

# Estimating the Position of Mobiles by Multi-Criteria Decision Making

Jongchan Lee, Byung-Han Ryu, and Jeehwan Ahn

**ABSTRACT**— In this study, we propose a novel mobile tracking method based on Multi-Criteria Decision Making (MCDM), in which uncertain parameters—the received signal strength, the distance between the mobile and the base station, the moving direction, and the previous location—are used in the decision process using the aggregation function in the fuzzy set theory. Through numerical results, we show that our proposed mobile tracking method provides a better performance than the conventional method using the received signal strength.

## I. INTRODUCTION

Location estimation technology has been used for obtaining information on transportation services. Sakagami et al. used the signal strength received at the multi-beam antenna of the base station in the multi-path environment and the angle of its arrival (AOA) [1]; Staras and Honikman used the time of arrival (TOA) of the signal from the mobile to the neighboring base stations [2]; and Rappaport et al. used the time difference of arrival (TDOA) of signals from two base stations [3]. Recently TOA and TDOA schemes were considered for IS-95B where the PN code of the CDMA system was used for the location estimation. However the AOA, TOA, and TDOA schemes have some problems as follows.

- They assume that the cellular system consists of Line of Sight (LOS) areas, and they obtain good results only under this condition.
- In a microcellular environment such as IMT-2000, there

are mostly Non-line of Sight (NLOS) areas, which are affected by specific reflections and diffractions. Therefore, these schemes have great errors in estimation.

- In a microcellular environment, the points of the same average signal strength form not a circular but a distorted contour. These schemes ignore the fact that the propagation rule is affected by many parameters.
- They rely only on information related to radio signals, such as the signal strength. Thus accuracy is affected by short-term fading, shadowing, and diffraction.

In this study, to enhance estimation accuracy, we propose a scheme based on Multi-Criteria Decision Making (MCDM) which considers multiple parameters: the signal strength, the distance between the base station and mobile, the moving direction, and the previous location. Figure 1 shows how our scheme divides a cell into many blocks based on the signal

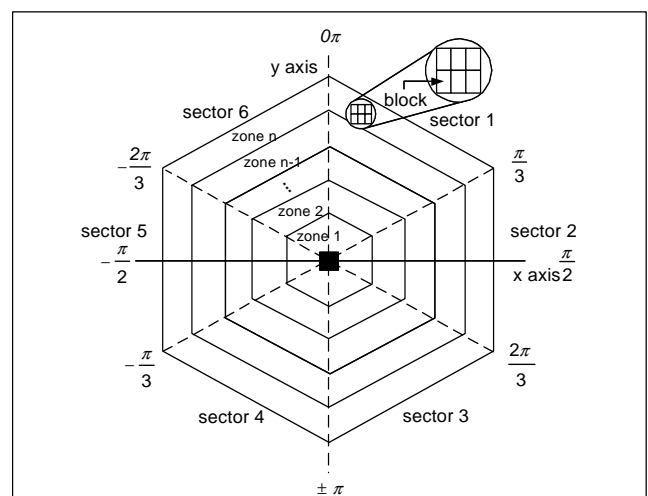


Fig. 1. Sector, Zone and Block.

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Jongchan Lee (phone: +82 42 860 5477, e-mail: chan2000@etri.re.kr), Byung-Han Ryu (e-mail: rubh@etri.re.kr), and Jeehwan Ahn (e-mail: jhahn@etri.re.kr) are with Mobile Communication System Research Department, ETRI, Daejeon, Korea.

strength and then using MCDM estimates stepwise the optimal block where the mobile is located.

This process is based on a three step location estimation which determines the mobile position by gradually reducing the area of the mobile position [4]. Using MCDM, the estimator first estimates the location sector in the sector estimation step, then estimates the location zone in the zone estimation step, and then finally estimates the location block in the block estimation step.

## II. ESTIMATION PROCEDURE

The location of a mobile within a cell can be defined by dividing each cell into sectors, zones, and blocks and relating these to the signal level received by the mobile at that point. The division is done automatically in three phases: sector definition, zone definition, and block definition. The location definition block is constructed with these results. The three phases are performed at the system initialization before the location estimation is executed. The sector definition phase divides a cell into sectors and assigns a sector number to blocks belonging to each sector. The zone definition phase divides each sector into zones and assigns a zone number to blocks belonging to each zone. The block definition phase assigns a block number to each block. In order to indicate the location of each block within a cell, a 2-dimensional vector ( $d$ ,  $a$ ) is assigned to each block. After the completion of this phase, each block has a set of block information.

The set of block information is called the *block object*. The block object contains the following information: the sector number, the zone number, the block number, the vector data ( $d$ ,  $a$ ), the maximum and the minimum values of the average pilot signal strength (PSS) for the LOS block, the compensated value for the NLOS block, and a bit for indicating “node” or “edge.”

```
class blockObject
{
private:
    unsigned int sector_num;
    unsigned int zone_num;
    unsigned int block_num;
    double vector(double d, double a);
    unsigned int los_sig(int min, int max);
    unsigned int nlos_sig;
    unsigned int node;
    unsigned int edge;
public:
    .
    .
    .
}
```

Using MCDM and the block object which is constructed as described above, the proposed scheme estimates the optimal block at which the mobile is located. This scheme is implemented as an estimator at the base station. The estimator is started with a timer, and the estimation is performed sequentially in three steps: sector estimation, zone estimation, and finally block estimation.

## III. MOBILE TRACKING BASED ON MCDM

### 1. Multi-Criteria Decision Parameters

In our study, the received signal strength, the distance between the mobile and the base station, the previous location, and the moving direction are considered as decision parameters. The received signal strength has been used in many schemes, but it has very irregular profiles due to the effects of radio environments. The distance is considered because it can explain the block allocation plan; however, it may also be inaccurate due to the effect of multi-path fading, etc. It is not sufficient by itself. We consider the previous location. It is normally expected that the estimated location should be near the previous one. Therefore, if the estimated location is too far from the previous one, the estimation may be regarded as inaccurate. We also consider the moving direction. Usually the mobile is most likely to move forward, less likely to move rightward or leftward, and least likely to move backward more than one block. The low-speed mobile (a pedestrian) has a smaller moving radius and a more complex moving pattern, while the high-speed mobile (a motor vehicle) has a larger radius and a simpler pattern.

In mobile tracking using MCDM, the decision function  $D$  is defined by combining the degree of satisfaction for multiple evaluation parameters, and the decision is made on the basis of this function. The evaluation parameter can be seen as a proposition. A compound proposition is formed from multiple evaluation parameters with a connective operator, and the total evaluation is performed by totaling the values for the multiple parameters with connective operators. In this method, errors in the evaluation parameters impose milder changes on the total evaluation value than in binary logics. This method can also consider multiple inaccurate and insufficient evaluation parameters simultaneously and can compensate for them. This results in the optimal decision. In our study the measure of the ratio was used for indicating the evaluation parameter and a weight was imposed according to the degree of importance of each evaluation parameter.

### 2. Membership Function

A membership function with a trapezoidal shape was used for determining the membership degree of the mobile because

it provided a more versatile degree between the upper and the lower limits than a membership function with a step-like shape. Let us define the membership functions for the pilot signal strengths from neighboring base stations. The membership function of  $PSS_i$ ,  $\mu_R(PSS_i)$ , is given by (1).  $PSS_i$  is the signal strength received from the base station  $i$ ,  $s_1$  is the lower limit, and  $s_2$  is the upper limit.

$$\mu_R(PSS_i) = \begin{cases} 0, & PSS_i < s_1 \\ 1 - \frac{PSS_i - s_1}{|s_2 - s_1|}, & s_1 \leq PSS_i \leq s_2 \\ 1, & PSS_i > s_2. \end{cases} \quad (1)$$

Now we define the membership function of the distance. The membership function of the distance  $\mu_R(D_i)$  is given by (2), where  $D_i$  is the distance between the base station  $i$  and the mobile [4].

$$\mu_R(D_i) = \begin{cases} 1, & D_i < d_1 \\ 1 - \frac{|D_i - d_2|}{|d_1 - d_2|}, & d_1 \leq D_i \leq d_2 \\ 0, & D_i > d_2. \end{cases} \quad (2)$$

The membership function of the previous location of the mobile  $\mu_R(L_i)$  is given by (3), where  $L_i$  is its current location,  $E_1, \dots, E_4$  is the previous location, and  $g_i$  is the physical difference between them [4].

$$\mu_R(L_i) = \begin{cases} 0, & L_i < E_1 \\ 1 - \frac{L_i - E_1}{|g_i|}, & E_1 \leq L_i \leq E_2 \\ 1, & E_2 \leq L_i \leq E_3 \\ 1 - \frac{L_i - E_3}{|g_i|}, & E_3 \leq L_i \leq E_4 \\ 0, & L_i > E_4. \end{cases} \quad (3)$$

The membership function of the moving direction  $\mu_R(C_i)$  is given by (4).  $C_i$  is the moving direction of the mobile,  $PSS_1, \dots, PSS_4$  is the pilot signal strength, and  $o_i$  the physical difference between the previous location and the current one.

$$\mu_R(C_i) = \begin{cases} 0, & C_i < PSS_1 \\ 1 - \frac{C_i - PSS_1}{|o_i|}, & PSS_1 \leq C_i \leq PSS_2 \\ 1, & PSS_2 \leq C_i \leq PSS_3 \\ 1 - \frac{C_i - PSS_3}{|o_i|}, & PSS_3 \leq C_i \leq PSS_4 \\ 0, & C_i > PSS_4. \end{cases} \quad (4)$$

### 3. Location Estimation

#### A. Sector Estimation Based on Multi-Criteria Parameters

The decision parameters considered in the sector estimation step are the signal strength, the distance, and the previous location. The mobile is estimated to be located at the sector neighboring the base station whose total membership degree is the largest. The sector estimation is performed as follows.

**Procedure 1** Membership degrees are obtained using the membership function for the signal strength, the distance, and the previous location.

**Procedure 2** Membership degrees obtained in Procedure 1 for the base station neighboring the present station are totaled using the fuzzy connective operator as shown in (5).

$$\mu_i = \mu_R(PSS_i) \cdot \mu_R(D_i) \cdot \mu_R(L_i). \quad (5)$$

We obtain (6) by weighting  $\mu_i$ . The reason for weighting is that the parameters used may differ in their importance.

$$\omega\mu_i = \mu_R(PSS_i) \cdot W_{PSS} + \mu_R(D_i) \cdot W_D + \mu_R(L_i) \cdot W_L, \quad (6)$$

where  $W_{PSS}$  is the weight for the received signal strength,  $W_D$  for the distance, and  $W_L$  for the location. Also  $W_{PSS} + W_D + W_L = 1$ , and  $W_{PSS}=0.5$ ,  $W_D=0.3$ , and  $W_L=0.2$ , respectively.

**Procedure 3** Blocks with the estimated sector number are selected from all the blocks within the cell for the next step of the estimation. The selection is done by examining the sector number in the block object information.

#### B. Zone Estimation Based on Multi-Criteria Parameters

The decision parameters considered in the zone estimation step are the signal strength, the distance, and the moving direction. From the blocks selected in the sector estimation step, this step estimates the zone in which the mobile may be located using the following procedure.

**Procedure 1** Membership degrees are obtained using the membership function for the signal strength, the distance, and the moving direction.

**Procedure 2** Membership degrees obtained in Procedure 1 are totaled using the fuzzy connective operator as shown in (7).

$$\mu_i = \mu_R(PSS_i) \cdot \mu_R(D_i) \cdot \mu_R(C_i). \quad (7)$$

We obtain (8) by weighting  $\mu_i$ .

$$\omega\mu_i = \mu_R(PSS_i) \cdot W_{PSS} + \mu_R(D_i) \cdot W_D + \mu_R(C_i) \cdot W_C, \quad (8)$$

where  $W_{PSS}$  is assumed to be 0.6,  $W_D = 0.2$ , and  $W_C = 0.2$ , respectively.

**Procedure 3** Blocks which belong to the estimated zone above are selected for the next step. It is done by examining the zone number of the blocks selected in the sector estimation.

### C. Block Estimation Based on Multi-Criteria Parameters

The decision parameters to be considered in the block estimation step are also the signal strength, the distance, and the moving direction. From the blocks selected in the zone estimation step, this step uses the following algorithm to estimate the block in which the mobile may be located.

**Procedure 1** Membership degrees are obtained using the membership function for the signal strength, the distance, and the moving direction.

**Procedure 2** Membership degrees obtained in Procedure 1 are totaled using the fuzzy connective operator as shown in (9).

$$\mu_i = \mu_R(PSS_i) \cdot \mu_R(D_i) \cdot \mu_R(C_i). \quad (9)$$

We obtain (10) by weighting  $\mu_i$ .

$$\omega\mu_i = \mu_R(PSS_i) \cdot W_{PSS} + \mu_R(D_i) \cdot W_D + \mu_R(C_i) \cdot W_C, \quad (10)$$

where  $W_{PSS}$  is assumed to be 0.6,  $W_D = 0.1$ , and  $W_C = 0.3$ , respectively.

**Procedure 3** The selection is done by examining the block number of the blocks selected in the zone estimation.

## IV. PERFORMANCE EVALUATION

In our study we assume that low-speed mobiles (pedestrians) occupy 60% of the total population in the cell and high-speed mobiles (vehicles) 40%. The moving velocity is assumed to have a uniform distribution. The walking speed of pedestrians is 0-5 km/h, the speed of vehicles 10-100 km/h. The speed is assumed to be constant during walking or driving. Each block is a square and its side is assumed to have the length of  $n$  m. The time needed for a high speed mobile to pass through a block is calculated from  $BT = 4r/(\pi \cdot v)$ , here  $r$  is the length of the road segment crossing at each block and  $v$  the mobile speed.  $BT$  is dependent on  $r$ . We can consider four different values— $r$ ,  $n$  m (crossing diagonally),  $3n/4$  m ( $3/4$  crossing),  $n/2$  m ( $1/2$  crossing), and  $n/4$  m ( $1/4$  crossing)—according to which portion of a block each road segment crosses through. If  $BT$  is too small, we cannot obtain enough samples to calculate the average signal strength. We consider the following

simulation parameters regarding the received signal strength. The mean signal attenuation by the path-loss is proportional to 3.5 times the propagation distance, and the shadowing has a log-normal distribution with a standard deviation of  $\sigma = 6$  dB. A value of the received signal strength less than  $-16$  dB is regarded as an error, which is therefore excluded from the calculation.

To evaluate the error probability of the proposed scheme in each estimation stage, the mobiles in the track boundary and the sector boundary are generated according to a Poisson distribution. All the mobiles generated above are assumed to cross the sector boundary lines and the track boundary lines. In addition, the curved path passes through the handoff area. Pedestrian mobiles appear at sector and track boundary areas and move toward the neighboring sector or track. Vehicles appear at track boundary areas and move toward the neighboring track.

According to the simulation results, we found that most estimation errors occurred when mobiles passed through sector and zone boundary lines or through a curved path. Estimation errors for low speed mobiles were mostly observed while they were moving through a curved path. On the other hand estimation errors for high speed mobiles were observed when they were moving through either sector boundary lines or a curved path.

Figure 2 shows the estimation result for the situation where the mobile moves along a straight or curved sector boundary area. In this figure the horizontal and vertical axes represent the relative location of the area observed and the path generated in this simulation. A left or right turn causes abrupt signal distortions, but their effect on the estimation can be compensated for by using information on the previous location and the distance to the base station. Especially, the possibility of selecting a faulty location far away from the present location can be reduced by using information on the previous location.

Figure 3 shows the estimation accuracy depending on the

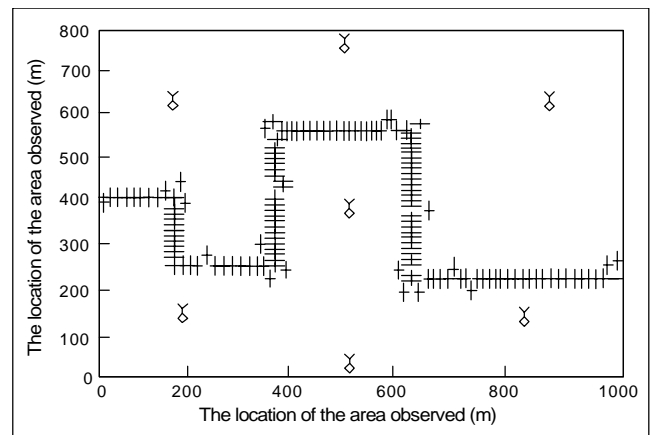


Fig. 2. The estimation results on the move.

mobile speed and block size. The estimation accuracy increases rapidly as the mobile speed decreases or the block size increases. The quality of those estimates is improved because moving direction and previous location and distance are considered and, therefore, errors during the signal evaluation step decrease.

Figure 4 shows the effect of the block size on the estimation performance of MCDM and the existing schemes. As the block size becomes smaller, the accuracies of the three schemes decrease. The accuracies of AOA and TOA decrease rapidly. On the other hand, the performance of MCDM is least affected by block size because it additionally utilizes the previous location and distance between the mobile and the base station for estimation.

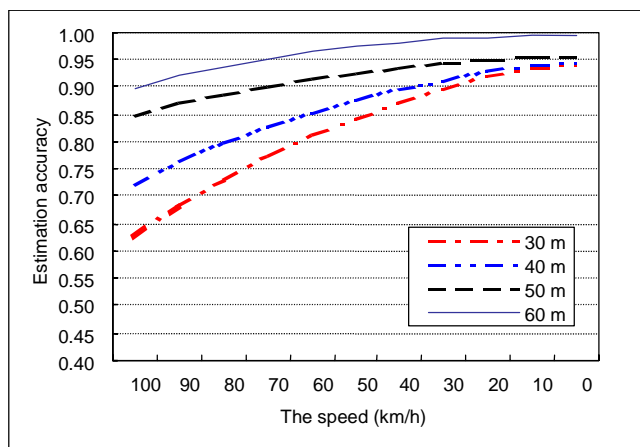


Fig. 3. The estimation accuracy versus the mobile speed.

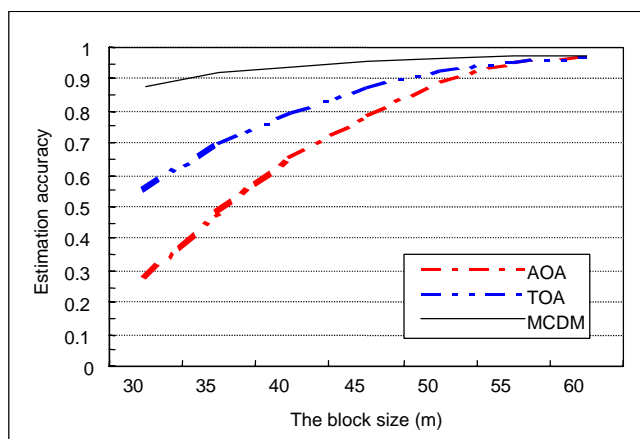


Fig. 4. The estimation accuracy versus the block size.

## V. CONCLUSION

In this study, we proposed a mobile tracking method based on MCDM for estimating mobile location more accurately by considering multiple parameters – signal strength, the distance

between the base station and mobile, moving direction, and previous location. We have demonstrated that our scheme increases the estimation accuracy when the mobile moves along a boundary area. Further, we have shown that the proposed scheme is little affected by an increased mobile speed or a decreased block size. The effect of weight factor variations on the estimation performance of our scheme and the determination of the optimal weight should be the subject of a future study.

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