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RADIO LINK MEASUREMENT METHODOLOGY FOR LOCATION SERVICE APPLICATIONS

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Abstract

The aim of this paper is the methodology of measurements executed in a radio link for the realization of radiolocation services in radiocommunication networks, particularly in cellular networks. The main results of the measurements obtained in the physical layer of the universal mobile telecommunications system (UMTS) are introduced. A new method for the utilization of the multipath propagation phenomenon to improve the estimation of the distance between the mobile station (MS) and the base station (BS) is outlined. This method significantly increases the quality of location services in systems which use a radio interface with direct sequence code division multiple access (DS CDMA).

Keywords: radio link measurements, location service, radiolocation, radionavigation.

1. Introduction

Over the last decade, the deployment of wireless communications has been increasing significantly. Currently, it is estimated that there are approximately 5.2 billion cellular users in the world[1], representing over 74% of the world population. In order to provide both an increase in capacity and better quality communications, the wireless industry already twenty years ago has begun to migrate from analog cellular networks to digital networks. The move from analog to digital technology has improved the functionality of cellular networks and has broadened the spectrum of available services. One of these new services is wireless position location (WPL) [1]. In cellular networks there are two aspects of WPL: location service (LCS) and location based service (LBS). The LCS deals with the capabilities to locate the target (a mobile station or a mobile terminal), triggered by either external or internal requests. It specifies all the necessary network elements, interfaces, communication protocols and messages due to the implementation of the positioning functionality in a cellular network. The LBS utilizes the available location information of the mobile station for value-added applications accessible to mobile subscribers or to other third parties.

This paper concentrates in particular on the LCS in the third generation (3G) cellular networks which use direct sequence code division multiple access (DS CDMA) modulation. This type of multiple access is used in the UMTS or in the IS-95 and CDMA2000 systems. The DS CDMA assigns each user a unique pseudonoise (PN) spreading sequence [2], unlike a frequency division multiple access (FDMA), where each user is assigned a different frequency (channel) and time division multiple access (TDMA), where each user is assigned a different time slot.

Generally, there are four categories of usage of the location service [3]:

[1] www.gsacom.com

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- *commercial* will typically be associated with an application that provides a value-added service to the subscriber of the service, through the knowledge of the mobile station location and, optionally, velocity. This may be, for example, a directory of restaurants in the local area of the mobile station, together with directions for reaching them from the current MS location;
- *internal* will typically be developed to utilize the location information from the MS for access network internal operations. This may include, for example, location assisted handover[2], traffic and coverage measurement;
- *emergency* will typically be part of a service provided to assist subscribers who place emergency calls;
- *lawful intercept* will use the location information to support various legally required or sanctioned services.

The LCS feature employs one or more positioning methods in order to determine the location of a mobile station. Determining the position of the MS involves two main steps:

- radio signal measurements; and
- position estimate computation based on measurements.

One of the major sources of error for radio signal measurements in cellular networks is multipath propagation. Algorithms that have been developed for the location of the MS are based on the assumption that a direct path (line of sight – LOS) exists between the MS and every BS. Unfortunately, in urban environments, for example, LOS paths rather do not exist. Consequently, the MS or BSs will receive the desired signal from reflections and/or diffractions, not from a direct path. Non-line of sight (NLOS) propagation causes incorrect estimation of position of the MS.

This paper describes and evaluates a new technique which attempts to reduce the effect of the multipath propagation and to produce location estimates nearer the actual location. It is organized as follows. Section 2 briefly reviews different location methods in the UMTS system. Section 3 presents a new method of range estimation between the mobile station and the base station in the multipath propagation environment. Measurement investigation in real-live urban surroundings is described in section 4. Finally, section 5 summarizes the results and addresses several topics for future research.

2. Radiolocation method in the 3G cellular network

The technical specification for the UMTS system specifies the following basic positioning methods [4]:

- cell ID method,
- observed time difference of arrival (OTDOA) method assisted by a network configurable idle period,
- network-assisted GPS methods.

The cell ID is the simplest and the most inexpensive method in mobile location. It is implemented as a network based method, and thus it does not require any changes in the terminal, but only minor software changes in the network. Therefore, it is implemented as a default location technique in all cellular networks in the world. The position of a mobile station is estimated on the basis of the coverage area of the serving cell. This information is received by paging, location area update, cell update or routing area update. The accuracy of this method depends heavily on the size of the serving cell, and more precisely, on the size of the corresponding antenna sector. Typical cell ranges in urban areas are smaller than 1 km and

[2] The term *handover* or *handoff* in cellular networks refers to the process of transferring an active call from one physical or logical channel to another.

have in dense urban areas a few hundred meters. Nowadays, instead of the above mentioned disadvantages, the cell ID location method is the most popular technique in many mobile networks [5].

The accuracy of the cell coverage based approach can be improved by using the round trip time (RTT) measurement that can be obtained from the serving base station. That information gives the distance between the base and the mobile station. To increase the accuracy of the location service we can use more distances between the mobile station and auxiliary base stations. In this case, for example, the path loss model can be used to compute the distance to the MS, assuming the transmission power from auxiliary base stations is known. This method is called received signal strength (RSS) [6]. Generally, there are two basic classes of systems that use RSS to estimate location: those based on known radio propagation analytical relationships, and those that involve searching a database that is composed of measured signal strengths in a location-specified survey. The latter class is often referred to as fingerprinting. A third class can be defined as a combination of the first two – a database is formed from the use of analytical equations or derived from ray tracing software [7]. In the cellular networks, the error potential of signal strength measurements is much higher than that of timing measurements, but in the cell ID the RSS method is only possible for a distance calculation between MS and auxiliary BSs (Fig. 1).

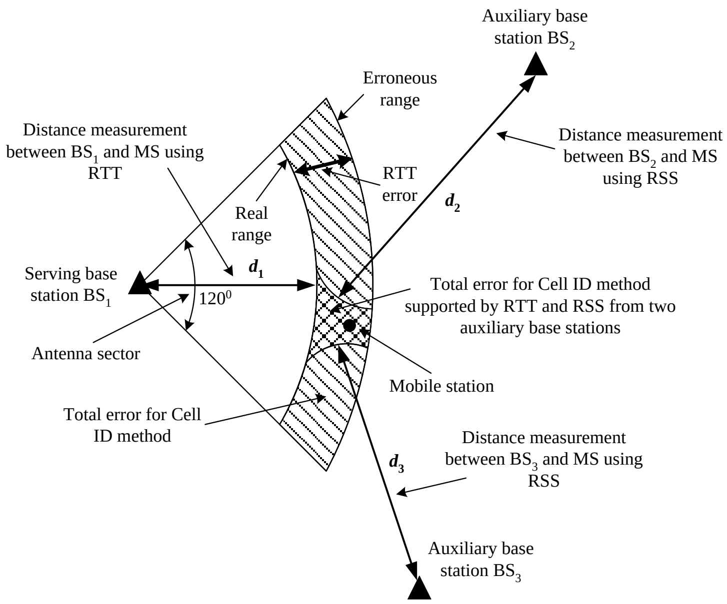

Fig. 1. Cell ID method supported by RSS.

The OTDOA method is based on the mobile measurements of the relative arrival times of the pilot signals from different base stations. In order to calculate its location, the mobile station must receive a signal from at least three base stations. One hyperbola defines a measurement from two base stations. The location can be calculated with two measurement pairs, i.e. with three base stations. In order to facilitate the OTDOA location measurements and to avoid near-far problems[3], the UMTS standard includes idle periods in downlink (IPDL), during which transmission of all channels from any base station is temporarily seized

[3] In DS CDMA cellular mobile communications, transmission power must be controlled in both uplink and downlink with regards to a near-far problem. All stations (mobile or base) operate on the same carrier except that they use different PN codes. The signal from a near MS received by a BS can have a much larger amplitude than the amplitude of a MS farther away. The interference caused by a near MS acts as strong interference to a MS farther away, and can disable its communication with a BS. Thus, both near and far MSs must adjust their transmission power in such a way that their signals arrive at the BS with equal levels.

[8]. A typical frequency of idle periods is 1 slot (about 667 μs) every 100 ms, i.e. 0.7 % of the time [9]. During those idle periods the mobile is able to receive the pilot signal from the adjacent cells even if the best pilot signal on the same frequency is very strong.

The most accurate location measurements can be obtained with an GPS receiver integrated in the mobile station. The network can provide additional information, like visible GPS satellites, reference time and Doppler, to assist the mobile GPS measurements. The assistance data improves the GPS receiver sensitivity for outdoor measurements, speeds up the acquisition times and reduces the GPS power consumption. It is obvious that the GPS system does not work in the indoor surroundings.

In the next sections of this paper, the cell ID methods will be elaborated, particularly the RSS methods for the supported range estimation between the mobile station and auxiliary base stations.

3. New method of range estimation

Multipath and non-line-of-sight (NLOS) propagation are the dominant sources of error for the majority of positioning methods. Multipath propagation means that a signal reaches the receiving antenna not only on a single path but also on various paths of different lengths and with different degrees of attenuation. It basically results from the combination of reflection, diffraction and scattering. In this section the multipath propagation effect will be applied to improve the estimation accuracy of the distance between the mobile station and the base station in an urban environment [10]. The properties of the RAKE receiver will be utilized to this end.

The error introduced by NLOS propagation causes a large bias in the location estimates of mobile stations. In order to provide more accurate location estimates, measures must be taken to reduce or remove the effect of the bias. Very little research can be found in the literature that addresses the problem of NLOS propagation. Generally, there are two methods to mitigate the error caused by NLOS propagation. The first, so called LOS reconstruction, adjusts the corrupted measurements based on a time-series of range estimates [11]. The second approach, so called NLOS measurement weighting, is based on a recursive least squares formulation [12].

Direct sequence spread spectrum communication systems utilize the RAKE receiver (an extension of the matched correlator receiver) for data detection. The RAKE receiver consists of parallel correlators known as fingers and a maximal ratio combiner. The correlators are set up to resolve the strongest multipath signals arriving at the receiver. The signals are identified by the searcher algorithm and are specified by relative offsets in the PN sequence [13]. Typically, the number of fingers in the RAKE receiver is between three and six [14]. Essentially, the RAKE receiver mitigates the effects of multipath propagation and can measure the following parameters which can be potentially utilized for the LCS process [15]:

- strongest primary signal and basic strongest multipath components of that primary signal,
- multipath power (MP),
- received signal code power (RSCP),
- relative power (RP).

Multipath power is the measure of the total power in the dominant signal (spread in time due to multipath echoes) that is relative to its power in the main transmission path. The received signal code power is the received power on one code measured on the primary common pilot channel (P-CPICH)[4] and is reported from the physical layer [16]. Relative

[4] The P-CPICH is an unmodulated code channel. It does not carry any higher layer information and is used for call selection.

power is a parameter which describes the difference between the value of average power for the dominant propagation path and the values of power for significant propagation paths.

The parameters mentioned above will be used to study a new path loss formula for a more accurate calculation of the distance between the mobile station and base stations in the cell ID method.

3.1. Description of the new method

The new analytical description of the propagation loss for the cell ID method was worked out, using about five thousand measurement investigation results and applying multidimensional regression analysis with many independent variables [17, 18], based on the main parameters described above. Using the regression analysis, the following formulas to calculate the propagation loss in the five variants which gave the best results[5] out of a dozen considered, have been obtained:

Variant I

At the beginning of our considerations, we modified the well known Okumura-Hata model [19], taking into account only the carrier frequency and the distance between the mobile station and the base station. The modified formula is as follows

$$L_{V1} = 48.68 + 29.26 \cdot \lg d\ , \tag{1}$$

where d is the length of radio link in [m]. The radio link budget was based on RSCP power for the dominant propagation path.

Variant II

The assumptions in this variant were same as the assumptions in variant I, except that an average value of the RSCP is used for the radio link budget. The propagation loss in [dB] for the considered variant is described by

$$L_{V2} = 51.52 + 29.20 \cdot \lg d\ . \tag{2}$$

Variant III

The propagation model worked out for this variant describes most exactly the path loss in [dB] in all cases considered. It is based on the knowledge of the carrier frequency (f = 2 GHz), the distance between the mobile station and the base station, and M_P parameter in the linear scale, defined as a ratio of the average total power from all significant propagation paths to the average power from a dominant component, i.e.

$$L_{V3} = 46.85 + 29.28 \cdot \lg d + 20.13 \cdot \lg M_P\ . \tag{3}$$

Variant IV

The radio link budget in this variant was based on the RSCP power. The remaining assumptions were the same as in variant III. The formula describing the propagation loss in [dB] is as follows

$$L_{V4} = 50.15 + 29.21 \cdot \lg d + 15.14 \cdot \lg M_P\ . \tag{4}$$

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[5] A criterion of quality was the smallest mean error of distance estimation between the mobile station and the base station in all cases considered.

Variant V

The last but not least of the presented variants is based on the knowledge of the carrier frequency, the length of the radio link, and parameters W_i (i = 1, 2, 3) expressed in [dB] and defined as the difference between the average RSCP power for the dominant propagation path and the RSCP power for the next three significant propagation paths. The radio link budget was based on the average RSCP power for the dominant propagation path. The propagation model (in [dB]) worked out for this variant can be introduced as follows

$$L_{V5} = 74.17 + 20 \cdot \lg d + 0.34 \cdot W_1 - 0.15 \cdot W_2 - 0.19 \cdot W_3 . \qquad (5)$$

3.2. The error analysis

The error analysis was made as a comparison between the values of the measured propagation loss, and the distance between the mobile station and the base station in a typical urban environment and those values calculated by using the proposed formulas of the described models. The mean error (ME) and the root mean square error (RMS) have been applied. These errors are defined by the expressions (6) and (7) respectively [20]:

$$ME = \frac{1}{N}\sum_{i=1}^{N}(x_{meas,i} - x_{reg,i}) , \qquad (6)$$

$$RMS = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_{meas,i} - x_{reg,i})^2} , \qquad (7)$$

where $x_{meas,i}$ is the value of the measured path loss or the distance in i-th position of the receiver equipment (i = 1, ..., N), $x_{reg,i}$ means the path loss value or the distance computed by using the equations (1) – (5) for i-th position, and N is the total number of the results considered.

As it is generally known, the mean error shows the scattering of the measured values around the theoretical ones calculated with use of the verified propagation model. The root mean square error is the matching quality of the investigated model with the measured data.

4. Measurement investigation

In order to confirm our assumption, we examined the propagation characteristics obtained from a field test in the metropolitan area of Gdansk-Wrzeszcz. One base station and a mobile station were used in the field test (Fig. 2). The base station consisted of an omnidirectional antenna (gain = 2.15 dB). The height of the antenna was 34 m. The base station transmitted a primary common pilot channel (CPICH) which was in accordance with the UMTS standard for a downlink physical channel at about 2 GHz. The mobile station contained a high performance handheld spectrum analyzer with an over-the-air measurement option (the spectrum analyzer imitated the RAKE receiver) and an omnidirectional antenna (gain = 2.15 dB). During the experiment we measured the strongest primary signal and up to the three strongest multi-path components of that primary signal, MP, RSCP, and RP parameters.

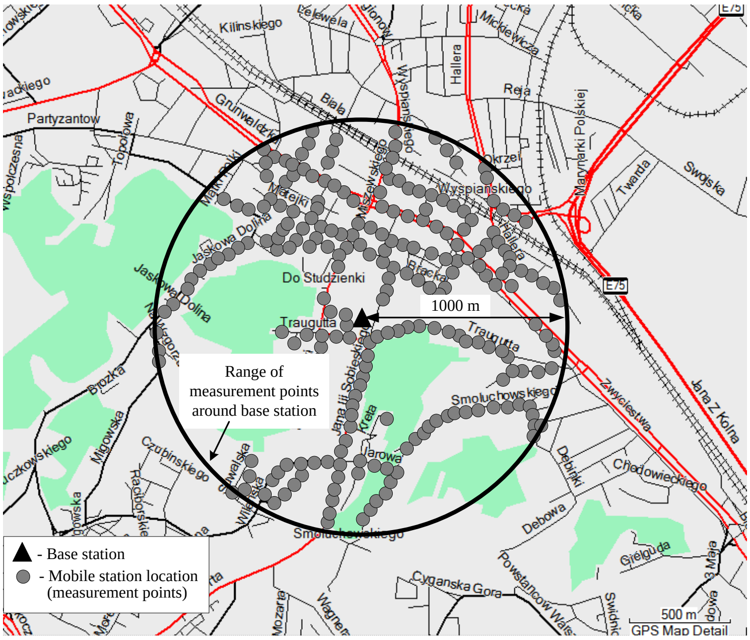

Fig. 2. View of a field test in the metropolitan area of Gdansk-Wrzeszcz[6].

Block diagram of the equipment set used in the measurement campaign in the field test is presented in Fig. 3.

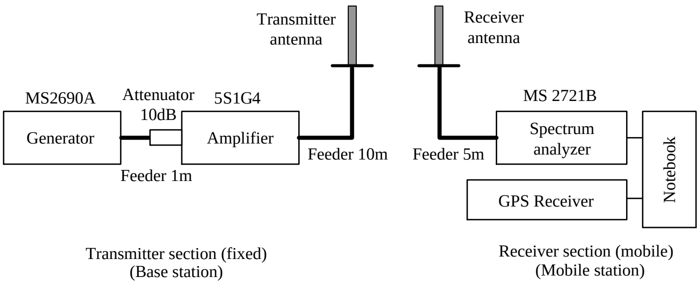

Fig. 3. Block diagram of measuring equipment set.

Practical applications of the cell ID methods are based on possible universal algorithms, which are valid in the whole cellular network. Owing to this fact, the purpose of our investigation was to search for new analytical equations for more accurate distance estimation between the MS and the BS (path loss estimation) in a multipath propagation environment. New equations will be very useful for the cell ID method application in 3G cellular systems. The three most popular propagation models for the UMTS path loss prediction were analyzed first of all. The equations are as follows [21]:

– Okumura-Hata (OHU) model adapted to the UMTS parameters

$$L_{OHU} = 137.4 + 35.2 \cdot \lg d \, , \tag{8}$$

where d (in [km]) represents the distance between the mobile station and the base station;

– pedestrian test environment (PTE) model

$$L_{PTE} = 148 + 40 \cdot \lg d \, , \tag{9}$$

– vehicular test environment (VTE) model

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[6] The figure was worked out using GPMapa ver. 4.0 Tool.

$$L_{VTE} = 40 \cdot (1 - 4 \cdot 10^{-3} \cdot \Delta h_b) \cdot \lg d - 18 \cdot \lg \Delta h_b + 21 \cdot \lg f + 80, \quad (10)$$

where Δh_b (in [m]) is the height of the base station antenna, measured from an average rooftop level.

Unfortunately, the equations above do not correspond satisfactorily with the distance prediction for the RSS methods. Therefore, new equations described in section 3.1 were worked out. Mean errors and root mean square errors for all cases considered are presented in Table 1.

Table 1. Mean errors (ME) and root mean square errors (RMS) for all cases considered.

Propagation model	ME Propagation loss [dB]	RMS Propagation loss [dB]	ME Distance between MS and BS [m]	RMS Distance between MS and BS [m]
OHU model, equation (8)	2.02	5.43	-53.36	123.16
PTE model, equation (9)	-6.21	5.85	113.09	107.68
VTE model, equation (10)	11.87	5.63	-373.55	212.90
Variant I, equation (1)	0.00	5.24	-21.55	132.16
Variant II, equation (2)	0.00	5.31	-23.12	138.93
Variant III, equation (3)	**0.00**	**4.97**	**-21.10**	**130.50**
Variant IV, equation (4)	0.00	5.16	-23.30	139.24
Variant V, equation (5)	0.00	5.32	-92.15	237.05

As we can see in Table 1, the smallest mean error in distance estimation between the mobile station and the base station was obtained for variant III. The propagation path loss and the distance calculated by using the proposed analytical model (variant III) matches very well the results of the measurement campaign for all propagation path cases, which is confirmed by the low values of the mentioned mean errors and the acceptably low values of root mean square errors.

The example distribution of the theoretical and measured propagation path loss as a function of the radio link length is shown in Fig. 4, where L_{meas} are the measured values, and L_{reg} represents trend curve of the theoretical values calculated by using a new formula (3).

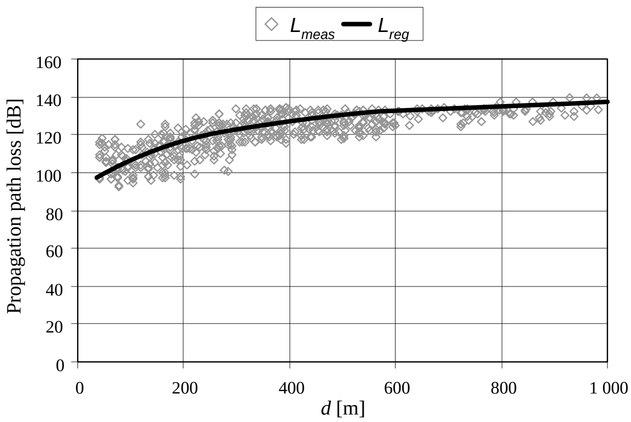

Fig. 4. The distribution of theoretical and measured values of the propagation path loss in all cases.

In the Fig. 4 we can see the correspondence between the theoretical and measured values of the propagation path loss. This correspondence shows the usefulness of the proposed propagation model for the RSS location method in urban environments. Our investigations proved that the multipath propagation phenomenon can be utilized to increase the accuracy of the location service in the UMTS system.

5. Simulation results

The cellular network is divided into cells (radio zones). For easier manipulation, these cells are modeled in a simplified way as hexagons. Most models show the base station in the middle of the cell. In our case we consider three base stations and one mobile station, which is located in an urban environment. These base stations make up an equilateral triangle and the distances between the triangle peaks are 1 km. In numerical calculations, m = 10 000 positions of mobile station were drawn. Then, using the two methods outlined above: Cell ID+RTT method and proposed Cell ID+RTT+RSS, utilising the proposed new propagation model to predict distance between MS and auxiliary BSs – equation (3), the mobile station position was estimated. The cumulative probability distribution functions (CDF) of the absolute position error were obtained from the simulation investigations. The absolute position error is defined as

$$\Delta d = \sqrt{(x - x_0)^2 + (y - y_0)^2}\ , \tag{11}$$

where x and y represent the real coordinates of a mobile station and x_0 and y_0 the estimated coordinates of a mobile station. All the timing values have been assumed to be accurate within ± one half of a chip (the uniform random time error corresponds to a maximum distance error of about ± 39 m). The simulation results are shown in Fig. 5.

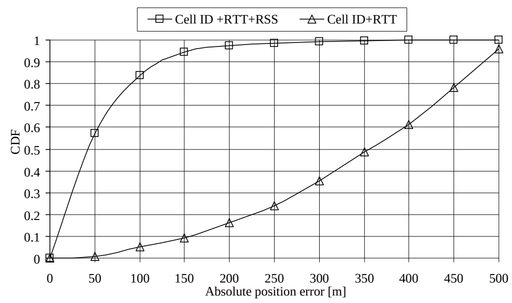

Fig. 5. The CDF of the absolute position error for Cell ID+RTT and Cell ID+RTT+RSS methods.

The cell ID method, within the measured round-trip time (Cell ID+RTT), which is commonly used in nowadays generation UMTS networks, was compared with the proposed method. The proposed method seemed to be much better in location estimation than the Cell ID+RTT. For example, the absolute position error for the Cell ID+RTT+RSS method is less than 80 m in 80 % of the time while the error for the Cell ID+RTT is less than 450 m in 80 % of the time. The complexity of localization processes of these methods is comparable.

6. Conclusions

The aim of this paper is to provide a short overview of the wireless location service in cellular networks, particularly based on DS CDMA system. Multipath propagation and NLOS propagation are identified as the major source of error in the LCS. The method for improving the accuracy of the RSS method in a multipath environment is presented. The new propagation models take into account the specific characteristics of the radio wave propagation mechanism in urban cellular systems. The models have been verified by measurements. The verification confirms the usefulness of the new method for the location service in the DS CDMA system. The proposed formula can be implemented in a simple way in the existing location platforms which are based on the Cell ID method.

Several areas for further research are possible. They mainly concern the methods to improve the accuracy of the location process in the multipath environment. Numerous approaches can be pursued including frequency domain, super-resolution, and other techniques that can closely identify space multipaths to increase the accuracy of the LCS. The area that requires the most attention is the problem of the NLOS propagation. The biased measurements that are produced in such an environment are well-known. For example, one possible way is to estimate the bias occurring in the location process of the MS in order to remove its effect on the measurement [11, 12].

To sum up, parallel approaches must be developed, possibly improving the observability of the unknowns by adding additional measurements or information to the system.

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