \gamma_2, \ldots, \gamma_N\}$ under LoS and NLoS conditions, $p(LoS)$ and $p(NLoS)$ are the prior probabilities of the LoS and NLoS events, and H_0 and H_1 denote the LoS and NLoS signal propagation conditions.

2.1. Distribution Tests

In the case of LoS conditions the samples of the received signal envelope have distributions different from those received in NLoS conditions. If the distribution of the LoS is known, this fact can be used for identification of the communication channel characteristics. The aim of the distribution tests is to test, whether the samples of the received signal envelope belong to a specific distribution, so that the LoS or NLoS condition can be identified. A number of well-known tests to identify the communication channel characteristics are briefly described in [3]. In the following text, the most commonly used test *Kolmogorov-Smirnov Test* is explained.

The objective of the *Kolmogorov-Smirnov Test* is to identify whether the received signal samples originate from the known distribution related to the LoS conditions. Suppose that there are L measurements ordered as $r_1, r_2, \ldots r_L$. The empirical cumulative distribution function of these observations (measurements) is defined as [3]:

$$F_0(i) = \frac{v(i)}{L}; \quad i = 1,2,..L, \tag{5}$$

where $v(i)$ is the number of observation points. The following hypothesis can be formulated [9]:

$$H_0 : \forall(i); F_0(i) = F_{\exp}(i), \tag{6}$$

$$H_1 : \exists(i); F_0(i) \neq F_{\exp}(i), \tag{7}$$

where $F_{exp}(i)$ is the cumulative distribution function of the known expected probability distribution typical for the signal samples received in the LoS conditions. The task of the Kolmogorov-Smirnov Test is to find the D-statistic, which is defined as the greatest discrepancy between the measured and the expected comulative distribution functions as [3]:

$$D = \max_{1 \le i \le L} \left| F_0(i) - F_{\exp}(i) \right|. \tag{8}$$

The computed D-statistic is compared against the critical D'-statistic for the same sample size, which can be computed based on the given level of significance. When the level of significance equals 0,05 the critical D'-statistic is [3]:

$$D' = \frac{1{,}358}{\sqrt{\mathrm{L}}}. \tag{9}$$

If $D \le D'$, the hypothesis is validated. The distribution function of the measured received signal samples corresponds with the expected distribution function related to the LoS conditions. Otherwise, if $D > D'$, the distribution function of the measured samples is not considered as the expected distribution and, thus, hypothesis is rejected. The received signal samples originate in NLoS communication [3], [9].

2.2. Kurtosis Parameter

The kurtosis is a statistical parameter that indicates the variance variation of the signal amplitudes. It is defined as the ratio of the fourth order moment of the data to the square of the second order moment [5]:

$$\kappa = \frac{E\left[\left(|h(t)| - \mu_{|h|}\right)^4\right]}{E\left[\left(|h(t)| - \mu_{|h|}\right)^2\right]^2} = \frac{E\left[\left(|h(t)| - \mu_{|h|}\right)^4\right]}{\sigma_{|h|}^4}, \qquad (10)$$

where $\mu_{/h/}$ and $\sigma_{/h/}$ are the mean and standard deviation of the received signal samples $h(t)$, respectively. Kurtosis is characterized by the high value for the signal received in LoS conditions [1], and by low value for signal received in NLoS condition (the signal id more noise-like),[8]. Two ways can be used for LoS/NLoS decision. Kolmogorov-Smirnov goodness-of-fit test can be used to analyze how well the measured data characterize the prior distribution which represents the LoS channel [5] or the decision is simply taken as [1]:

$$if \quad \kappa < \lambda_\kappa \quad \Rightarrow NLoS, \qquad (11)$$

$$if \quad \kappa \geq \lambda_\kappa \quad \Rightarrow LoS, \qquad (12)$$

where λ_κ is the threshold value between the LoS and NLoS conditions. If Kurtosis takes the values above the defined threshold it goes of LoS condition and vice versa, if it takes the values less than the defined threshold it goes of NLoS condition. The advantage of Kurtosis is that it can be calculated directly on the received signal, no estimation algorithm is needed. This keeps easy and quick the identification process and it implies that no estimation errors of the estimation algorithm are introduced [8].

The similar analysis as discussed in the previous part can be performed using other parameters named Mean Excess Delay τ_m and RMS Delay Spread τ_{rms}. While the Kurtosis provides information about the amplitude statistics of the received signal samples, these two parameters provide the statistic that characterizes the delay information of the multipath channel obtained from its Power Delay Profile [5]. These parameters are expressed as [10]:

$$\tau_m = \frac{\sum_k P(\tau_k)\tau_k}{\sum_k P(\tau_k)}, \qquad (13)$$

$$\tau_{rms} = \sqrt{\tau_m^2 - (\tau_m)^2}, \qquad (14)$$

where $P(\tau_k)$ is the power of the k-th path of the Power Delay Profile with time delay τ_k and

$$\tau_m^2 = \frac{\sum P(\tau_k)\tau_k^2}{\sum_k P(\tau_k)}. \qquad (15)$$

The comprehensive description of the LoS/NLoS identification methods the reader can found in [3]. To achieve satisfactory node distance estimation, it is desirable to determine whether the communication path between a transmitter-receiver pair is LoS or NLoS. If it is identified as NLoS, the impact on localization accuracy can be suppressed either by the simple discarding of the measurements identified as NLoS or by using some of the NLoS mitigation techniques [4]. The first mentioned approach is possible only when there are enough measurements identified as LoS, therefore the approach of using the NLoS mitigation techniques seems to be preferable.

3. Brief Overview of the Localization System Based on Cooperative Trilateration

Philosophy of the positioning system is based on the trilateration principle used as a fundamental localization method for cellular mobile networks where each mobile node, which has the connection with minimum three reference nodes, anchors, can be located. Three anchors with known position are sufficient for two-dimensional localization. This method belongs to the Range-based positioning systems, where one of the localization parameters must be determined in order to calculate the final position of the localized node. Currently we use the measurement of the Time of Arrival parameter determined from the wireless channel impulse response. The positioning system also belongs into the Anchor-based systems therefore it assumes the existence of a couple of real reference nodes with known location. The algorithm consists of more phases. Each node situated in the vicinity of minimum three reference nodes with known location, is able to calculate its own position. In the first phase all mobile nodes which are in the range of at least 3 steady real beacons are localized. The second and every other phase are like the first one. Difference is that all mobile nodes already localized in the previous phase become virtual beacons. The algorithm is finished when:

- positions of all mobile nodes were determined already,
- it is not possible another mobile nodes position determine (undetermined nodes have not sufficient number of anchors in range).

Every phase of the proposed algorithm consists of the following four steps:

- selection of a mobile node suitable for localization process,
- the calculation of the distances between the mobile node which should be located and all anchors in its range,
- selection of the appropriate anchors in order to calculate the unknown node location,
- trilateration and position calculation for unknown mobile node.

At the beginning of the each phase the nodes, which have not been already calculated the location are selected. Each of the nodes includes the database of its neighbours, the distances to them according to the measured ToA parameter and also the information if these neighbours are anchors or not. From this database of the available reference nodes only one triplet is selected using the following procedure:

- every anchor triplet that is considered is created,
- only those triplets where all pairs of circles are intersected are considered,
- the triplet which include the anchors with steady position are preferred,
- this nearest triplet (according to ToA parameter) is preferred from all. This triplet creates the triplet of anchors suitable for calculation of the final position of unknown node by trilateration.

If a suitable triplet of anchors in the range of unknown node exists, the localization process can be carried out. As it is stated above, the process of trilateration is used for calculation of the position of unknown nodes where $[x,y]$ represent the coordinates of the unknown node (which should be calculated), $[x_{i,j,k},y_{i,j,k}]$ represent the location of the reference nodes and $r_{i,j,k}$ represent the estimated node distances between unknown node and the reference nodes separately:

$$\left(x-x_{i,j,k}\right)^2+\left(y-y_{i,j,k}\right)^2=r_{i,j,k}^2 . \qquad (16)$$

Ideally, the final position is represented by the only common intersection of three circles. The negative impact of wireless communication channel causes inaccurate calculation of distances between nodes. Hence the final position is calculated as a centre of the area which is represented by a triplet of suitable intersections.

4. Simulations and Results

In our simulations we have used the existing model of the wireless channel impulse response generation for IEEE 802.15.4a ultra wideband technology, which is described in more details in [11]. It is the result of the research activity of the members of the Mitsubishi Electric Research Laboratories and provides the generation of the channel impulse response for different types of the environment such as residential, office, open outdoor and industrial. In our simulations we have used the CIR for “LoS and NLoS OFFICE” environment.

In most cases the time of arrival of the received signal is assumed as the time of arrival of the first detected path. The problem occurs, when the direct path is missing in the received signal channel impulse response. This fact causes considerable distance estimation errors, which leads to the incorrect localization. For NLoS mitigation problem, especially in case of NLoS communication with undetected direct path, we have proposed the low complexity NLoS mitigation technique for ToA estimation described in the following part. In Fig. 1, the diagram of the ToA estimation for different types of communication channel is introduced.

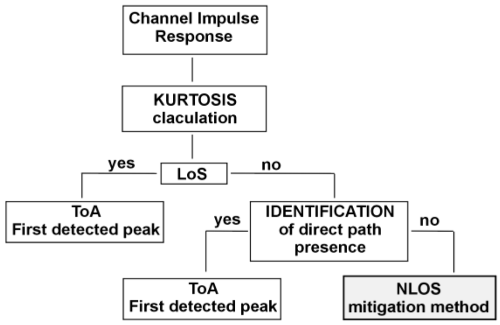

Fig. 1: Diagram of the ToA estimation for different types of communication channel.

In part of LoS/NLoS identification we have used the Kurtosis parameter “KP” calculation with a detection threshold between the LoS and NLoS communication conditions of 100. The desired threshold value of KP has been obtained from the experimental observations for several assumed thresholds from 60 to 220, where 100 has brought the most successful results of LoS/NLoS identification, Fig. 2. Than in the simulations, according to the calculated KP the algorithm decided the communication conditions. If KP $\geq$ 100 it identified the “LoS OFFICE” environment, else if KP < 100 the “NLoS OFFICE” environment was identified. Using 1000-times randomly generated CIR for “OFFICE” environment the LoS/NLoS identification by using Kurtosis calculation was successful in 84,7 %.

The part of IDENTIFICATION of direct path presence was not the aim of this paper. It will be the aim of our research activity in the next period. In this paper we have focused on LoS estimation problem in the case of *NLoS channel with Undetected Direct Path (UDP)*. We proposed the low complexity UDP mitigation method in order to improve the distance estimation, which is next explained using the concrete example of the transmitter-receiver pair 10 m distant. The receiver received the signal as is depicted in Fig. 3 (the time components from t_1 to t_9). It can be seen that in the received channel impulse response the direct path is missing. We need to estimate the assumed time of arrival of the blocked direct path. The correction ToA parameter can be obtained using the following procedure:

$$C_{LoS} = \frac{\sum_{i=2}^{k}(t_i - t_{i-1})}{k-1}, \qquad (17)$$

where t_i is the time of arrival of the i-th path received above the level of significance, which represents the paths within 10 dB from maximum peak, k is the number of significant paths and C_{LoS} is the mean of the time differences between pairs of these neighbouring paths, named as "ToA correction parameter".

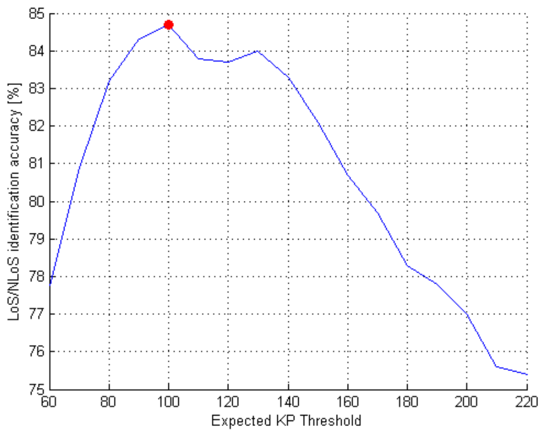

Fig. 2: Dependence of the successful rate on the KP threshold.

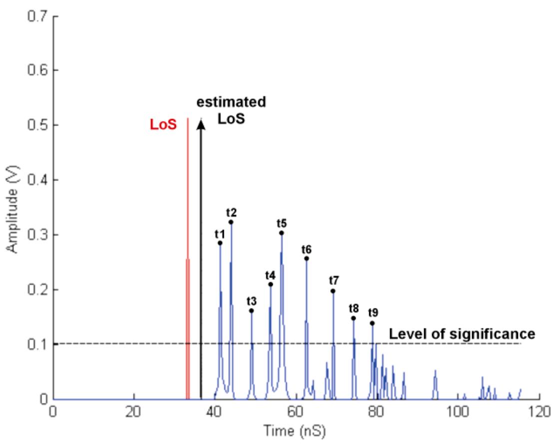

Fig. 3: LoS estimation explanation.

The assumed time of arrival of the estimated LoS path is derived as:

$$ToA_{estimated-LoS} = t_1 - C_{LoS}. \qquad (18)$$

This example is explained using Tab. 1, which contains the times of arrival of the mentioned significant paths with the differences between them. As it can be seen in the Tab. 2 and Tab. 3, the proposed NLoS mitigation method produced better results of the estimated ToA parameter and final distance estimation of 1,414 m, which represents the improvement of distance estimation error of 41 %. This procedure has been tested on 1000-times randomly generated CIRs for transmitter-receiver pairs distant at 10 m. Generally, the distance estimation error has been reduced by 22,6 %, Tab. 4.

Tab.1: Time of arrival of the significant paths and the time differences between them.

i	t_i [ns]	t_i-t_{i-1} [ns]
1	41,3	---
2	44,0	2,7
3	49,0	5,0
4	53,7	4,7
5	56,3	2,6
6	62,7	6,4
7	69,3	6,6
8	74,3	5,0
9	79,0	4,7

Tab.2: ToA and distance estimation by using the first detected peak.

ToA_{t1} [ns]	Estimated distance [m]
41,3	12,4

Tab.3: ToA and distance estimation by using the proposed NLoS mitigation method for ToA estimation enhancement.

C_{LoS} [ns]	$ToA_{estimated-LoS}$ [ns]	Estimated distance [ns]
4,71	36,62	10,986

Tab.4: The comparison of the distance estimation error using both ToA estimation techniques.

ToA estimation	Distance estimation error [m] for nodes distant at 10 m
First detected path	1,541
NLoS mitigation method	1,193

Finally, the proposed ToA estimation method has been tested also in cooperative trilateration based algorithm described in the section 3. We simulated only the harsh communication conditions between pairs of mobile nodes – NLoS with UDP. We have studied the impact of the proposed NLoS mitigation method on the potential enhancement of the distance estimation error.

Our simulations were carried out in MATLAB programming environment and for statistical relevance were repeated one hundred times. We have used the network which consisted of the 40 mobile nodes deployed on the area of 30 × 30 m with all receivers' radio range of 10 m. Three steady triangle-shaped beacon nodes were located in the middle of localization area. We assumed precise time synchronization between nodes.

If we used the first algorithm, where the ToA parameter is determined according to the time of arrival of the first detected peak, the localization error was 29,96 % in comparison with the size of area side. By using the proposed NLoS mitigation method the localization error was reduced to 27,77 %. In both cases the behaviour of the algorithm was successful enough with a number of the localized nodes above 90 %, Tab. 5.

Tab.5: Positioning algorithm evaluation after proposed NLoS mitigation technique implementation.

Used ToA estimation method	Localization error [%]	Number of successfully localized nodes [%]
First detected path	29,96	91,65
NLoS mitigation method	27,77	93,30

5. Conclusion

This paper presents the low complexity NLoS mitigation technique and its application in the proposed cooperative localization algorithm based on circular trilateration. In general, the proposed method for ToA estimation enhancement improves the time of arrival accuracy, but it has several drawbacks. In some cases, if there are less significant paths in the channel power delay profile which are more distant from each other, the ToA estimation can be inaccurate. The method, how to improve the proposed NLoS mitigation method will be the aim of the future research activity.

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References

[1] DECARLI, N., D. DARDARI, S. GEIZICI and A. A. D'AMICO. LOS/NLOS Detection for UWB Signals: A Comparative Study Using Experimental Data. In: *IEEE International Symposium on Wireless Pervasive Computing (ISWPC)*. Modena: IEEE, 2010. pp. 169–173. ISBN 978-1-4244-6855-3. DOI: 10.1109/ISWPC.2010.5483704.

[2] VOSSIEK, M., L. WIEBKING, P. GULDEN, J. WIEGHARDT, C. HOFFMANN and P. HEIDE. Wireless local positioning. *Microwave Magazine*. 2003, vol. 4, iss. 4, pp. 77-86. ISSN 1527-3342. DOI: 10.1109/MMW.2003.1266069.

[3] YU, K., I. SHARP and J. GUO. *Ground-Based Wireless Positioning*. Chichester: John Wiley & Sons, 2009. ISBN 978-0-470-74704-9.

[4] GUVENC, I. and Ch.-Ch. CHONG. A Survey on TOA Based Wireless Localization and NLOS Mitigation Techniques. *Journal: IEEE Communications Surveys & Tutorials*. 2009, vol. 11, iss. 3, pp. 107-124. ISSN 1553-877X. DOI: 10.1109/SURV.2009.090308.

[5] GUVENC, I., Ch.-Ch. CHONG and F. WATANABE. NLOS Identification and Mitigation for UWB Localization Systems. In: *Wireless Communications and Networking Conference, 2007. WCNC 2007*. 2007. *IEEE*. Kowloon: IEEE, 2007, pp. 1571-1576. ISSN 1525-3511. ISBN 1-4244-0658-7. DOI: 10.1109/WCNC.2007.296.

[6] HATAMI, Ahmad. *Application of Channel Modeling for Indoor Localization Using TOA and RSS*. Worcester, 2006. Dissertation Thesis. Worcester Polytechnic Institute.

[7] ALSINDI, Nayef, C. DUAN, J. ZHANG and T. TSUBOI. NLOS Channel Identification and Mitigation in Ultra Wideband ToA-based Wireless Sensor Networks. In: *Proceedings of 6th Workshop on Positioning, Navigation and Communication (WPNC)*. Hannover: IEEE, 2009. pp. 59–66. ISBN 978-1-4244-3292-9. DOI: 10.1109/WPNC.2009.4907804.

[8] MUCCHI, L. and P. MARCOCCI. A new UWB indoor channel identification method. In: *CrownCom 2007. 2nd International Conference on Cognitive Radio Oriented Wireless Networks and Communications*, 2007. Orlando: IEEE, pp. 58–62. ISBN 978-1-4244-0814-6. DOI: 10.1109/CROWNCOM.2007.4549772.

[9] TOMAN, Eduard. *Statisticka interferencia v casovych radoch*. Bratislava, 2007. Diploma Thesis. Comenius University in Bratislava.

[10] DOBOS, L. and F. JAKAB. *Multimedia in mobile networks*. Kosice: TU-FEI, 2005. ISBN 80-8086-000-9.

[11] MOLISCH, Andreas F., Kannan BALAKRISHNAN, Dajana CASSIOLI, Chia-Chin CHONG, Shahriar EMAMI, Andrew FORT, Johan KAREDAL, Juergen KUNISCH, Hans SCHANTZ, Ulrich SCHUSTER and Kai SIWIAK. IEEE 802.15.4a Channel Model – Final Report. In: *Document IEEE 802.1504-0062-02-004a* [online]. 2005. Available at: http://grouper.ieee.org/groups/802/15/pub/04/15-04-0662-02-004a-channel-model-final-report-r1.pdf.

[12] POVENDRAN, R., C. WANG and R. SUMIT. *Secure Localization and Time Synchronization for Wireless Sensor and Ad hoc Networks*. New York: Springer Science+Business Media, 2007. ISBN 978-0-387-32721-1.

[13] SRINIVASAN, A. and J. WU. A Survey on Secure Localization in Wireless Sensor Networks. Boca Raton: CRC Press, Taylor and Francis Group, 2008.

[14] HEIDARI, M., F. O. AKGUL and K. PAHLAVAN. Identification of the Absence of Direct Path in Indoor Localization Systems. In: *IEEE 18th International Symposium on Personal, Indoor and Mobile Radio Communications, 2007. PIMRC 2007*. Athens: IEEE, 2007. pp. 1–6. ISBN 978-1-4244-1144-3. DOI: 10.1109/PIMRC.2007.4394450.

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