Hybrid Algorithm for Locating Mobile Station in Cellular Network

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ABSTRACT

Locating mobile stations have been attracting an increasing attention from both researchers and industry communities and it is one of the most popular research areas of cellular network. Locating mobile stations using Time of Arrival, Time Difference of Arrival, Angle of Arrival and Received Signal Strength techniques have been widely used. However, more accurate results have been achieved by combining two or more of these techniques. A hybrid algorithm for locating mobile station is proposed by combining Received Signal Strength, Signal Attenuation and Time Difference of Arrival in this paper.

Keywords

Mobile Station, Location Identification, Cellular Network

1.0 INTRODUCTION

The past few years have seen unprecedented growth in the number of wireless users, applications, and network access technologies which lead to many issues and challenges in wireless network such as authenticating to the hotspot provider, wireless-hop security, radio frequency range, network performance and quality of service, network management and location and context-awareness. The rise of a cell-phone culture (Geser, 2002 & Piller, 2000) has substantially changed the way people plan and manage their daily activities and social interactions. It allows people to access the Internet where ever they are and when ever they want.

There are basically two ways to determination the physical location or location identification of any mobile user. The first is by using a satellite-based global positioning system and the second is by measuring the distance from cellular antenna towers to the user.

The general idea of locating a mobile station was introduced in 1969 by Figel et al. (1969) when they tried to determine a vehicle location using signal attenuation method. From there on, various research on locating mobile stations lead to the discovery of various locating techniques. The techniques are received signal strength measurement (Figel et al., 1969), angle detection (Porter, 1971), arrival time measurement (Staras and Honickrnan, 1977) and hybrid techniques (Chan and Ho, 1994).

2.0 LOCATING MOBILE STATION TECHNIQUES

The techniques are based on three main elements which are the signal strength, arrival time and angle of arrival. Each technique has its own strength and limitation.

2.1 Received Signal Strength

The signal strength method based on the attenuation of the signal is the distance between the Mobile Station (MS) and Base Station (BS) which can be calculated either at the MS location or at the BS location. RSS is not widely used due to the complex propagation mechanisms (Juang et al., 2006).

Aso et al. (2002) presents the MS location estimation using the Maximum Likelihood (ML) Method in sector cell systems. They propose the propagation modeling for signal strength in sector cell systems and shows that the estimation accuracy of sector cell system is superior to that of omni cell systems because the amount of information for location estimation has increased and that the error criterion of location estimation is reduced as the standard deviation is decreased or the number of BSs is increased.

Lin et al. (2005) proposes a mobile location scheme using weighted centroid method based on the ratios of distances between mobile and base stations derived from the differences of signal attenuations. The proposed method does not require perfect path loss and shadowing models, and is capable to be applied in existing systems without hardware modifications.

2.2 Time of Arrival

Time of arrival (TOA) is a network based multilateral method that estimates the location of the mobile by measuring the time that a signal takes to travel from the mobile station to the base station. In the traditional geometric interpretation, time of arrivals generate circles whose intersections provide the estimate of the transmitter. Caffery (2000) proposed a new geometrical interpretation in which straight lines of position (LOPs), rather than the circular LOPs, are used to determine the position of the transmitter. The straight LOPs come from a simple observation regarding the geometry of the system and are not obtained from linearization.

Cheung et al. (2004) proposed two time of arrival based location algorithms from the spherical interpolation (SI) approach, which reorganizes nonlinear equations to linear equations via introduction of an intermediate variable. The first least squares algorithm directly extends the SI using the TOA measurements by adding the range variable which is represent the root of the sum of the squared coordinates of the MS position which will be determined. The second constrained weighted least squares (CWLS) method is an improved version of the first algorithm with the use of weighting matrix and constraint. They have shown that the CWLS approach can attain the Cramér–Rao lower bound and optimal circular error probability under sufficiently small noise conditions.

Cheung and So (2005) proposed a simple algorithm for mobile location estimation using time of arrival measurements of the signal from the mobile station received at three or more base stations, via modifying the classical multidimensional scaling technique.

2.3 Time Difference of Arrival

Time difference of arrival (TDOA) follows a similar concept of time measurement embraced in the TOA, except that TDOA uses time differences measurements rather than absolute time measured as TOA does.

Xing et al. (2006) proposed a new efficient technique Major Base Station Circulating to do the job by using more than one major base station without any extra measurement. It has been proved by simulations that the new technique not only has the high ability to avoid the ambiguous and unreasonable problems in calculating the objects position, but also can be used to improve the precision of the TDOA localization.

2.4 Angle of Arrival

Angle of arrival estimates the location of a mobile area using triangulation by measuring the angle of arrival of the received signal at two base stations. This technique is rarely used alone due its inaccuracy (Chen et al., 2002).

Deng and Fan (2000) analyzed and modeled TOA and AOA errors in four typical cellular environments. Based on the analysis, a hybrid TOA/AOA positioning (HTAP) algorithm which utilizes TOA and AOA information delivered by serving base stations (BS) is proposed by combining TOA with AOA measurements and added to the BS coordinate. HTAP will produce an accurate location estimate when MS is close to the serving BS. However, when MS is far from serving BS, location estimate obtained by HTAP can be used as a initial location in their system to help least square (LS) algorithm converge easily.

Andreu et al. (2006) presents an approximation of the ML position estimator based on AOA measurements applying the Divide-And-Conquer approach which divide the ML estimation in smaller problems each one with a closed-form solution. Numerical simulations show that the proposed algorithm outperforms the previous contributions and presents a generic way to combine AOA and TDOA measurements

2.5 Hybrid Techniques

Hybrid techniques have been successfully adopted by the wireless location industry and there exist several schemes that combine one or more methods from terrestrial TOA, AOA, TDOA and RSS to achieve the desired accuracy.

Kbar and Mansoor (2005) present a new calculation method to locate the mobile phone in urban district. Their hybrid method uses signal strength to estimate the timing delay and comparing it with the measured time of arrival of the signal. The minimum timing value of the two results would be accepted and averaged for n samples. This will improve the accuracy and reduce the effect of multi-path signaling that both timing signaling and signal strength methods suffer from. In addition, a new calculation method has also been presented to find the location of MS based on the BSs coordinates by formulating three equations to measure the distance from the estimation MS location to three BSs depends on the coordinate of the BSs, this is done by solving equation one and two, one and three. The exact solution of MS is the common location calculated.

Juang et al. (2006) propose Signal Attenuation Difference of Arrival (SADOA) scheme to combine with TDOA method which is based on the ratio of distances between the mobile and base stations derived from differences of signal attenuations. Each SADOA measurement yields a circle on which the mobile may lie. The proposed hybrid SADOA/TDOA scheme uses Taylor-series expansion to linearize the circles and hyperbolas and iteratively computes the mobile position based on least squares estimation. Without perfect path loss modeling and hardware modification, the proposed scheme reduces location errors compared with either technique separately.

3.0 PROPOSED HYBRID LOCATING TECHNIQUE

The basic components that based on this propose technique are RSS, SA and TDOA.

SA between two stations can be expressed as (Lin et al., 2005)

$$A(dB) = k_1 + k_2 \log_{10} f - k_3 \log_{10} h_b - k_4 \log_{10} h_m + 10 n \log_{10} d + x \quad (1)$$

Where A(dB)is the signal attenuation, k_1, k_2, k_3 *and* k_4 denote different constants in the same clutter type of environment, f is the carrier frequency, h_b and h_m are, respectively, the heights of BS and MS, n is the path loss exponent, and x is a zero-mean Gaussian random variable.

The power loss for free space propagation, L_T, in the RSS technique can be

$$L_T = L_b - G_T - G_R \text{ (dB)} \quad (2)$$

Where L_b is power loss at the receiver, G_T is the gain of the transmitter and GR is the gain of the receiver. (Kbar and Mansoor, 2005)

Juang et al. (2006) assume each BS_i is capable of performing TOA observation, t_i, then TDOA observation is defined as $T_i = t_i - t_1$, i =2,…., N. Expressing TDOA observation as a function of station coordinates, a hyperbola has the form

$$cT_i = \sqrt{(x - x_i)^2 + (y - y_i)^2} - \sqrt{(x - x_1)^2 + (y - y_1)^2} \quad (3)$$

Where c is the speed of light, T_i is the TDOA observation, (x_1, y_1) and (x_i, y_i) is the coordinates of BS_1 and BS_i, respectively, and (x, y) is the unknown MS position.

From these three equations it could be possible to enhance the RSS techniques by considering the SA in the RSS measurement through determine the attenuation that could occur in the signal and subtract it from the RSS measurement. In addition for that TDOA measurement will be calculated. Each RSS, TDOA measurement yields a circle, hyperbola on which the mobile may lie, so by linearizing the circles and hyperbolas it could be used to estimate the MS position. The proposed technique will use Taylor-series expansion to linearize the circles and hyperbolas and iteratively computes the mobile position based on least square estimation.

4.0 CONCLUSION

Accuracy in determining mobile stations depends on the techniques that are used. There are more than one method to linearize non linear equation that is used in location detection. Taylor series method showed its strength in providing accurate results when it has an accurate initial guess. The RSS technique that is proposed in this hybrid technique is not widely used due to the complex propagation method but this can be overcome by subtracting the SA. This is expected to reduce the error measurement that occur because of the propagation environment. SA provides a good initial guess for Taylor series method to linerize the equations.

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