行政院國家科學委員會專題研究計畫成果報告
第三代行動通訊系統定位功能之研究

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1、中文摘要

（關鍵字：手機定位，通道估測）

本報告提出一種適用於未來第三代行動通訊系統的手機定位技術。該技術可在基地台端設置天線陣列來達成。基地台由上鏈信號來估測手機電波的到達時間及來向。由估測的電波到達時間及來向就可以決定手機的位置。我們提出決定直接波到達時間的法則。我們亦提出使用非等間隔排列的天線陣列來估測電波來向的方法。為改進定位的準確度，我們提出使用多個量測資料來決定手機位置的方法，結果顯示手機位置的精確度提升了許多。我們在幾種不同的環境進行手機定位的實驗，包括室內的環境，電波穿透進入建築物內的環境，室外的環境以及兩個基地台重疊的環境，模擬及實驗的結果，皆顯示本文所提方法確實可行。

2、英文摘要：

（Keywords：Subscriber Geolocation, Channel Estimation）

In this paper we develop subscriber geolocation techniques for future W-CDMA applications. These techniques can be realized by a single base station (BS) equipped with an antenna array. The BS uses received uplink signals to estimate the time of arrival (TOA) and direction of arrival (DOA) of the direct path connecting from the mobile station (MS) to the BS. The MS's position is then determined by the estimated TOA and DOA. We have proposed a downward search method to estimate the TOA of the direct path. We also have proposed a method which utilizes non-uniformly spaced array to determine the DOA of the direct path. The benefit of this method is that we can use less antenna elements but still have better estimation performance than that of a uniform array with the same aperture size but more elements. To improve the accuracy of geolocation, we have proposed methods which utilize estimations from multiple snapshots to locate the MS. We found that the geolocation performance can be improved significantly. We have conducted experiments in several typical environments, including a pico-cell environment, an environment with a signal penetrating through buildings, a macro-cell outdoor environment and a cell covered by multiple base stations. Simulation and experimental results have verified the effectiveness of our proposed methods.

3、Introduction

As the technology of wireless communication moves from the second to the third generation, improved functionality and broader spectrum of wireless systems are available for system operators and subscribers [1, 2]. One of these services, wireless location, received much attention over the past few years due to the Federal Communication Commission's (FCC) 1996 report and order [3]. The FCC requires that all wireless service providers provide location information for Enhanced-911 (E911) safety services.

One of the major error sources for geolocation in wireless systems is non-line of sight (NLOS) propagation. The algorithms that have been developed for location are based on the assumption that a direct path exists between the MS and the BS. Unfortunately, a line of sight (LOS) path does not always exist and the BS frequently receives the desired signal from reflections or diffractions. The measured time of arriveal (TOA) and direction of arrival (DOA) may not be correct in this situation. Since over 60% of the time only one BS serves a given MS in third generation communication systems, we want to use a single BS to locate the subscriber. To remove errors caused by NLOS propagation and to meet E911 requirements , we will propose new TOA and DOA estimation methods to improve the accuracy of subscriber geolocation.

4、 Methods for TOA and DOA Estimation and Subscriber Geolocation

The BS array receiver consists of M antenna elements. The wideband signal received by each element is down converted to baseband and then passed through a matched filter to give the delay profile. A TOA estimation algorithm is then used to determine the direct LOS path. Assuming the time bin of the direct LOS path has been determined, the delay profiles of each element at this time bin have been sampled and the sampled value at the mth element is denoted by E_m. A DOA estimation algorithm is then used to determine the DOA of the direct LOS path. From the determined TOA and DOA, the position of the MS is obtained.

In wideband measurements, a delay profile, which characterizes the power received at different time delays, is measured and recorded. The direct LOS path has the shortest distance among all multipath components. We usually consider the path having the strongest signal strength as the direct path. In a multipath environment, due to shadowing and fading effects, the direct path may not have the greatest amplitude in the delay profile but it always has the smallest TOA. Therefore it is not proper to consider the time bin with the largest signal strength value in the delay profile as the TOA of the direct path. In the following, we propose a method called the "downward search method" to determine the direct LOS path. The method is described as follows：

1. Given a delay profile find the maximum value along the delay axis.
2. Determine a decision value. The threshold value is obtained by subtracting the decision value from the maximum value.
3. The TOA of the LOS path is then determined by searching the position which first crosses the threshold.

The array structure of the BS receiver can be either a uniformly spaced or non-uniformly spaced array. For the uniformly spaced array, we can apply the fast Fourier transform (FFT) algorithm or other super-resolution algorithms such as ESPRIT [4] on the sampled E_m to derive the spatial spectrum. The position of the peak value on the spatial spectrum then gives the DOA of the MS. For the non-uniformly spaced array, the summation values $\sum E_m e^{-jkd_m \sin\theta}$ for all θ, where d_m is the position of the mth element, are calculated, and the corresponding θ that maximizes $\sum E_m e^{-jkd_m \sin\theta}$ for all θ is then determined as the DOA of the MS.

Once we have determined the TOA and the DOA at the base station, theoretically, we can immediately locate the subscriber. In a real environment, however, the estimated TOA and DOA may not be accurate enough due to bad signal quality or fast channel fading, and the estimated location may be inaccurate and of no use. In this section we will propose algorithms to increase geolocation accuracy. In fading environments signal quality usually changes with time. However, the MS position changes little for consecutive snapshots. If the a priori information about the channel properties and subscriber's motion is utilized to assist the TOA and DOA estimation, we believe that the estimation performance can be improved. We propose several methods which utilize the statistical properties of the received signals and the mobile's motion to determine the TOA and DOA.

In the first method assuming the instantaneous TOA and DOA of each snapshot have been obtained, then the resultant TOA and DOA are determined by using a moving average for a fixed number of consecutive TOA and DOA values.

In the second method, we gather a fixed number of successive snapshots into a group and use the TOA and DOA obtained by the snapshot with the largest SNR to represent the TOA and DOA for this group.

In the third method, we also gather a fixed number of successive snapshots into a group. The resultant TOA and DOA values are then determined by the one that appears most often in this group.

In the fourth method we drop those snapshots in which the peak value of the corresponding delay profile is below a given threshold.

In the fifth method we consider the motion property of the MS. Usually, a rough estimate of the MS's speed and distance can be obtained. We also know that the speed and distance will not exceed certain values. Even under extreme circumstances, the distance and angular shifts between consecutive snapshots should not exceed the limiting values. By utilizing the above a priori information, the TOA and DOA estimates can be corrected into a reasonable region.

When the MS is in soft handover, two or more BSs will serve the MS simultaneously. All of the serving BSs can make their own TOA and DOA measurements and locate the MS. Several algorithms can be used to locate the MS. For example, the mean value of each estimated position, the weighted mean of the estimated positions or the position obtained by the BS which has the best signal quality etc.

5、Experimental Results for Subscriber Geolocation

In this paper, we use a vector channel sounder to measure the actual channel characteristics from which the TOAs and DOAs of the MS are derived.

In the first experiment the measurement environment is along the corridors of the fifth floor of the Electrical Engineering Department building. The layout of the fifth floor is shown in Fig.1. The receiver, denoted by RX, is in a fixed position and the transmitters, denoted by dots, are moved from one position to another for each measurement. All 30 positions are distributed on three different routes. The cumulative distribution function of the location errors for different bandwidths are shown in Fig.2.

These days people frequently use mobile phones inside buildings. In this scenario, signals have to penetrate through the building. The MS's internal GPS will not work well because the signal strength received from GPS will be very weak in indoor environments. Therefore, the geolocation problem with the MS being indoors is more important and has attracted more attention. It is usually assumed that waves penetrating through buildings will suffer high attenuation due to walls and reflections from walls, floors and ceilings etc. This may cause geolocation to be difficult and complicated. In this subsection we will demonstrate geolocation results of an MS in typical indoor environments.

The layout of the measurement environment is shown in Fig.3(a), which is part of the campus of National Taiwan University. The BS, marked by RX, is placed on the 13th floor of the Center for Condensed Material Science (CCMS) Building. The transmitter, or MS, is moving along the corridors of different floors in two different buildings far away from the BS. One building is the College of Engineering (CE) and the other is the Electrical Engineering (EE) Department. The MS moves along corridors of the 3rd-7th floors of the CE building and corridors of the 3rd-5th floor of the EE building. Distances between the BS and the MSs are over 500m.

The location results obtained by single snapshots with BW=7.5MHz are shown in Fig.4(b). It is seen that the location performance is very poor because the signal level at many snapshots are close to the noise floor.

We then use the statistical methods to reduce the location error. We drop all snapshots with path loss greater than 90dB. The location results using statistical method 5 for BW= 7.5Mhz are shown in Fig.3(c). It is seen that the estimated locations are almost all confined inside the building.

In the third experiment we use two base stations to locate the MS. Shown in Fig.4(a) is a map of the section of the National Taiwan University campus used to perform the experiment. The receiving array of the vector channel sounder is first placed on the rooftop of the CE building. The transmitter is moved along Route 1 and Route 2 and measurement data is recorded. Then the receiver is moved to the 13th floor of the CCMS building. The transmitter is also moved along the same routes. Although the measurements are conducted at different times, we process the recorded data at the same time as if two BSs receive the transmitting signals simultaneously.

We use the downward search to estimate TOA and the nonuniform array algorithm to estimate DOA. The location error CDFs for different bandwidths without and with selection are shown in Fig.5 (b),(c) and Fig.5(d),(e) respectively. For route 1 and route 2, it is seen that 80% of location errors are below 55m and 86m respectively for a single BS when the BW is 60MHz. The 80% location error is reduced to 40m and 55m after selection.

6. Conclusion

In this paper, we have achieved several important results. We have proposed a downward search method to estimate the TOA of the direct path in multipath environment. We have analyzed the array signal properties in multipath environment. We have proposed the DOA estimation method using a non-uniform array. Considering channel properties and subscriber motion, we have proposed new methods based on multiple snapshots to locate subscriber position. We have found that geolocation performance can be improved significantly. We have also proposed location methods for multiple base stations. Experiments in several typical environments including the pico-cell environment, signal penetrating into buildings, and macro-cell environments were conducted. Employing the proposed methods, we demonstrated location results and verified the effectiveness of our geolocation techniques.

Reference

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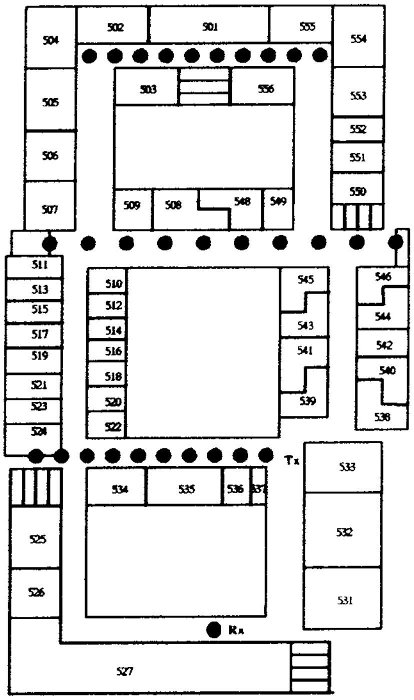

Fig.1

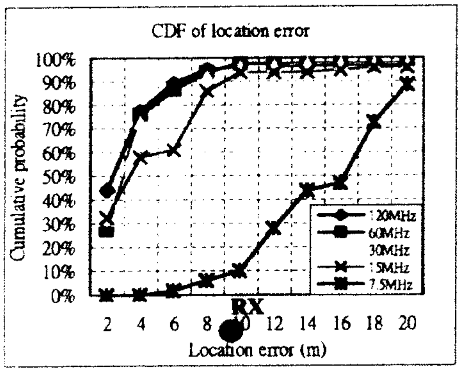

Fig.2

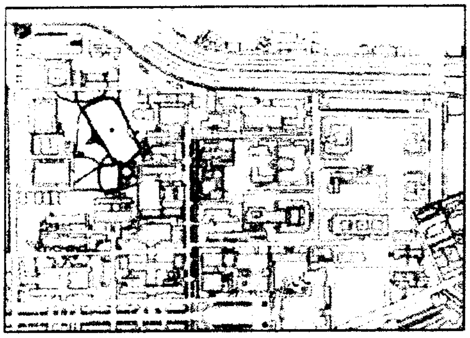

Fig.3(a)

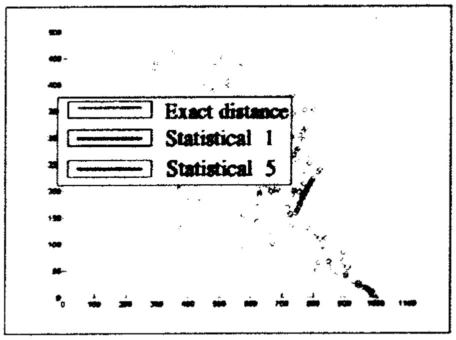

Fig.3(b)

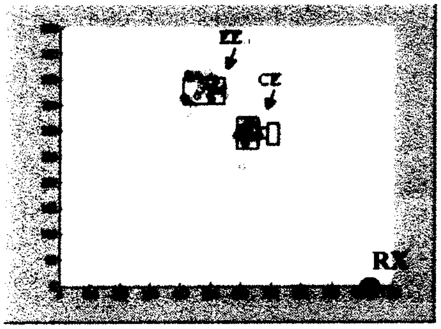

Fig3.(c)

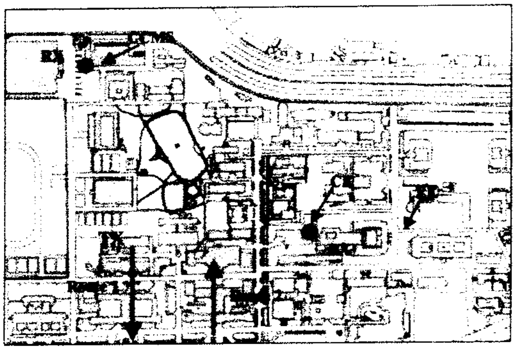

Fig.4(a)

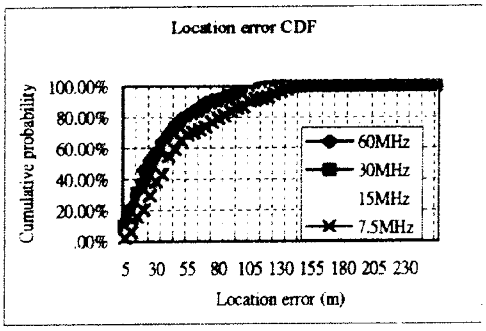

Fig.4(b)

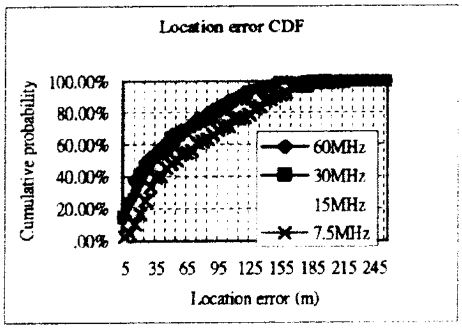

Fig.4(c)