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A Survey of Positioning Techniques and Location Based Services in Wireless Networks

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Abstract—Positioning techniques are known in a wide variety of wireless radio access technologies. Traditionally, Global Positioning System (GPS) is the most popular outdoor positioning system. Localization also exists in mobile networks such as Global System for Mobile communications (GSM). Recently, Wireless Local Area Networks (WLAN) become widely deployed, and they are also used for localizing wireless-enabled clients. Many techniques are used to estimate client position in a wireless network. They are based on the characteristics of the received wireless signals: power, time or angle of arrival. In addition, hybrid positioning techniques make use of the collaboration between different wireless radio access technologies existing in the same geographical area. Client positioning allows the introduction of numerous services like real-time tracking, security alerts, informational services and entertainment applications. Such services are known as Location Based Services (LBS), and they are useful in both commerce and security sectors. In this paper, we explain the principles behind positioning techniques used in satellite networks, mobile networks and Wireless Local Area Networks. We also describe hybrid localization methods that exploit the coexistence of several radio access technologies in the same region, and we classify the location based services into several categories. When localization accuracy is improved, position-dependant services become more robust and efficient, and user satisfaction increases.

Index Terms—Positioning techniques; GPS; GSM; Wi-Fi; Location Based Services; hybrid positioning systems

I. INTRODUCTION

Numerous geolocation technologies are used to estimate client (person or object) geographical position. The large diversification of existing wireless Radio Access Technologies (RAT) and the increasing number of wireless-enabled devices are promoting the extensive application of Location Based Services (LBS) [1]. Position-dependant services include: emergency services such as rescue response [2] and security alerts, entertainment services like mobile gaming [3], medical applications [4] and a wide variety of other applications.

Global Positioning System (GPS) is the most common technology which supports outdoor locating services [5]. Satellites orbiting around the Earth continuously broadcast their own position and direction. Broadcasted signals are used by the receivers to estimate satellites positions as well as the distance between satellite and receiver. Having these distance measurements, trilateration [6] is usually used to estimate receivers position. Accuracy of the estimated positions depends on the number of visible satellites. Hence, it does not work well for indoor positioning, and it depends on weather conditions.

Base stations of the mobile terrestrial radio access networks, such as Global System for Mobile communi-

cations (GSM), are the reference points for mobile client localization. Cell-Identification (Cell-ID) estimates client position using the geographical coordinates of its serving base station in cellular networks [7–9]. Other positioning methods are based on the fingerprinting database, and they make use of Received Signal Strength (RSS) measurements [10–13]. However, positioning accuracy is restrained by interference, multipath and non line-of-sight (NLOS) propagation.

A Wireless Local Area Network (WLAN) offers connectivity and internet access for wireless enabled clients within its coverage area. For example, IEEE 802.11 [14] (commonly known as Wi-Fi) is widely deployed, and it is also used for localizing Wi-Fi enabled devices. The fingerprinting approach is often used in Wi-Fi positioning systems [15, 16]. It is based on Received Signal Strength Indication (RSSI) measurements in the localization area. Positioning systems using Wi-Fi are considered cost effective and practical solutions for indoor location tracking and estimation [17].

Positioning techniques performance comparison is done using several metrics [8] such as applicability, latency, reliability, accuracy and cost. A technique is more accurate when the estimated position of a client is closer to the real geographical position. Positioning accuracy is getting more important with the increasing use of position dependant applications. Indeed, it is crucial for emergency location services. Hence, hybrid positioning systems, such as [18, 19], are introduced to improve accuracy and reliability of the existing localization technologies.

In this paper, we describe the main positioning techniques used in satellite networks like GPS, in mobile networks, such as GSM, and in wireless local area networks such as Wi-Fi. The coexistence of several wireless radio access technologies in the same area allows the introduction of hybrid positioning systems, and promotes the diversification of position dependant services. We explain some of the hybrid localization techniques that coordinate information received from different radio access technologies in order to improve positioning accuracy. Such improvements increase user satisfaction, and make LBS more robust and efficient. We also classify these services into several categories.

The rest of the paper is organized as follows: in (II) we explain the principles behind positioning techniques used in satellite and mobile networks. Wi-Fi localization methods are reported in (III). We describe hybrid positioning systems in (IV). Section (V) contains a classification of LBS. Concluding remarks are given in section (VI).

II. POSITIONING IN GPS AND MOBILE NETWORKS

GPS consists of a network of 24 satellites in six different 12-hour orbital paths spaced so that at least five are in view from every point on the globe [20]. Satellites serve as reference points when estimating client position. They continuously broadcast signals containing information about their own position and direction. Distance between satellite and receiver is determined by precisely measuring the time it takes a signal to travel from the satellite to the receivers antenna.

Once the distances between visible satellites and the GPS receiver are measured, client position is estimated via the trilateration method, commonly known as triangulation [5]. Three distance measurements are required to perform position estimation. In fact, the estimated position is the intersection of three spheres having the satellites as centers and the calculated distances as radii.

GPS accuracy is largely reduced by several factors such as signal delays, satellite clock errors, multipath distortion, receiver noise and various environment noises [21]. To overcome visibility problems between satellites and receivers, assisted-GPS is proposed. It benefits from the coexistence of satellite networks along with terrestrial wireless access networks (i.e. mobile networks or Wireless Local Area Networks) in the same area. Therefore, superior accuracy, availability and coverage are offered for indoor use or in urban areas. Refer to [22] for more information about Assisted-Global Positioning System.

In mobile networks, such as GSM, many techniques are used to estimate client position. Contrarily to the satellites that are continuously moving around the globe, base stations (BS) of the mobile networks have fixed geographical positions. In addition, each BS broadcasts its Cell-ID and Location Area Identifier (LAI) to the mobiles within its coverage area. Therefore, each mobile can approximate its own position using the geographical coordinates of its serving base station in Cell-ID method [9].

Angle of Arrival (AoA) measurements [23, 24] of several radio links between the base stations and the mobile are also used to estimate client position. Hence, user position is approximated according to these angle measurements and using information about base stations geographical coordinates. Time of Arrival (ToA) [25, 26] requires synchronization between the different network elements (i.e., base stations and mobile stations). The time difference between bursts sent by the mobile are converted into distance. Hence, trilateration is used to estimate client position. Other methods use received signal strength measurements to localize mobile stations. For example, received signal power is converted into distance via propagation models or empirical models. In addition, the fingerprinting method [27] compares RSS measurements with the values stored in a database for specific points in the localization map in order to approximate client position.

Time Difference of Arrival (TDoA) [28, 29] technique is inspired by ToA. Indeed, in ToA, the positioning entity measures signal propagation time from the emitter to the receiver. Time measurement is converted into distance

that is used to estimate client position. However, TDoA technique requires the simultaneous transmission (for each base station) of two signals having different frequencies. These signals will reach the receiver at different times. Therefore, the time difference is measured and converted into distance. Once we have three distance measurements, trilateration is used to estimate client position. Enhanced Observed Time Difference (E-OTD) [30] requires synchronization between network entities (base stations and mobiles). Each base station broadcasts messages within its coverage area. A mobile station compares the relative times of arrival of these messages to estimate its distance from each visible base station.

Localization techniques in mobile networks can be classified in two categories: network-based and client-based. In network-based positioning techniques, the network collects necessary information to estimate client position. Time, angle or distance measurements performed by the base stations are usually forwarded to a positioning server deployed in the network. The required information when estimating user position is stored in the positioning database. Thus, positioning server has information about the positions of all the users in the system. However, client-based localization techniques are characterized by the absence of a centralized positioning entity. In fact, each client performs time, angle, power or distance measurements locally. Thus, it approximates its own position using local measurements and information broadcasted from the base stations.

Fig. 1 shows a qualitative comparison of the positioning techniques described in this section. Performance criteria used for localization techniques comparison are accuracy and coverage. A positioning technique is better when it has lower accuracy error (distance between the estimated position and the real geographical position) and greater coverage.

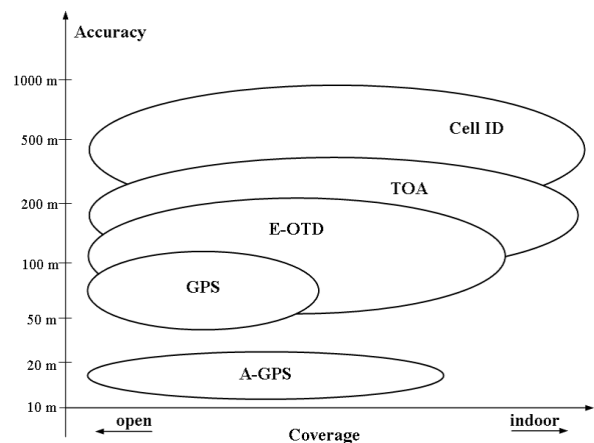


Fig. 1. Positioning techniques comparison [9]

III. WLAN POSITIONING TECHNIQUES

The increasing number of Internet users, the recent development of wireless technologies and the proliferation of mobile and web applications have boosted the implementation of WLANs. For instance, the IEEE 802.11 standard [14] (commonly known as Wi-Fi) is widely

deployed nowadays. The base station of a Wi-Fi network is called “Access Point.” Fig. 2 shows three access points serving several Wi-Fi clients located within their coverage area.

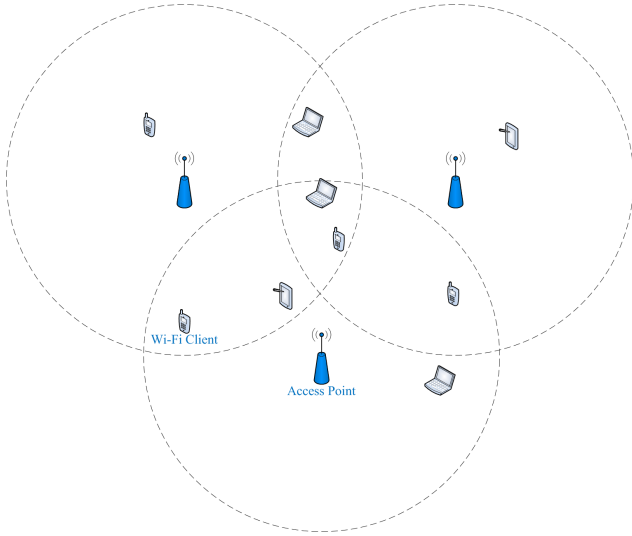


Fig. 2. Wi-Fi network having several clients

Traditionally, a Wi-Fi network provides Internet access to wireless-enabled clients located within its coverage area. In addition, it allows interconnectivity between wireless devices existing in the same network. Recently, Wi-Fi networks are having additional applications. For example, we can benefit of the coexistence of several radio access technologies in the same geographical area. Heterogeneous networks offer the possibility to steer user sessions preferentially to a given Radio Access Technology, such as Wi-Fi or Universal Mobile Terrestrial radio access System (UMTS), according to service type [31] and network load. Moreover, the wide deployment of Wi-Fi networks allows the introduction of numerous location-based services.

Wi-Fi positioning techniques are similar to those used in mobile networks. However, the most common technique used to localize a client in Wi-Fi networks is based on RSSI measurements. In the remainder of this section, we classify Wi-Fi positioning techniques into several categories, and we describe the basics of RSSI-based localization methods.

ToA [32] and TDoA perform time measurements to calculate the distance between Wi-Fi client and access points. Hence, three distance measurements are required to estimate user position via trilateration [33]. Such methods belong to the category of time-based positioning techniques, and they require time synchronization between network entities. In Cell-ID category, users scan the received radio beacons to estimate the closer access point. They use either predefined radio propagation models or experimental fingerprinting data to estimate user position.

AoA method uses directional antennas to measure the angle of arrival of signals transmitted by the clients. Hence, client position is estimated via the geometry of triangles in angle-based positioning techniques. However, the most common positioning techniques in Wi-Fi networks are based on RSSI measurements [34]. Some of them are based on propagation models [35] to translate signal power

into distance. Other methods use empirical models, and they store RSSI measurements in a positioning database. Therefore, localization methods in Wi-Fi are classified into four main categories: Cell-ID, time, RSSI and angle. Fig. 3 illustrates the classification of Wi-Fi positioning techniques.

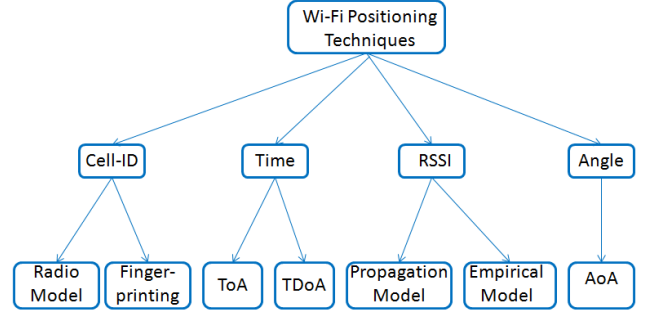


Fig. 3. Categories of Wi-Fi positioning techniques

Received signal strength indication measurements are quantified levels that reflect the real power of a received wireless signal. When propagating in free space, the transmitted radio frequency signal is subject to degradation due to attenuation, reflection, diffraction and scattering. Indeed, several propagation models formulate signal strength degradation as a function of the traveled distance and the transmission frequency. For instance, Hata-Okumura [36] model approximates Path Loss (PL) according to the distance between emitter and receiver, antenna characteristics and transmission frequency. Hence, RSSI measurements are compared with theoretical values of the received power (calculated using propagation models) in order to find the distance traveled by the signal. Three distance measurements are required to estimate Wi-Fi-enabled client position via trilateration. In fact, it is the intersection of three circles having the access points as centers and the calculated distances as radii.

Other positioning techniques based on RSSI measurements use empirical models to estimate user position. Instead of approximating the distance between Wi-Fi clients and access points, the localization area is divided into smaller parts using a grid. Each point of the grid receives several Wi-Fi signals from the neighboring access points. RSSI measurements are performed under different conditions (*e.g.* time, interference, network load) in order to increase positioning accuracy. If n is the number of Wi-Fi access points, an n -tuple $(\overline{RSSI}_1, \overline{RSSI}_2, \dots, \overline{RSSI}_n)$ containing mean RSSI values is created for each point (x, y) in the map. Such positioning technique is called RSSI fingerprinting, and it occurs in two phases: an offline fingerprinting phase and an online positioning phase.

In the first phase, RSSI measurements are done for each point in the positioning map (under different network conditions). At the end of this phase, positioning database is created. It contains mean RSSI values for every point in the grid [37]. However, the second phase performs online RSSI measurements for signals received from the neighboring access points. The positioning entity compares live RSSI measurements with the values stored in the database. Therefore, client position is estimated as the entry (x, y)

in the database that best matches the actual measurements [38]. Accuracy of RSSI-based positioning techniques in Wi-Fi networks depends on the number of access points involved in the localization problem.

IV. HYBRID POSITIONING SYSTEM

The wide usage of position dependant services increases the need for more accurate position estimation techniques. Due to the limitations of positioning methods that use data from one single RAT, hybrid positioning techniques are proposed to increase accuracy. They make use of the collaboration between different wireless access networks existing in the same geographical area, such as GPS and GSM, to exchange additional position related data.

The main factors that reduce accuracy of GPS are multipath distortion and visibility problem between satellites and receivers [20]. Therefore, a hybrid positioning technique called Assisted-Global Positioning System (A-GPS) [22] is introduced to overcome these limitations. In fact, GSM Base Transceiver Stations (BTS) are involved in the positioning problem along with the satellites. Additional data about BTS geographical position and proximity to the mobile is used together with GPS localization information in order to estimate client position. Moreover, authors of [39] propose a Wi-Fi GPS based combined positioning algorithm. Indeed, localization data from the Wi-Fi network is used when the number of visible satellites is less than four.

In cellular networks, positioning accuracy is restrained by the non-line-of-sight propagation and by interference mitigation techniques. Thus, inconsistent information is provided as entry when resolving the localization problem. Authors of [18] describe a hybrid positioning scheme that combines TDoA technique measurements obtained from the cellular network with GPS range information to improve the accuracy of mobile client position estimation. The obtained accuracy should be within the limits required by emergency location services.

ToA technique is very frequently used for positioning in mobile networks. However, it requires synchronization between mobiles and base stations. In addition, ToA is restricted by multipath and non-line-of-sight propagation problems. Hence, this positioning technique is assisted by additional information from AoA technique. Angle measurements are performed by the serving base station using antenna arrays. The usage of ToA assisted AoA technique improves positioning accuracy, especially in bad propagation environments [26].

In wireless local area networks, such as Wi-Fi, RSSI fingerprinting technique depends on the number of access points involved in the localization process. The validity of mean RSSI measurements stored in the database also affects positioning accuracy. We exploit the coexistence of Personal Area Networks (PAN) along with Wi-Fi in the same geographical area to improve positioning accuracy. In fact, RSSI measurements are done for all the existing wireless technologies, and results are stored in the positioning database. Therefore, Wi-Fi fingerprinting uses additional RSSI information from wireless PANs existing in the same area such as Bluetooth and ZigBee networks.

More information about this hybrid technique is found in [38].

V. LOCATION BASED SERVICES

In wireless networks, the knowledge of user geographical position allows the introduction of numerous position dependant applications. These applications are known as location-based services, and they are useful for service providers as well as for mobile clients.

The wide deployment of radio access technologies and the increasing development of wireless-enabled devices are promoting the extensive use of LBS. As mentioned in the previous sections, numerous positioning techniques are used to estimate client position. However, the main parameter for LBS efficiency is accuracy of the positioning technique. Indeed, users are more satisfied when the estimated position is closer to the real geographical position, and when the probability of erroneous estimations is reduced.

Location-based services are related to the position of the user making the request. They are classified [40] as emergency services (*e.g.* security alerts, public safety and query of the nearest hospital), informational services (*i.e.*, news, sports, stocks and query of the nearest hotel or cinema), tracking services (like asset/fleet/logistic monitoring or person tracking), entertainment services (for example: locating a friend and gaming) and advertising services (such as announcements or invitation messages broadcasted by the shops to the nearby mobile clients). Moreover, future applications of LBS include support to the studies on climate change, seismology and oceanography.

Position dependant services are useful for mobile mapping, deformation monitoring and many civil engineering applications [41]. They have revolutionized navigation (on land, in the air and at sea) and intelligent transportation system by increasing their safety and efficiency. However, user location privacy security poses a potentially grave threat [1]. In fact, it is possible to access user location information anytime and anywhere. Therefore, many privacy protection methods are introduced to deal with the contradiction between location privacy protection and quality of service in LBS. Some of them protect user ID information by hiding the true ID when requesting the service. Other methods do not submit the exact location to the server, but they send a region containing user exact position.

VI. CONCLUSION

In this paper, we surveyed the major positioning techniques used in wireless networks. Global positioning system is the most common technology for outdoor locating services. Localization techniques in mobile networks, such as global system for mobile communications, perform time, angle or signal power measurements to estimate user position. In Wi-Fi networks, received signal strength indication fingerprinting approximates user position within the coverage area. Accuracy depends on the number of access points involved in the positioning process.

Hybrid positioning techniques are proposed to satisfy the increasing need for positioning accuracy. They make

use of the collaboration between multiple radio access technologies existing in the same geographical area. For instance, Assisted-GPS uses information from the mobile network to improve positioning accuracy in GPS. Location-based services are based on the knowledge of user position. They include emergency, informational, tracking, entertainment and advertising services. LBS are useful for service providers and for the clients. Accuracy improvements increase user satisfaction, and make the localization services more robust and efficient.

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