Enhanced Positioning Techniques for Hybrid Wireless Network

A. Zvikhachevskaya[1], V. Gourov[2], A. Awang Md Isa[2], L. Mihaylova[1]
[1]Lancaster University, Department of Communication Systems, UK
[2]Technical University of Sofia, Bulgaria
a.zvikhachevskaya@lancaster.ac.uk
vassilgourov@yahoo.com
a.awangmdisa@lancaster.ac.uk
mila.mihaylova@lancaster.ac.uk

Abstract: The objective of this paper is to propose a reliable and accurate positioning method, which provides location estimates for the mobile user in heterogeneous wireless network (IEEE802.11/WiFi, IEEE802.16/ WiMAX and LTE technologies). The propose data fusion methodology utilises measurements and features such as Time of Arrival (TOA) measurements and multiple input, multiple output (MIMO) antennas and wireless links between mobile users in order to enhance the mobile-centric positioning accuracy. Therefore, in this paper not only a new reliable concept of mobile user positioning is proposed, but also it is applied to case scenarios where various wireless networks are present. The results are satisfy the FCC requirements for the mobile-centric positioning solution.

1. Introduction

Wireless communication technological advances, such as mobile phones, personal digital assistants (PDAs), personal computers (PCs), and in general wireless enabled mobile stations, have become the enabler of viable location and positioning-based services. Therefore, the focus of this paper is to provide an accurate and reliable service for the mobile user in heterogeneous wireless network. As a result a lot of researches are oriented towards resolving viable applications and 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. Although such services are already exist, there is still a lot to be done in order to fully fulfill the user's expectations.

This paper is organised as follows. Section 2 presents a brief review of the existing location and positioning techniques. In Section 3 the proposed location and positioning method explained. In Section 4 simulation results are evaluated. Finally, Section 5 concludes the paper.

2. Existing positioning techniques

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

Meanwhile, a recent research topic is positioning within the heterogeneous wireless network. TOA with MIMO and reference distance between users, offers an alternative, to the conventional methods, way to enhance positioning capabilities and accuracy [Ro07, Ma07, Vo08]. It is decided to apply the propose data fusion algorithm for heterogeneous networks because in reality, wireless network provider will deploy BSs in a way so their coverages do not overlap, while different networks normally cover the same location.

3. System Architecture

The proposed system architecture is illustrated in Fig.1. WiMAX, WiFi and LTE wireless networks are modeled according to the IEEE 802.16, IEEE 802.11g and LTE standards. The scenario consists of three BSs that initially are not synchronised and each belongs to one of the wireless network technologies. Positioning targets are two MSs for which the position estimation will be performed. It is assumed that MSs are in a connectivity range for all of them.

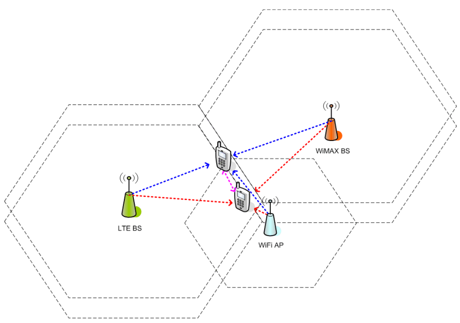

Figure 1: Heterogeneous Wireless Network Architecture

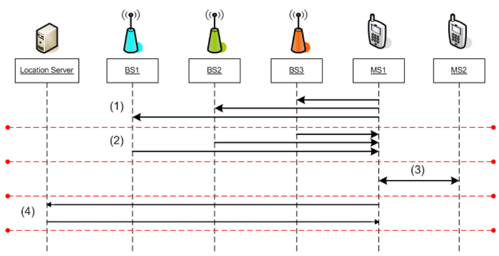

Figure 2: Proposed Positioning Protocol

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.2. 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 MS cannot perform the positioning itself (e.g. the channel corruption), collected measurements are sent to a location server. Here, the MS position can be calculated. Firstly, the position of the MS location is calculated separately. Afterwards the measured distance between the MSs is compared to the calculated distance between them and if there is a difference the MSs positions are recalculated or adjusted.

4. Data Fusion

4.1 Time of Arrival with MIMO Features

TOA is one of the classical positioning methods. Firstly, it is assumed that the signal round trip time is measured and used to synchronise the BS and MS. The distance between a BS and a MS can be calculated using that the wireless signal propagates at the speed of light (c = 3 x 10^8 m/s)

$$r_i = \left(t_j - t \right) c \qquad (1)$$

Where t is the exact time when the MS sends the signal and t_j is the time when the signal reaches the BS_i. MIMO features are when multiple transmitter and/or receivers (multiple antennas) are used in either side of the BS-MS link. 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. This project uses the Least Square (LS) data fusion method and to be more exact the Linear Least Square (LLS) and Non-Linear Least Square (NLLS) methods [FF10] [STK05]. LS methods are used to approximate a set of measurements when measurements are subject to inaccuracies because of NLOS, noise or other conditions.

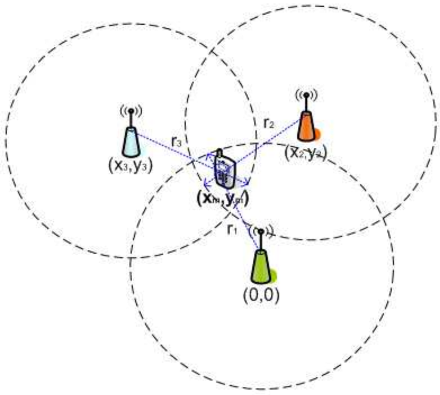

Figure 3: Positioning Utilising TOA Measurements and MIMO Features

It is used the conventional linear least squares (LLS) estimation, the MIMO TOA based method with M BSs estimates [Is11]

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

where $\boldsymbol{x}$ is the true position of MS, $\boldsymbol{x}_i$ 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,..., $N_t \cdot N_r$.

3. Simulation Results

This section contains preliminary results from two simulations.

The first simulation aims to compare the positioning accuracy of a system using MIMO features. Different antenna modes are set from single input single output (SISO) to 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]. In Figure 4, it can be observed that the average RMSE for the 4x4 MIMO system using NLLS algorithm gives the best results.

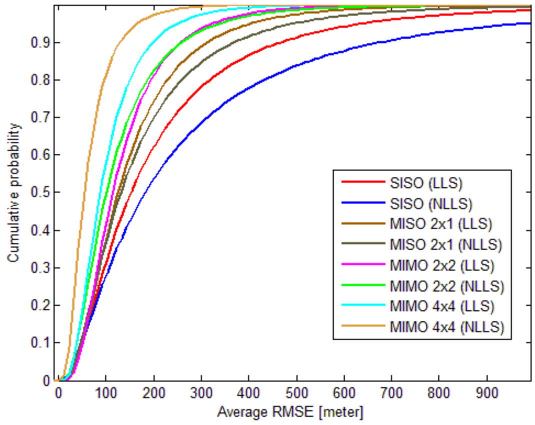

Figure 1: CDF Comparison for LLS and NLLS Algorithms under Various Antenna Mode Configurations

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

1. Each MS position is calculated separetely as well as distance between them;
2. If the distance estimate result in close estimates then the estimated positions are accepted.
3. If there is a dramatic difference between "previous" and a new position estimates of MSs then the positon will be recalculate, because the calculation will be considered as "wrong".

Fig. 5 illustrates how the short-range MS-MS link improves the positioning accuracy.

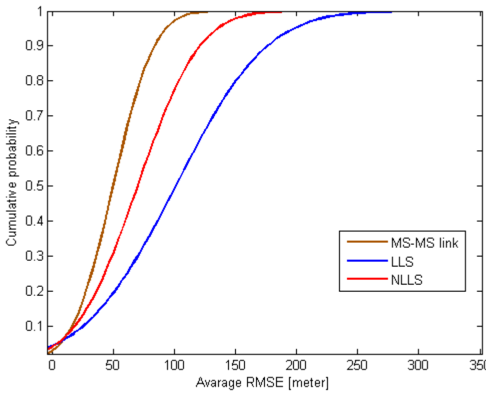

Figure 2: CDF Comparison for LLS and NLLS Algorithms and 2 MS cooperation

4. Conclusion

This paper presents the potential of using various wireless networks for the positioning services. It was shown that utilization of MIMO features improves the positioning of the TOA data fusion technique. Simulation results also show that a short-range link between multiple MSs can be used to improve the location estimation accuracy.

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