
Jung-Min Moon, Student Member, IEEE, and Dong-Ho Cho, Senior Member, IEEE

Abstract—We consider a wireless communication environment in which a large number of local area cells are deployed within the coverage of wide area cells. In this environment, a scanning operation to detect a suitable local area cell for handoff can degrade the performance of a mobile station, because repeated scanning trials are likely to cause disruption of service and require considerable consumption of power. Therefore, we propose and analyze a hierarchical scanning algorithm that is capable of providing MS-specific neighbor cell information. Simulation results show that the proposed algorithm can significantly reduce the number of scanning trials required to detect a suitable local area cell for handoff.

Index Terms—Scanning, handoff, neighbor cell information, received signal strength, cell overload probability.

I. INTRODUCTION

In next generation wireless networks, the technical capability for both mobile and nomadic access will be integrated to support various services and applications. In planning for the development of these systems, it is expected that two different kinds of cell, or BS, will be deployed. The first is the wide area cell, in which data rates of up to 100Mbps for MSs moving at high speed will be supported. The second is the local area cell, in which data rates of up to 1Gbps for MSs that are static or moving very slowly will be supported [1]. Especially in areas where applications with a high data rate are used, numerous local area cells may be deployed. In this circumstance, a scanning operation to detect a suitable local area cell for handoff will take a long time because of the large number of cells to be scanned. It causes several problems, such as increasing handoff latency, imposing a large buffer size, and wasting battery power [4][5].

Much research has been done on reducing the time spent in the scanning operation [2][3][4][5]. Although this research aimed at scheduling and controlling the scanning operation as effectively as possible, environments in which a large number of cells are deployed were not taken into account.

Therefore, we propose a hierarchical scanning algorithm that is capable of providing MS-specific neighbor cell information even in environments where numerous local area cells are deployed. The key idea is to reduce the set of BSs to be scanned by indicating the first BS whose signal is received strongly by the MS. In addition, the probability that the cell may experience overload is utilized to avoid unnecessary scanning trials for overloaded cells. We here present an analytical model for the proposed algorithm and evaluate its efficiency in terms of the number of scanning trials required to detect a suitable local area cell for handoff.

II. HIERARCHICAL SCANNING ALGORITHM

The overall procedure of the hierarchical scanning algorithm is shown in Fig. 1. We assume that the serving BS of the wide area cell has a functionality to manage local area cells in its coverage. Thus, it can broadcast a MOB_NBR-ADV message that contains information required to identify local area cells for handoff. In order to prevent the size of messages from increasing, a set of local area cells that are located uniformly in the wide area cell is included in the message.

The proposed algorithm consists of two steps. In the first step, the MS attempts to find any BS in which the measured value of the received signal strength (RSS) is greater than a pre-defined threshold. The objective in this step is to indicate the BS (called the post BS in this letter) that can be utilized to provide neighbor cell information corresponding to each MS’s own situation. Note that the post BS is one of the BSs whose information is included in the MOB_NBR-ADV message. Thus, the generation of MS-specific neighbor cell information can be achieved by indicating the post BS.

In the second step, the MS informs the serving BS of its post BS. Then, the serving BS provides information of the local area cells that are located near to the post BS. This information is provided by sending a NOM_SCN-REQ and NOM_SCN-RSP message, which are newly introduced. These terms represent a scanning request and response for nomadic access, respectively. In addition, the load information of each
cell is included in the NOM_SCN-RSP message. Thus, the MS tries to scan the non-overloaded cells first and performs a full scan if there is no suitable cell among them.

### III. ANALYTICAL MODEL FOR PROPOSED ALGORITHM

First, we examine the property of the RSS during the scanning operation. We assume that the MOB_NBR-ADV message contains the information of $m_{bs}$ BSs. Let the random variable $X$ denote the RSS from any BS in the MOB_NBR-ADV message evaluated at an arbitrary location of the MS. Here, we discover an interesting property of $X$ as follows.

- The probability distribution of $X$ can be approximated by a Rayleigh distribution with a parameter $\beta$ and an offset $x_o$, that have effects on the mean and variance of $X$.

$$f_X(x) \approx \frac{x-x_o}{\beta^2} \exp\left\{-\frac{(x-x_o)^2}{2\beta^2}\right\} \quad (1)$$

Fig. 2 shows the comparison between the probability density functions (PDFs) obtained from a simulation and the Rayleigh distribution. The simulation was performed in such a way that the RSS from all the BSs in the MOB_NBR-ADV message is measured at all possible locations in the wide area cell.

According to the observation of Fig. 2, the right side tail of the PDF can be well approximated to the Rayleigh distribution. Note that the right side tail is formed by a set of BSs whose signal is received strongly by the MS. Since they must be the candidates for handoff, the approximation should well model the right side tail. In this respect, we can conclude that the RSS from an arbitrarily chosen BS can be modelled as a Rayleigh-distributed random variable. In addition, the PDF in case (b), when $m_{bs} = 9$, is shifted to the left compared to case (a), when $m_{bs} = 4$. This occurs because the number of BSs far from the MS is increased, while that close to the MS remains the same. Thus, the value of $x_o$, which decides the mean or amount of shift, becomes larger in case (b). However, $\beta$ has the same value since we are assuming uniformly located local area cells in the wide area cell, so the variance is not changed. Based on this new property of the RSS, the analytical model for expecting the number of scanning trials is developed.

Let $P_{sen,1}$ denote the probability that a post BS is indicated at the first scanning trial and $x_{sen}$ be the receiver sensitivity of the MS, which is used as the threshold in the first step. By using the PDF of $X$, which is approximated to the Rayleigh random variable, $P_{sen,1}$ can be written as follows:

$$P_{sen,1} = \Pr\{X \geq x_{sen} \mid 1\text{st trial}\} = 1 - F_X(x_{sen}) = \exp\left\{-\frac{(x_{sen}-x_o)^2}{2\beta^2}\right\} \quad (2)$$

If the MS fails to indicate a post BS at the first scanning trial, the probability of indicating a post BS at the second trial will be increased because the number of BSs to be scanned is decreased by one. So, the probability of indicating a post BS at the $i$-th trial denoted by $P_{sen,i}$ can be expressed as follows:

$$P_{sen,i} = \Pr\{X \geq x_{sen} \mid i\text{-th trial}\} = P_{sen,1} \left(1 - P_{sen,1}\right)^{c(i/m_{bs})}, \quad \text{for } 2 \leq i \leq m_{bs} \quad (3)$$

where $c$ denotes the controlling factor, which determines how fast the probability in (3) is increased. For example, in the case of $c = 1$, it is linearly increased and in the case of $c > 1$, it is exponentially increased.

As a result, we define the discrete random variable $M$ that represents the number of scanning trials until the MS indicates its post BS. The PDF of $M$ can be written as follows:

$$h_{sen}(m) = \begin{cases} P_{sen,1}, & \text{for } m = 1 \\ \prod_{u=1}^{m-1} (1 - P_{sen,u}) P_{sen,m}, & \text{for } 2 \leq m \leq m_{bs} \end{cases} \quad (4)$$

Equation (4) is concerned mainly with the property of the RSS and it corresponds to the analytical model for expecting the number of scanning trials in the first step.

Next, we examine the utilization of load information in the scanning operation. Let the random variable $Y$ denote the cell load, which is defined by a percentage of the resources that are currently in use. A truncated normal distribution on $[0, 1]$ is adapted to characterize $Y$ and its CDF is denoted by $F_Y(y)$. Thus, we can compute the cell overload probability denoted by $P_{over}$ for the threshold $y_{th}$.

$$P_{over} = \Pr\{Y \geq y_{th}\} = 1 - F_Y(y_{th}) \quad (5)$$

Let the discrete random variable $L$ denote the number of non-overloaded cells in the NOM_SCN-RSP message. If the message contains information about $n_{bs}$ BSs, the PDF of $L$ can be written as follows:

$$\Pr\{L = j\} = \binom{n_{bs}}{j} (1 - P_{over})^j (P_{over})^{n_{bs} - j} \quad (6)$$

In order to consider a local area cell as a target cell for handoff, two conditions must be satisfied: (i) The RSS should be greater than a pre-defined threshold and (ii) the cell should not be overloaded. According to the proposed algorithm, a full scan is performed if the MS fails to detect a target cell among the non-overloaded cells. Thus, we can obtain the PDF of the number of scanning trials in the second step, given that there are $L$ non-overloaded cells.

$$h_{act\mid L=j}(n) = \begin{cases} P_{act,1}, & \text{for } n = 1 \\ \prod_{u=1}^{n-1} (1 - P_{act,u}) P_{act,n}, & \text{for } 2 \leq n \leq j \\ \prod_{u=1}^{n} (1 - P_{act,u}), & \text{for } n = n_{bs} \end{cases} \quad (7)$$

where $P_{act,i}$ is defined as (3) using the different threshold $x_{act}$, which is greater than the receiver sensitivity $x_{sen}$.
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The simulation scenario was as follows. The MS indicated its post BS using the MOB_NBR-ADV message and decided a target cell for handoff using the additional information in the NOMSCAN-RSP message. In this simulation, we set the transmit power of each local area cell to 26dBm, the threshold of RSS in the first step $s_{sen}$ to $-90$dBm, and that in the second step $x_{act}$ to $-80$dBm. In addition, $y_{th} = 0.85$ was used for the threshold of cell load.

IV. SIMULATION RESULTS

The simulation scenario was as follows. The MS indicated its post BS using the MOB_NBR-ADV message and decided a target cell for handoff using the additional information in the NOMSCAN-RSP message. In this simulation, we set the transmit power of each local area cell to 26dBm, the threshold of RSS in the first step $s_{sen}$ to $-90$dBm, and that in the second step $x_{act}$ to $-80$dBm. In addition, $y_{th} = 0.85$ was used for the threshold of cell load.

Thus, the number of scanning trials in the second step can be written as follows using the discrete random variable $N$:

$$h_{\text{act}}(n) = \sum_{j=1}^{n_{\text{act}}} h_{\text{act}}(L=j)(n) Pr(L = j) \quad (8)$$

Finally, let the discrete random variable $K$ represent the total number of scanning trials in the proposed algorithm. The value of $K$ can be simply obtained by adding two discrete random variables, $M$ and $N$, that are involved in the first and second steps of the proposed algorithm, respectively.

$$K = M + N \quad (9)$$

The PDF of $K$ is equal to the convolution of the PDF of $M$ and $N$ as follows, because they are independent discrete random variables and $K$ is equal to the sum of $M$ and $N$.

$$h_{K}(k) = (h_{\text{sen}}*h_{\text{act}})(k) = \sum_{u=-\infty}^{\infty} h_{\text{sen}}(u) h_{\text{act}}(k-u) \quad (10)$$

Equation (10) represents the analytical model for expecting the total number of scanning trials when the proposed algorithm is applied. The model validation and performance evaluation are explained in the next section.

V. CONCLUSIONS

We have studied a hierarchical scanning algorithm for the purpose of reducing the number of scanning trials. MS-specific neighbor cell information can be generated by indicating a post BS. In addition, the analytical model for the proposed algorithm was developed based on an interesting property of RSS, which can be approximated as the Rayleigh random variable. Simulation results showed the efficiency of the proposed algorithm, in respect that the MS can detect a suitable local area cell for handoff through a smaller number of scanning trials compared to the non-hierarchical algorithm.

REFERENCES