LOW LATENCY SCANNING ALGORITHM USING RECEIVED SIGNAL STRENGTH FOR FLEXIBLE NETWORK MOBILITY

Jung-Min Moon* and Dong-Ho Cho†
School of Electrical Engineering and Computer Science
Korea Advanced Institute of Science and Technology (KAIST)
Email: jmmoon@comis.kaist.ac.kr*, dhcho@ee.kaist.ac.kr†

Abstract—To support highly flexible network mobility in mobile communication systems, various types of movable network entities, especially mobile base stations (M-BSs), will appear in near future. In this environment, a scanning process to identify the availability of neighbor M-BSs for handoff should be newly designed, because a conventional method does not reflect the motion of base stations. Therefore, we propose an efficient scanning algorithm based on the concept of sample vectors and comparison metrics for estimating the relative motion of a serving M-BS and a user. By using the proposed algorithm, the user can avoid unnecessary scanning trials for the neighbor M-BSs that are moving away from the user and simulation results show a substantial performance gain with respect to the interruption time caused by the scanning process.

I. INTRODUCTION

In future mobile communication networks, a significant increase in capacity and a high flexibility in mobility, which are ranged from personal area to global access domain, are expected to be realized for maximizing user satisfaction. According to the degree of mobility that could be supported by the networks, two different types of access systems are now being developed [1]. The first is a nomadic/local area access system that will support users who are static or moving very slowly with the data rates of up to approximately 1 Gbps. The development of femtocells to improve both indoor coverage and capacity can be viewed as one of the examples in this category. The second is a mobile/wide area access system that will support users moving at high speed on highways or fast trains (60 km/h to 250 km/h, or more) with the data rates of up to approximately 100 Mbps. Especially in the second type of access system, not only fixed base stations and relay stations but also movable network entities, which are generally called moving networks, will be introduced. To make seamless interworking among the above mentioned technologies, suitable mobility management and handoff mechanisms should be provided. In this context, much research has been conducted in the field of dynamic location registration, efficient scanning of neighbor base stations and overall handoff protocol design.

In this paper, we are dealing with the environment where movable network entities travelling with ground vehicles or aerial vehicles are introduced. Here, it is assumed that direct communications between these movable network entities and mobile users can be performed through wireless links, so we denote these movable network entities as mobile base stations (M-BSs). The concept of the M-BS is presented in several systems such as the IEEE 802.16j multihop relay systems and military tactical networks [2][3]. In the IEEE 802.16j multihop relay systems, the development of mobile relay stations (M-RSs) that are travelling with transportation vehicles is one of the key research items. Thus, the main scenario of application is to support mobile users who are located inside the M-RS by relaying traffic and signaling between the base station and the mobile users through the M-RS. On the other hand, in the military tactical networks, reliability in communications must be provided. So, more than one wireless link are needed to overcome harsh environmental conditions. Thus, direct message exchanges between the M-BS, which may belong to tank or airborne networks, and mobile users, or soldiers, are basically required while still maintaining several relay links. Especially if we consider the situation where mobile users are directly served by the M-BS, the scanning process to identify the availability of neighbor M-BSs for handoff [4] should be newly designed, because a conventional scanning process does not reflect the motion of base stations. Therefore, an efficient way of scanning neighbor M-BSs when the highly flexible mobility is supported will be discussed in this paper.

Many related works have been studied to enhance the performance of scanning and handoff process. The primary objective in this filed of research is to reduce the time, or power consumption, required to detect a target base station for handoff and to decide optimal handoff initiation timing. In this circumstance, T. Chung et al. [6][7] proposed network discovery algorithms based on the motion detection of a user. In their works, the user’s motion was classified into three states by measuring received signal strength (RSS): approaching, stationary and leaving states. Then, the network discovery was performed only in the leaving state for power saving. S. Woon et al. [8] and S. Yoo et al. [5] proposed an effective link triggering method to prepare handoff in advance. In their works, the time to initiate handoff was determined based on the variation of RSS from the serving base station and the user velocity, so packet loss rate during the handoff was largely reduced. Even though the efficiency of these works was already verified by numerical and simulation results, the introduction of movable network entities, or M-BSs, and the relative motion between the M-BS and the user were not considered in the scanning and handoff process.
Therefore, we propose an efficient scanning algorithm that can be utilized when the user connected to the serving M-BS tries to detect a suitable target M-BS for handoff. The main idea of the proposed algorithm is to generate sample vectors for estimating the relative motion of the serving M-BS and the user. Then, it is possible to set the priority for scanning neighbor M-BSs according to a proposed comparison metric that is based on the sample vectors and the variation in RSS. Through this procedure, the user can avoid unnecessary scanning trials for the neighbor M-BSs that are moving away from the user and simulation results show that there is a substantial performance gain in terms of the interruption time caused by the scanning process.

The rest of the paper is organized as follows. In Section II, overall description of the proposed algorithm and its analytical model are presented. Next, performance evaluation through simulation works is discussed in Section IV and conclusions are made in Section V.

II. LOW LATENCY SCANNING ALGORITHM FOR M-BS

Here, we explain a general aspect of the scanning process to clarify the problem to be discussed in this paper. Then, the detail of a proposed algorithm and its analytical model are described.

A. Brief Summary of Scanning Process

The aim of scanning is to identify and monitor the status of neighbor base stations (BSs) for initial network entry or handoff [4]. To achieve this purpose, a mobile station (MS) periodically measures certain parameters, such as RSS, based on information about neighbor BSs provided by a serving BS. Then, a target BS for initial network entry or handoff is decided by using scanning results. Note that communications between the serving BS and the MS are temporarily unavailable during scanning process, because a radio interface of the MS is tuned to other frequency bands of neighbor BSs. Thus, we should minimize this gap of communications, or interruption time, by designing an efficient scanning process.

B. Overall Description of Proposed Algorithm

For the purpose of developing an efficient scanning algorithm in the consideration of M-BSs, we assume that several M-BSs and MSs are freely moving in two-dimensional space. In addition, a serving M-BS has a capability to inform the MSs of its motion vector, or the speed and direction, with the assistance of positioning systems. However, in the case of the MSs, there is no particular way to understand their motion vectors exactly, so a proper estimation method should be used.

As shown in the block diagram of Fig. 1, the first stage of a proposed algorithm is to generate sample vectors in the MS side. Here, the generation of the sample vectors means to make a set of motion vectors that may include the estimated vector that properly describes the motion of the MS. Thus, the speed is decided by randomly choosing in a certain interval and the directions are decided by equally dividing all directions in the space. Based on both the generated sample vectors of the MS and the provided motion vector of the serving BS, it is possible to expect the distance between the serving M-BS and the MS for each sample vector. Then, the corresponding changes in the value of the RSS from the serving BS can be derived. These results are used to determine the sample vector that most properly describes the motion of the MS by comparing the estimated value of the RSS with the actually measured value of the RSS from the serving BS. Note that the comparison is performed by using the proposed comparison metric, which will be discussed in Section II-C.

By using the comparison metric for each sample vector and the positioning information of neighbor M-BSs, which is supported by the serving M-BS, we can set scanning priority for neighbor M-BSs. Therefore, the reduction of scanning latency can be achieved by giving a lower priority to the neighbor M-BSs that are moving away from the MS, or have less probability to be a target M-BS for handoff.

C. Analytical Model of Proposed Algorithm

In this subsection, we present an analytical model of a proposed algorithm, mainly focusing on how to set the scanning priority for neighbor M-BSs. Let \( \vec{v}_{m,k} \) denote the motion vector of a serving M-BS at time \( k \). By using the standard basis vectors, \( \vec{e}_1 \) and \( \vec{e}_2 \), in two dimensional space, \( \vec{v}_{m,k} \) can be written as follows:

\[
\vec{v}_{m,k} = v_m k \cos \phi \cdot \vec{e}_1 + v_m k \sin \phi \cdot \vec{e}_2
\]

(1)

where \( v_m \) and \( \phi \) represent the speed and the direction of the serving M-BS, respectively. In a similar way, the \( i \)-th sample vector \( \vec{v}_{s(i),k} \) that is generated for estimating the motion of an MS can be written as follows:

\[
\vec{v}_{s(i),k} = v_s k \cos \theta_i \cdot \vec{e}_1 + v_s k \sin \theta_i \cdot \vec{e}_2
\]

(2)

where \( v_s \) is a sample value of speed and \( \theta_i \) is a sample value of \( i \)-th direction that is set to be equal to \( 2\pi i/N \), so total \( N \)
sample vectors are made. Then, the expected distance $d_i[k]$ between the serving M-BS and the MS at time $k$, which is estimated by using $v_s(i,k)$, can be expressed as follows:

$$d_i[k] = ||\hat{v}_{m,k} - \hat{v}_{s(i),k}|| = k\sqrt{(v_m \cos \phi - v_s \cos \theta_i)^2 + (v_m \sin \phi - v_s \sin \theta_i)^2}$$  (3)

Thus, the corresponding RSS change, which is measured by the MS, can be obtained based on path loss and log-normal shadowing model in the MS side. Let $P_t[k]$ and $P_s[k]$ denote transmit power and the estimated value of the RSS from the serving M-BS, respectively. Then, $P_i[k]$ can be expressed as follows:

$$P_i[k] = P_t[k] - \alpha - \beta \log_{10}(d_i[k]) - \psi_{dB,s}$$  (4)

where $\alpha$ and $\beta$ are decided by the path loss model and $\psi_{dB,s}$ represents the shadow fading with a standard deviation $\sigma_s$. Also, the actually measured value of the RSS from the serving BS, denoted by $P_m[k]$, can be expressed as follows:

$$P_m[k] = P_t[k] - \alpha - \beta \log_{10}(d_m[k]) - \psi_{dB,m}$$  (5)

where $d_m[k]$ denotes the actual distance between the serving BS and the MS and $\psi_{dB,m}$ represents the shadow fading with a standard deviation $\sigma_m$ whose value may be different from $\sigma_s$ to reflect the difference between the estimated and measured values of the RSS.

To generate a reasonable comparison metric, let $x_{i,k}$ be the RSS difference between the measured and estimated values at time $k$ when the sample vector $\hat{v}_{s(i),k}$ is used. Then, $x_{i,k}$ can be expressed as follows:

$$x_{i,k} = P_i[k] - P_m[k] = \beta \log_{10}(d_i[k]/d_m[k]) - \psi_{dB,s} + \psi_{dB,m}$$  (6)

Here, we can find that $x_{i,k}$ is a normally distributed random variable, because $P_i[k]$ and $P_m[k]$ are independent and modelled by the log-normal shadowing. Thus, its probability distribution can be written as follows:

$$x_{i,k} \sim N\left(\beta \log_{10}(d_i[k]/d_m[k]), \sigma_s^2 + \sigma_m^2\right)$$  (7)

As a result, we suggest a comparison metric for each sample vector that is formed by averaging the square of $x_{i,k}$ during observation time $K$. Thus, if the comparison metric for the $i$-th sample vector has the smallest value, it indicates that the $i$-th sample vector most properly describes or approximates the actual motion of the MS in a probabilistic sense. The comparison metric $y_i$ for the $i$-th sample vector can be written as follows:

$$y_i = \frac{1}{K} \sum_{j=1}^{K} \frac{x_{i,j}^2}{\sigma_s^2 + \sigma_m^2} = \frac{\sum_{j=1}^{K} \left(\frac{x_{i,j}}{\sqrt{\sigma_s^2 + \sigma_m^2}}\right)^2}{\psi_i}$$  (8)

By examining the known probability distribution of $x_{i,k}$ and the form of the comparison metric in (8), we can find that $y_i$ is a random variable having the noncentral chi-square distribution [10], because it is the sum of the square of the $K$ independent random variables whose probability distribution is represented in (7). Thus, the probability distribution of $y_i$ is as follows:

$$y_i \sim \chi^2(K)$$

where

$$\lambda = \frac{1}{\sigma_s^2 + \sigma_m^2} \sum_{j=1}^{K} \left(\frac{\beta \log_{10}(d_i[j]/d_m[j])}{\sigma_s^2 + \sigma_m^2}\right)^2$$  (9)

In (9), $K$ specifies the degree of freedom, or the observation time, and $\lambda$ is the parameter related to the mean. Note that for the noncentral chi-square random variable, the mean and variance are $K + \lambda$ and $2(K + 2\lambda)$, respectively [10].

With the assumption that each neighbor M-BS is positioned in the direction corresponding to each sample vector, scanning priority can be set as an increasing order of the comparison metric. Since we know the probability distribution of the comparison metric in (9), the number of scanning trials required to detect a suitable target M-BS for handoff can be calculated in advance. For example, Fig. 2 shows the probability distribution of each comparison metric when $U = 4$ sample vectors are generated. If the marked distribution represents the distribution formed by desired sample vector, which leads to select a correct target M-BS, the number of scanning trials denoted by $N_s$ can be obtained as follows:

$$N_s = \sum_{u=1}^{U} uP_u$$  (10)

where $u$ and $P_u$ denote the number of scanning trials and corresponding probability, respectively. According to the probability distribution of the comparison metric in (9) and the illustration in Fig. 2, $P_u$ can be calculated as follows:

$$P_1 = \Pr\{Z < z_1\} = F(z_1), \quad \text{for } u = 1$$

$$P_u = \Pr\{z_{u-1} \leq Z < z_u\} = F(z_u) - F(z_{u-1}), \quad \text{for } 2 \leq u \leq U$$

$$P_U = \Pr\{Z \leq z_U\} = 1 - F(z_{U-1}), \quad \text{for } u = U$$  (11)

In (11), $F(z)$ represents the cumulative distribution function of comparison metric $Z$ for the desired sample vector and each $z_t$ represents the intersection point of the distributions for the desired sample vector and the other sample vectors, as shown in Fig. 2. If the value of the comparison metric for the desired sample vector lies within the interval $Z \in [0, z_1)$,
it has the largest probability to be the minimum among all the comparison metrics. Thus, the M-BS corresponding to the desired sample vector gets the first priority for scanning. In a similar way, in the case of \( Z \in \{ z_1, z_2 \} \), the M-BS gets the second priority for scanning, and so on. Consequently, we can expect the number of scanning trials by performing the weighted summation of the scanning priority \( u \) for the correct target M-BS and the corresponding probability \( P_u \), as described in (10).

III. PERFORMANCE EVALUATION

The simulation environment for performance evaluation is illustrated in Fig. 3. We consider a serving M-BS and six neighbor M-BSs that are moving in a certain direction. In this situation, an MS connected to the serving M-BS tries to detect a suitable target M-BS for handoff. To further investigate the effect of the motion of the MS, both the simple mobility, which has the fixed speed and direction, and the random waypoint mobility [11], which changes the speed and direction at a random time interval are applied. Some related parameters for the simulation are listed in Table I.

Here, we adapt the interruption time caused by performing a scanning process as a main performance indicator. The number of scanning trials that we have analyzed in the previous section can be mapped into interruption time \( T_{in} \) according to following equation [12]:

\[
T_{in} = 10 + 40 + 20 N_s \quad (ms) \quad (12)
\]

where 10 ms is the interruption time caused when the MS changes its frequency band from the serving M-BS to the target M-BS and 40 ms is the time required to exchange information for scanning between the serving M-BS and the MS. In addition, 20 ms is the scanning latency generated to measure downlink signal from a neighbor M-BS and \( N_s \) denotes the number of scanning trials.

When a conventional method is used, neighbor M-BSs are scanned in an arbitrary order, because there is no such mechanism to assign the scanning priority. So, each neighbor M-BS has the same probability to be scanned and the interruption time can be calculated as follows:

\[
T_{in,c} = 10 + 40 + 20 \sum_{i=1}^{M} \frac{i}{M} \quad (ms) \quad (13)
\]

where \( M \) denotes the total number of neighbor M-BSs. On the other hand, when a proposed method is used, the derivation of the scanning priority for the neighbor M-BSs can be possible by using comparison metric. Thus, unnecessary scanning trials for the neighbor M-BSs that are moving away from the MS may be effectively avoided. Therefore, the interruption time could be reduced. Then, we now examine performance gain with respect to the interruption time for several different parameters.

Fig. 4 shows the interruption time over different values of the observation time \( K \) for the cases that the conventional method and the proposed method are used. Both the simple mobility and the random waypoint mobility are applied to test more realistic situation. Basically, we can notice that the proposed method provides a smaller amount of the interruption time compared to the conventional method. In particular, the proposed method has the performance gain of about 30.6 % for the simple mobility and 15.2 % for the random waypoint mobility when \( K = 10 \). The reason for this result is that the motion of the MS and the M-BS is considered when the scanning priority is determined. As the observation time becomes longer, the interruption time is continuously decreased when the simple mobility is applied. It is because the variance of the comparison metric has a smaller value for larger \( K \), so more accurate estimation of the relative motion between the MS and the M-BS can be conducted. However, if the random waypoint mobility is applied, the interruption time keeps the same value when \( K > 10 \). In this case, the MS randomly changes its speed and direction at an arbitrary time interval. Consequently, the effective observation time for detecting the motion of the MS is randomized. Thus, we can find that the interruption time is eventually saturated.

![Fig. 3. Simulation environment for performance evaluation](image-url)
To investigate the robustness of the proposed method, the interruption time over the standard deviation of shadowing $\sigma_m$ is represented in Fig. 5. Although the channel variation due to shadow fading is high, the proposed method still has performance gain. For example, we can see a performance gain by about 32.0 % for the simple mobility and 15.1 % for the random waypoint mobility when $\sigma_m = 10$ dB. Particularly, there is little change in view of the interruption time when the random waypoint mobility is applied. It means that the proposed method is more dependent on the observation time than the channel variation as the motion of the MS tends to be random.

Next, the effect of the estimation error between the actual speed of the MS whose value is set to 60 km/h in this simulation and the estimated speed $v_s$ of the MS is examined in Fig. 6. We vary the estimated speed $v_s$ from 10 km/h to 120 km/h. The minimum interruption time is obviously achieved when the estimated speed is close to the actual speed. In addition, the performance gain is shown as 14.7 % for the simple mobility and 8.8 % for the random waypoint mobility in the case of $v_s = 90$ km/h. These values of the gain are about a half of the gain when there is no estimation error, or $v_s = 60$ km/h. However, the proposed method still outperforms the conventional method even though the estimation error exists.

Finally, we look into the interruption time over the speed of the M-BS. As shown in Fig. 7, the interruption time is decreased until $v_m = 50$ km/h and keeps similar values when $v_m > 50$ km/h. This phenomenon is observed because the proposed method is designed based on the periodic measurement of the RSS. Note that each value of the RSS is more clearly distinguished when there is enough distance between two measurement locations. So, the comparison metric gives more reliable information for a certain level of the moving speed of the M-BS. In addition, the proposed method tends to have the same gain as the conventional method when the relative motion between the MS and the M-BS is small, because each comparison metric has a similar value. Thus, the small amount of the gain is observed in the case of $v_m = 10$ km/h. Therefore, we can see that the proposed method is suitable in the environment where the relative motion between several
movable network entities and users should be taken into account to develop proper scanning and handoff mechanisms.

IV. CONCLUSIONS

In this paper, we have developed an efficient scanning algorithm in the consideration of an M-BS, which is introduced in order to support highly flexible network mobility. Through an RSS measurement and the suitable design of comparison metric for estimating the relative motion of a serving M-BS and an MS, a substantial amount of reduction in interruption time, which is generated during scanning process, could be achieved. Thus, we are expecting that the proposed algorithm gives desirable effects on the performance of the scanning process with respect to the accurate and seamless detection of a target M-BS for handoff and the save of the power consumption required in this process. Especially, the usefulness of the proposed algorithm is substantially recognized in the military tactical networks where a central node for managing communications is carried on fast ground vehicles or unmanned aerial vehicles.

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