Enhanced Positioning Techniques for Hybrid Wireless Networks

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Abstract: This paper presents a reliable and accurate positioning method, which provides location estimates for the mobile user in a wireless network where IEEE802.11/WiFi, IEEE802.16/WiMAX, 3GPP LTE and Bluetooth wireless technologies are deployed. The developed data fusion algorithm utilises measurements and features such as Time of Arrival (TOA) and multiple input, multiple output (MIMO) antennas and wireless links between mobile users in order to enhance the positioning accuracy. Therefore, in the proposed concept of mobile user positioning is proposed and it is applied to hybrid wireless network environment. Results satisfy the FCC requirements for the network and mobile-centric positioning solution.

1. Introduction

The basic task of wireless-based communication technologies is to enable the mechanism of data transmission among users (terminals) of the network. As wireless technologies improve with time, it is possible for the transmitted signal to be used by wireless systems not only for data exchange but also for the purpose of location and positioning services. One of the most active research fields, considered to have very high potential, is based on services and applications that allow users to determine their current position. These services can be used as tracking, emergency, monitoring, security and intelligent transportation system applications, etc. Although such services already exist, there is still a lot to be done in order to fully fulfill the user’s expectations. The need for such application is dictated by the necessity to located people (objects) within certain environment and definite the time frame. It can be part of services of manufacturing, special emergency services, healthcare, etc. As a result a lot of research is oriented towards resolving viable applications and services.

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Wireless communication technological advances, such as mobile phones, personal digital assistants (PDAs), personal computers (PCs), and in general wireless mobile stations, have become the enabler of viable location and positioning-based services. Therefore, the focus of this paper is to develop a technique that provide an accurate and reliable service for the mobile user in the environment where IEEE802.11/WiFi, IEEE802.16/WiMAX and 3GPP LTE technologies wireless technologies coexist.

This paper is organised as follows. Section 2 presents a focused review of the existing location and positioning techniques. In Section 3 the proposed location and positioning method is described and analysed. In Section 4 results are evaluated. Finally, Section 5 provides conclusions to the developed and tested solutions.

2. Existing Positioning Techniques

Various examples of location and positioning methods have been developed depending on the properties of the signal, types of networks and environmental properties. The following are, but not exclusively the most commonly used measurements: received signal strength (RSS), angle of arrival (AOA), time of arrival (TOA) and time difference of arrival (TDOA) [Be08]. These methods can be used in combinations depending on the data fusion methodology, in order to improve the positioning accuracy [VC04, CCL10].

Wireless-based systems and applications find their use in various existing wireless networks. Among them are wireless local area networks (WLAN), such as WiFi which is mostly in use for the indoor positioning because of its scarification requirements. Wide area network technologies such as cellular communication networks (GSM, WiMAX) and global positioning system (GPS); radio frequency identification (RFID) technology which relies on remotely storing and retrieving data using tags and readers. Multiple RFID tags are used for the accurate object detection and it is based on the principle of measurements of the RF signal strength between a reader and a tag.

This paper focuses on a recent research topic in positioning within hybrid wireless networks that utilise TOA measurements, MIMO features and reference distance between users, which offers an alternative solution to the conventional methods. It is dedicated to enhance the positioning capabilities and location accuracy [Ro07, Ma07, Vo08]. The proposed data fusion algorithm is applied to the hybrid wireless network. In reality, wireless network provider will deploy base stations (BSs) in a way so that their areas of coverage do not overlap, while different networks normally cover the same location. Hence, it is possible to use all available wireless technologies in a certain environment.

3. System Architecture

There are many open problems related with the various positioning solutions, e.g.:

- A GPS system is unable to perform the service in the non line of sight (NLOS) condition; lack of support for the indoor positioning (satellite),

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- WLAN technologies are lacking coverage range;
- Mobile radio is lacking accuracy of connection for the rural environment;
- etc.

Hence, the question is how to use position an object and which technology would be most appropriate in a certain environment. Also it is important to study the performance of the proposed algorithm on the environment where combinations of all available radios to improve accuracy of the service.

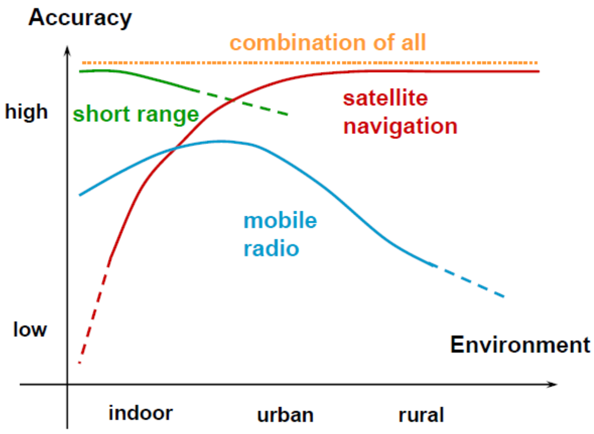

Figure 1: Accuracy depends on Environment [ST09]

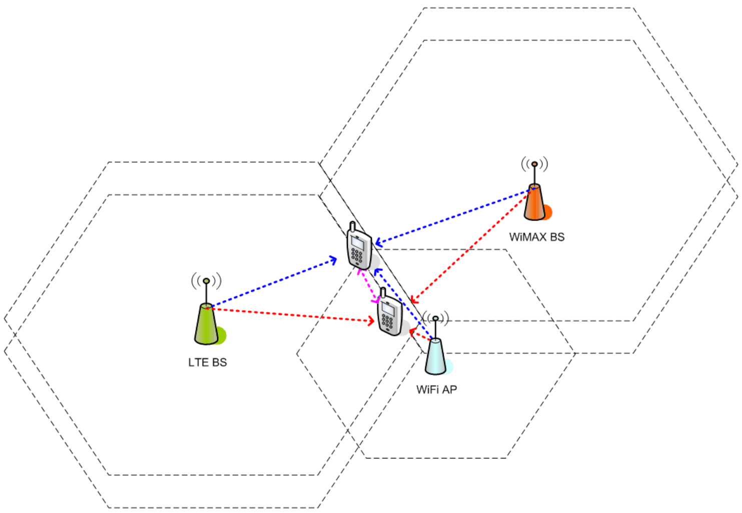

Figure 2: Heterogeneous Wireless Network Architecture

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In Fig.1 the dotted line represents the combination of possibly available for location and positioning communication systems for the indoor, urban and rural environments. Moreover, it shows that incorporation of various communication technologies could guarantee higher accuracy in object location which does not depend on applied environment.

The proposed system architecture is illustrated in Fig.2. WiMAX, WiFi, Bluetooth and 3GPP LTE wireless networks are modeled according to the respective standard requirements. The scenario consists of three BSs that initially are not synchronised and each corresponds to one of the wireless network technologies. The targets of interest are two MSs for which the position estimation will be performed. It is assumed that MSs are in the connectivity range for all of them.

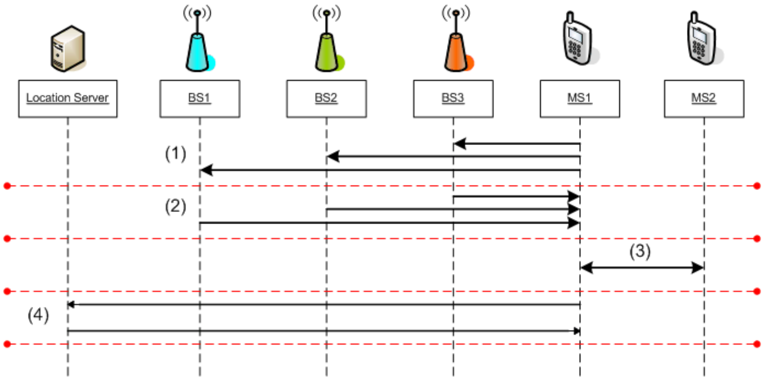

Figure 3: Proposed Positioning Protocol for Hybrid Wireless Network

A mobile-assisted positioning protocol is proposed in order to specify all the steps required from the "ping" until the provision of the estimated position. All the required steps from the positioning request until the position estimation are illustrated in Fig.3. Initially, the MS performs a search for all the available networks. It is assumed that the MS supports WiFi, WiMAX, LTE and Bluetooth connectivity.

(1) Once the device is aware of the available networks, it 'pings' them.
(2) All BSs answer to the 'ping' with acknowledgment which allows the mobile terminal to calculate the round trip time (RTT).
(3) MSs calculate the distance between them based on the TOA measurements.
(4) This protocol suggests data fusion performed in the mobile device. If the algorithm cannot be run on the MS, collected measurements are sent to a location server. Here, the MS position can be calculated. Firstly, the position of each MS location is calculated separately. Then, the measured distance between the MSs is compared with the calculated distance and if there is a significant difference in MSs positions then distances are recalculated again.

4. Data Fusion

4.1 Positioning via Time of Arrival with MIMO Features

A concept of the TOA method [IS11] is in multiplying the propagation time (t_i - t_0) by the propagation speed of the signal. The propagation delay can be converted into a distance between the transmitter and the receiver. This method is for the *2D* range calculations can be illustrated as shown in Fig. 4, where r_1, r_2, and r_3 are distances between the transmitter and receiver stations. The signal is transmitted at the time moment t_0 and received by readers at the time moments t_1, t_2, and t_3, respectively.

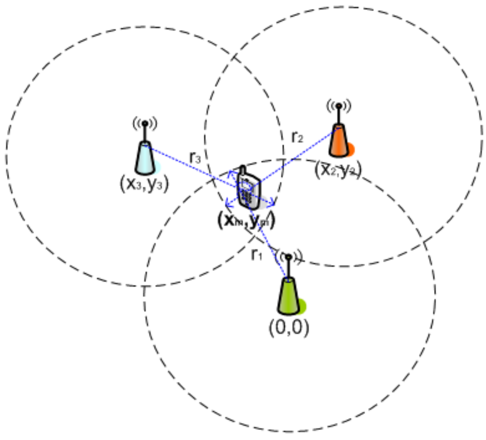

Figure 4: Positioning Utilising TOA Measurements and MIMO Features

Disadvantages of the TOA method are:

- the clocks of the tag and the reader must be *synchronised* in order to have confidence in the measurement of the elapsed time;
- the clock synchronisation system must be developed which has high *costs* in terms of development time and effort;
- three or more readers are required, which also adds to the *cost* and *complexity* of the system.

The distances between the MS and BSs are calculated then using a trilateration [BA00], the conventional linear least squares (LLS) and non-LLS estimation [IS10] algorithms. The following equations are used to calculate the MS position with LLS. Note that to simplify the calculations, the equations are formulated so that the centres of the spheres are on the z=0 plane. Also the formulation is such that one center is at the origin.

$$r_1^2 = x_m^2 + y_m^2, \quad (1)$$

$$r_2^2 = (x_2 - x_m)^2 + (y_2 - y_m)^2, \quad (2)$$

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$$r_3^2 = (x_3 - x_m)^2 + (y_3 - y_m)^2, \tag{3}$$

where r_1, r_2, and r_3 are distances between the transmitters and receivers, x and y are coordinates respectively as shown in Fig.4.

Then subtracting (1) from (2) and (3) from (1) gives

$$r_2^2 - r_1^2 = x_2^2 - 2x_2x_m + y_2^2 - 2y_2y_m, \tag{4}$$

$$r_3^2 - r_1^2 = x_3^2 - 2x_3x_m + y_3^2 - 2y_3y_m, \tag{5}$$

The above equations can be written as

$$\begin{bmatrix} x_2 & y_2 \\ x_3 & y_3 \end{bmatrix} \begin{bmatrix} x_m \\ y_m \end{bmatrix} = \frac{1}{2} \begin{bmatrix} K_2^2 - r_2^2 + r_1^2 \\ K_3^2 - r_3^2 + r_1^2 \end{bmatrix}, \tag{6}$$

where

$$K_i^2 = x_i^2 + y_i^2, \tag{7}$$

the equation (6) can be rewritten in the form

$$Hx = b, \tag{8}$$

where

$$H = \begin{bmatrix} x_2 & y_2 \\ x_3 & y_3 \end{bmatrix}; x = \begin{bmatrix} x_m \\ y_m \end{bmatrix}; b = \frac{1}{2} \begin{bmatrix} K_2^2 - r_2^2 + r_1^2 \\ K_3^2 - r_3^2 + r_1^2 \end{bmatrix}$$

Note the equations so far are for three measured distances only. If more measurements are present they can be added to the equation as well.

$$H = \begin{bmatrix} x_2 & y_2 \\ x_3 & y_3 \\ : & : \end{bmatrix}; b = \frac{1}{2} \begin{bmatrix} K_2^2 - r_2^2 + r_1^2 \\ K_3^2 - r_3^2 + r_1^2 \\ : \end{bmatrix}$$

Hence the LLS solution is

$$\hat{x} = (H^T H)^{-1} H^T b. \tag{10}$$

MIMO technology is a wireless technology that uses multiple transmitters and receivers to transfer more than one signal. It takes advantage of a radio-wave phenomenon called *multipath* where the reflected signal reaches the receiving antenna multiple times via different angles and slightly different times [SA05]. Furthermore, the MIMO technology controls the multipath by using multiple, “smart” transmitters and receivers with an added “spatial” dimension to dramatically improve performance with the increase of the range.

A position technique based on TOA is by utilising MIMO features was proposed in [IS11]. We decided to study further positioning via TOA utilising MIMO features by applying it to the proposed heterogeneous wireless network scenario and the cooperative scheme. The MIMO antenna is considered as a diversity antenna, so that only TOA measurements are taken into account.

It is possible to study the performance when the conventional 1 x 1 systems use single antennas at both ends compare results with the MIMO case. Hence, as it is shown in [IS11] and proved by our implementation, that the MIMO is not only improving the capacity of a wireless link but also can be used to advance the accuracy of the positioning system.

It is assumed that each BS has a number of transmit antennas (*Nt)* and each MS has a number of receive antennas *(Nr).* In this case, depending on the number of antennas, multiple different signals are simultaneously transmitted over minimum of *N* paths, which is equal to *Nt* x *Nr.* Each *Nr* received signal is a combination of all the transmitted signals and noise. Because of the MIMO features more signals will be detected by the MS which will improve the location accuracy [Is11].

Measurements from one BS are not sufficient to estimate a MS location. It is necessary to combine the gathered information from multiple BSs. Data fusion is the process of combining measurements from multiple BSs in order to calculate the MS location. In this work the Linear Least Squares (LLS) and Non-Linear Least Squares (NLLS) methods [FF10] [STK05] are used. LLS methods are used to approximate a set of measurements when measurements are subject to inaccuracies because of NLOS, noise or other conditions. Hence, considering the MIMO TOA based method with *M* BSs estimates [IS11], the mobile position estimates are as presented in (11).

$$\hat{x}_{MIMO} = \arg\min_x \sum_{i=1}^{M}\sum_{i=1}^{P}\sum_{j=1}^{n}\left|\delta_{i,n}^{1} - \left\|x - x_i\right\|\right|^2, \tag{11}$$

where x is the true position of MS, x_i and δ, denote the coordinates of i^{th} BS and the range measurement between the i^{th} BS and the MS with l^{th} pilot (preamble) signal, respectively, $i = 1,2,...,M$ and $n = 1,2,..., Nt \times Nr$.

5. Simulation Scenarios and Performance Evaluation

Results from two scenarios are evaluated. The first simulation compares the positioning accuracy of a system using MIMO features. Different antenna modes are set from single input single output (SISO), 2x2 and 4x4 MIMO antennas. This scenario considers three BSs (one for each wireless technology) and one MS. The distance error has been calculated based on 1000 independent positioning estimates for each antenna configuration. The TOA measurements are simulated with additional Gaussian (st. dev. 1dB) noise and NLOS parameters. The position is calculated using the trilateration method based on LLS and NLLS algorithms. [Ma07]. Results are presented in a relation of Average root mean square error to cumulative probability [CD10].

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In Figure 5, it can be observed that the average RMSE for the 4x4 MIMO system using NLLS algorithm gives the best results.

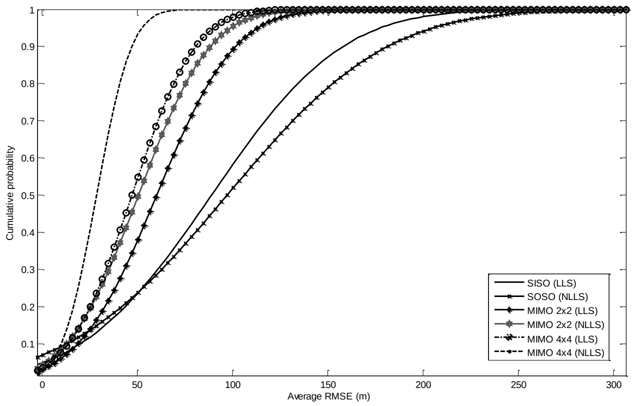

Figure 5: Average RMSE comparison for TOA under Various Antenna Configurations

The second simulation introduces an additional MS. The same network technologies and features are considered as in the first scenario. The MSs are located in a close distance to each other (10-15m) and in line-of-sight (LOS), so that the measurement has a low noise error. Algorithm is as follows:

1. Each MS position is calculated separately as well as distance between them;
2. If the result of distance estimate is in a close comparison to TOA method estimates then the positioning result is accepted;
3. If there is a dramatic difference between MSs and TOA position estimates, hence the calculation of the position will be considered as “wrong“. Therefore, new position estimates for the MSs will be recalculated.

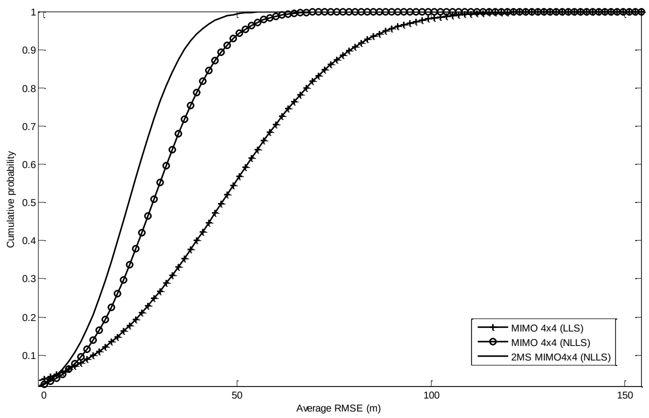

Figure 6: Average RMSE Comparison for LLS and NLLS Algorithms and 2 MS cooperation

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Fig. 6 illustrates that the short-range MS-to-MS link improves the positioning accuracy by using the proposed positioning protocol (and considered as Bluetooth connectivity) for hybrid wireless network presented in Fig.3.

6. Conclusions

This paper presents the potential of using various wireless networks for the positioning services. It is shown that utilisation of MIMO features improves the positioning of the TOA data fusion technique up to 200m. Simulation results also show that a short-range link between multiple MSs can be used to improve the location estimation accuracy for up to 20m (average RMSE).

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