Overview of User Location in Cellular Networks

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Abstract – **An additional application for wireless location is presented -the concept of user location in cellular networks. Different radiolocational and triangulation methods for subscriber location are represented. A brief comparison between these contrivances is made.**

Keywords – **subscriber location, wireless location, TOA, OTD, E-OTD, AOA, A-GPS, ICEST 2003.**

I. Introduction

The contemporary telecommunication market is the one of the most modern and dynamically developing market structures. Unremittingly new methods to increase the potentialities of the wireless network are searched. The number of clients grows progressively. It becomes necessaries to additional services. One new service is on the way to give new appearance of the network - subscriber location service. Recently, in a few tested areas, rental cars equipped with location devices and map displays have aided visitors in an unfamiliar territory. Taxi and delivery drivers have utilized location technology in Tokyo to navigate the myriad of streets [1]. Fleet operators use location technology to improve product delivery times and the efficiency of the fleet management process. In cellular telephone networks, location technology could be used for radio resource and mobility management. The Federal Communications Commission (FCC) requires that starting October 1, 2001, all wireless carriers be able to provide the position (or location) of an emergency 911 caller to the appropriate Public Safety Answering Point (PSAP) [2]. Location technologies not requiring new, modified, or upgraded mobile stations (MS) must determine the caller's longitude and latitude within 100 meters for 67% of the emergency calls, and 300 meters for 95% of the calls. If new, modified, or upgraded handsets are required, the requirements are more stringent: 50 meters for 67% of the calls, and 150 meters for 95% of the calls. For successfully resolving this problem many radio location and navigations methods are used.

II. Overview of Existing Location Systems

Location technologies [4] fall into two major categories: **network-based solutions** and **handset (mobile station MS)-based solutions**. It depends on network environment there are some differences and summaries. It is normal to exist hybrid systems, systems that use many different signals (synchronization signal, information, SMS signal, .. etc.) in the different existing world networks [5].

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The most common system used for cellular location if so named **"Cell-ID based positioning system"** location. The entire service area of a mobile phone network consists of a mosaic or honeycomb of overlapping radio cells, each centered on a base station where the radio antenna is installed. The size of the cells varies according to the intensity of user traffic, and each one is uniquely identifiable by its cell ID. Cell-based location does not require any modifications to the users mobile phones nor to the network. The accuracy is depended on the size of the cell in large cities and conurbations, where the cells are very small and highly concentrated (so-called pico-cells), it is possible to identify a users location to within about 300 meters, In more thinly populated areas and in more isolated regions, a single cell is theoretically capable of covering a radius of up to 35 kilometers. Cell-ID based positioning system have most mobile networks including the most European countries and the Asia Pacific countries [6].

Other radiolocation technology is Positioning using Signal Strength (**SS**). The measurement employs a well-known mathematical model describing the path loss attenuation with distance [7]. This model is reflected in Eq. 1 - Path Loss Attenuation Model:

$$Pl(d) = Pl(d_0) + 10n\log(d/d_0) + X_\sigma \qquad (1)$$

In this equation, $Pl(d)$ (is the path loss as a function of the distance between a transmitter and a receiver. $Pl(d_0)$ is the path loss at a known reference distance d_0, n is 2 for free space and usually higher for wireless channels, and X_σ a zero mean Gaussian random variable reflecting the variation in average received power. X_σ of special interest in this model since it describes the influences of shadowing in an ideal environment (free space and Line-Of-Sight (LOS) propagation) the transmitter lies on a circle centered at the receiver [6].

Some of several fundamental approaches for implementing a radiolocation system including those based on signal-strength are angle of arrival (AOA) and time of arrival (TOA)[8,1]. It is important to note that line-of-sight (LOS) propagation is necessary for accurate location estimates. Angle of Arrival (AOA) techniques estimate the location of a mobile station (MS) by using directive antennas or antenna arrays to measure the AOA at several base stations (BS) of a signal that is transmitted by the MS [8]. Simple geometric relationships are presented in Fig. 1. Consider the error due to multipath propagation, but do not consider angle estimation errors. It is assumed that the MS uses an omnidirectional antenna, so that. In the absence of an LOS signal component, the antenna array will lock on to a reflected signal that may not be coming from the direction of the MS. Even if an LOS component is present, multipath will still interfere with the angle measurement. The accuracy of the AOA method diminishes with increasing distance between the MS and BS due

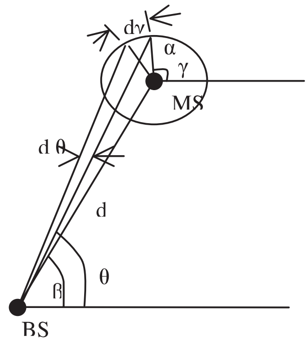

Fig. 1. MSBS geometry assuming a ring of scatterers for macrocells.

to fundamental limitations of the devices used to measure the arrival angles as well as changing scattering characteristics. For macrocells, scattering objects are primarily within a small distance of the MS, since the BSs are usually elevated well above the local terrain [8,10]. Consequently, the signals arrive with a relatively narrow AOA spread at the BSs (Fig. 1 [1]). For microcells, the BSs may be placed below rooftop level. Consequently, the BSs will often be surrounded by local scatterers such that the signals arrive at the BSs with a large AOA spread. Thus, while the AOA approach is useful for macrocells, it may be impractical for microcells.

Other systems to measurement position of an object are time based systems. It uses a Time-Of-Arrival (TOA) method. The position of an object is found by measuring the propagation time of a signal travelling from a mobile station to a fixed transceiver or vice versa. Geometrically, this provides a circular locus centered at the transceiver. In order to be able to resolve this location ambiguity for a two-dimensional environment, two more measurements have to be made. A TOA system has some disadvantages. Firstly, it requires all transceivers (either at the network-side or the object itself) to have precisely synchronized clocks. Secondly, multipath propagation caused by signal reflections has a strong influence on the accuracy of the location estimate and can be overcome only by employing sophisticated techniques that screen out unwanted portions of the original signal [1,11]. On the basis of that is development some methods that can increase the timing measurements [12,13] – Fourth Order Cumulating Estimation of Signal Parameters via Rotational Invariance Techniques (FOC-ESPIRT) approaches [13]. The approaches based on higher-order cumulates are powerful in suppressing the Gaussian noise. The Generalized Successive Interference Cancellation (GSIC) is a computationally effective approach when the multipath channel is long and sparse [12].

The idea behind the Time-Difference-Of-Arrival (TDOA) method is to determine the relative position of a transceiver by examining the difference in time rather then the absolute arrival time. A straightforward method of TDOA estimation is to form the cross-correlation between signals received at a pair of BSs. Suppose that the signal $d(t)$ is received at $\mathrm{BS_A}$ corrupted by noise n_A such that $s_A(t) = d(t) + n_A(t)$ The same signal is received at $\mathrm{BS_B}$ with a delay of D and also corrupted by noise $n_B(t)$, giving $s_B(t) = d(t-D)+n_B(t)$).

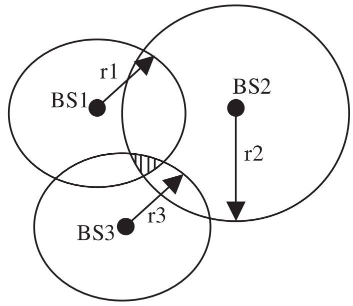

Fig. 2. The location of the MS is constrained to the intersection area (shaded region) of circles of radius $c(\tau_i - \tau)$ centred at each BS.

The cross-correlation function of these signals is:

$$C_{A,B}(\tau) = \frac{1}{T}\int_0^\infty S_A(t)S_B(t+\tau)\mathrm{d}t \qquad (2)$$

The TDOA estimate is the value τ that maximizes $C_{A,B}$. This approach requires the analog signals $s_A(t)$ and $s_B(t)$ to be digitalized and transmitted to a common processing site. Also, a strict time reference is required at each BS. In the IS-95A CDMA standard, all BSs are referenced to a systemwide time that uses the GPS time scale [1]. Because of properties of the PN codes, the TOA estimates can be derived from the pseudo-noise (PN) code acquisition and tracking algorithms employed in Spread Spectrum (SS) receivers [15]. Two approaches are generally used to calculate the location of an MS from TOA or TDOA estimates. One approach uses a geometric interpretation to calculate the intersection of circles (Fig. 2) or hyperbolas (Fig. 3), depending on whether TOA or TDOA is used. This approach becomes difficult if the hyperbolas or circles do not intersect at a point due to time measurement errors. A second approach calculates the position using a nonlinear least-squares (NL-LS) solution [1], which is a more statistically justifiable approach. The algorithm assumes that the MS, located at (x_0, y_0), transmits its sequence at time τ_0. The N BS receivers located at coordinates (x_1, y_1), (x_2, y_2),...(x_N, y_N) receive the sequence at times τ_1, τ_2,...τ_N. As a performance measure, we consider the function[1]:

$$f_i(x) = c(\tau_i - \tau) - \sqrt{(x_i - x)^2 + (y_i - y)^2}\,, \qquad (3)$$

where c is the speed of light, and $x = (x, y, \tau)^T$. This function is formed for each BS receiver, $I = 1, ...N$, and all the $f_i(x)$ could be zero with the proper choice of x, y, and τ. However, the measured values of the arrival τ_i times are generally in error due to multipath and other impairments, and non-LOS propagation introduces errors into the range estimates that are derived from the arrival times.

In a GSM network a (Base Station) BS sends synchronization information (i.e. training sequence in the synchronization burst transmitted on the synchronization channel) to a mobile station on how to advance their frame timing to ensure correct frame synchronization with the serving BS. After two consecutive inter-cell handovers, three timing advances are known to the network and therefore provide sufficient information to compute the mobile phones position. Additional handovers may contribute to the improvement of

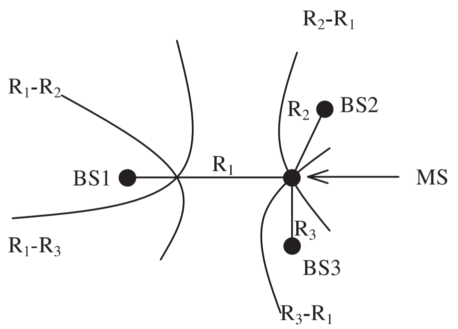

Fig. 3. Principals of Time-Difference-Of-Arrival (TDOA) (Hyperbolical geometric interpretation)

the location estimate. The positioning method is referred to as **Timing Advance** (TA) and can be classified as a TOA technique, and the nature of the architecture is network-based. The system can be implemented without modifications to the current generation of GSM mobile stations [6].

The **Observed Time Difference Positioning (OTD)** employs TDOA measurements in order to determine the position of a mobile station. Through TA, the latter has information about the propagation delays to different BS and can therefore detect the time difference between them. The system can either work mobile-based or network based depending on whether the GSM terminal calculates its position from two independent measurements or if the information is passed on to the network. For the latter, the network computes the location estimate by solving the hyperbolic Eq. 3 presented in the preceding chapter. A major drawback of the positioning concepts based on GSM signaling aspects is their limited accuracy. The evaluation of positioning architectures based on TAs and OTDs resulted in a resolution ƒ 554 m given LOS propagation [5] and may be further degraded by multipath propagation effects. The given accuracy figure is a direct result of the limited bit resolution of TA and OTD measurements. Since the this accuracy specification will likely not meet the requirements for emergency location reporting in the U.S., alternative approaches have to be undertaken. This could be achieved, for example, by overlaying an autonomous TDOA positioning system. The method to measure the Observed Time Difference (OTD) on a terminal has been used since radar systems were first invented over 50 years ago and has been successfully adapted to E-OTD by the major standardization bodies for cellular networks. E-OTD method can be related to both network based and terminal based positioning techniques. If the BSs are not synchronized, such a system operates by placing fixed reference measuring points. E-OTD seems to be a promising candidate for enabling positioning at current and future mobile network systems (in UMTS networks this technology is called OTDOA (Observed Time Difference of Arrival) [9].

An obvious idea is to use the Global Positioning System (GPS) [14,16] and incorporate GPS receivers into mobile phones, especially considering substantial increase in GPS accuracy after the May 2000 removal of deliberately introduced errors through Selective Availability (SA) [4,9]. This can successfully incorporate with Handset-based techniques. Assisted-GPS (A-GPS) technology overcomes the downsides of the conventional GPS solution, and achieves high location accuracy at reasonable cost [14,4]. The assistance to the mobile phone trying to determine its own location comes from the network over the air-interface, and this distributed approach leads to performance levels that exceed those of conventional GPS. What makes this technology work so well is that the wireless network, using its own GPS receivers, as well as an estimate of the mobiles location down to cell/sector, can predict with great accuracy the GPS signal the handset will receive and convey that information to the mobile. With this assistance the size of the search space is greatly reduced, and the time-to-firstfix (TTFF)[4, 14] shortened from minutes to a second or less. In addition, an A-GPS receiver in the handset can detect and demodulate signals that are order of magnitude weaker than those required by conventional GPS receivers. Only a partial GPS receiver is required in the handset to achieve this functionality, but legacy terminals cannot be used and new handsets are required for the technology to operate. The A-GPS technology concept is shown in Fig. 4. The main system components are a wireless handset with partial GPS receiver; AGPS server with reference GPS receiver that can "see"the same satellites as the handset (DGPS service can be used as well); and wireless network infrastructure, that is, base stations and a mobile switching center (MSC)[4].

The classification in Table 1[4] gives short overview and description in location technologies. It is made according to where signals are measured, since subsequent calculations for location determination can be done anywhere in the system. (In the Table, BS denotes a wireless base station, MS a mobile handset, PDE is position-determination equipment, RTD is the real time difference, and LMU stands for Location Measurement Unit).

III. Conclusion

The subscriber location is a very interesting area in the additional application of radio communication networks. There are many "pure" radio navigational technics utilized. Most of the ideas in subscriber location could be applied successfully for bistatic radar systems, which are based on the existing radio systems and subsystems.

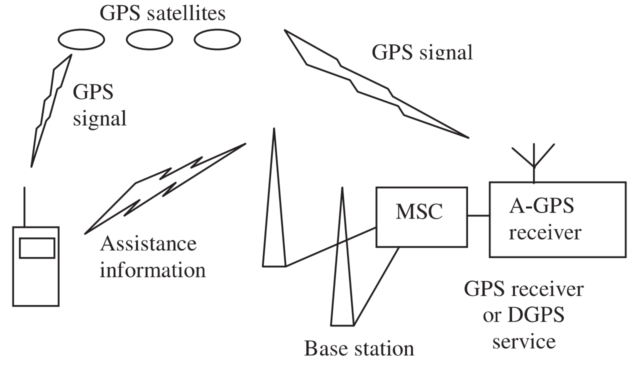

Fig. 4. Assisted-GPS concept

Table 1. Location technologies short description

MS-Based location	Global Positioning System (GPS)	Built into the handset is a full-fledged GPS receiver that operates as a standalone device (see description in the Section on GPS).
	Assisted GPS (A-GPS)	A partial GPS receiver in the handset is aided in its operation by the wireless network (see description in the Section on A-GPS).
	Observed Time Difference (OTD)	MS monitors signals from at least three BSs and observes time differences of arrivals. BS locations are known and fixed and position is calculated by triangulation after subtracting OTD from RTD. LMU required if BSs not synchronized (e.g. GPS at each site). Added network traffic is minimal (data are gathered at MS,) but handsets need firmware upgrade. In GSM, method is known as Enhanced OTD (E-OTD).
Network-Based Location	Time of Arrival (TOA)	MS signal is received by at least three BSs, which measure TOA independently and send data to PDE where location is calculated. No handset modifications are needed, but network requires upgrade and signaling is increased.
	Time Difference of Arrival (TDOA)	At least three BSs monitor MS signals using dedicated location receivers. Location estimate based on apparent arrival time differences between pairs of sites. Strict time synchronism among all BSs is a must. Time difference measurements less accurate in analog and digital narrowband systems (AMPS, TDMA,) leading to inferior performance.
	Angle of Arrival (AOA)	Special antenna arrays and location receivers in BS determine AOA of the MS signal. Location is found at the intersection of apparent arrival directions. At least two BSs needed, but three or more used to increase accuracy and reduce uncertainty due to multipath. No modifications to MS are needed.
	Multipath Fingerprinting	MS location found by matching the multipath-produced "fingerprint" of the signal received by one or more BSs with location/fingerprint database. Technique requires continuous database management and updating.
	Timing Advance (TA)	During link establishment MS aligns its frame/slot times with the serving BS, and uses this as a measure of its distance to BS (TDMA or GSM). Using network-enforced handoff, at least three measurements with different BSs are made and location is determined via triangulation. Sequential measurements make the method unreliable when MS is moving. No modifications to handsets and minor changes in BS software.
Network/MS-Based Location	Enhanced Forward Link Triangulation (E-FLT)	Solution unique to CDMA. Primarily based on TDOA using forward-link signals received by MS. Performance enhanced by complementary methods, including pattern matching of RF characteristics, statistical modeling, round trip delay measurements, and AOA.
Hybrid-Type	TDOA & Received Signal Strength (RSS)	Combine highly accurate with highly robust methods, and use multiple inputs to improve both the robustness and coverage. E.g., in A-FLT/A-GPS, A-FLT can extend coverage deep indoors where not enough GPS satellites are visible; in TDOA/AOA, AOA enables operation even when only two BSs can receive the MS signal.
	TDOA & AOA	
	A-FLT & A-GPS	
	E-OTD & A-GPS	

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