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User Localization in UMTS by Spectrum Estimation Method

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***Abstract*—Geo-location techniques have recently become more important since Location Aware Wireless Systems are spreading all over the world and Location Based Services have now become a kind of necessity for users. TOA and TDOA are the most useful methods of geo-locating but the resolution of location estimation is dependent on the accuracy of TOA/TDOA estimation of received signals. The accuracy of TOA/TDOA estimation in usual methods such as correlation in different types of propagation environment is not precise enough especially when there is no line of sight signal between transmitter and receiver or the LOS signal is not the strongest received signal compared with the others. Therefore, in these cases it is necessary to find and apply methods to distinguish the LOS signal from other signals and extract the TOA of LOS signal so that reasonable resolution for the estimation process can be achieved. In this paper one of the spectrum estimation methods called MUSIC is applied in time domain and its efficiency and ability in extracting TOA for received signals will be shown.**

***Keywords*— CRLB; ML MUSIC; TDOA; TOA; UMTS**

I. INTRODUCTION

Enormous developing of wireless communication systems and cellular networks along with increasing demands for location based services has made policy makers of wireless networks to improve and develop positioning techniques and algorithms in such networks. In addition FCC regulations such as E-911 and emergency aids help to make this process faster and faster [1-3]. These emergency aids can be reached to users by ALI[1]. Therefore, finding an efficient method or algorithm that more accurate and cheaper as well as easier to implement on hardware is a must. There are two main methods for user Geo-location [4, 5]. The first one helps the use of GPS devices and is called GPS aided and the second utilizes the signal propagating in the cellular networks. Each has its own advantages and disadvantages, for example for indoor Geo-location, GPS cannot be useful. Replacing the role of satellites in the GPS service by that of base stations, the second method appears. This method uses the signals exist inherently in underlying communication network and tries to estimate user position by observing parameters that are dependent to location. This method can furthermore be divided in two main approaches; mobile based and network based. The difference is the role of mobile station and base station (BTS) in measuring the signals and estimating/calculating the location. In this paper, we focus on mobile-based techniques. The best way to determine a location of the users in a cellular network is to use signals between the BTS and mobile stations in order to extract location information of the user. This method have been vastly used in wireless sensor networks [6-8] and cognitive radios [9, 10]. To do this there are a lot of signal parameters having location information such as RSS[2], AOA[3] etc. However, the best candidate is TOA[4] since the least changes in the network structure is needed and it has less error compared with other methods such as AOA [6, 11, 12]. Note that renewal theory framework is one method of obtaining different metrics in systems using signals transmitted in the communication networks [11-14]. In this paper, a time application of a spectrum estimation method is introduced as an efficient method for geo-locating of users in a UMTS system. This paper includes four sections. Section II explains the MUSIC[5] algorithm and the way that it has been applied in time domain to extract time information of received signals especially LOS[6] signal is shown. Section III describes simulation process for UMTS cellular network and in section IV the simulation results and conclusions is shown.

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II. MUSIC ALGORITHM

MUSIC algorithm is a spectrum estimation method that is described below. To understand how it is applied in the time domain first it is necessary to explain it in the frequency domain. Suppose the received signal, $u(n)$, consists of L uncorrelated sinusoidal signals added with zero mean white noise in this way:

$$u(n) = \sum_{l=1}^{L} \alpha_l e^{j\omega_l n} + z(n) \tag{1}$$

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[1] Automatic Location Identification

[2] -Received signal strength

[3] -Angle of arrival

[4] Time of Arrival

[5] Multiple Signal Classification

[6] Line Of Sight

In which $z(n)$ is additive white noise with zero mean and variance σ^2 . The goal of algorithm is to estimate the frequencies of the signal. Let R be the (M+1) by (M+1) ensemble averaged correlation matrix of the signal. This matrix can be written as below:

$$\mathbf{R} = \mathbf{SDS}^H + \sigma^2 \mathbf{I} \tag{2}$$

Where H indicates Hermitian transpose and I is the (M+1) by (M+1) identity matrix. S is an (M+1) by L matrix of the form and is called the frequency matrix.

$$\mathbf{S} = \left[\mathbf{s}_1, \mathbf{s}_2, \ldots, \mathbf{s}_L \right] = \begin{bmatrix} 1 & 1 & \cdots & 1 \\ e^{-j\omega_1} & e^{-j\omega_2} & \cdots & e^{-j\omega_L} \\ e^{-j2\omega_1} & e^{-j2\omega_2} & \cdots & e^{-j2\omega_L} \\ \vdots & \vdots & \ddots & \vdots \\ e^{-jM\omega_1} & e^{-jM\omega_1} & \cdots & e^{-jM\omega_L} \end{bmatrix} \tag{3}$$

D is the correlation matrix of the sinusoids and therefore of dimension L by L. Since the sinusoids are assumed to be uncorrelated, D is diagonal, nonsingular, and of rank L [6,10].This method is an eigenvalue based algorithm, so let the eigenvalues of R be $\lambda_1 \geq \lambda_2 \geq \ldots \geq \lambda_{M+1}$ written in an increasing order so are the eigenvalues of matrix $\mathbf{SDS}^H$ ($v_1 \geq v_2 \geq \ldots \geq v_{M+1}$). If the L signals in the S have different frequencies, columns of matrix S will be linear independent to each other thus the $(M+1-L)$ least Eigen values of matrix $\mathbf{SDS}^H$ will become zero. Considering Eq. (2) it can be written as:

$$\lambda_i = \begin{cases} v_i + \sigma^2 & i = 1, 2, \ldots, L \\ \sigma^2 & i = L+1, \ldots, M+1 \end{cases} \tag{4}$$

According to Eq.(4), the eigenvalues may be partitioned into two sets or subspaces, those corresponding to the signals and those that correspond to noise. The corresponding

Eigen vectors may be similarly partitioned. If $\mathbf{q}_1, \mathbf{q}_2, \ldots, \mathbf{q}_{M+1}$ are the eigenvectors of matrix R then:

$$\begin{aligned} &\mathbf{Rq}_i = \sigma^2 \mathbf{q}_i, && i = L+1, \ldots, M+1 \\ &(\mathbf{R} - \sigma^2 \mathbf{I})\mathbf{q}_i = 0 && i = L+1, \ldots, M+1 \end{aligned} \tag{5}$$

According to Eqs. (2) and (5) the following equation can be obtained:

$$\mathbf{SDS}^H \mathbf{q}_i = 0 \quad i = L+1, \ldots, M+1 \tag{6}$$

Since the columns of matrix S are linear independent and D is also diagonal, Eq. (6) can be retrieved as:

$$\mathbf{S}^H \mathbf{q}_i = 0 \quad i = L+1, \ldots, M+1 \tag{7}$$

Hence, MUSIC is looking for the frequencies that are in the signal plus noise subspace and also are orthogonal to noise subspace. Now it is easy to understand Time Estimation with MUSIC. The main goal of explaining MUSIC in this paper is to use it for TOA/TDOA estimation for geolocation. To explain it, first consider a mathematic model for multipath channel, the impulse response can be shown as:

$$h(t) = \sum_{k=0}^{L_p-1} \alpha_k \delta(t - \tau_k) \tag{8}$$

In which L_p is the number of path in channel and the coefficient α_k has both real and imaginary parts (complex number) to determine attenuation and phase distortion for the kth path and τ_k is the time delay of kth path, thus the transmitted signal after passing through the channel can be written as:

$$\begin{aligned} &y(t) = s(t) * h(t) \\ &y(t) = s(t) * \left\{ \sum_{k=0}^{L_p-1} \alpha_k \delta(t - \tau_k) \right\} \\ &y(t) = \sum_{k=0}^{L_p-1} \alpha_k s(t - \tau_k) \end{aligned} \tag{9}$$

This received signal at the receiver then will pass through the correlation receiver (matched filter), so:

$$\begin{aligned} &y_r(t) = s(t) * y(t) \\ &y_r(t) = s(t) * \left\{ \sum_{k=0}^{L_p-1} \alpha_k s(t - \tau_k) \right\} = \sum_{k=0}^{L_p-1} \alpha_k r_{ss}(t - \tau_k) \end{aligned} \tag{10}$$

In the equation above, $y_r(t)$ is the signal output of the correlator and $r_{ss}(t - \tau_k)$ is an autocorrelation function of $s(t)$. Let write equation (10) in a frequency domain:

$$Y_r(f) = \sum_{k=0}^{L_p-1} \alpha_k R_{ss}(f) e^{-j2\pi f \tau_k} \tag{11}$$

And therefore:

$$\frac{Y_r(f)}{R_{ss}(f)} = \sum_{k=0}^{L_p-1} \alpha_k e^{-j2\pi f \tau_k} \qquad (12)$$

Note that Eq.(12) is similar to Eq. (1). If f and τ_k are replaced with each other, it means these two equations are dual to each other, one of them is in time domain and useful to extract frequency information and the other is in frequency domain and useful to extract time information (TOA), these two equations can be simply illustrated as follows:

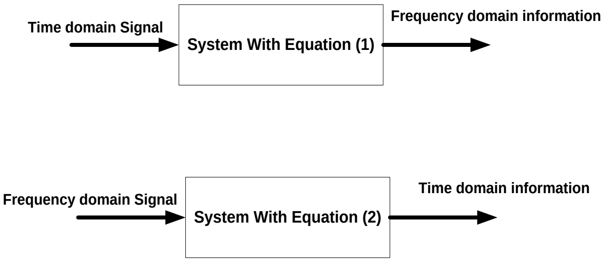

Fig. 1 MUSIC and its duality

So in order to estimate time of arrival of the received signals we should first divide signal spectrum of match filter output by Fourier transform of autocorrelation function of $s(t)$ and then give this information to the MUSIC algorithm to get TOAs.

III. SIMULATION RESULTS AND CONCLUSIONS

Fig. 2 describes the simulation algorithm and Fig. 3 illustrates the network structure. TA_IPDL is used to select active BTSs [5,9]. Three items should be considered in the propagation path model:

1-propagation path loss and the shadowing effect 2-multipath fading 3-additive white Gaussian noise. The generalized HATA model is used to represent propagation loss. It is known as COST-231 and introduced by closed form equations described in [11,12] but propagation loss is not intuitively deterministic value, so in order to consider its random effect (called shadowing effect) we use equation below:

$$L_{dB} = \overline{L}_{dB} + X_{\sigma} \qquad (9)$$

In Eq. (5) X_{σ} is a Gaussian random variable with zero mean and variance σ^2 .The amount of σ^2 depends on propagation model, terrain and etc. $\overline{L_{dB}}$ is the average value of propagation loss calculated by mentioned model (COST-231).The AWGN noise (additive white Gaussian noise) is added to signal of each BTS and finally it passes through the Rayleigh fading channel with 4 paths and 80Hz Doppler frequency. Since all these measurements are done at a pilot channel of UMTS, we should use DS-CDMA signal in downlink (gold and OVSF codes for scrambling and channelization codes) and chip rate should be set to 3.84Mchip/s. Note that two steps pulse shaping (both at transmitter and receiver) of root-raised cosine filter with roll of factor 0.22 is also applied.

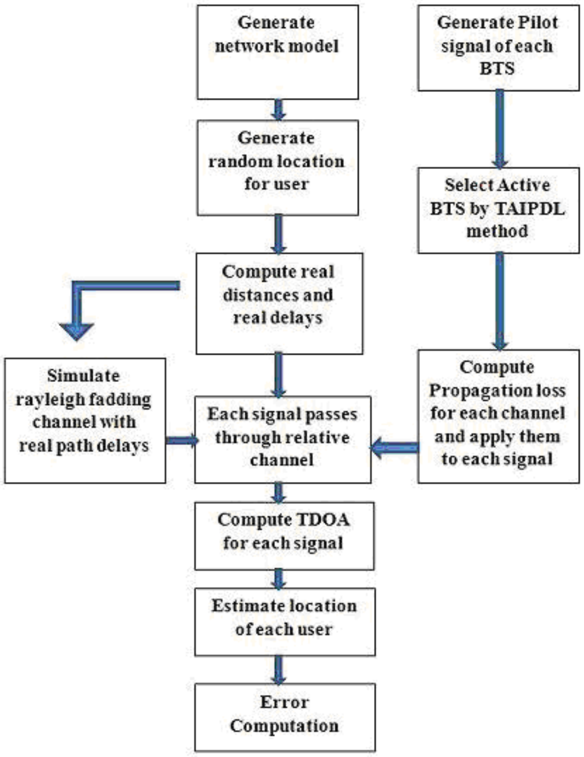

Fig. 2 Simulation process algorithm

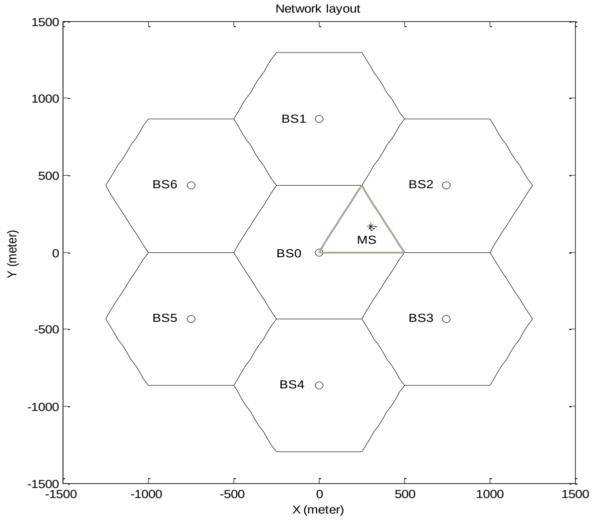

Fig. 3 Network structure

To justify the efficiency of MUSIC in extracting TOA/TDOA (as a supper-resolution method), it is compared to the most popular method called Correlation. Cumulative distribution function (CDF) of geolocation error is the best evaluation parameter to compare these two. This curve that is achieved by more than 1000 times running computer program (it is written in m file MATLAB and is linked to Simulink) is plotted in Fig. 4. It shows that MUSIC with a probability of 90% can reached to error of less than 42 meters while correlation at the same conditions can achieve to the radial error of 80 meters.

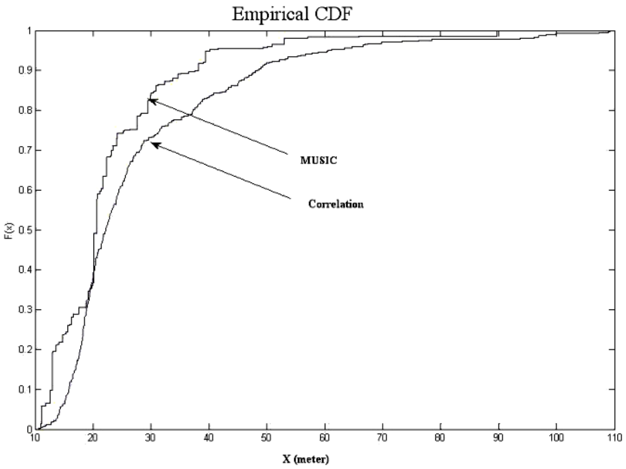

Fig.4 Cumulative density function of geolocation error

Fig. 5 shows when time delays of deferent paths (TOA/TDOA of deferent paths) are so closed to each other such as geolocation in indoor conditions, geo-location estimation by means of MUSIC becomes more efficient than the other one for instance when time deference of received signals for two nearest paths decreases from 500nsec to 10nsec, geolocation error for MUSIC increases from 23 meters to 57 meters while that for correlation method increases from 31 to 95 meters.

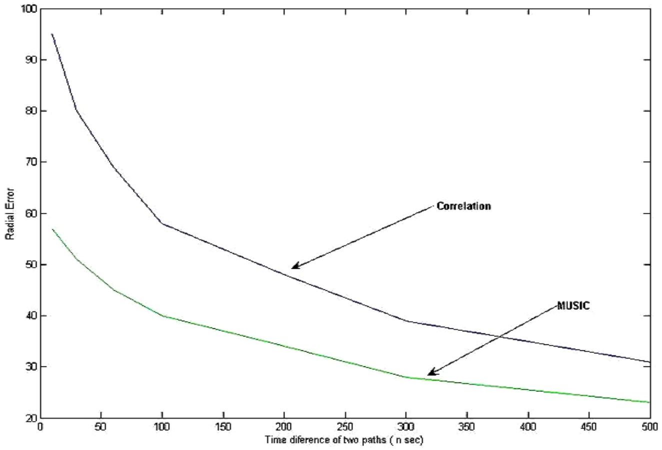

Fig.5 Error versus two nearest paths

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