

AN ELECTROMAGNETIC-TIME DELAY METHOD FOR DETERMINING THE POSITIONS AND VELOCITIES OF MOBILE STATIONS IN A GSM NETWORK

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1. INTRODUCTION

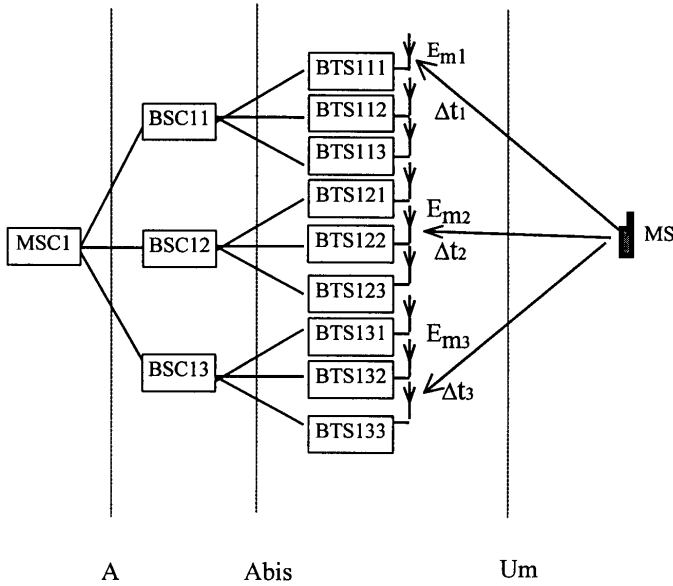
A reliable estimation of the positions and velocities of mobile stations (MSs) in a GSM network is useful for many reasons [1–5]. For GSM itself, the position and velocity estimator can help the network to dynamically optimize its resource assignment [7–10]. If the positions and velocities of the MSs are determined, large cells can be assigned to fast moving MSs and microcells to slow moving or temporarily static MSs. Thus handovers between cells would be reduced to a minimum number and service quality of the network would be enhanced, for a large number of handovers always consumes a lot of network resources and failures of handovers would lead to call-drops and data loss. Also,

with a knowledge of the positions, they can be prevented from registering into far cells instead of nearby cells. Such faulty registrations occur due to microwave reflections cases, and usually result in loss of connection between MS and BTS. Another usage of this estimator is to provide an efficient way to locate the accurate position of a MS bearer whenever he or she calls for an emergency help. In PSTN networks, as we know, an accurate position of a phone user can be obtained through a database. But in mobile networks, other methods should be applied to solve the problem.

Hellebrandt et al. [1] proposed a method for determining the position and velocity of mobiles by evaluating subsequent signal strength measurements to different base stations, which is an alternative approach to the more popular way of using the global position system (GPS). The GPS system requires that at least three satellites are not shadowed from the MS in order that usable GPS data can be received, which makes the system unreliable in urban areas with buildings or on roads surrounded by high buildings or mountains. Pent et al. [2] proposed a method to position the GSM mobile stations using absolute time delay measurements. Since the time delay measurement data provided by the GSM system is not accurate enough, the position accuracy achieved by this method is 150 m.

In this paper, we propose a hybrid method to determine the positions and velocities of MSs in a GSM network. This method can be implemented within the existing GSM standard without any additional hardware changes. The method operates at two levels. At a lower level, time delay method (TDM) is used to obtain coarse values for distances between a MS and three or more BTSs. At a higher level, field strength method (FSM) uses the coarse distance estimates obtained using TDM as initial values to obtain refined values for distances. The accurate position of a MS then can be determined by the refined distance values. Subsequently, the velocity of a MS can be obtained using the FSM estimates of the sequential positions of the MS. Least mean square (LMS) method is used to determine the refined distances in the FSM algorithm and to estimate the actual position of the MS from the refined distance estimates.

The paper is organized in the following manner. Section 2 describes three methods for determining the positions and velocities of the a MS. These three methods are namely, FSM, TDM, and a hybrid method. The hybrid method is a combination of the FSM and TDM. Section



Legend:

MSC: Mobile Switch Center

BSC: Base Station Controller

BTS: Base Transceiver

MS: Mobile Station

A: standard CSM interface between MSC and BSC

Abis: standard GSM interface between BSC and BTS

Um: standard GSM interface between BTS and MS, air interface

E_{mx} : field strength picked up by a BTS

Δt_x : microwave propagation time between the MS to a BTS

Figure 1. A simplified GSM system structure.

3 addresses some of the practical considerations related to the simulation experiments. In Section 4 simulation results are presented and discussed. Finally, our conclusions are given in Section 5.

2. METHODOLOGY

The problem addressed in this paper is in the context of the GSM system shown in Fig. 1. The signals emitted from a MS are picked up by many BTSs. It is required that the position and velocity of MS

be determined from a knowledge of the electric field strength E_{mx} at each BTS antenna, and the propagation time delay Δt_x for the signal to travel from MS to BTS. In the next two sections (Sections 2.1 and 2.2) we present two methods to estimate the position and velocity of a MS. In section 2.3, a hybrid method which combines the two methods is proposed to achieve a more accurate and versatile method.

2.1 Field Strength Method (FSM)

Measurement of the signal power at the BTS has been used for locating a MS in mobile networks[1–5]. An empirical formula to model the received power is used to estimate the MS position, with no reference to the antenna radiation pattern or the altitude differences between the MS and BTS [1]. To get a model closer to the true picture of the MS to BTS communication link, an electric field strength based technique is introduced in the following formulation. The estimator is based on the fundamental Maxwell equations [6] applied to the MS to BTS radiation link. This non-empirical model for the link equation may be used to characterize different types of antennas and to account for the different heights at which the MS and the BTS are placed with respect to the ground. All the simulation studies reported in this paper are for BTS of various heights above the ground. Another advantage of using the exact expression for the signal field strength is the possibility of including the effects of the MS velocity in the signal model by making the distance r between the MS and BTS dependent on the velocity of the MS. However in our simulation studies the modification of the power spectrum and signal field strength due to the velocity of the MS was not considered. The main objective here is to proposed and establish the possibility of using FSM and to improve the performance of FSM by using the time delay data available in the GSM system.

The geometry of the MS and a BTS positions is shown in Fig. 2(a). The BTS is at a height of z_j above the ground. The dipole antenna of a MS is represented by a finite length $z_2 - z_1$ of thin conductor. In order to get the equation for the electric field radiated by this omnidirectional antenna, the field strength equation for an infinitesimal current element, shown in Fig. 2(b), is obtained from

$$\mathbf{E}(R, t) = \frac{-\partial \mathbf{A}(R, t)}{\partial t} - \nabla \Phi(R, t) \quad (1)$$

where the vector potential $\mathbf{A}(R, t)$ for the infinitesimal current element

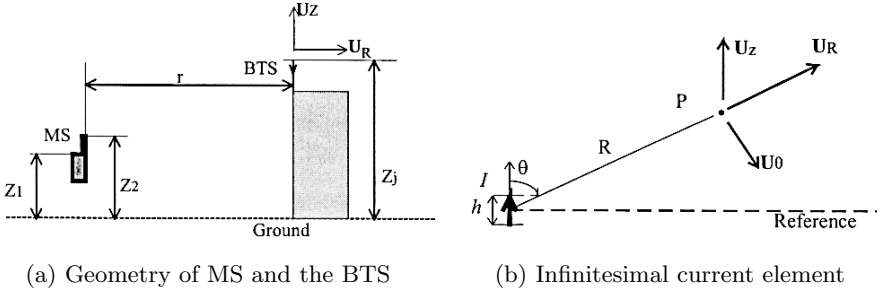


Figure 2. Antenna model.

Ih is given by

$$\mathbf{A}(R, t) = \mathbf{u}_z \frac{\mu_0 [I] h}{4\pi R} \quad (2)$$

where h is the length of the element and the $[I] = I(t - R/c)$, and c is the speed of light. The static potential $\Phi(R, t)$ is given by:

$$\frac{1}{c^2} \frac{\partial \Phi(R, t)}{\partial t} + \nabla \cdot \mathbf{A}(R, t) = 0 \quad (3)$$

From (3), $\Phi(R, t)$ is found as

$$\Phi(R, t) = -c^2 \int_0^t \nabla \cdot \mathbf{A}(R, \tau) d\tau - c^2 \int_{-\alpha}^0 \nabla \cdot \mathbf{A}(R, \tau) d\tau \quad (4)$$

In spherical coordinates, using spherical coordinate unit vectors $\mathbf{u}_R$ and $\mathbf{u}_\theta$, (2) may be expressed as

$$\mathbf{A} = \frac{\mu_0 [I]}{4\pi R} h (\mathbf{u}_R \cos \theta - \mathbf{u}_\theta \sin \theta) \quad (5)$$

Hence, taking the divergence of (5),

$$\nabla \cdot \mathbf{A}(R, t) = -\frac{\mu_0}{4\pi} \left(\frac{1}{Rc} \frac{d[I]}{dt} + \frac{[I]}{R^2} \right) h \cos \theta \quad (6)$$

Thus the first term on the right side of (4) may be obtained from (6):

$$\int_0^t \nabla \cdot \mathbf{A}(R, \tau) d\tau = -\frac{\mu_0}{4\pi} \left(\frac{[I]}{Rc} + \frac{[Q']}{R^2} \right) h \cos \theta \quad (7)$$

where

$$[Q'] = \int_0^t [I] d\tau \quad (8)$$

The second term in (4) is given by

$$\int_{-\alpha}^0 \nabla \cdot \mathbf{A}(R, \tau) d\tau = \frac{\mu_0}{4\pi} \frac{1}{R^2} Q_0 h \cos \theta \quad (9)$$

where Q_0 is the net electric charge deposited on the antenna element prior to the application of the current I . In most systems $Q_0 = 0$. Setting

$$[Q] = [Q'] + Q_0 \quad (10)$$

and from equations (4), (7), and (9), we have

$$\Phi(R, t) = \left(\frac{\mu_0}{\varepsilon_0} \right)^{1/2} \left(\frac{h \cos \theta}{4\pi R} \right) [I] + \left(\frac{h \cos \theta}{4\pi \varepsilon_0 R^2} \right) [Q] \quad (11)$$

Substituting (5) and (11) into (1) results in

$$\begin{aligned} \mathbf{E}(R, t) = & \mathbf{u}_R \frac{h \cos \theta}{4\pi} \left[\left(\frac{\mu_0}{\varepsilon_0} \right)^{1/2} \frac{2[I]}{R^2} + \frac{2[Q]}{\varepsilon_0 R^3} \right] \\ & + \mathbf{u}_\theta \left[\frac{h \sin \theta}{4\pi} \frac{\mu_0}{R} \frac{d[I]}{dt} + \left(\frac{\mu_0 [I]}{\varepsilon_0 R^2} \right)^{1/2} + \frac{[Q]}{\varepsilon_0 R^3} \right] \end{aligned} \quad (12)$$

In cylindrical coordinates, using cylindrical coordinate unit vectors $\mathbf{u}_r$ and $\mathbf{u}_z$, (12) may be written as

$$\begin{aligned} \mathbf{E}(r, z, t) = & \mathbf{u}_r \left[\frac{3h}{4\pi} \left(\frac{\mu_0}{\varepsilon_0} \right)^{1/2} \frac{rz}{(r^2 + z^2)^2} [I] + \frac{\mu_0 h}{4\pi} \frac{rz}{(r^2 + z^2)^{2.5}} \frac{d[I]}{dt} \right. \\ & \left. + \frac{3h}{4\pi \varepsilon_0} \frac{rz}{(r^2 + z^2)^{2.5}} [Q] \right] \\ & + \mathbf{u}_z \left[\frac{h}{4\pi} \left(\frac{\mu_0}{\varepsilon_0} \right)^{1/2} \frac{2z^2}{(r^2 + z^2)^2} - \frac{r^2}{(r^2 + z^2)^2} [I] \right. \\ & \left. - \frac{\mu_0 h}{4\pi} \frac{r^2}{(r^2 + z^2)^2} \frac{d[I]}{dt} \right. \\ & \left. + \frac{h}{4\pi \varepsilon_0} \left(\frac{z^2}{(r^2 + z^2)^{2.5}} - \frac{r^2}{(r^2 + z^2)^{2.5}} \right) [Q] \right] \end{aligned} \quad (13)$$

Using (13), we may derive an expression for the electric field radiated by a finite length of thin current carrying conductor. Before using (13) for the MS antenna, the equation is further simplified. From Fig. 2(b), it can be seen that the receiving antenna of BTS will only pick up the E_z , the vertical polarized signal. Ignoring the E_r and assuming that $[Q] = 0$, we get the simplified version of (13)

$$\mathbf{E}'(r, z, t) = \mathbf{u}_z \left[\frac{h}{4\pi} \left(\frac{\mu_0}{\varepsilon_0} \right)^{1/2} \frac{2z^2}{(r^2 + z^2)^2} - \frac{r^2}{(r^2 + z^2)^2} [I] - \frac{\mu_0 h}{4\pi} \frac{r^2}{(r^2 + z^2)^2} \frac{d[I]}{dt} \right] \quad (14)$$

Setting $h = dz$, and redefining variable z as $z = z_j - z$, $dz = -dz$ in (14) and integrating (14), we may obtain the electric field radiated by a finite length of thin wire. For such a wire antenna of a MS, integrating (14), we get

$$E(r, z, t) = \frac{\mu_0}{4\pi} \left[\frac{z_j - z_1}{\sqrt{r^2 + (z_j - z_1)^2}} - \frac{z_j - z_2}{\sqrt{r^2 + (z_j - z_2)^2}} \right] \frac{d[I]}{dt} \quad (15)$$

Now $[I]$ can be expressed by $Ae^{j\omega(t-R/c)}$ where A stands for the amplitude and ω for the frequency of the current. Thus,

$$\frac{d[I]}{dt} = j\omega A e^{j\omega(t-R/c)} \quad (16)$$

The signal processor operates only on the magnitude of the received electric field. Hence the necessary term for the model is

$$\left| \frac{d[I]}{dt} \right| = \omega A \quad (17)$$

Therefore (15) for the electric field strength can be expressed in the following form:

$$E(r, z) = E_0 \left[\frac{z_j - z_1}{\sqrt{r^2 + (z_j - z_1)^2}} - \frac{z_j - z_2}{\sqrt{r^2 + (z_j - z_2)^2}} \right] \quad (18)$$

where

$$E_0 = \frac{\mu_0 \omega A}{4\pi} = 10^{-7} \omega A \quad (19)$$

$$A = \sqrt{\frac{P}{R}} \quad (20)$$

In (20) P is the signal power radiated by the MS and R is the radiation resistance of the MS antenna.

To determine the two dimensional position and velocity of a MS, the field strengths from the MS received by a minimum of three BTSs are required. The theoretical electric field strengths received by the three BTSs are

$$\mathbf{E} = [E_1, E_2, E_3] \quad (21)$$

The measured electric field strengths received at BTSs for a single MS are

$$\mathbf{E}_m = [E_{m1}, E_{m2}, E_{m3}] = \alpha \mathbf{E} + \mathbf{n} \quad (22)$$

where the subscript m stands for measurements, α for signal fading and $\mathbf{n}$ for channel noise [12]. The model of the fading and noise channels are described in greater detail in Section 3.2.

The parameters used for the simulation experiments are listed in Table. 1.

Parameters	Description
$z_1 = 1.0 \text{ m}$	height of the lower part of the antenna of MS
$z_2 = z_1 + \lambda/2$	height of the upper part of the antenna of MS
$z_j = [z_{j1}, z_{j2}, z_{j3}]$	height of the antenna of the BTSs
$\omega = 2\pi \times 900 \text{ MHz}$	signal frequency in GSM system
$\lambda = 2\pi c/\omega$	signal wave length in GSM system
$c = 3.0 \times 10^8 \text{ m/s}$	light travel speed
A	Amplitude of the microwave signal
$P = 0.02 \sim 2W$	typical emission power of MS
$R = 73\Omega$	resistance of the antenna of MS
$\mathbf{PB} = [\mathbf{PB}_1, \mathbf{PB}_2, \mathbf{PB}_3]$	positions of the BTS m/s
$\mu_0 = 4\pi \times 10^{-7}$	Magnetoconductance of vaccum

Table 1. Parameters used in simulation.

Assume that the above parameters are all known, the problem is to obtain the position of MS, i.e., $\mathbf{PM}(x, y)$. The first step is to get the distance between the MS and the BTSs:

$$\mathbf{r} = [r_1, r_2, r_3]$$

The least mean square (LMS) method is used to get $\mathbf{r}$. The electric field strength $\mathbf{E}(\mathbf{r})$ at a distance $\mathbf{r}$ from the MS is given by

$$\mathbf{E}(\mathbf{r}) = \mathbf{E}(\mathbf{r}_0) + \frac{\partial \mathbf{E}}{\partial \mathbf{r}} \Delta \mathbf{r} + \mathbf{0}(\Delta \mathbf{r}) = \mathbf{E}_0 + \mathbf{J}_0 \Delta \mathbf{r} + \mathbf{0}(\Delta \mathbf{r}) \quad (23)$$

where $\mathbf{0}(\Delta \mathbf{r})$ can be ignored when $\Delta \mathbf{r}$ is very small compared with $\mathbf{r}$ and

$$\mathbf{J}_0 = \begin{bmatrix} \partial E_1 / \partial r_1 & 0 \\ \partial E_2 / \partial r_2 & 0 \\ 0 & \partial E_3 / \partial r_3 \end{bmatrix} \quad (24)$$

From (18) we have

$$\frac{\partial E}{\partial \mathbf{r}} = -E_0 \left[\frac{z_j - z_1}{[r^2 + (z_j - z_1)^2]^{3/2}} - \frac{z_j - z_2}{[r^2 - (z_j - z_2)^2]^{3/2}} \right] \mathbf{r} \quad (25)$$

The error between measurement and theoretical value for the field strength is given by

$$\varepsilon = \mathbf{E}_m - \mathbf{E}(\mathbf{r}) = (\mathbf{E}_m - \mathbf{E}_0) - \mathbf{J}_0 \Delta \mathbf{r} \quad (26)$$

let

$$\mathbf{u} = \varepsilon^T \varepsilon \quad (27)$$

The minimum of ε^2 is obtained when,

$$\frac{\partial \mathbf{u}}{\partial \mathbf{r}} = \mathbf{0} \quad (28)$$

From (26), (27) and (28), the main iteration equation for $\mathbf{r}$ is obtained as,

$$\mathbf{r}^{k+1} = \mathbf{r}^k + (\mathbf{J}_k^T \mathbf{J}_k)^{-1} \mathbf{J}_k^T (\mathbf{E}_m - \mathbf{E}^k) \quad k = 0, 1, 2 \dots \quad (29)$$

The distance from MS to each of the BTSs is obtained from (29). However, the goal is not to get $\mathbf{r}$, but the position of MS, i.e., $\mathbf{PM}$. We use LMS method again to obtain $\mathbf{PM}$ from $\mathbf{r}$. The main iteration equation to get $\mathbf{PM}$ from $\mathbf{r}$ resembles (29) and is given by,

$$\mathbf{PM}^{k+1} = \mathbf{PM}^k + (\mathbf{J}_k^T \mathbf{J}_k)^{-1} \mathbf{J}_k^T (\mathbf{0} - \mathbf{Errp}_k) \quad (30)$$

Where

$$\mathbf{Errp} = |\mathbf{PM} - \mathbf{PB}| - \mathbf{r} \quad (31)$$

and $\mathbf{J}_k$ is redefined as

$$\mathbf{J}_k = \begin{bmatrix} \partial Errp_1/\partial x & \partial Errp_1/\partial y \\ \partial Errp_2/\partial x & \partial Errp_2/\partial y \\ \partial Errp_3/\partial x & \partial Errp_3/\partial y \end{bmatrix} \quad (32)$$

The velocity of the MS can be obtained from sequential position values using the formula below.

$$\mathbf{V}^k = (\mathbf{PM}^k - \mathbf{PM}^{k-1})/T \quad (33)$$

where T stands for the time interval between two discrete positions of the MS.

The flow chart for the algorithm to obtain $\mathbf{PM}$ and $\mathbf{V}$ is given in Fig. 3.

2.2 Time Delay Method (TDM)

GSM system provides useful data named Time Advance (TA) measurements [7]. These data give the measurement values of twice the propagation time for the microwave signal to travel between a MS and a particular BTS. By using the respective TA measurement data, the distance between a MS and some of the BTSs ($\mathbf{r}$ values) can be estimated easily. Referring to Fig. 1, the distances between MS and three BTSs are $\mathbf{r} = [c\Delta t_1, c\Delta t_2, c\Delta t_3]$, where c is the speed of light and $[c\Delta t_1, c\Delta t_2, c\Delta t_3]$ are propagation times between the MS and three BTSs. The position of the MS now can be determined by using (30).

However, this TDM can only give rather coarse $\mathbf{r}$ values, because the TA measurements provided by GSM system is not accurate enough. They are quantified as the numbers of T_b , and T_b is a time unit and it is equal to the duration for transmitting one binary bit in the Um interface, i.e., $48/13 \mu s$. The distance corresponding to a duration of T_b is $r = cT_b/2 = 554 \text{ m}$. Hence the estimation error equals the quantization error, which is equal to half of the quantization step, which is $r/2 = 277 \text{ m}$. Pent et al have improved this method to get a measurement accuracy of 150 m by processing the TA data with extended Kalman filter (EKF) [2]. Also, they have pointed out that this error hides the altitude differences between the MS and the BTSs since the altitude information is discarded [2], However in the FSM allowance is made for the altitude difference in the model used for parameter estimation.

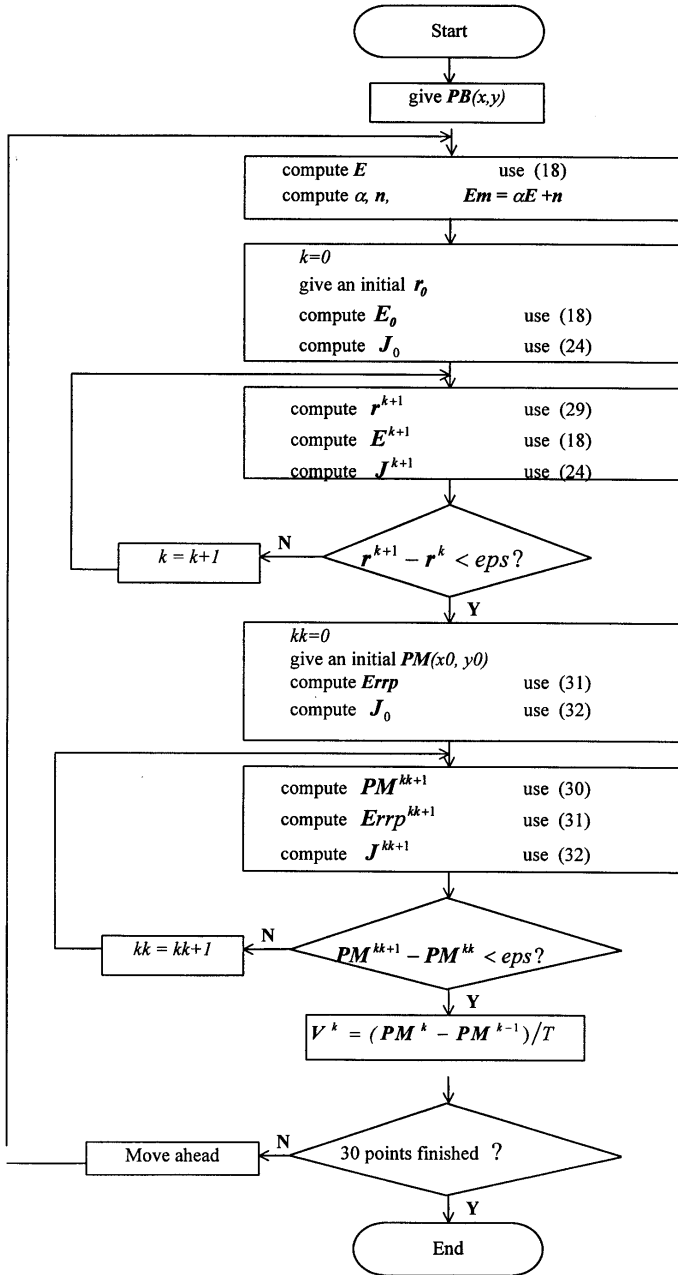


Figure 3. Simulation flow chart.

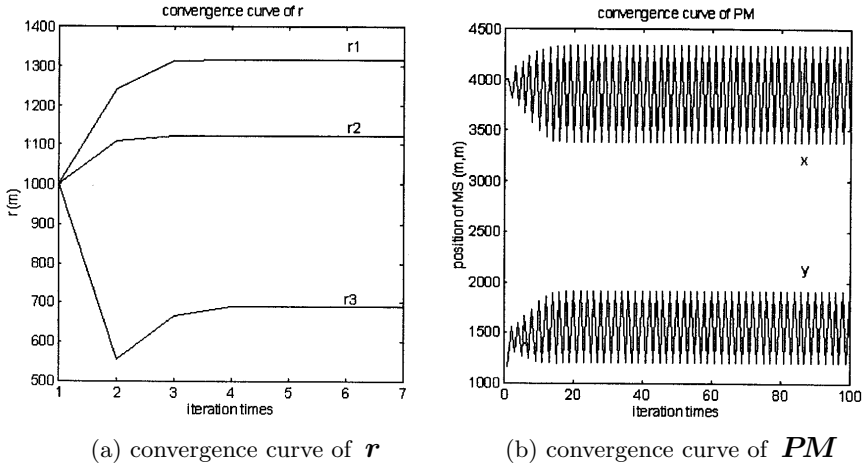


Figure 4. FSM convergence curves with fixed initial $\mathbf{r}$ values.

Although the accuracy of the $\mathbf{r}$ and $\mathbf{PM}$ estimations obtained by using TDM is poor, it was found to be a useful method to obtain the initial value for FSM.

2.3 Hybrid Method

Simulation studies using the FSM described in section 2.1 showed that a reasonably accurate estimate of $\mathbf{PM}$ can be obtained provided that the algorithm does not oscillate. Oscillations usually occurred when the given initial value of $\mathbf{r}$ is too far away from the actual value, as shown in Fig. 4. Normally, for an initial value having a deviation within $\pm 50\%$ of the actual value, the FSM algorithm was found to converge very well, giving an accurate position measurement. Fig. 4 shows the movement of estimated values of $\mathbf{r}$ from (29) and the estimates of $\mathbf{PM}$ from (30). It is seen that although $\mathbf{r}$ values converge to the final values smoothly, the $\mathbf{PM}$ values tend to fluctuate. Further studies of the FSM estimation show that the $\mathbf{r}$ values obtained are incorrect when oscillations such as that shown in Fig. 4(b) develop. The FSM algorithm tends to be highly dependent on the initial values given. For the results shown in Fig. 4, the initial $\mathbf{r}$ values were set to [1000 m, 1000 m, 1000 m].

On the other hand, although TDM usually gives a rather coarse position, the algorithm is rather simple and never oscillates. Therefore,

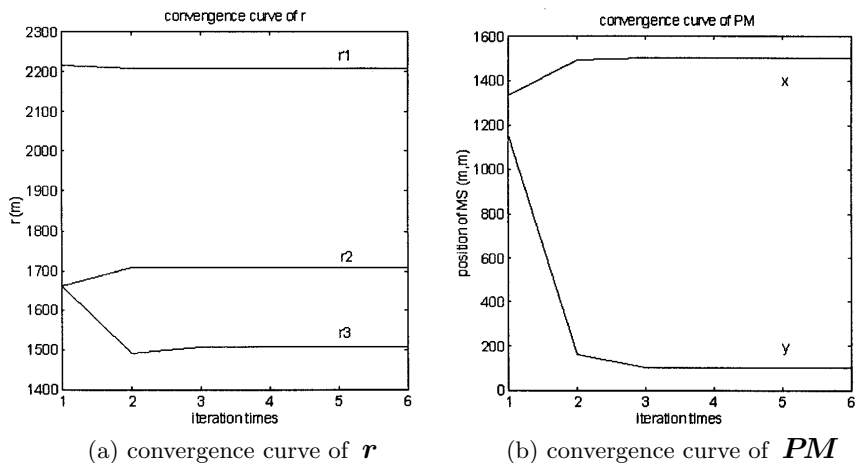


Figure 5. FSM convergence curves with initial r values provided by TDM.

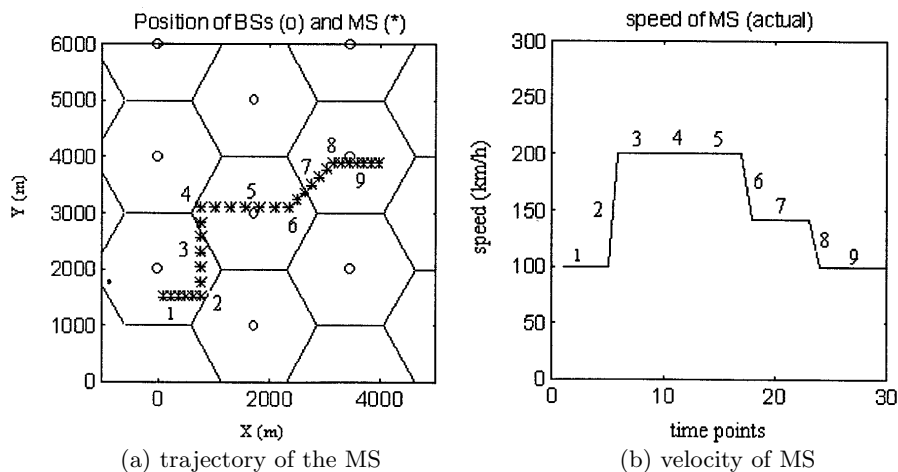


Figure 6. Actual positions and velocities of the MS.

it can be used to provide the initial r values for FSM. This hybrid method was implemented and found to work very well, as the results shown in Fig. 5 indicate.

stepnumber	direction	speed (km/h)	acceleration
1	east	100	0
2			1.16
3	north	200	0
4			-0.35
5	east	200	0
6			0
7	northeast	140	0
8			-0.23
9	east	100	0

Table 2. Movement steps of the MS.

3. COMPUTER EXPERIMENTS

3.1 Simulation Scenario

We have written the program for the FSM, TDM and hybrid algorithms in MatlabTM. A MS is allowed to move in an area of $6\text{ km} \times 6\text{ km}$. Nine BTSs are placed within the $6\text{ km} \times 6\text{ km}$ area with a distance of 2 km between two adjacent BTSs. The nine BTSs have the following altitudes: 30 m, 40 m, 50 m, 20 m, 35 m, 45 m, 60 m, 40 m, 55 m. The MS travels along the zigzag route shown in Fig. 6(a), moving through three cells. The velocity of the MS changes in a step fashion as shown in Fig. 6(b) and Table 2. The MS was allowed to cross over two cellular boundaries and to move close to two BTSs, this is done to determine the stability of the estimator when the distance between a MS and a BTS is very small. In all the simulations the transmission power was assumed to be constant, so that when the MS is close to a particular BTS, the relative field strength at this BTS will be much higher than the field strength at the other two BTSs. Automatic gain control was not incorporated in these simulation experiments.

At least three BTSs are necessary to determine the position and velocity of a MS. In the selection of the three BTSs, we followed the following rule. Select four BTSs receiving the highest field strengths and discard the one with the highest electric field strength. Selecting the first four BTSs gives accurate data, while discarding the one with the highest field strength guarantees the data from BTSs too near to

the MS is not used. Estimating the position of the MS with respect to a BTS too near to it causes the algorithm to oscillate. Note that a MS can not be very near to more than one BTS at only one time. This is the reason for discarding the data from the BTS with the highest electric field strength.

3.2 Channel Model

The algorithm developed is tested under fading and AWGN noise channel conditions. The channel models used in the simulation are described below. In all the channels, the SNR is defined as the ratio between the mean power of the signal and the mean power of the noise.

(a) Gaussian noise channel

We have a random number generator which generates Gaussian distributed random numbers $N_{gaussian}(A_n, \sigma)$ [11], where σ is the variance and A_n is the mean amplitude of the noise. The Gaussian noise channel parameters can be obtained from the field strength of E and SNR by

$$A_n = \frac{E}{10^{SNR/20}} \quad (34)$$

Thus in a Gaussian noise channel the electric field strength received can be simulated by with SNR given by

$$E_{gaussian} = E + N_{gaussian}(A_n, \sigma) \quad (35)$$

with SNR given by

$$SNR = 20 \lg \frac{E}{N_{gaussian}(A_n, \sigma)} \quad (36)$$

(b) Rayleigh fading channel

Rayleigh distributed random numbers can be simulated by two sets of independent Gaussian distributed random numbers with zero mean and equal variances. The maximum value of the distribution is at the value of the variances which are set to 1 [12, 13].

$$N_{rayleigh} = \sqrt{N_{gaussian}(0, 1)^2 + N_{gaussian}(0, 1)^2} \quad (37)$$

Thus, in a Rayleigh fading channel the electric field strength received can be simulated by

$$E_{rayleigh} = N_{rayleigh}E + N_{gaussian}(A_n, \sigma) \quad (38)$$

and

$$SNR = 20 \lg \frac{E}{N_{gaussian}(A_n, \sigma)} \quad (39)$$

(c) Rician channel

In Rician channel, the electric field strength received can be characterized as follows [12].

$$E_{rician} = \sqrt{(E + N_{gaussian}(0, \sigma)^2 + N_{gaussian}(0, \sigma)^2 + N_{gaussian}(A_n, \sigma)} \quad (40)$$

and

$$SNR = 20 \lg \frac{E}{N_{gaussian}(A_n, \sigma)} \quad (41)$$

As we know, GSM systems normally work in a SNR of 20 dB in its Um interface. In some cases it may drop to 15–18 dB [9], The FSM-TDM hybrid algorithm was tested for SNR of 10 dB, 20 dB and 40 dB.

4. RESULTS AND DISCUSSION

We tested the FSM-TDM hybrid algorithm under various fading and noise channels, including Gaussian, Rayleigh and Rician [12]. These channel were described in section 3. Some sample simulation results are given in Fig. 7 to Fig. 10.

In Fig. 7 is shown the simulation results for Gaussian noise channel. For a SNR of 10 dB, the position accuracy is 80 m, and the velocity accuracy is 40 km/h. For a SNR of 20 dB, the position accuracy is 30 m, and the velocity accuracy is 15 km/h. For a SNR of 40 dB, the position accuracy is 3 m, velocity accuracy is 2 km/h.

In Fig. 8 is shown the simulation results for Rayleigh noise channel. For a SNR of 10 dB, the position accuracy is 170 m, and the velocity accuracy is 100 km/h. For a SNR of 20 dB, the position accuracy is 60 m, and the velocity accuracy is 30 km/h. For a SNR of 40 dB, the position accuracy is 6 m, velocity accuracy is 3 km/h.

In Fig. 9 is shown the simulation results for Rician noise channel. The (position, velocity) accuracy for SNR of 10 dB, 20 dB and 40 dB are (200 m, 120 km/h), (80 m, 50 km/h) and (7 m, 5 km/h) respectively.

Fig. 10 shows the relationship between accuracy and SNR. As expected, the accuracy increases rapidly when SNR increases. The curve corresponds to an exponential function. For a SNR of 20 dB, the accuracy for position measurement is acceptable in all three channels.

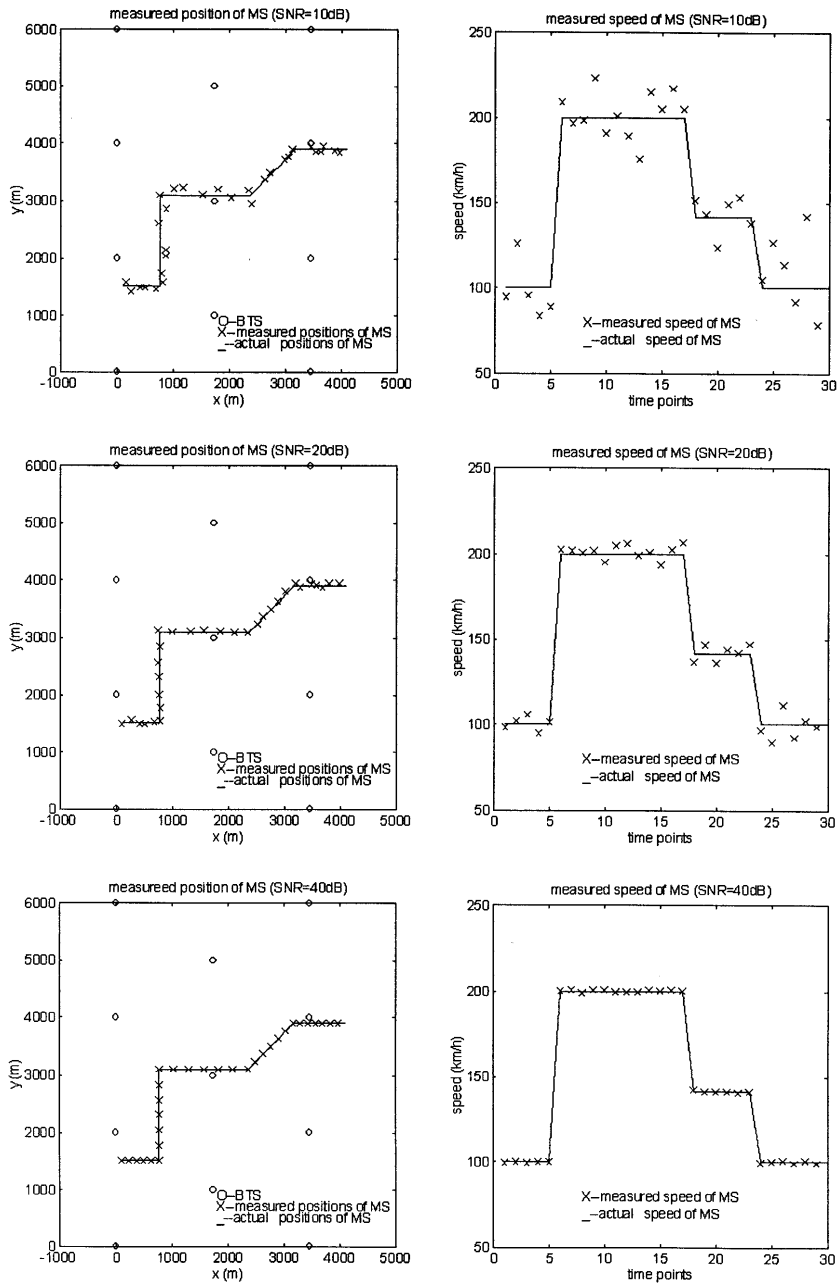


Figure 7. Simulation results in Gaussian channel.

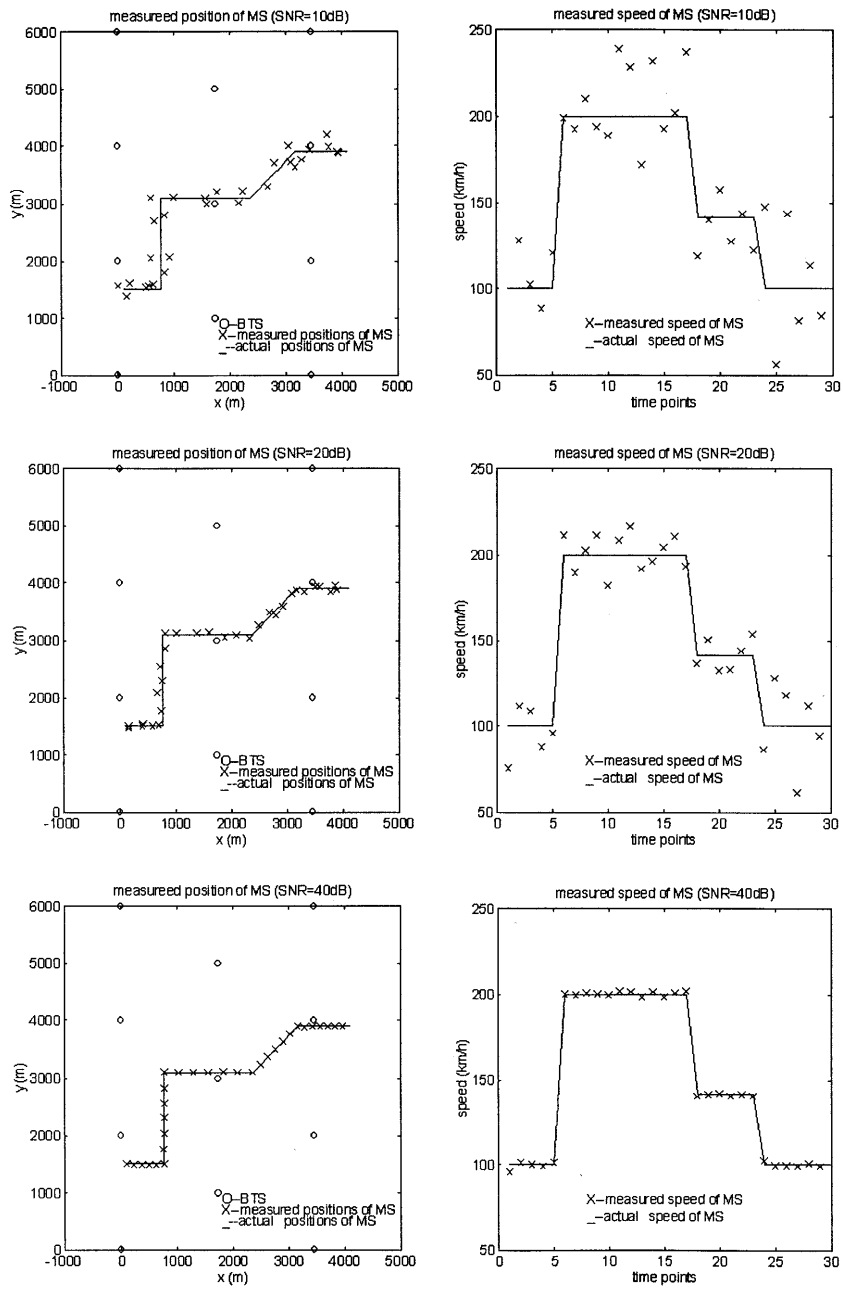


Figure 8. Simulation results in Rayleigh channel.

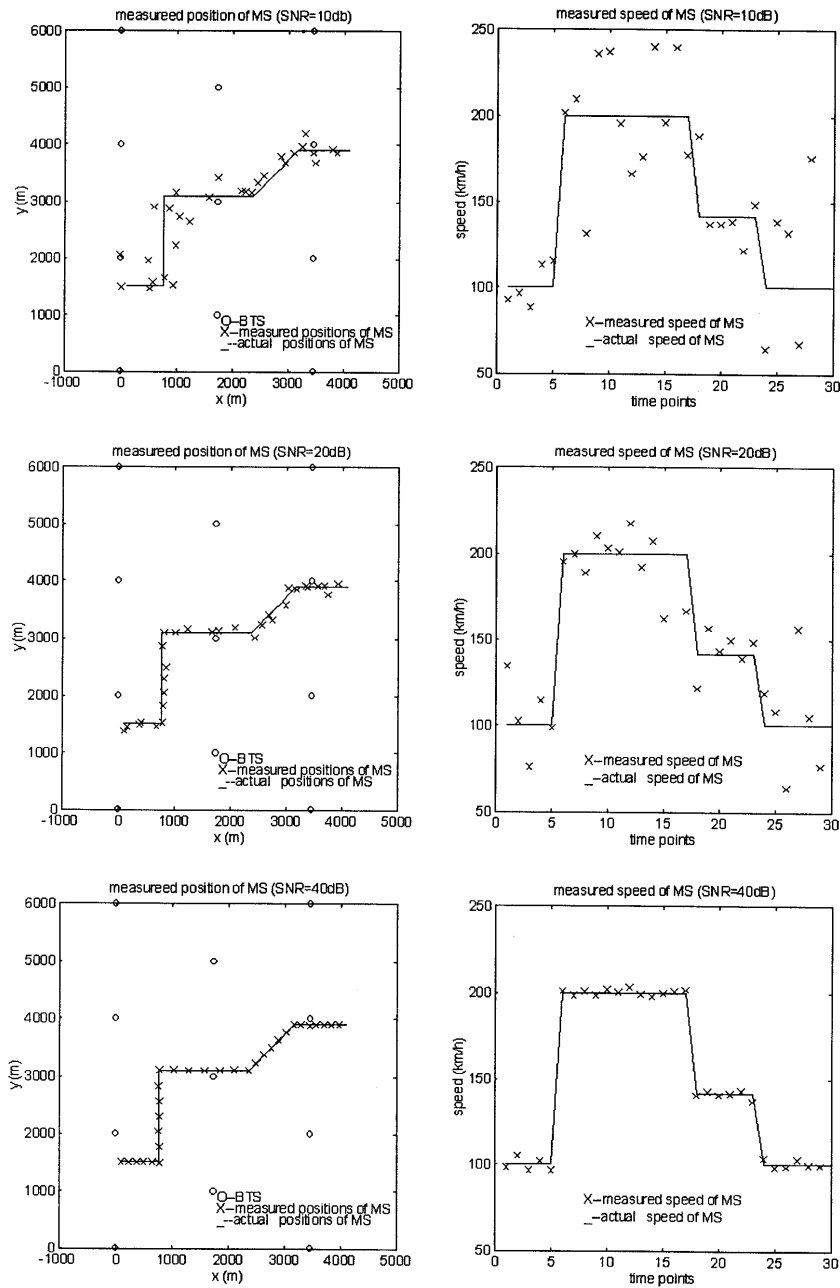
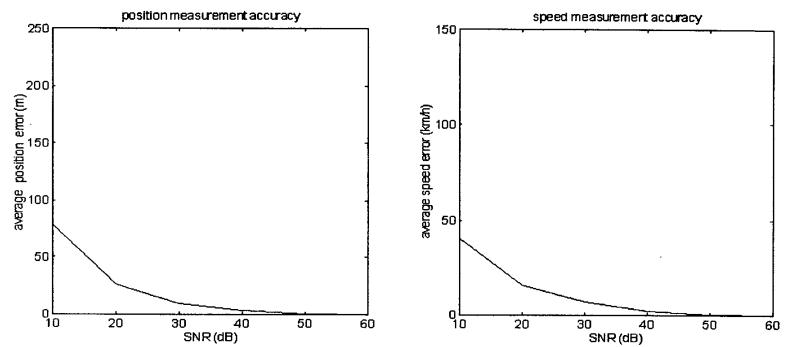
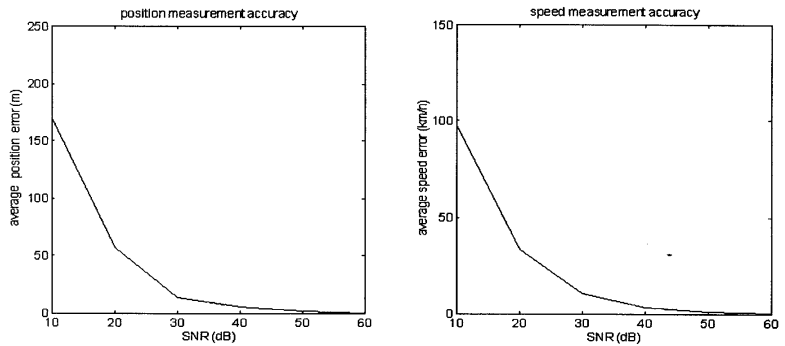


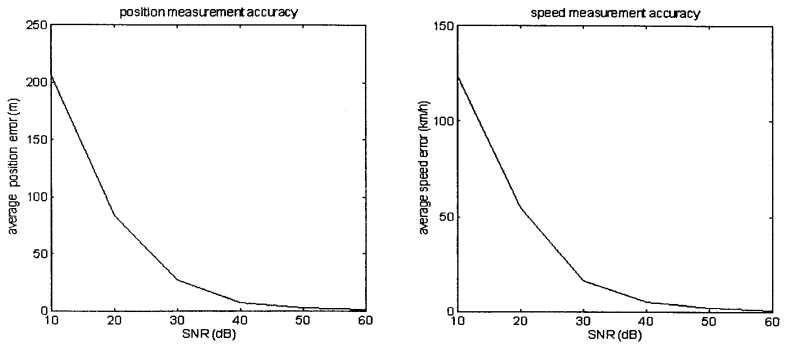
Figure 9. Simulation results in Rician channel.



(a) Gaussian noise channel



(b) Rayleigh fading channel



(c) Rician fading channel

Figure 10. Simulation accuracy Vs. SNR.

However the velocity estimation has an error of $\pm 7.5\%$, $\pm 15\%$ and $\pm 25\%$ for the Gaussian, Rayleigh and Rician channels respectively. In the context of space-time processing of wireless communication signal [14], the FSM-TDM hybrid estimator is a promising tool to improve the quality of wireless networks.

5. CONCLUSION

We have proposed a hybrid method for determining the positions and velocities of mobile stations in a GSM network by concurrently processing subsequent time delay and field strength measurements for a single MS at different BTSs. The TDM estimator is used to give initial $\mathbf{r}$ values for the FSM estimator. The FSM applies LMS to get refined $\mathbf{r}$ values using the field strength picked up by different BTSs, and applies LMS again to get the position of MS from the $\mathbf{r}$ values. The convergence characteristics were found to be satisfactory. For a SNR of 20 dB, position measurement accuracy is 30 m in a Gaussian channel, 60 m in a Rayleigh channel and 80 m in a Rician Channel. The velocity accuracy for SNR of 20 dB is 15 km/h in a Gaussian channel, 30 km/h in a Rayleigh channel and 50 km/h in a Rician channel, for a MS moving at speed in the range of 100 to 200 km/h.

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