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Ad Hoc Networks for Cooperative Mobile Positioning

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1. Introduction

Wireless ad-hoc networks have received huge attention during recent years due to the potential applications in different fields such as emergency, disaster relief, battle-fields, automotive, social networks and entertainment. They are rapidly deployable, self-organizing, and require no fixed infrastructure for communications. (Huang et al., 2008)

At the same time, localization in wireless networks is becoming a hot topic for society, industry and research. The needs of location information has driven companies to build mobile handsets with embedded GPS receivers (which is nowadays the most popular mass market solution for positioning), causing huge increase in costs, size, battery consumption, and a long time for a full market penetration (Sayed et al., 2005). However, it is also known that the GPS is not always the most suitable solution for localization. In adverse environments, such as outdoor urban canyons and indoor, it is not an easy task to obtain location information, due to the signal blocking, multipath conditions and the infeasibility to have a continuous tracking of at least four satellites (Mayorga et al., 2007).

The Fourth generation (4G) communication systems also stimulate the need of providing alternative ubiquitous localization solutions, regardless the environment (i.e., outdoors and indoors), which should overcome, or at least complement, the drawbacks of GPS-based and GPS-free systems (Della Rosa, 2007). Traditional alternative technologies make use of time difference of arrival (TDOA) measurements from the serving cellular system where the Base Stations (BSs) are considered as fixed reference points (Sayed et al., 2005).

Different type of measurements, such as received signal strength (RSS), are widely used in local area scenarios, where Wi-Fi Hot Spots deployed in big cities allow user terminals to predict their locations by means of known fixed positions (Sayed et al., 2005).

Unfortunately, when localization is performed in indoor environments the accuracy is highly dependent on the wireless channel conditions since several error sources cause huge signal fluctuations detected at terminal level, severely decreasing the final location estimation accuracy (Della Rosa et al., 2010).

Recently, in alternative to traditional methods, a new branch of positioning techniques has been developed: the *Cooperative Mobile Positioning* (Figueiras & Frattasi, 2010), which makes use of hybrid schemes and exploits the benefits in terms of accuracy of short-range measurements provided by the ad-hoc networks (Della Rosa, 2007).

In this chapter we will explain the basics of Cooperative Mobile Positioning and demonstrate the applicability of the technique in real cases, demonstrating that the exploitation of the most reliable RSS measurements detected in the ad-hoc links represent a valid and complementary approach to traditional non-cooperative methods, and that the *hybrid network model* adopted is the most natural environment in which cooperation among terminals is established and best exploited without additional hardware components (Figueiras & Frattasi, 2010) (Della Rosa et al., 2010).

2. Mobile positioning

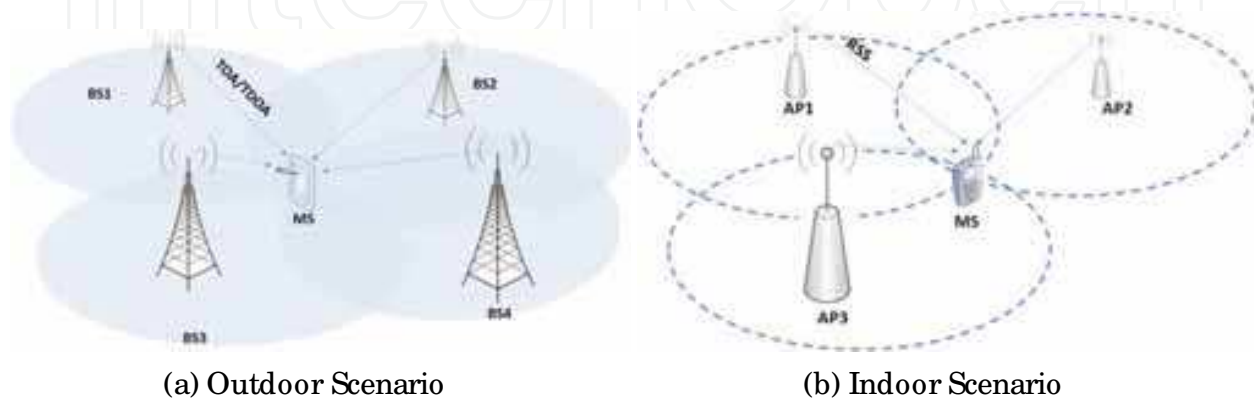(a) Outdoor Scenario   (b) Indoor Scenario

Fig. 1. Conventional Positioning

Several different radio navigation methods, based on different measurements and operation principles, have been used in practical positioning applications (Sayed et al., 2005; Syrjarinne, 2001). The positioning techniques can be categorized as mobile based and network based methods. In mobile based methods, the mobile station (MS) measures parameters from signals it receives from BS and uses the measurements to determine its position. In network based methods the base stations measure parameters from signals coming from the mobile, and the position calculation is performed in a positioning server connected to the network. The following measurements and positioning techniques can be used for positioning a MS in communication systems:

2.1 Angle Of Arrival (AOA)
AOA utilizes multi-array antennas which are used to estimate the angle of the line of arrival of the signal. The position of the MS can be located at the intersection of the lines if more than one AOA measurement is performed, as shown in Fig.2.a. This positioning method is called triangulation. Antenna arrays capable for AOA measurements are large in size, and thus more suitable to be measured by BS rather than MS. Therefore AOA lends itself easily to network-based positioning. The AOA is considered mainly as outdoor positioning method using BSs of cellular networks (Sayed et al., 2005), but results on AOA positioning in WLAN infrastructure have also been reported (Wong et al., 2008). Reflections and non-line-of-sight (NLOS) conditions distort the direction of arrival of the signals, deteriorating the accuracy of AOA positioning.

2.2 Time Of Arrival (TOA)
TOA information from the MS to a station with known coordinates (navigation satellites, BSs of wireless communication networks, etc.) or vice versa can be estimated if both entities

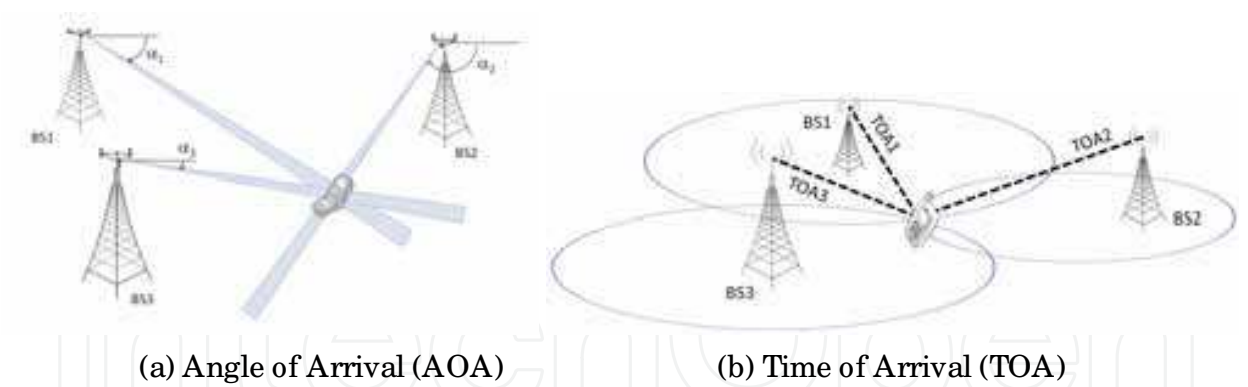(a) Angle of Arrival (AOA)   (b) Time of Arrival (TOA)

Fig. 2. Angle of arrival and Time of Arrival based positioning

are precisely synchronized in time. The distance between MS and BS can be obtained from TOA, since electromagnetic waves propagate at constant speed of light. To estimate the position of the MS, TOAs to at least three stations in different locations are required for trilateration; all the BSs have also be perfectly synchronized to each other (Rappaport et al., 1996). In trilateration the position estimate is the intersection of circles with radii determined from TOA measurements and centers at the known BS coordinates, as shown in Fig.2.b. Reflections and non-line-of-sight (NLOS) conditions distort the TOA of the signals.

2.3 Time Difference Of Arrival (TDOA)

TDOA is based on estimating the difference in the arrival times of the signals coming from two different transmitters to the receiver. Geometrically a particular TDOA value defines a hyperbola between the two receivers on which the MS may be located. As seen in the (Fig.3.), the position of the MS can be estimated at the intersection of the hyperbolas if more than one TDOA measurement is performed (Misra et al., 2006). One of the benefits of this technique is that it does not require knowledge of the absolute time of the transmission, i.e., the receiver time does not need to be synchronized with the transmitter, but the transmitters need to be synchronized with each other.
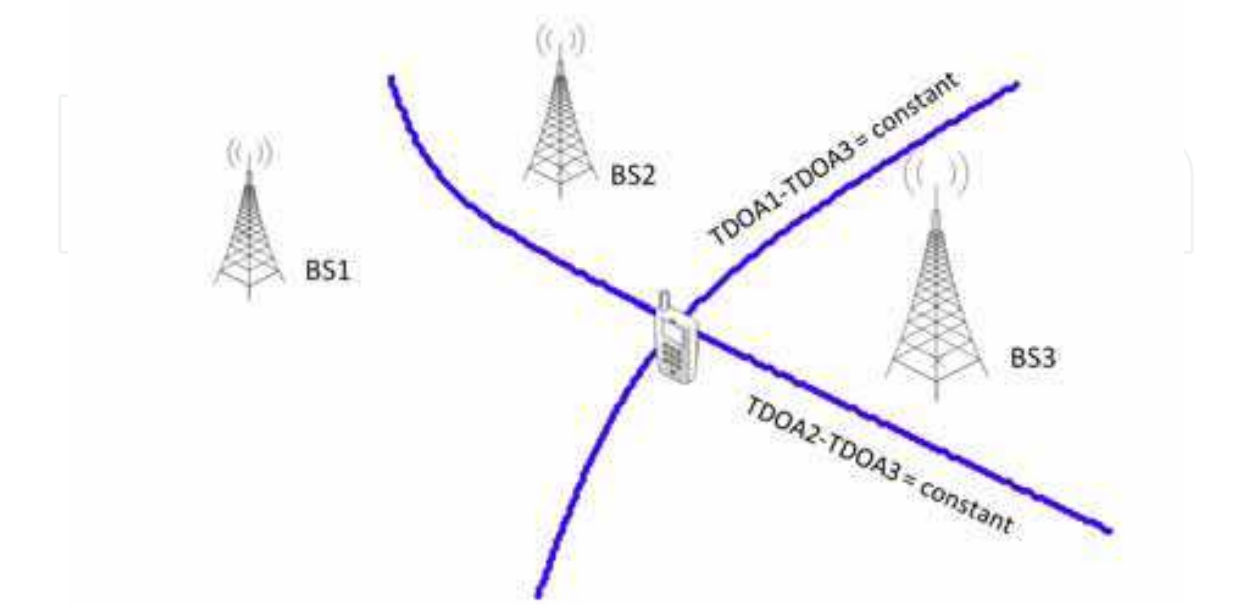

Fig. 3. Time Difference of Arrival (TDOA)

2.4 Received Signal Strength (RSS)

In RSS based positioning, the MS location is estimated using models that relate the strength of the received radio signal either to the distance between the MS and the signal emitter or to the MS location directly. Typically at least some parameters in the applied models are determined experimentally to adapt the model to the application environment. RSS based positioning methods can be divided into three main categories: cell identifier based, pathloss-based, and fingerprinting. For consumer market positioning applications, the RSS observables are considered to be more easily available than AOA or TOA, as the RSS can be passively listened from the access points (APs) of the infrastructure WLAN, without adding any extra load to the network. According to IEEE 802.11 standard, the infrastructure APs periodically transmit beacon frames, which contain information for network identification, broadcasting network capabilities, and for other control and management purposes (Wallbaum et al., 2005). The MS can sweep from channel to channel and record information from any beacon it receives. This process is performed regularly to determine the AP with the best link quality. This allows the MS to determine the cell identifiers and signal strengths of all APs visible for the MS. In many mobile devices, such as mobile phones, PDAs and laptop computers, this information is easily available through Application Programming Interfaces (API) of standard WLAN services.

2.4.1 Cell ID based positioning

In cell identifier method, the MS scans the available WLAN channels. As the position estimate it reports the position of the AP from which it received the strongest signal (Fig.4). In cell identifier method, a MS needs prior information about the locations of APs and their unique Media Access Control (MAC) addresses. Therefore, the system set-up for positioning is relatively easy. Granularity of the position estimate is determined by the distances between MS and AP. Because of the coarse granularity of the estimate and noise introduced by the environment, this method is applicable in scenarios where rather coarse accuracy is sufficient.
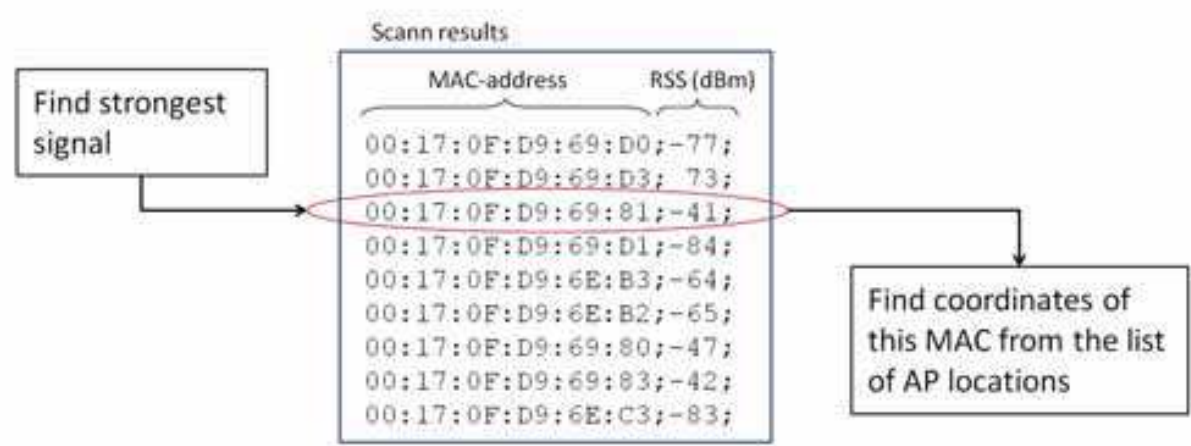

Fig. 4. Cell ID positioning based on RSS measurements

2.4.2 Fingerprinting

Fingerprinting approaches are based on experimental models that relate the measured RSS values directly to the measurement position. These models are generated from off-line collected data from several locations that sufficiently cover the area where positioning is

needed. The principle of fingerprinting based positioning is illustrated in Fig.5. For each location, from the off-line collected data a typical signal pattern is extracted and saved to the fingerprint database with the coordinates of the location (Fig.5.a). In positioning phase, the current set of RSS measurements from the APs in the coverage area are compared to the patterns stored in database. The coordinate estimate is obtained from the database entry whose stored signal pattern has the closest match with the measured signal vector (Fig.5.b). Compared to other RSS based methods, fingerprinting algorithms are considered to be more robust against signal propagation errors such as multipath or attenuations generated by walls and other structures; fingerprinting actually make use of these location dependent error characteristics of radio signals. In estimation phase, new measurement vectors are related with the information stored in fingerprint database. A known disadvantage in fingerprinting approaches is the fact that the collection of the data for fingerprint database is laborious and time consuming (Wallbaum et al., 2005; Bahl et al., 2000).
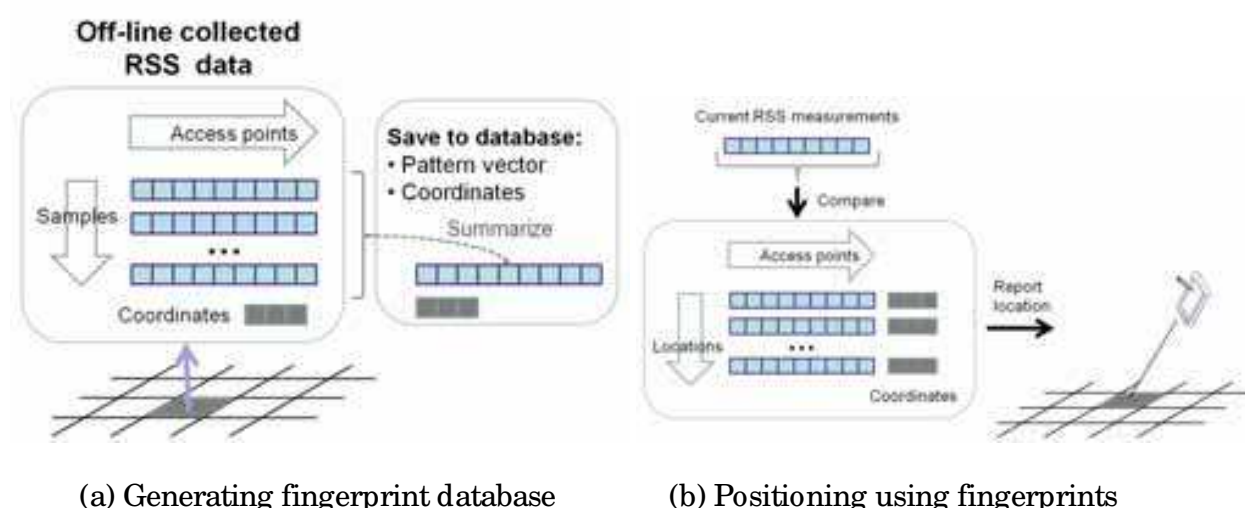

(a) Generating fingerprint database   (b) Positioning using fingerprints

Fig. 5. Fingerprinting

2.4.3 Pathloss-Based positioning

Pathloss models of radio signals are used to translate RSS measurements to distances between the MS and APs. After the distances are estimated from RSS measurements, trilateration methods are used to estimate the position of the MS (Fig.6). To obtain a unique solution, the MS needs from measure RSS to at least three distinct APs. As in cell ID based methods, the MS needs prior information about the MAC addresses and locations of APs, which is easily acquired, at least when compared with fingerprint databases. In indoor environments, multipath and attenuation caused by walls, other structures, and even people complicate the modeling of signal propagation. Because of this, the positioning errors in pathloss-based positioning are typically larger than in fingerprinting (Bahl et al., 2000). On the other hand, methods that utilize path-loss models to estimate distances are needed for example if signal properties of ad-hoc WLAN connections between two MSs need to be used for positioning, because dynamic information about moving AP locations is difficult if not impossible, to be incorporated in fingerprint databases. Because of the low system set up cost of pathloss-based positioning, and its better suitability for incorporating measurements from ad-hoc connections, we concentrate on pathloss-based positioning in this research.
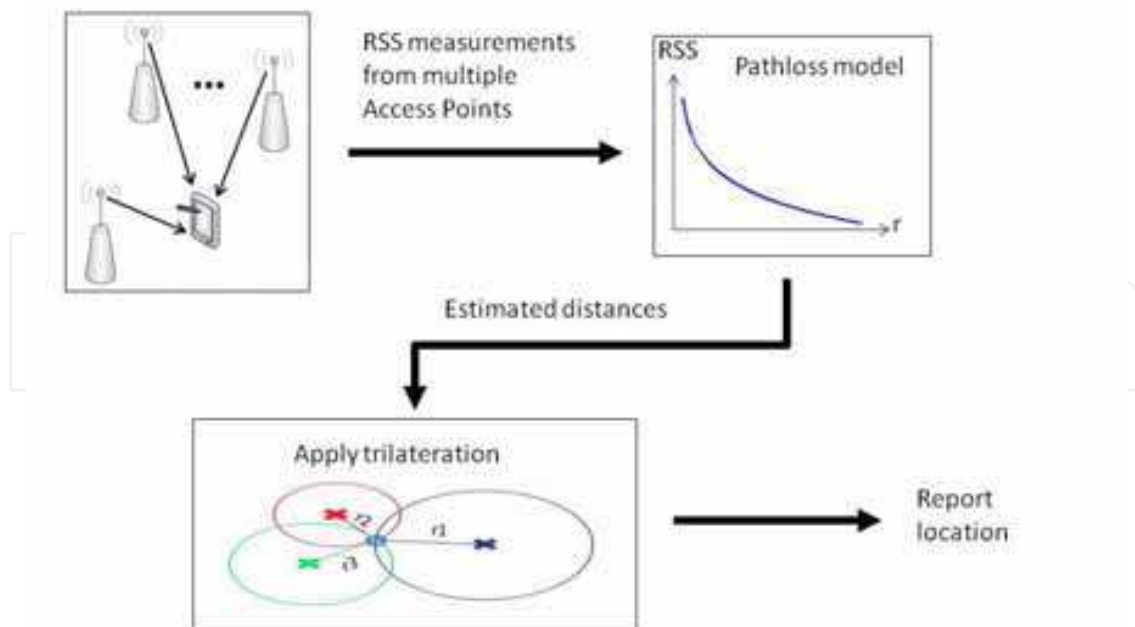
Fig. 6. Pathloss based positioning

3. Cooperative mobile positioning

Cooperative Mobile Positioning is a recent research topic for wireless communication systems (Figueiras & Frattasi, 2010) (Sand et al., 2008) concerning the development of innovative techniques and positioning schemes to enhance location accuracy in adverse scenarios, where conventional methods are not able to offer desired levels of accuracy. In such context, heterogeneous technologies and mobile terminals coexist and cooperate with the objective of helping each others for enhancing accuracy of their estimated positions. This can be accomplished by sharing link information with peer nodes connected in ad-hoc mode and exploiting their spatial diversity with advanced positioning algorithms (Sand et al., 2008).

Raising up as a new branch of positioning techniques, the fundamental idea is simple: making use of the short-range mobile-to-mobile measurements connected in ad-hoc mode, where usually unreliable long-range measurements coming from the deployed fixed reference points are provided (Frattasi & Monti, 2007) (Della Rosa, 2007). In this scenario ad-hoc connections play the dual important role of serving as medium for collecting the RSS information and exchanging data among neighboring nodes.

The exploitation of spatial proximity estimated within a group of neighboring mobiles has the strong potential to enhance the location estimation accuracy (Mayorga et al., 2007) and it can be easily applied in case of (i) outdoor environments, by merging the measurements from the cellular links and ad-hoc networks; (ii) indoor environments, by replacing the cellular and ad-hoc segments with wireless local area network (WLAN) communications in infrastructure and ad-hoc mode, respectively; and (iii) GPS-equipped mobiles, where the location estimation can be enhanced in areas where the stand-alone GPS might not be sufficient (Mayorga et al., 2007). Sharing radio signals that are just enough to ensure network connectivity among mobiles, the ad-hoc network model achieves better performances over the stand-alone cellular one (Della Rosa et al., June 2007) (Mayorga et al., 2007).
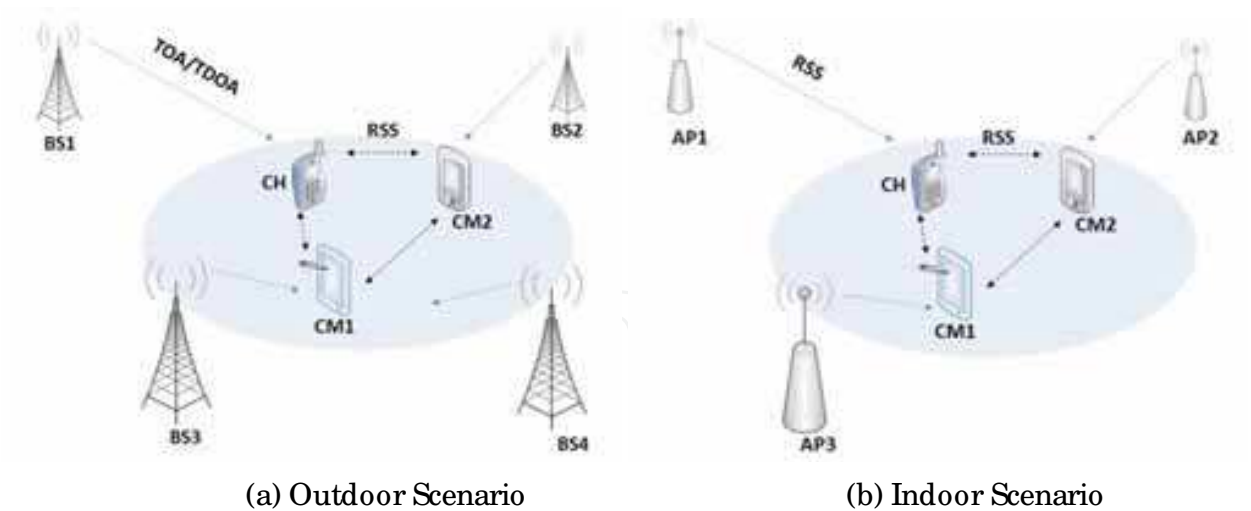
(a) Outdoor Scenario   (b) Indoor Scenario

Fig. 7. Cooperative Positioning

3.1 Data-fusion and cooperative filtering

The use of data-fusion and positioning algorithms is fundamental to combine heterogeneous long- and short-range measurements and estimate the final location of MSs. Efficient methods and mathematical models able to deal with error sources are needed in wireless positioning. The most promising approaches proposed in (Figueiras & Frattasi, 2010) (Frattasi, 2007) (Della Rosa et al., June 2007) make use of Least Squares (LS) methods and Bayesian filters. LS methods allow the estimation of the position by minimizing the error between detected and expected measurements, by making use of Non-Linear-least-Squares

(a) Conventional   (b) Cooperative
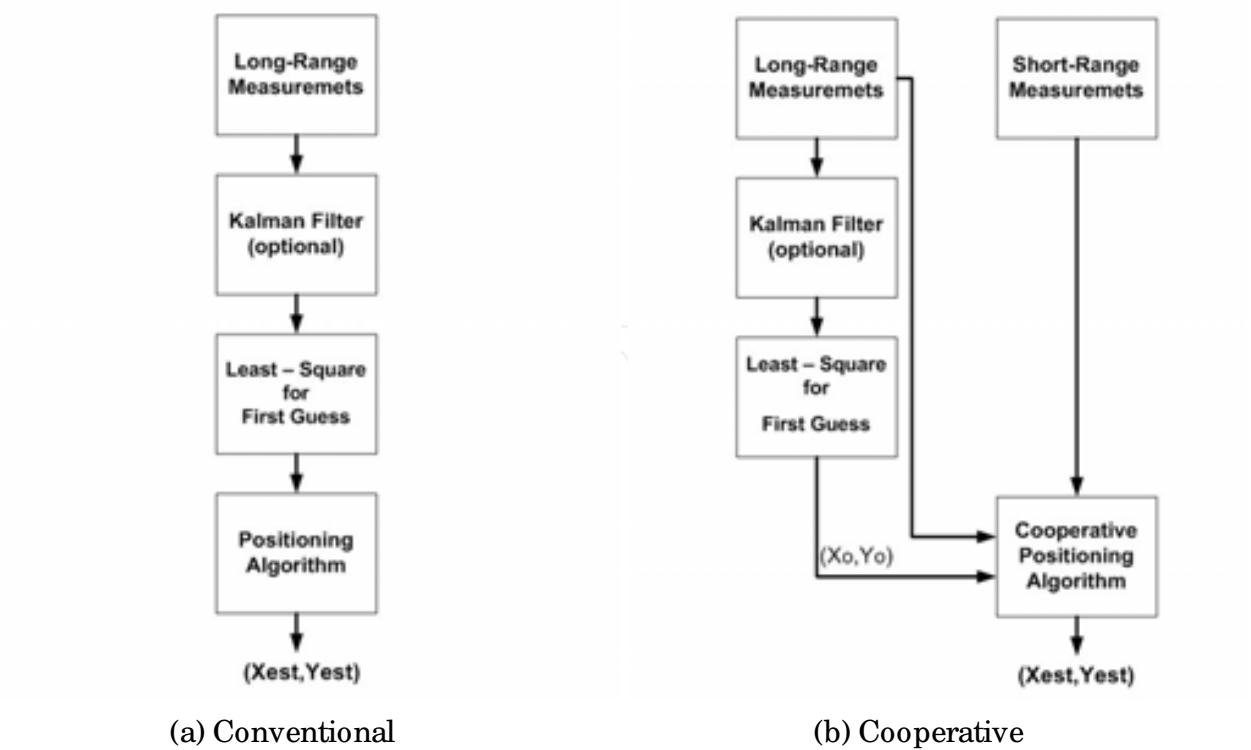
Fig. 8. Block Scheme for conventional and cooperative positioning (Della Rosa et al., June 2007) (Della Rosa et al., 2010).

(NLLS) and Weighted- Non-Linear-least-Squares (W-NLLS) (Frattasi, 2007), where the objective function to be minimized represents the main engine for processing the hybrid measurements (Della Rosa, 2007). Bayesian filters are a valid alternative to the previous ones. However, the non-linear characteristics between measurements and positions make the common Kalman Filter (KF) not applicable for solving this problem. Better results come from Extended Kalman Filters (EKF), widely used for both positioning and tracking by linearizing the models and applying then the classical KF to the linearized system (Figueiras & Frattasi, 2010) (Sand et al., 2008). In the examples proposed in this chapter, we will show results achieved by using an EKF (Della Rosa, 2007) in simulations and a NLLS algorithm (Della Rosa et al., 2010) in the experimental activity.

### 3.2 Ad-hoc networks and Measurements-Sharing protocol

Exploiting the ad-hoc connectivity in wireless communications has the advantage of not depending on fixed infrastructures. A central BS (or AP) is not needed at all and the overall serving area is self-defined by the area where the nodes (MSs) are deployed (Hekmat, 2006). Ad-hoc networks can be formed fast, just when they are needed and for the specific needs of each user. When used in a mesh fashion all the nodes are aware of the others within the coverage range.

An interesting ability of the ad-hoc networks is also that it is self-configuring. If one of the nodes linking the others accidentally fails, the overall network adapts the other nodes to the new configuration and rebuilds by itself.

With the benefits offered by the ad-hoc networks, the cooperative mobile positioning can be handled in terms of scalability, self-configuration, re-configuration and flexibility (Breed, 2007). In every-day life, peer-to-peer connections and data exchange are more and more common among users, becoming one of the most efficient methods for exchanging inter-systems data. During the years, several applications have been proposed for ad-hoc networks but only recently it has also been recognized as a complementary technology for enhancing location accuracy of mobile terminals (Figueiras & Frattasi, 2010) (Della Rosa, 2007). However, using ad-hoc networks in localization is still not fully independent on fixed infrastructures. On the other hand, the localization information obtained and shared by ad-hoc networks can complement and improve the infrastructure based localization, especially in cases when relation between the localization result and fixed reference systems (coordinates, geographic location) is desired.

Localization of mobile nodes is always a difficult task, due to the radio signal that is both environment and hardware dependent. A common situation is that the receiving mobiles are in NLOS (Fig. 9(a))with respect to the transmitting BS or AP, meanwhile measurements coming from ad-hoc neighbors are much more reliable. Fig. 9(b) show the RSS measured in a typical indoor environment as depicted in Fig. 17 where more fluctuating measurements (in black) are detected at AP-MS link if compared with the short-range ones (in red and blue) detected between MS-MS connected in ad-hoc mode.

Recognizing the beneficial impact of the ad-hoc links, the cooperative technique proposed (Frattasi, 2007) (Figueiras & Frattasi, 2010) (Della Rosa, 2007) can be applied as follows. Assuming a cluster of MSs connected in ad-hoc mode in a mesh configuration, a MS can be nominated as the cluster-head and its neighbors as cluster-members; (i) all the mobiles perform long-range measurements (TOA/ TDOA or RSS)from the available BSs/ APs links broadcasting the signals; (ii) the cluster-head looks for potential cooperative peers in the ad-hoc coverage area; (iii) it sends its cooperation-requests with an ack/ nack procedure;
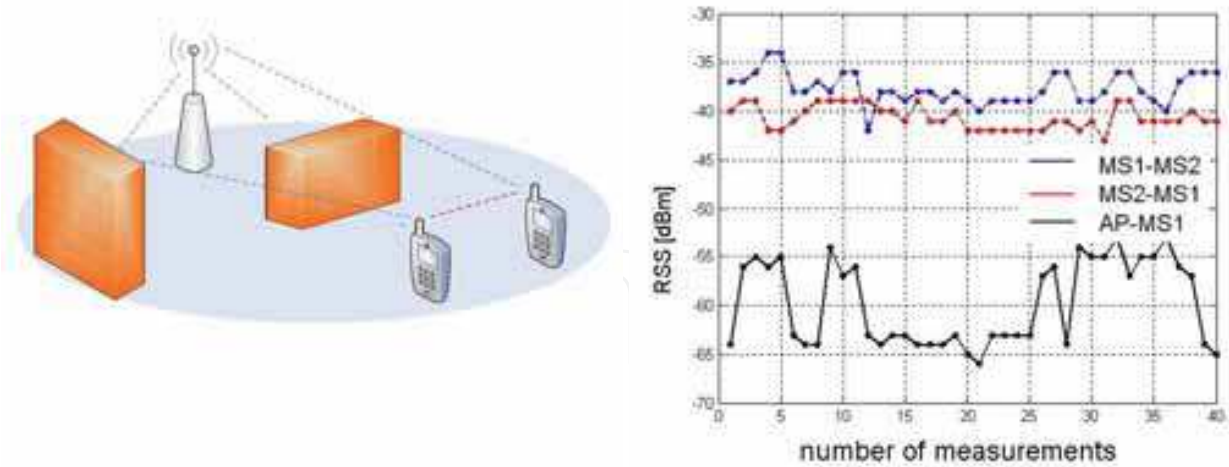
(a) Long-range and short-range links.   (b) Long-range and short-range RSS measurements.

Fig. 9. Long- and short-range RSS measurements in indoor environments.

(iv) if cluster-members accept the request, the connected mobiles measure the RSS of their ad-hoc links; (v) cluster-members measure the RSS from the available APs and send the recorded data sets to the cluster-head; (vi) after receiving all the needed information, the position of each member is obtained by a cooperative data-fusion method implemented in each mobile by appropriately combining and weighting the long- and short-range raw measurements using the chosen algorithm (EKF/ NLLS/ W-NLLS)(Della Rosa, 2007) (Frattasi, 2007) (Mayorga et al., 2007)[10]. A potential protocol for outdoor and indoor environments (using TDOA and RSS for long-range measurements respectively) is shown in Fig. 10(a) and Fig. 10(b).

(a) Outdoor   (b) Indoor
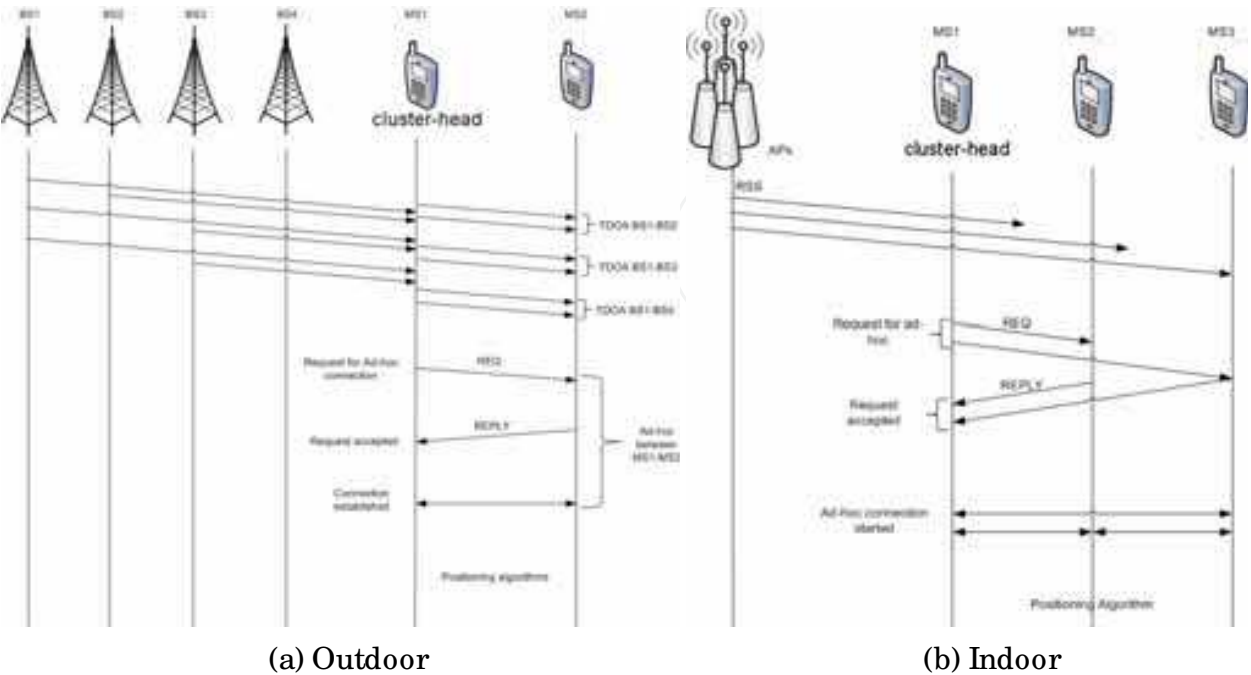
Fig. 10. Protocol for measurements and data exchange.

4. Results

This section analyzes the results, where computer simulations and experiments have been performed by developing proof of concepts for different scenarios: (i) a hybrid cellular/ ad-hoc framework implemented in Matlab (Della Rosa, 2007) (Mayorga et al., 2007) and (ii)a small-scale experiment using real devices in a WLAN/ ad-hoc network (Della Rosa et al., June 2007) (Della Rosa et al., 2010).

While the cellular/ ad-hoc scenario is a simulated hybrid MobileWiMAX/ WLAN system, the WLAN/ Ad-hoc framework proves the feasibility of the cooperative techniques for heterogeneous MSs with different embedded wireless cards. In the latter it is also shown that the cooperation can be used to avoid long time-consuming calibration phases of different mobiles when performing RSS-to-distance conversions for AP-MS and MS-MS links(Della Rosa et al., 2010).

4.1 Outdoor: Cellular/Ad-hoc:

The system architecture of the simulator is shown in Fig. 11. While the cellular system is simulated according to the IEEE 802.16e standard (Mayorga et al., 2007), the ad-hoc links between MSs are modeled according to the IEEE 802.11a PHY (Mayorga et al., 2007). The scenario reproduces four synchronized BSs, with maximum synchronization error of 1ms among them. The cell radius is r = 3 km, and two MSs placed at distance of 20m from each others. MSs are assumed to be connected to the serving BS, (e.g. BS1). A mobility model simulates users moving with constant velocity of 3 km/ h along parallel straight lines.

Typically (Della Rosa, 2007) 20 meters are enough for establishing ad-hoc connections; specially when the devices are in LOS, as in our simulated environment.

The full chain of blocks (cellular environment, mobility models, positioning estimators) is depicted in Fig. 11 where the physical layer (PHY) of the IEEE 802.16e standard is Orthogonal Frequency Division Multiplexing (OFDM) modulation. While in free-space the traveling time of the radio signal is only dependent upon the distance BS-MS, in real situations it is strongly delayed by channel impairments, having a direct impact on the TDOA values estimated at the receiver. For this reasons a channel model has been simulated according to (Della Rosa, 2007) (Mayorga et al., 2007).
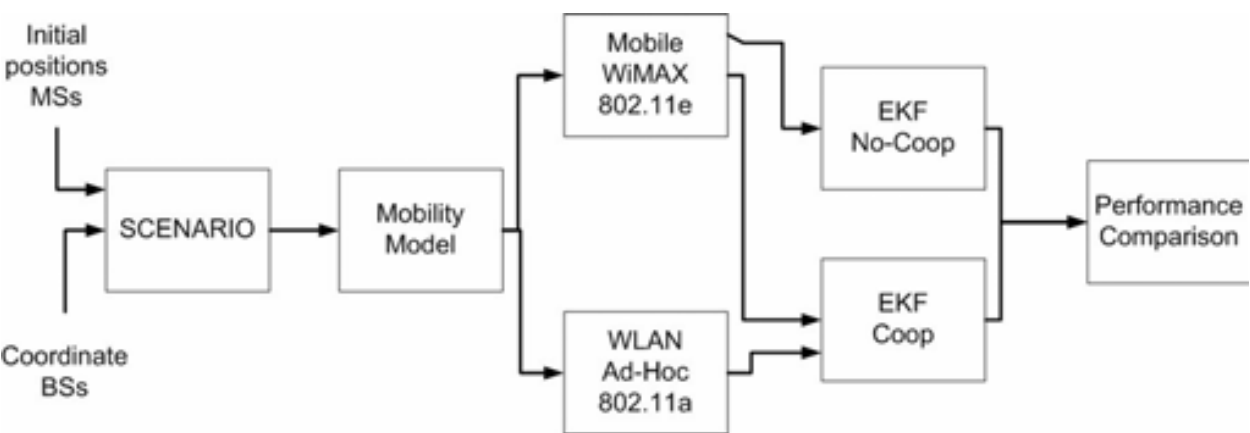

Fig. 11. Simulator Blocks (Della Rosa, 2007).

TDOA measurements are calculated at terminal level for each MS by performing cross-correlations of the signals arriving from the deployed BSs with respect to the reference one.

Also the IEEE 802.11a PHY is based on OFDM modulation (for more details the reader can refer to (Della Rosa, 2007) and (Mayorga et al., 2007)). But, differently from the AP-MS links, the MS-MS links measure RSS values, meaning that the implementation of a path loss model with small scale fading effects for a LOS scenario is also required.

Finally an EKF is used as data-fusion algorithm and positioning filter according to (Figueiras & Frattasi, 2010) (Della Rosa, 2007).

TDOA measurements are generated according to the 802.16e standard and combined with the RSS measurements within the ad-hoc network in the cooperative case. In non-cooperative case only TDOA measurements are considered.

Fig. 12 describes the simulated and estimated path of the users moving in parallel where the estimated positions for MS1 and MS2, respectively, with and without cooperation are shown. The average Root-Mean-Squared-Error (RMSE) is evaluated through the estimated path and the resulting Cumulative Distribution Function (CDF) of the RMSE describes the improvements by using only two cooperative MSs in the simulated environment (Fig. 13). It is worth mentioning that the proposed example requires the handsets to be equipped both with WiMAX and Wi-Fi modules. The resulting performances achieved show that cooperation reduces the average RMSE with respect to conventional stand-alone positioning methods (Figueiras & Frattasi, 2010) (Della Rosa, 2007).
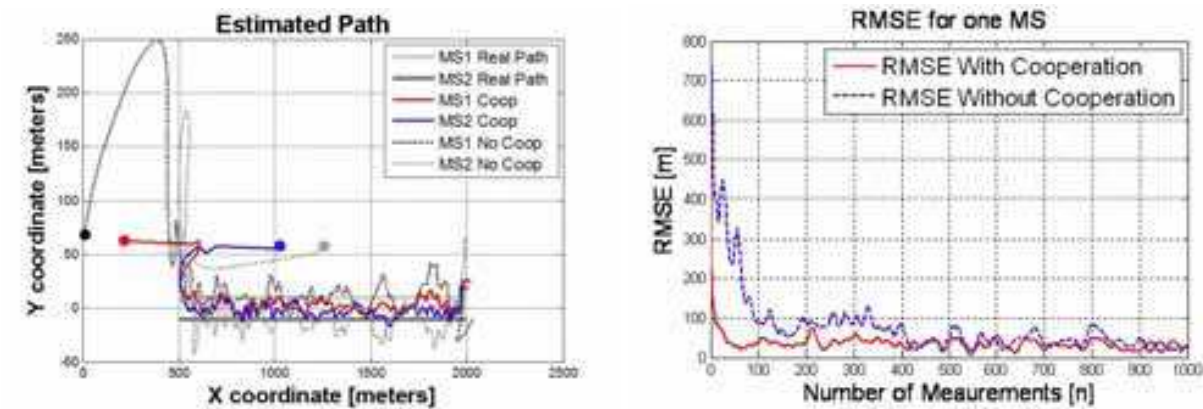
(a) Estimated Path (b) Example of RMSE improvements for one MS.

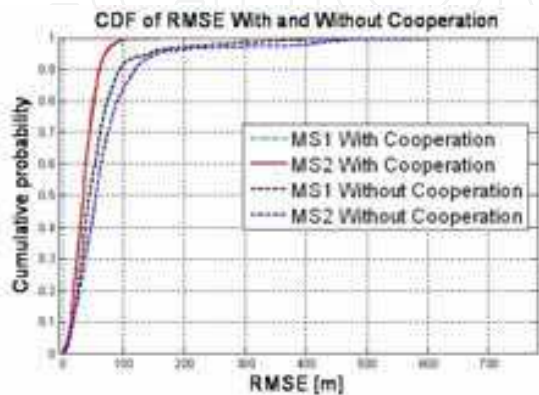Fig. 12. Estimated Path and RMSE with and without cooperation.

Fig. 13. CDF of RMSE With and Without Cooperation for two MSs.

4.2 Indoor: WLAN /Ad-hoc:

In this section a proof of the applicability of the cooperative techniques is shown with a real-life small scale experiment, performed in an indoor scenario as in (Della Rosa et al., 2010) (Della Rosa et al., June 2007), where the long-range measurements are represented by RSS from APs-MSs and the short-range measurements are the RSS measured at MS-MS ad-hoc links. Having precise enough measurements is an important first step for wireless positioning. However the behavior of data collected in real environments differ from the simulated ones since unpredictable errors appear quite often, causing huge fluctuations in RSS and consequently degradation of the final position estimation accuracy. Hence it is not straightforward to understand the distance-dependent behavior of the wireless signals propagating in the air. Converting power measurements for estimating the distance among APs-MSs and MSs-MSs is a crucial and time consuming activity since several parameters affect the accuracy of the measurements. Multipath, shadowing, presence of humans and objects, signal blocking, overlapping channels, walls, noise and sensitivity of the wireless cards embedded in the MSs (Della Rosa et al., 2010) introduce several complications when developing positioning applications aiming to locate heterogeneous mobiles, especially because different vendors use different chipsets with different Radio Frequency (RF) characteristics.

Experiments (Della Rosa et al., 2010) show that different laptops placed at the same distance from APs record RSS values which differ several dBm from each others due to the different embedded wireless cards (Fig. 14).
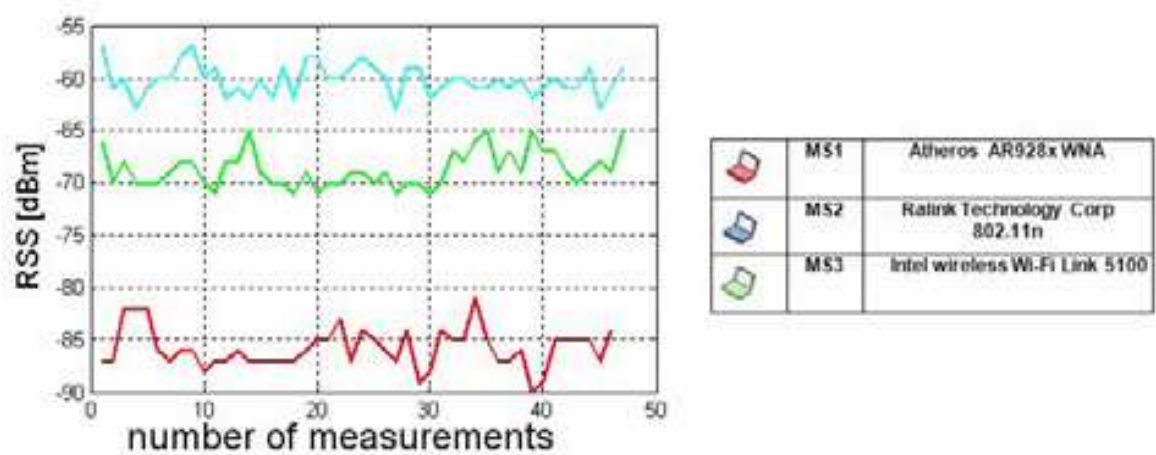

Fig. 14. RSS of laptops placed at same distance from AP, with different embedded wireless cards.

Theoretical path-loss models provided in literature are not accurate enough to reach high localization accuracy performances and exhaustive device calibrations are needed to find precise models for each mobile in use. Even after calibration, the obtained model is usually useful only for the calibrated one (Della Rosa et al., 2010).

What if we would like to develop robust and more scalable positioning applications? Every mobile (every wireless card) should be accurately re-calibrated. The cooperative technique helps in the aforementioned problem by exploiting ad-hoc connections and spatial constrains allowing the on-the-fly calibration of peer heterogeneous mobiles with different embedded wireless cards. We can imagine the situation described in Fig. 15.

One MS, (MS1) is calibrated according to the accurate procedure depicted in Fig. 15(a) (and discussed in (Della Rosa et al., June 2007) (Della Rosa et al., 2010)) and another MS, the non-

calibrated (MS2) enters the coverage area of the ad-hoc network. MS1 and MS2 are placed at distances d1 and d2, respectively, from AP1 as shown in Fig. 15(b), and recording the RSS from AP1. MS2 sends the recorded RSSs to MS1 via ad-hoc connection. MS1, after having measured also the RSS of the ad-hoc connection with MS2, estimates the distance between the MSs; it is assumed that the MS2 transmits also info about its transmission power. MS1 estimates the distance d1 from AP1 and the distance d3 from MS2. The distance d2 should not exceed the radius of d3 estimated by MS1. At this point MS1 calculates a correction parameter for MS2, to allow MS2 to apply the path-loss model of MS1. After receiving the correction parameter, MS2 can finally estimate the distance from AP1.

| (a) Conventional | (b) Cooperative |

Fig. 15. Conventional and Cooperative calibration for multiple devices.

| (a) Experimental pathloss for one MS | (b) Pathloss models with correction factor. |
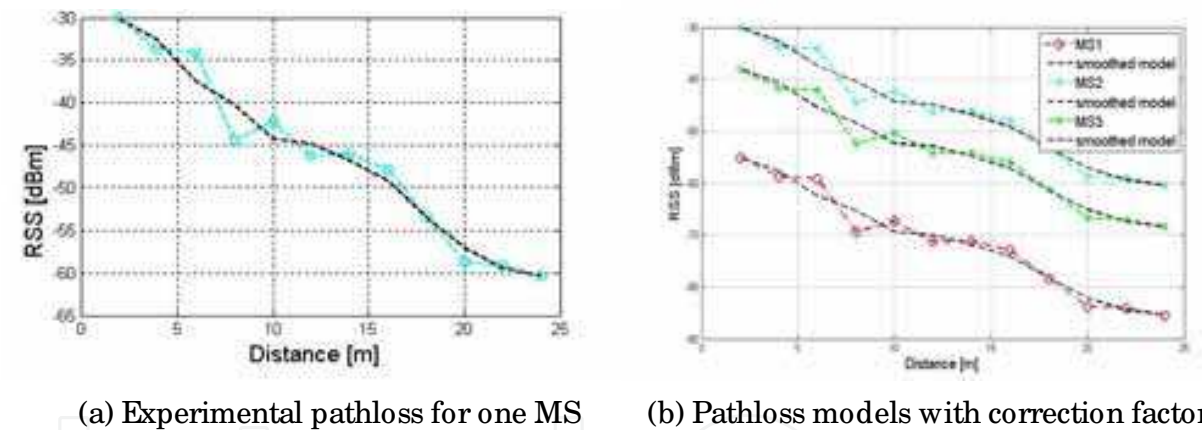
Fig. 16. Pathloss model for different mobiles.

It is worth mentioning that the closer the MSs are in the cooperative calibration phase, the better accuracy in calibration can be achieved. This process is performed iteratively; it is more precise if the two mobiles are static during the calibration procedure. Once the MSs are calibrated, the cooperative mobile positioning technique can be applied using the protocol proposed in Fig. 10(b).

The experiment took place at the 3rd floor of Tietotalo building, Tampere University of Technology, Department of Computer Systems, Finland. A typical office area with dimensions of 50x50 square meters was used as testing environment, where several objects, rooms, walls and furniture are deployed inside the area, causing severe signal obstructions between APs and MSs as expected.

Four APs Cisco 802.11 a/ b/ g and three laptops with their own embedded wireless cards were used. A C++ application has been developed for measuring and recording real-time RSS from each AP and also the RSS from ad-hoc links among MSs. All the measurements

were logged into text files and processed with Matlab scripts in both calibration and positioning phase. A Cooperative-NLLS algorithm was performed according to (Figueiras & Frattasi, 2010) (Della Rosa et al., 2010) (Frattasi, 2007) and results were compared with the non cooperative approach (Mayorga et al., 2007).

Fig. 17 shows the averages of the estimated positions for the three MSs with cooperation (circles with border) and without cooperation (circles without border). Laptops icons represent the real positions of the mobiles. It is demonstrated as in such adverse environments, the ad-hoc network has a beneficial impact in positioning accuracy for all the devices. Moreover, as the number of cooperative users increases, also the positioning accuracy gets improved (Figueiras & Frattasi, 2010).
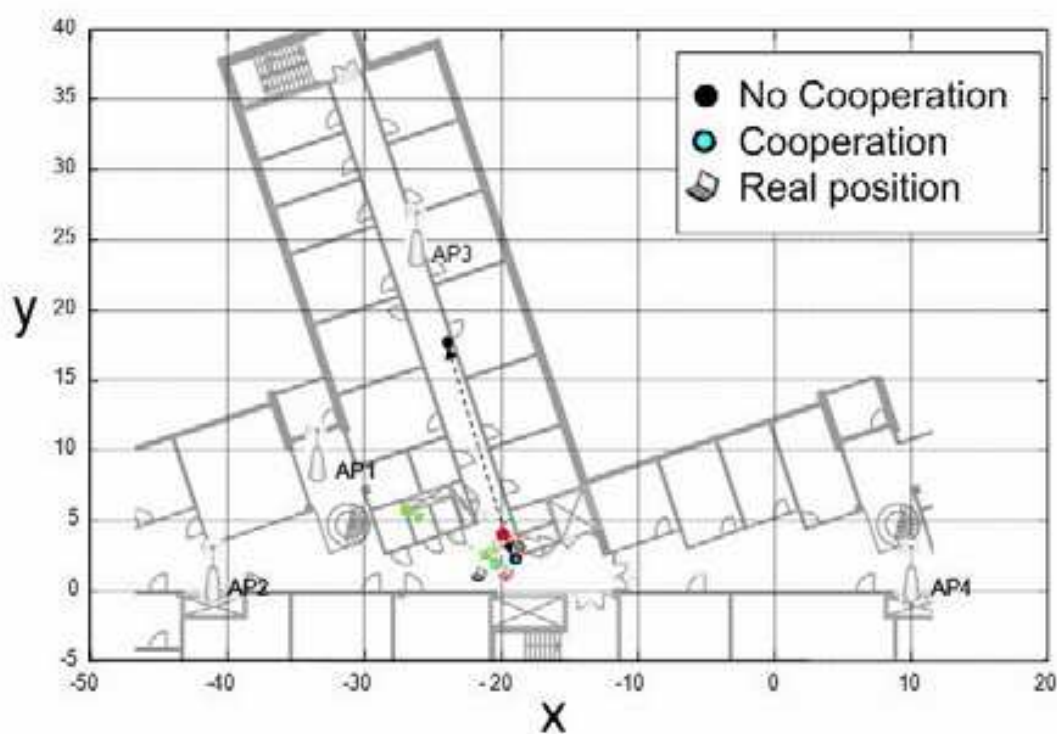
Fig. 17. Estimated Positions.

The achieved performances are highlighted in Fig. 18 by showing the CDF of the RMSE of the three mobiles.

5. Conclusion

In this chapter we have described the basics of Cooperative Mobile Positioning and the exploitation of ad-hoc networks in adverse positioning environments. Our test results from simulations and real life experiments show that, thanks to the short-range measurements available from ad-hoc links, the positioning accuracy is improved when compared to the accuracy of the non-cooperative approach. The ad-hoc link measurements present lower absolute errors than measurements in long-range cellular links; they are more stable and contain less signal fluctuations.

Although we have provided examples on Mobile WiMAX and WiFi technology, the cooperative technique can be adapted and exploited by replacing one or both technologies with different and newer ones.
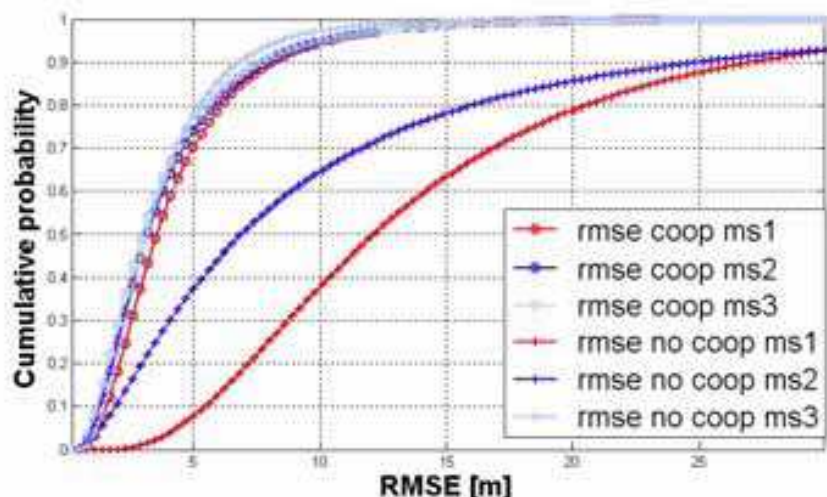
Fig. 18. Cumulative Distribution Function of the RMSE.

6. References

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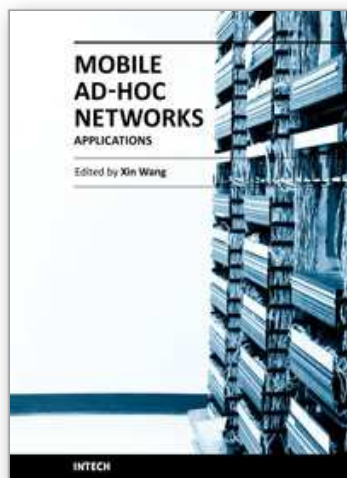
Being infrastructure-less and without central administration control, wireless ad-hoc networking is playing a more and more important role in extending the coverage of traditional wireless infrastructure (cellular networks, wireless LAN, etc). This book includes state-of the-art techniques and solutions for wireless ad-hoc networks. It focuses on the following topics in ad-hoc networks: vehicular ad-hoc networks, security and caching, TCP in ad-hoc networks and emerging applications. It is targeted to provide network engineers and researchers with design guidelines for large scale wireless ad hoc networks.

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