A Simple and Efficient Method of Multipath Rejection (MPR) in Multipath Fading Channels for Location Estimations

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***Abstract* — This paper proposes and evaluates a simple and efficient method to mitigate the positioning error caused by Multipath fading channels. Using geometric properties of the correlated received signals and Monte Carlo simulations, a lookup table has been developed to correct the TDOA estimation error. The performance of this multipath rejection (MPR) method has been evaluated for 3GPP wireless network standards. Simulation results show that the proposed method reduces the TDOA estimation error significantly and therefore improves the accuracy of mobile position estimation.**

***Index Terms* — Position estimation, TDOA, Power Delay Drofile, MPR.**

I. INTRODUCTION

With the increase of location based applications, location finding techniques are becoming more important. Meeting required accuracy in location estimation, a variety of applications and location based services such as E-911, location sensitive billing, vehicle fleet management and intelligent transportation systems will be feasible [1].

The unknown position of the mobile station should be determined based on the measurements of signals transmitted between mobile stations (MS) and base stations (BS). There are different ways to utilize these signals for positioning purposes, but the most popular estimation method for accurate positioning is Time Difference Of Arrival (TDOA) [2]. TDOA relies on the processing of time difference of arrivals of different base station signals in a mobile receiver. Each TDOA determines that the MS should lie on a hyperbolic with constant range difference between the two transmitting base stations and with two or more TDOA measurements, the MS position can be calculated.

The basic problem of TDOA based positioning techniques is the accurate estimation of TDOA of arriving signals [3]. In cellular mobile networks, multipath, non-line-of-sight (NLOS) and multiple access interference (in CDMA-based network) are often the main sources of errors in position estimation techniques. Of these error sources perhaps the more critical ones are NLOS and multipath problems [4].

Multipath rejection (MPR) is used to improve the accuracy of TDOA estimates. MPR techniques attempt to detect secondary correlator peaks that occur before the highest peak of the correlator. This condition happens in multipath fading environments where the LOS path is detectable but is not the strongest path [5].

Supper resolution techniques are basically developed for spectral estimations. They usually use eigenvalue decomposition methods to extract spectral properties of signals [6]. These techniques also have been widely used for Direction Of Arrival estimations [7]. Recent works on supper resolution spectral estimation techniques have adopt them for time domain analysis of different applications. These applications include time of arrival estimation for positioning purposes. Among different supper resolution techniques, MUltiple SIgnal Classification (MUSIC) method is the most popular one in TDOA estimation [5]-[8]. Although these methods are accurate, they need strong processors, which make them impractical and/or non-economical for use in simple mobile handsets.

This paper first produces a correction factor look up table using the simple geometric measurement of the correlator output signal (measured delay profile) and then it uses this lookup table to improve the TDOA estimation accuracy and decrease the positioning error.

The organization of this paper is as follows. Section II explains the system model. Section III proposes the new MPR method and Section IV will discuss how the correction factor lookup table is developed and why we can trust on its results. Section V presents the position estimation results with new MPR method and compares them with other methods. And finally Section VI presents conclusions.

II. SYSTEM MODEL

The system model considered in this work consists of seven hexagonal cells. The task of positioning a mobile station is done by the same mobile station. This means that TDOA measurements and positioning calculations should be made at the mobile station. Therefore, the downlink signal model is required. The down link is based on 3GPP standards for Universal Mobile Telecommunication System (UMTS) [9].

In UMTS, mobile stations use the Common PIlot Channel signals (CPICH) for the purpose of TDOA estimation. The base station assigns 15% to 25% of its total composite power for transmission of CPICH, yet some mobile stations may be unable to hear (or receive) the CPICH from some neighboring base stations. This is especially true if a mobile station is close to its serving base station. In this case, the service base station makes much interference so that neighboring base stations cannot be heard. This is called hearability problem.

To overcome the hearability problem, Time Aligned Idle Period Downlink (TA-IPDL) method has been proposed in [10]. In TA-IPDL method all base stations in an approximately aligned period, either entirely cease their transmissions or only transmit the CPICH signal. During this idle period, mobiles listen to neighboring base stations and make their signal arrival time measurements.

In UMTS, the common pilot signal (or CPICH) is a predetermined sequence that is first multiplied by a complex scrambling code and is then multiplied by a channelization code. These channelization codes are Orthogonal Variable Spreading Factor (OVSF) codes, and hence, the channelization code used in each cell is unique. The resulted signal, after multiplication by channelization code, is QPSK modulated. This QPSK signal is filtered with a root raised cosine shaping filter with a roll off factor of 0.72, although the standard roll off factor for UMTS is 0.22. Choosing a larger roll off factor for CPICH causes an increase in the transmitted signal bandwidth and a decrease in the sidelobs of PN sequence autocorrelation function [9]. The output of the shaping filter passes through a multipath fading channel and sum of all these CPICH signals, transmitted by base stations, are received by a MS receiver.

In CDMA systems, the accuracy of TDOA estimation is limited to the chip rate and upsampling in the receiver. In this paper, MS receiver uses an upsampling of 8 times to increase its TDOA estimation accuracy. In this case and with an ideal channel, the positioning accuracy will be limited to 9.7 meters. The IPDL frequency is considered to be 10 Hz and position estimation will be updated every half a second.

III. Proposed Multipath Rejection Method

Paying attention to the geometric properties of the receiver correlator output leads to a very simple idea. Is it possible to use slope and value of the first detectable peak (the first peak, witch has a value greater than threshold) to develop a lookup table for improving the TDOA estimation accuracy? Fig.1 can help to demonstrate the idea more clearly. As it is shown, two different delay profiles measured by the correlator have been compared. Both of them are delay profiles for a single fading channel. The solid curve is obtained when the LOS path is a dominant path but the dashed one is when the LOS path is faded and other NLOS paths are dominant.

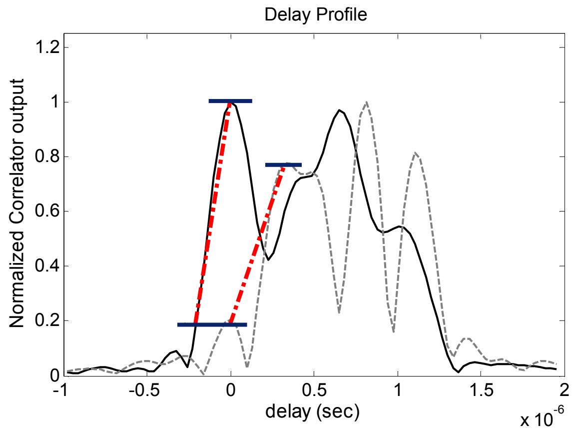

Fig. 1. Estimated delay profile for a multipath fading channel. Solid curve is obtained when LOS is the dominant path and dashed curve is obtained when fading has occurred and LOS is not the dominant path.

The point in here is that the time of arrival (TOA) for both delay power profiles is the same because both of them are for the same fading channel. However, if we choose the time arrival of the first peak whose amplitude is larger than a threshold as an estimate for TOA, clearly we are introducing a large error to the final position estimation. This can be seen from the large time difference of the first peaks, which are marked in Fig.1. So, using the time of arrival of the first peak can be erroneous. To overcome the source of this error, we may pay attention to other properties of the delay power profile. As can be seen in this figure, there are two distinct features in these two delay profiles. The first one is the amplitude of the first detectable peak, and the second one is the left side slope of that detectable peak. These two parameters may be used as the entries of a look up table, which provides the required correction factor for the position estimation of a mobile station.

To develop a lookup table, giving the required correction factor with two entries of a peak value and the left side slope of the peak value, first a large data base of delay profiles for the service area should be provided. Once the data base has been provided, the delay profiles should be normalized, then for each delay profile we should find the first peak that has a value greater than a threshold. After extracting the first peak, its value and left side slope can be stored. To calculate the left side slope we should use two points; first one is the detected peak and the second one is the point which its normalized value is equal to a constant value less than the detecting threshold (See Fig.1). The choice of this constant value depends on the value of the roll off factor and noise power in the system. A larger value for the roll off factor and/or the noise power necessitates choosing a larger value for this constant point.

To calculate the correction factor we should also have the information about the real TOA for each delay profile. The difference between real TOA and estimated TOA is the third point that should be stored in our data

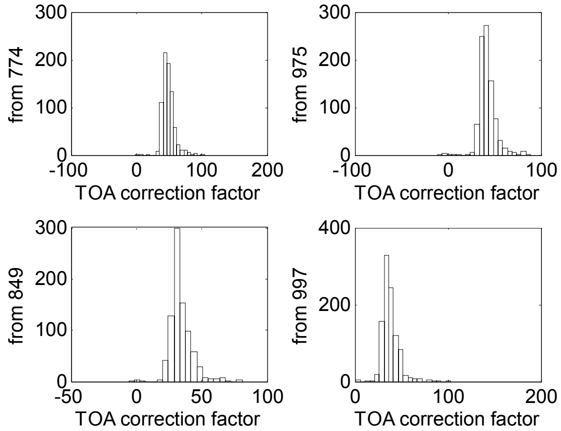

Fig. 2. Four sample probability histograms of collected data and measured improvement factor for a specific measured slope and maximum value

base. Now our data base is ready and we can use it to develop our TOA correction factor lookup table.

IV. Developing The Correction Factor Lookup Table

To develop the correction factor lookup table, we performed a Monte Carlo simulation and collected the results. We used 1000 random MS position and for each MS position we performed 50 independent measurements in 4 different SNR. For each random mobile position we choose multipath model from a set of 50 different multipath channels. All multipath channels contain the LOS path but the number of paths changes from 4 to 12. To collect the database, for each run, first we check if the peak value of the correlator output is greater than a threshold value. If the peak has reached its threshold (which means it can be used for positioning purpose), then we scale the output between 0 and 1, it is shown in Fig.1. To calculate the left side slope, we choose two points; the first peak which has a value greater than 0.4 and the first point, which its normalized value is 0.2 (See Fig.1). To find these points we should use an interpolation of the delay profile points. Delay factor is calculated by averaging the difference between the real and estimated TOA for each slope and peak value.

In Fig. 2, using our database, we have shown the correction factor probability histograms of the collected sample data of four random pairs of slope and peak values. As we can see, these probability histograms have small standard deviations around their mean values and this point leads us to choose the mean value as the TOA correction factor. The standard deviation here has an inverse relation to the uniqueness of the selected features. It means the less the standard deviation the more unique the selected features.

The final correction lookup table, developed based on the above method, is shown in Fig.3. In this figure the x and y axis are scaled values of slope and peak value and z axis is correction factor in samples. It can be seen that with the increase in max value and decrease in the measured slope, the correction factor has grater values.

V. Simulation Results

To demonstrate how effective the proposed MPR method is, we have simulated network model described in Section II., which is a Frequency Division Duplex (FDD) CDMA cellular system based on UMTS standards. MATLAB is used for the simulations. Each cell has six sectors and a the cell radius is considered to be 500 meters. Positioning measurements are performed only in one sector of the serving BS.

The model used for multipath fading channels has an average delay profile of 800 nsec and the effects of shadowing is modeled by a log-normal distribution with a standard deviation of $\sigma = 6\text{dB}$. To avoid hearability problem, we have used TA-IPDL method, which was described in Section II. To implement TA-IPDL, each BS will transmit its common pilot channel (CPICH) with a probability of 30% or will cease its transmission with a probability of 70%. The frequency of the IPDL is 10 Hz and the IPDL length has been chosen to be 2560 chips. For each simulation run, a random mobile position is chosen. During the IPDL, the mobile listens to the neighboring base stations in order to use their transmitted signals for positioning purpose. Position estimation is updated every half a second after 5 IPDL periods.

In order to Estimate the mobile position at least we need two TDOA measurements. If we had made exactly two TDOA measurements in our position updating interval, we should simply find the intersection of two hyperbolas [11]. If we had made more than two TDOA

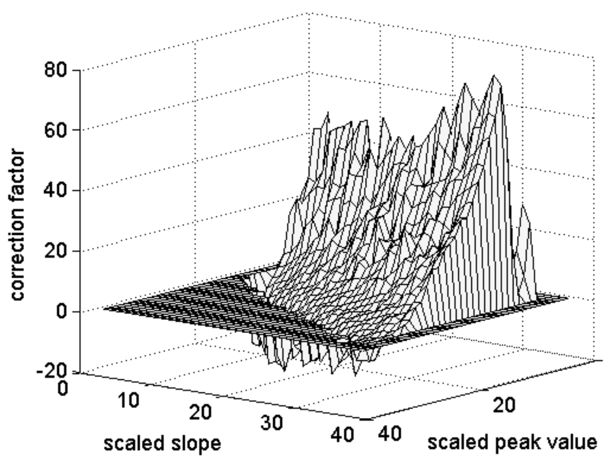

Fig. 3. Average correction factor Lookup table versus left side slope and value of the first detectable peak.

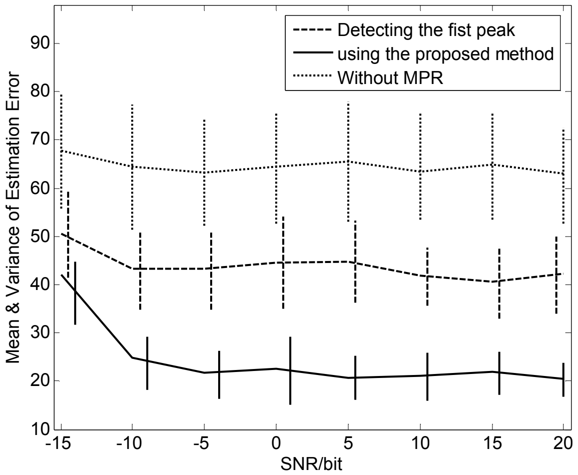

Fig. 4. Mean and variance of Circular Error using tree methods: the doted line considers the maximum of the received delay profile as TOA, the dashed line is when we extract the first local max and use it as TOA and the solid line is positioning accuracy using the proposed method

measurements, because of presence of noise and multipath, different hyperbolas will not meet each other at the same point. In this case we first find the intersection of each two of hyperbolas and then we choose the mean value as the mobile position. The cell and sector coordinates information have been also used to ignore unwanted or unacceptable results.

Fig.4 shows the positioning Simulation results. Doted line shows the positioning result when no MPR is used and TDOA is calculated using the strongest peak in the correlator output delay profile. The vertical lines show the standard deviation of the positioning error in different SNR. As it is shown, in fading environments even with the presence of a LOS path the positioning accuracy is not as good as it is expected. With an upsampling of 8 times, we expect a positioning accuracy better than 9.7 meters, but results show an average positioning error not better than 65 meters. It can be seen that even for large values of SNR/bit, improvement in the positioning is insignificant. Dashed line shows the results when the first detectable peak is extracted and considered as TOA and solid line shows the positioning error when TDOA is estimated using the new proposed method. It can be seen that the mean and standard deviation of the mobile position of the proposed method are, respectively, about 20 and 4 meters. As can be seen, there is a significant improvement in mean and standard deviation of final positioning error. Using the new MPR method, the effect of increasing the SNR/bit is still on the positioning accuracy is insignificant.

VI. CONCLUSIONS

We proposed a simple method to improve the TDOA estimation in CDMA mobile networks. The proposed method is based on this fact that there are some specific features of the estimated delay profile that can be extracted and used to improve the estimation of the mobile position. These features can be selected from the properties of the time or frequency domain of the received signal, but the point is uniqueness and simplicity of extraction of selected features. The proposed MPR method uses time domain geometric properties of received signal delay profile which can be extracted using a simple correlator. This method is easily implemented and the lookup table can be adopted for different propagation environments. One of the important properties of the proposed method is that there is no need to update our lookup table like some other techniques such as Database Correlation Methods [12]. The reason is that, this method exploits and uses the relations between different signal paths with different attenuations with geometric properties of received delay profile and hence it is less sensitive to the changes of the propagation environments.

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