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On NLOS Conditions in Wireless Localization

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Abstract
The intention of this document is to spur a discussion on techniques of identification, modelling, mitigation and elimination of non-line-of-sight (NLOS) propagation effects in wireless localization, especially for receive-signal-strength (RSS) approach. A survey of already existing solutions is provided, considering diversity and cooperative techniques, concepts of identification LOS/NLOS reference nodes, statistical approaches and hybrid systems. A review of on-topic research works conducted in the frame of the IC1004 Action is also given. While the analysis here is focused on indoor systems, it can be also applied to other environments like urban ones.

Keywords
indoor, localization, WSNs, radio propagation, channel characteristics, channel models.

1. Introduction

The COST Action IC 1004 and its Indoor Topical Working Group (TWG-I) are already active from more than one year, hence the main issues covered by TWGI are starting to crystallize. One of them is the topic of **indoor localization**, until now addressed directly in 8 TDs (7 research institutions involved) with 10 additional TDs being related [1]. The intention of this document is to open a discussion on how this topic will be dealt by TWGI in future 3 years and to exchange experience with the audience putting emphasis on two main sources of errors in indoor localization: multipath fadings and non-line-of-sight (NLOS) propagation conditions. While the errors resulting from multipath channel fadings can be easily avoided using classical diversity schemes, the issue of NLOS propagation is not so straightforward. In indoor environments, due to large number of walls, obstacles and moving people, the first arrival path between a transmitter and a receiver is rarely LOS. Consequently, each localization-aimed measurement, i.e. time-of-arrival (TOA), time-difference-of-arrival (TDOA), angle-of-arrival (AOA) or receive-signal-strength (RSS) one will be significantly biased leading to an erroneously estimated position.

The rest of this document is intended to be a survey of NLOS identification and mitigation techniques mainly. In Sections 2-8, different groups of already proposed solutions are reviewed. Section 9 contains a short overview of indoor localization IC1004 TDs and finally Section 10 includes the conclusions and some suggestions on future work.

Each time a localization system is considered in this paper, it is assumed that the system consists of:

- a certain number of anchors with known positions, being reference points for other nodes; anchors can freely communicate with each other and share their knowledge;
- at least one wireless node, stationary or mobile, which position is to be estimated.

The system can work (a) in the network-based mode when the wireless nodes transmit signals to the anchors or (b) in the mobile-based mode when the anchors transmit reference signals. The algorithms described below usually work for both modes, unless the anchors and wireless nodes have different capabilities (transmission power, sensitivity, antenna arrays, etc.).

2. Locating a mobile node

While diversity techniques can help to mitigate the adverse channel *fast fading* effects, they, in general, cannot overcome the problem of NLOS propagation. If the line-of-sight connection is blocked, using neither a different frequency, code nor extra antennas (located in the same place) will allow for a LOS transmission. NLOS propagation is related to *slow fading* effects. There is, however, one exception: when locating (tracking) a mobile node, a time diversity scheme can change NLOS into LOS conditions when the node to be located emerges from behind an obstacle (Fig. 1). The periods of LOS conditions can be here identified by sudden enhancements of the received signal. Fast and slow fadings can be distinguished taking into account the respective *coherence distance* of the radio channel [2]. Thus in NLOS situations, paradoxically, tracking a mobile node can be more feasible than locating a stationary one.

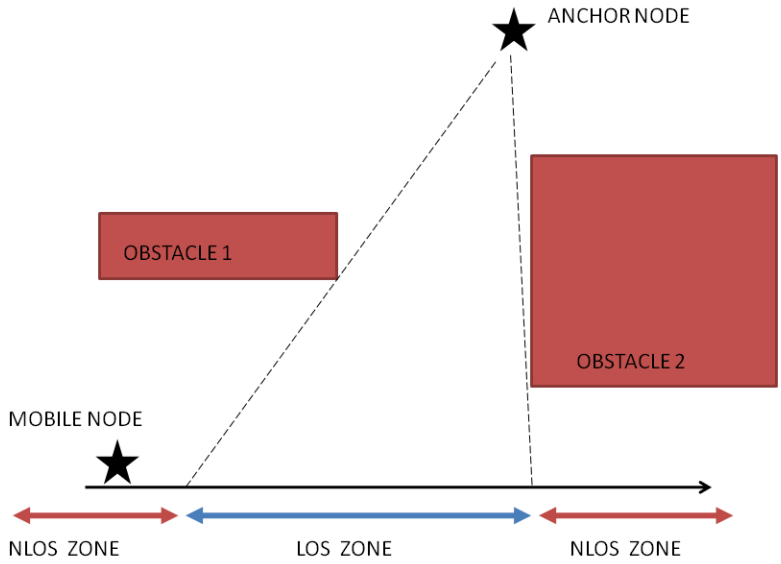

Fig. 1. An example of a mobile node moving between NLOS and LOS areas.

Other popular ideas of mitigating NLOS effects when tracking a mobile wireless device include data smoothing with Kalman filtering. As an input for the Kalman filter, the collected set of distance measurements or subsequent position estimates are taken [3-5]. In [6], the Kalman filter input data is additionally corrected by calculating first arrival paths for each anchor with Minimum Variance and Normalized Minimum Variance methods. When the movement parameters of the tracked object are also known, its velocity and the motion direction can be also a subject of an additional correction procedure, providing better tracking accuracy [7].

3. NLOS/LOS anchors identification

When the object to be localized is stationary and the environment is supposed to generate NLOS propagation conditions, one of the possible localization approaches is to distinguish between LOS and NLOS anchors, i.e. identify which anchors have a clear line-of-sight to the localized object. In [8] and [9], it is proposed to consider all subsets of the anchors set sufficient for the localization process, taking advantage of redundant anchors (when their number is larger than minimum to perform location estimation). For each anchor subset, the object position is estimated independently and then, the credibility of each estimation is calculated on the basis of residual errors resulting from the position estimation [8]. The final object location is calculated as a weighted sum of the estimations [8] or the best estimation (according to the maximum likelihood criteria) is taken [9].

In [10], NLOS signals are not only identified, but they are exploited in the localization process thanks to calculating the coordinates of their reflection points. It is feasible when anchor nodes are equipped with antenna arrays and thus are able to determine the angle-of-arrivals of received signals. Similar ideas of exploiting measured angle-of-arrivals are studied in [11, 12].

4. Statistical approaches

Another possible solution is to use the advanced statistics of the received signal. The analysis and simulation results reported in [13], limited however to modelled IEEE 802.15.4a UWB channels, show that the parameters like the kurtosis, maximum excess delay, and root-mean-square (RMS) delay spread can be efficiently exploited in order to decide if the path to an anchor is of LOS or NLOS type. In residential, urban and indoor office environments, the mean kurtosis is lower, while the maximum excess delay and RMS delay spread are higher in NLOS than in LOS channels. A similar approach is taken in [14]. Assuming that the variance of the measured time-of-arrivals of the received signals is greater in NLOS cases (observed previously also in [15]), the variance is used as a weighting coefficient when estimating the object location. In contrast to the abovementioned works, other statistics-based solutions [16, 17] suggest rejecting the data from redundant and suspected-of-being-NLOS anchors, while [18] adapts a combination of both ideas: some anchors are rejected and the rest of them are used with appropriate weights. Finally, [19] proposes to identify and compensate the NLOS biases.

Several authors propose to model the position bias introduced by NLOS anchors as a certain random variables, see e.g. [20-22]. These techniques are, however, very difficult to apply in practice, as the parameters of the random variable distributions are unknown and cannot be measured without *a priori* knowledge which anchors are NLOS.

5. Cooperative techniques

Cooperative localization is a broad group of techniques not only limited to NLOS scenarios, but more general, applicable in a case when there is a network consisting of a large number of wireless nodes having unknown positions and few anchors. The reference signals transmitted by anchors are not enough for a node to determine its position, thus the network nodes must cooperate exchanging some data between each other [23]. In the NLOS scenarios considered in this paper, cooperative techniques can be also helpful, but rather as additional tools to correct the wrongly (because of shadowed/obstructed radio paths to anchors) estimated

positions. Hence, they can be classified as *refinement* techniques [24]. According to the basic concept, the wireless nodes, after estimating their positions on the basis of anchor signals, perform the ranging measurements and exchange the position estimates with their neighbours. Then, each node calculates its own position again, using the data from neighbouring nodes [25]. This procedure can be repeated iteratively to minimize position errors resulting from erroneous NLOS anchor signals. Using additional confidence metrics is recommended in order to avoid position errors propagating through the network [25].
The idea described above was further developed/investigated in many research works, e.g. in [26] with the belief propagation theory, in [27] with factor graphs, in [28] with the message passing and in [29] with the iterative parallel project method.

6. UWB systems

While the most of the solutions described above are applicable for ultra wideband (UWB) systems also, there are some unique features that make UWB especially attractive for the localization purpose. UWB systems are working in extremely large frequency bandwidth (at least 500 MHz or 20% of relative bandwidth) and are characterized by very high time resolution and accurate time-of-arrival measurements. In fact, they can even take advantage of the multipath propagation phenomenon, as multipath components arriving to a UWB receiver can be distinguished and each of them can be analysed separately giving an information about its propagation path [30]. In [31, 32] the reflected multipath components are treated as direct ones coming from *virtual anchors* (the anchors being reflected images of a real anchor in the planes of walls or obstacles). If the environment topology (e.g. an indoor room) is known, NLOS radio paths and respective virtual anchors can be exploited in order to perform position estimation with only one anchor in the network [33].

The ability to distinguish the multipath components at a UWB receiver open the door for another UWB positioning technique called *passive localization* or UWB *radar networks*. Such a network consists of a UWB transmitter and a group of receivers following the changes in the registered channel impulse responses (CIRs). When an object or a person enters the monitored area, some of the CIRs will be modified. The comparison of CIR sets before and after the object appearance may enable to outguess the position of the localized object [34, 35]. UWB radar networks are completely insensitive to NLOS conditions, as each multipath component is resolved separately and assigned to a specific physical radio path. It should be noted however that the time resolution of UWB systems is still limited, so distinguishing all multipath components of a signal is not feasible in practice. Moreover, taking into account the large bandwidth of UWB systems, their transmission range is very short, usually few or a dozen of meters.

7. Fingerprinting

Fingerprinting (also called *mapping*) is a group of techniques based on comparison of received localization signals (usually time-of-arrival or receive-signal-strength) with training data gathered before a localization system is put to use [36-38]. The comparison can be performed with e.g. k-nearest-neighbours algorithm [37], neural networks [39] or probability distributions [40].

Speaking about NLOS conditions, fingerprinting techniques are very well suited to work without direct line-of-sight visibility between the localized object and the anchors, because their basic idea is just to match data patterns (to look for their similarities) independently what scenario these patterns describe in reality. However, the main feature of the fingerprinting systems is at the same time their main weakness: gathering training data is troublesome and frequently not feasible. Moreover, it means the localization system is not robust to environment and network topology changes.

8. Hybrid systems

There is also a quite significant number of research contributions describing hybrid localization solutions. It was proposed to deal with NLOS localization using joint TOA/AOA [41, 42, 11] or TDOA/AOA [43] measurements. In [44], a system based on camera images and RSS data from WLAN access points is described. In [45], RSS measurements are exploited together with data from motion sensors and binary foot-switches. Finally, in [4] it is proposed to use a system combining satellite navigation signals with ones coming from terrestrial networks.

9. IC1004 indoor localization contributions

Until now, the IC1004 on-topic works are focused on UWB and RSS techniques. In [46-48], an indoor UWB localization system using only a single anchor is investigated. The system is based in the fact that if the indoor room topology is well known, the reflected multipath components can be treated as coming from virtual anchors. In [46] the Cramer-Rao lower bound of the positioning accuracy is derived and in [48] the system performance is extended to tracking a mobile object. The document [49] analyzes the accuracy of a TDOA orthogonal frequency division multiplexing UWB localization system. In [50], a passive UWB localization is considered in a theoretical case of infinite temporal resolution of UWB receivers.

Documents [51] and [52] deal with RSS data. While in [51] the authors look for opportunities to increase the positioning accuracy of an indoor sensor network using frequency diversity, in [52] it is proposed to supplement the RSS data with images from local cameras. Finally, there is quite large number of TDs addressing the issues of indoor channel models. The document [53] explicitly analyzes the propagation channel models for the purpose of indoor localization.

10.Conclusions

This document gives a survey of wireless localization algorithms that deal with NLOS propagation conditions. The solutions for both mobile and stationary objects are provided. Techniques of NLOS identification and mitigation are given, statistical approaches are explained and solutions where the cooperation of multiple wireless nodes is necessary are also shown. Separate sections are devoted to UWB systems and fingerprinting techniques. Finally, research works conducted in the frame of the COST Action IC1004 are also summarized. As a future work it is planned to apply some of the above-described NLOS mitigation and statistical techniques in order to increase the accuracy of the RSS localization system reported in TD IC1004 (11)02068.

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