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MINIMIZING THE ERROR TRACKING OF MOBILE TERMINALS BY KALMAN FILTERING

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Abstract: A method to track mobile terminals in a cellular communication network is presented. It uses the received field strength from the surrounding base stations. A subsequent Kalman filtering is used to minimize the tracking error.

Keywords: cellular networks, Kalman filtering, position tracking

1. INTRODUCTION

According with the E911 requirements in the near future cellular operators have to precisely locate their users’ terminals in order to allow efficient actions in case of emergency calls. Also, if the location of a mobile is known with good accuracy, additional services can be offered to subscribers. Knowing the position of vehicles in a transport system, e.g., allows for an efficient planning and use of resources. Also, in case of a car breakdown or an emergency call, automatic monitoring of the position would be of great help for immediate assistance.

Various techniques are proposed in the literature with the ultimate goal of obtaining a good compromise between the accuracy of the mobile terminal positioning and the costs involved in implementing them. The present paper presents in section II an overview of different position location methods that could be used to position a mobile. In section III we focus on signal strength measurements and in section IV and V a calculation procedure and computer simulation are presented, respectively.

2. OVERVIEW OF POSITIONING METHODS

There are a number of different radio frequency based techniques that can be used for wireless position location (Reza, 2000). The techniques can be broadly classified into two categories: a first one based on modified handsets and the second one based on unmodified handsets.

2.1. Modified handset techniques

Modified handset techniques are easier to implement and more accurate in determining a mobile location. The GPS-based, mobile-assisted Time of Arrival (TOA) and mobile-assisted Time Difference of Arrival (TDOA) techniques fall into this category.

The GPS-based techniques require the installation of a GPS receiver in the handset and the transmission of the received GPS data on the uplink to the base station (BS) for further processing and position determination. The drawbacks of this technique include an increase in the size and weight of the handsets and an additional drain of the batteries in the mobile terminal.

In the mobile assisted TOA technique, the handset stamps the current time on any outgoing signal in the reverse channel. The base station determines the time required by the signal propagation to reach the base station and from that it determines the distance between the base station and the mobile unit. If at least three base stations take part in this process then the triangulation method can be used to determine the mobile position.

The modified handset TDOA method proposed for the CDMA systems uses the pilot tones transmitted by different base stations. The mobile measures the arrival time differences of at least three pilot tones. This gives rise to hyperbolic equations and by intersecting these hyperbolas, an estimation of the mobile unit's position can be found.

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2.2. Unmodified handset techniques

An unmodified handset solution requires that all the modifications be made at the network level (base stations and the switching centers), thus allowing for the positioning of the existing terminal units, too. Prominent options in this category include: Angle of Arrival (AOA), Time of Arrival (TOA) or Direction of Arrival (DOA), and Time Difference of Arrival (TDOA) techniques. It is also possible to combine two or more of these techniques to achieve a more accurate position location. Combined methods are commonly known as Hybrid Techniques.

The AOA method uses antenna arrays to estimate the signal direction of arrival. A single AOA measurement constrains the source along a line. The position of the signal source can be located at the intersection of two lines if two DOA estimates are available from two separate antennas.

In unmodified handset TOA technique base station transmits a particular command or instruction signal to the user and asks it to respond to that command signal. The total time elapsed between the transmission of the command signal and the reception of the acknowledgement one is recorded at the base station. The measured round trip delay includes the propagation delay of the signal traveling in both directions, plus a processing delay and a response delay of the mobile handset. If two additional base stations take part in this process then the triangulation method can be used to find the position of the user at the intersection of the circles determined by the time delay measurements.

The unmodified handset TDOA has a relative advantage over TOA in the sense that the TDOA does not require any time reference for determining the round trip delay. The TDOA technique estimates the time difference of arrival of the signal from the source at multiple base stations. This time difference gives rise to a hyperbola with the two receivers as foci. If another base station takes part in this process another hyperbola is defined and the intersection of the hyperbolas results in the position estimate of the source.

Both modified and unmodified handset-based techniques require supplementary parameters and specific actions to measure them as compared with the present operation of a cellular network. The proposed method tries to eliminate this requirements and to use instead a parameter already measured by the mobile terminal in all the present cellular networks: the received power level. As this level is not influenced only by the separation distance between the mobile terminal and a base station, ways should be found to eliminate the influence of the other factors. Our simulation results show that Kalman filtering is an efficient tool for this task.

3. ELECTROMAGNETIC WAVE PROPAGATION MODEL

The signal strength of an electromagnetic wave received by a moving vehicle in a cellular environment depends mainly on the transmitted power and separation distance between the receiver and the transmitter and is influenced by multiple environmental factors. The received power can be written as:

$$(1)\quad P_r = K\frac{P_t}{d^n}$$

where P_t is the transmitted power, d is the distance in Km, and n is a power factor, while K models the rest of all other factors that affect the received power. The power factor n is equal to 2 in free space, but ranges from 3 to 6 in urban or suburban areas.

Taking the logarithms on both sides of (1) one obtains:

$$(2)\quad 10\log(P_r) = 10\log K + 10\log P_t - 10\cdot n\cdot \log d$$

and this equation describes a straight line in a Cartesian coordinate system ($\log(d)$, $\log(P_r)$). The combined first two terms on the right side of (2) defines the line *intercept point* and the term $10\cdot n$ is its slope, denoted in the context as the *path loss slope*. The line intercept point gives the received power level at 1 Km distance from the transmitter.

Noting that the environment influence depends on the receiver location, that is K is a function of the distance d, one should conclude that (2) remains a straight line only on average values. There are local deviations of the received power from the average value predicted by (2) and this is the *fading*. Computing a mobile terminal position based on the signal strength it receives from different base stations with precisely known positions yields mobile terminal positioning with errors due to the local fading. Efforts should be made to keep these errors smaller than some preset limits.

4. ALGORITHM PRINCIPLE

Our proposed method aims at decreasing the mobile terminal position tracking error while maintaining the associated computing effort at reasonable levels and uses two approaches recently presented in the literature (Hellebrandt and Mathar, 1999; Song, 1994; Reza, 2000; Willassen, 1998).

Based on the known position, the transmitted power, and the antenna radiation pattern of a base station one can predict with high accuracy the received power in a given location of the service area. For a measured received power the mobile terminal could locate itself on a specific level contour around the base station. Using at least three base stations the mobile terminal could find its position in the service area with an error given by the propagation prediction accuracy (Fig. 1).

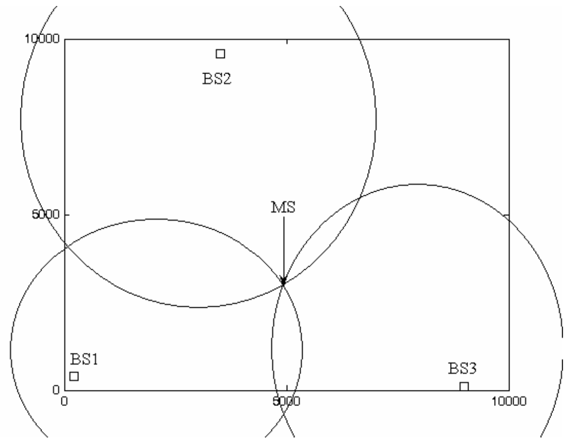

Fig.1. Positioning error in the absence of fading

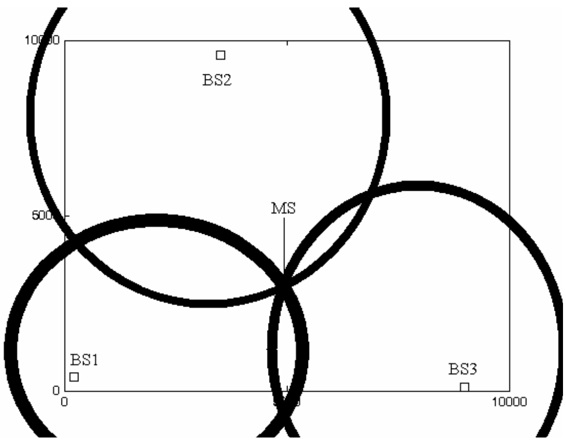

Fig.2. Positioning error in the presence of fading

The positioning error is increased because of the fading and this error component is, by far, the most important one (Fig. 2). The Kalman filtering greatly reduces this error component by correlating a new position estimate with its previous value by noting that for a given time step Δt in position evaluation the new position could not differ by more than $v \cdot \Delta t$ from the previous one, v being the estimated mobile speed. The Kalman algorithm yields an estimate of the speed at every iteration step. The position estimate is the one that minimizes the sum of differences (in absolute values) between the measured received power from at least three base stations and its predicted value in the estimated position.

In order to maintain the computing effort at a minimum the power contour levels around a base station are discretized and so the error minimization problem consists simply in evaluating the sum of errors in a finite number of points around an initial estimated position value.

5. COMPUTER IMPLEMENTATION AND RESULTS

The proposed method was implemented in a Matlab environment for an area of 10x10 Km^2 with three base stations. The Kalman filtering is implemented as in (Song, 1994). The mobile terminal moves with constant speed on a seven segment trajectory. The tracking error is evaluated for different fading levels and its values are presented in Table I together with the ones obtained simply by triangulation from the measured received power levels.

Table 1 Tracking error as a function of area gridding step and fading level

Fading level	Area gridding step (m) 50		100		150		200	
	No filtering	*Kalman filtering*	No filtering	*Kalman Filtering*	No Filtering	*Kalman filtering*	No filtering	*Kalman filtering*
0	18	*60*	37	*68*	71	*82*	71	*68*
0.5	64	*66*	68	*65*	91	*72*	91	*65*
1	121	*77*	121	*73*	131	*75*	131	*78*
2	227	*89*	244	*94*	230	*99*	252	*104*

One could see from the simulation results presented in the Table I that the positioning error remains under 100 m for all the fading values even for a gridding step of 200 m. Also, the error is not decreased by the filtering process only in the unrealistic case of the complete absence of fading (first line in the Table I).

For real situations where fading is present the Kalman filtering greatly reduces the position tracking error. The error after filtering is not significantly influenced by the area gridding step, a major advantage for the associated computing effort as it allows a coarser gridding without an increased error penalty.

An example of a mobile terminal estimated trajectory is presented in Fig. 3. The dots in the figure represent the discrete points in the area gridding mesh obtained as position estimates based solely on the received power level and its comparison with the power level contours around each of the three base stations. The solid line is the seven segment trajectory the mobile terminal moves with a constant value of 100 Km/h, while the dashed line is its estimated trajectory after Kalman filtering. The positioning error is greater at trajectory corners and it is clearly smaller in real situations as a mobile terminal could not abruptly change its moving direction as the ideal trajectory suggests.

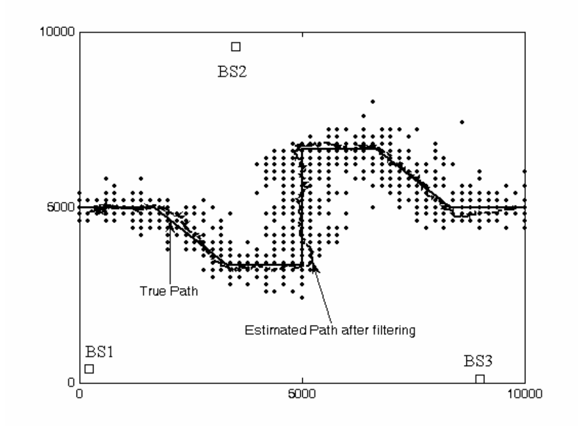

Fig.3. Tracking error for a seven segment trajectory

6. CONCLUSIONS

The paper overviews the location techniques used in cellular networks and proposes an algorithm to fulfill this task which is not costly to implement and precise enough. Its efficiency is tested by computer simulation. A subsequent Kalman filtering greatly reduces the positioning errors.

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