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# Speed-Sensitive Handover Scheme over IEEE 802.16 Multi-Relay Networks

DongHo Kim*, SoonSeok Kim* and YongHee Lee*

**Abstract**—Multi-Relay Networks should accommodate mobile users of various speeds. The cellular system should meet the minimum residency time requirements for handover calls while considering an efficient use of available channels. In this paper, we design speed-sensitive handover under dynamic hierarchical cellular systems, in which mobile users are classified according to the mean speed of mobile users and each class has its cellular layer. In order to meet the minimum residency time, the cell size of each cellular layer is dynamically determined depending on the distributions of mean speeds of mobile users. Since the speed-dependent non-preferred cell can provide a secondary resource, overflow and take-back schemes are adopted in the system. We develop analytical models to study the performance of the proposed system, and show that the optimal cell size improves the blocking probability.

**Keywords**—Multi-Relay Networks, Handover

## 1. INTRODUCTION

The existing IEEE 802.16 is a series of Wireless Broadband standards known as WiMAX as an important technology for providing high-speed Internet access to home and business subscribers in a wide area cellular network[1]. Handover is a key factor for the quality of wireless communication services. Due to the geographical problem, significant data loss occurrs, the coverage region for high data rates is decreased, and even dead spot areas in the coverage region occurr. IEEE 802.16j adopts multihop or relay technologies in order to eliminate dead spot areas and extend the coverage region. In IEEE 802.16j networks, the Relay Stations (RSs) relay signaling and data messages between the Multihop Relay BS (MR-BS) and the Mobile Station (MS)[2, 3]. Therefore, handover issues for the RS on IEEE 802.16j have been carried out[4].

The increasing demands for mobile communications are proceeding with a strong tendency toward increasing need for high traffic capacity and mobility in the access links within the wireless links[5, 6]. Since the micro-cell of the micro-cellular systems makes an efficient use of available channels by using low-power transmitters to allow channel reuse at much smaller distances, the micro-cellular systems with an extremely small cell radius can meet the traffic demand[7, 8]. However, the micro-cell increases the number of cell boundary crossings for high-mobility users, and the increasing handover rates of ongoing calls may cause an excessive processing load in the network. Furthermore, the handover calls of fast-moving users cannot meet

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the minimum residency time requirements for each handover call that must perform a handover procedure within the cell. The macro-cellular systems with a larger cell radius can meet the need of the high mobility. But, the macro-cell of the macro-cellular systems requires high-power transmitters and cannot meet the traffic demand. Therefore, it seems natural that interest in the micro-cellular systems with hierarchical macro-cell overlays has emerged for enhancing the traffic capacity and accommodating the fast-moving users.

IEEE 802.16j should accommodate MSs of various speeds. Unfortunately, most of the contributions do not consider the speeds. In this paper, we propose speed-sensitive handover for IEEE 802.16j multi relay networks. IEEE 802.16j provides a cellular system in which the RS region is the micro-cell and the MR-BS region is the macro-cell.

Each optimal cell size in multi-tiered cells, speed-sensitive cell selection methods and procedures for new calls and handover calls should be defined to reduce the forced termination of calls and to provide multiple service coverage and load-balancing capability for various mobility classes in the hierarchical systems. We must make a decision determining whether requests of the new calls and the handover calls should go to the RS or the MR-BS. The cell selection method is crucial to the performance of a hierarchical cellular system, since the micro-cell cannot meet the minimum residency time requirements and this may direct the calls of a fast-moving MS to the micro-cell, and the macro-cell cannot provide the resources for the calls of a slow-moving MS and this may direct the calls to the micro-cell. From this perspective, in this paper we design a speed-sensitive handover protocol for IEEE 802.16.

The rest of this paper is organized as follows: In section 2, we will describe the system models. In section 3, we will analyze the total handover time and the optimal cell size considering the mean speed of mobile users. We will propose a speed-sensitive handover protocol and analyze the performance of the blocking probability in the speed-sensitive handover in section 4. Finally, section 5 will conclude the paper.

## 2. SYSTEM MODEL

To provide a speed-sensitive handover for IEEE802.16 networks, we consider the hierarchical cellular structure of IEEE 802.16 networks. Fig. 1 shows the structure. The MR-BS cell overlays the RS cells, and an overlaying cell is bigger than an overlaid cell in the hierarchical cellular structure.

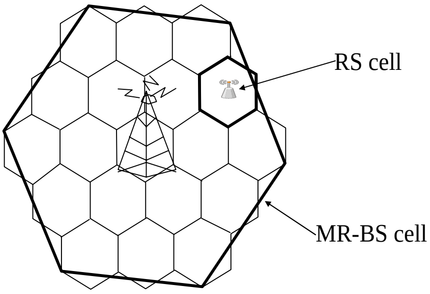


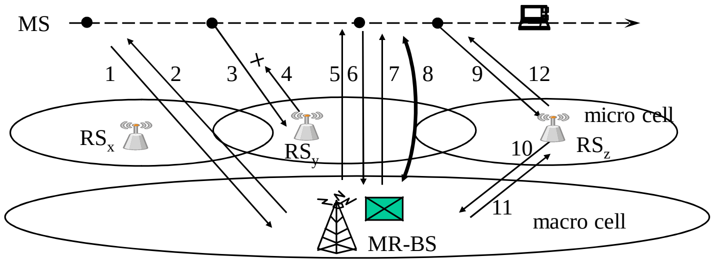
Fig. 1. The hierarchical cellular structure of an IEEE 802.16 network for speed-sensitive handover

There are two types of handover. The handover between the same cellular layer is called an intra-layer handover, and the handover between different cellular layers is called an inter-layer handover. Handover between a MR-BS and a RS is an inter-layer handover, and the other handover is an intra-layer handover. MR-BS determines whether an incoming handover is an intra-layer handover or inter-layer handover.

## 2.1 Inter-layer handover

An intra-layer handover fails when a target cell cannot provide channels due to a shortage of channels, or when an MS leaves the target cell before a handover procedure for the MS is completed. The inter-layer handover can solve these problems; an MR-BS prevents the intra-layer handover and permits the inter-layer handover.

Fig.2 shows the scenarios of a speed-sensitive inter-layer handover. When a fast-moving MS sends a HO_REQ message to the MR-BS of a macro-cell under normal conditions, the MR-BS returns a HO_RSP message to the MS via the current serving $RS_x$, which includes a blocked result. When a fast-moving MS sends a HO_REQ message for the $BS_y$ to the MR-BS, the MR-BS returns a HO_RES message to the MS which includes a blocked result. The MS may lose its current radio link, and the MR-BS can detect the status of the MS. Then the MR-BS returns a HO_RSP message to the MS which includes a success result, and initiates the handover ranging and association procedures. After the inter-layer handover, if the MS enters the $RS_z$ cell, the MS can receive the HO_RSP message for the $RS_z$ from the MR-BS which includes success results, and then another inter-later handover can be possible.



1 HO_REQ
2 HO_RSP(blocked)
3 HO_REQ
4 HO_RSP(fail)
5 HO_RSP(success)
6 ASSOCIATE_REQ
7 ASSOCIATE_RSP
8 Resume Data TX
9,10 HO_REQ
11,12 HO_RSP(blocked or success)

Fig. 2. MR-BS determines whether an incoming handover is an intra-layer handover or inter-layer handover

## 2.2 Intra-layer handover

Fig.3 shows the intra-layer handover control message flow between RSs. An MS monitors the beacon messages, which are periodically broadcasted by all neighboring RSs. In addition to indicating the signal strength from the RSs, the beacon messages contain the residual capacity currently available at the RSs.

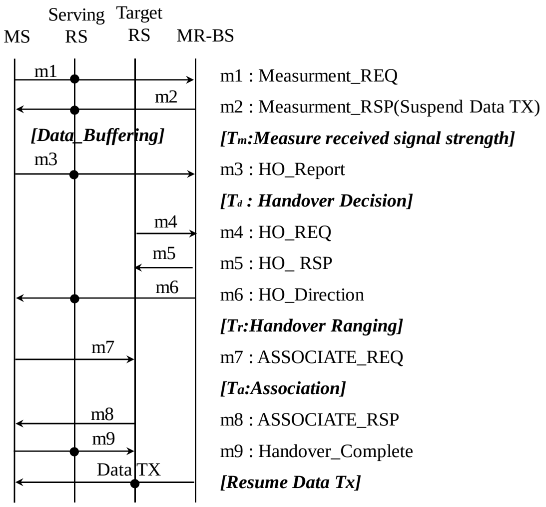


Fig. 3. Intra-layer handover control message flow

## 3. OPTIMAL CELL SIZE FOR SPEED-SENSITIVE HANDOVER

### 3.1 Inter-layer handover

In order to analyze the performance of the handover scheme, we calculate the total handover time $T_H$, which is the total time needed to perform handover procedure shown in Fig.3. $T_H$ is given by

$$T_H = \sum_{i=1}^{9} M_i + T_m + T_d + T_r + T_a \tag{1}$$

where $M_i$ is the time spent in performing Message(i) in Fig.3.

The time to send a message, $M_i$, consists of transmission time $\alpha_i$, propagation time $\beta_i$, and processing time $\gamma_i$ for the control message.

$$M_i = \left( \alpha_i = \frac{M_s}{L_r} \right) + \beta_i + \gamma_i \tag{2}$$

Messages (1), (2), (3), (6), (7), (8) and (9) may require retransmissions due to the losses over the wireless link. $n_f$ is the number of failures before the first success in a sequence of independent Bernoulli trials with probability $q$ of failures on each trial. Then

$$T_i = M_i, \qquad i = 4,5 \tag{3}$$

$$T_i = \sum_{n_f=0}^{\infty} T_i(n_f) * q^{n_f} (1-q), \qquad i = 1,2,3,6,7,8,9 \tag{4}$$

Table 1. System parameters

| | | |
|---|---|---|
| Bit Rates ($L_r$) | Wireline Link<br>Wireless Link | 155 Mbps<br>10 Mbps |
| Propagation Times ($\beta$) | Wireline Link<br>Wireless Link | 500 $\mu$sec<br>1 msec |
| Processing Time ($\gamma$) | MR-BS<br>RS | 0.5 msec<br>0.5 msec |
| Miscellanies | Measure received signal strength ($T_m$)<br>Handover Decision ($T_d$)<br>Handover Ranging($T_r$)<br>Association($T_a$)<br>Message Size ($M_s$)<br>Link Failure Probability ($q$) | 5 msec<br>0.5 msec<br>20 ms<br>50 ms<br>50 bytes<br>0.5 |

$$\text{Where } T_i(n_f) = M_i + n_f * (T_w + M_i), \qquad i = 1,2,3,6,7,8,9 \tag{5}$$

Consequently,

$$T_i = M_i + (T_w + M_i) * \frac{q}{1-q}, \qquad i = 1,2,3,6,7,8,9 \tag{6}$$

Therefore,

$$T_H = \sum_{i=1,-4,-5}^{9} (T_w + M_i) * \frac{q}{1-q} + (T_4 + T_5) + T_m + T_d + T_r + T_a \tag{7}$$

Table 1 lists the system parameters for calculating the total handover time and the total handover time $T_H$ is given 0.1038sec as result of (7).

## 3.2 Optimal cell size

An MS or MR-BS can determine user mobility from cell sojourn times to select a cell of a micro-cell or a macro-cell size. The sojourn time depends on the distance traveled by an MS or the mean speed of an MS. Since the distance should consider moving direction, changes of direction, shape of cell and point of entry, the distance requires a calculating burden. Therefore, the distance is not of interest. What is of interest is not instantaneous MS speed, which varies continuously, but the mean speed of the mobile over several minutes to present. We then calculate the effect of the mean speed.

Although a handover call generally has higher priority than a new call, for simplicity we assume that a new call is handled exactly in the same manner as a handover call. Consequently, the new call failure probability of the fast-moving MSs is the same as the handover call failure of the fast-moving MSs. We then calculate the probability that handover calls will fail due to the MS leaving the cell before handover procedure can be completed.

In the development of the analytical model we introduce the following assumptions:

- The cells of the same size are all identical hexagonal cells.
- Call service time and cell residence time follow exponential distributions with mean $1/\mu$ and $1/\eta$, respectively.

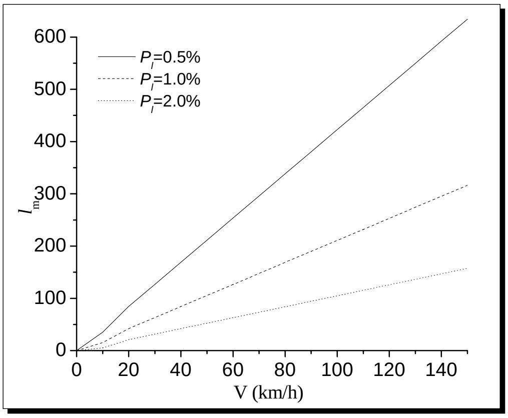


Fig. 4. Minimum length $l_m$ for one side of a cell for restricting $P_l$

We will use a simple flow-based model [9] that assumes mobile terminals are uniformly distributed in a cell and the direction of movements of each MS with a mean speed of $V$ direction is uniformly distributed on $[0, 2\pi]$. The call handover rate $\eta$, of an MS into the target cell is given by

$$\eta = \frac{VL}{\pi S} = \frac{2V}{\pi l \sin(\pi/3)} \tag{8}$$

Where $L$ is the length of the perimeter of a cell, $S$ is the cell area, and $l$ is the length of the one side of the hexagonal shaped cell.

Let $T$ be a random variable of time to the next consecutive handover. We assume that $T$ is exponentially distributed, thus the failure probability $P_l$ that an MS leaves the cell before the total handover time $T_H$ is given by

$$P_l = P[T < T_H] = 1 - e^{-\eta T_H} \tag{9}$$

From (1) and (2), the minimum length $l_m$ of one side of a cell is given by

$$l_m = \frac{2VT_H}{\pi \log\left(\frac{1}{1-P_l}\right)\sin\left(\frac{\pi}{3}\right)} \tag{10}$$

Fig.4 shows minimum length $l_m$ of one side of a cell, which sustains the probability $P_l$, when the mean speed of MSs is changing. We can see that higher mobility requires larger length of the perimeter of a cell in order to sustain the same probability $P_l$.

## 4. PROPOSED SCHEME

In this section, we will propose a dynamic hierarchical cellular system for the speed-sensitive handover and analyze the performance of blocking probabilities in the hierarchical cellular system.

## 4.1 Dynamic Hierarchical Cellular System

Fig.5 shows a dynamic hierarchical cellular system where a layer-1 cell is referred to as the MR-BS cell and a layer-0 cell is referred to as the RS cell. For simplicity, we assume that the cells of the same cellular layer have all identical cell size. A layer-1 overlays $O_i$ layer-0 cell. The total number of channels allocated to a cell of layer-i is $m_i$. The layer-0 and layer-1 of the system operates as follows:

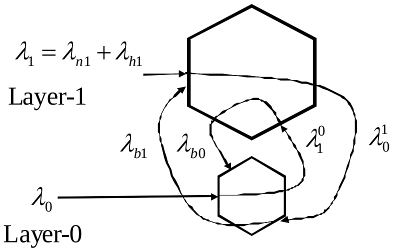


Fig. 5. Dynamic hierarchical cellular system

- New calls of $MS_i$ (arrival rate $\lambda_{ni}$) are first directed to a cell of layer-*i*. If the cell cannot provide traffic channels for a new call, since layer-*i*-1 makes more efficient use of available channels than layer-*i*, the call can be overflowed into an overlaid cell of layer-*i*-1. The overflowed new call can be served in the overlaid cell, if the overlaid cell can provide traffic channels for the call. Otherwise, the call will be lost.
- Handover calls of $MS_i$ (arrival rate $\lambda_{hi}$) are first directed to a cell of layer-*i*. If the cell cannot provide traffic channels for a handover call, the handover call can be overflowed into an overlaid cell of layer-*i*-1. The overflowed handover call can be served in the overlaid cell, if the overlaid cell can provide traffic channels for the handover call. Otherwise, the handover call will be lost.
- All the successfully overflowed calls can be taken back to a preferred cell when the MS of calls is crossing the boundary of any cell.

## 4.2 Performance Analysis

Consider the overflow and take-back traffic model shown in Fig.5. In the development of the analytical model we introduce the following assumptions:

- The cells of layer-*i* are all identical hexagonal cells with one side length $l_i$.
- New calls of $MS_i$, which were first directed to the cell of layer-*i*, arrive at a Poisson process with mean $\lambda_{ni}$.
- Call service time follows exponential distributions with mean $1/\mu$.
- Cell residence time of layer-*i* follows exponential distributions with mean $1/\eta_i$.

The blocking probability $P_{bi}$ of new calls and handover calls is given by the Erlang loss formula.

$$P_{b0} = \frac{\dfrac{\left(\lambda_{t0}/\mu_0 + \lambda_{t0}^{(1)}/\mu_0^{(1)}\right)^{m_0}}{m_0!}}{\displaystyle\sum_{j=0}^{m_0} \frac{\left(\lambda_{tj}/\mu_j + \lambda_{t0}^{(1)}/\mu_0^{(1)}\right)^{j}}{j!}} \tag{11}$$

$$P_{b1} = \frac{\dfrac{\left(\lambda_{t1}/\mu_1 + \lambda_{t1}^{(0)}/\mu_1^{(0)}\right)^{m_1}}{m_1!}}{\displaystyle\sum_{j=0}^{m_1} \frac{\left(\lambda_{t1}/\mu_1 + \lambda_{t1}^{(0)}/\mu_1^{(0)}\right)^{j}}{j!}} \tag{12}$$

Where $\lambda_{ti}$ is the aggregate traffic rate considering the take-back traffic rate into a cell of layer-*i* due to MT$_i$s, and $\lambda_{ti}^{j}$ is the aggregate traffic rate into the cell of layer-*i* due to MT$_j$s. $\mu_i$ is the service rate of MT$_i$s in a cell of layer-*i, and* $\mu_i^{j}$ is the service rate of MT$_j$s in the cell of layer-*i*.

From the user's point of view, the dropping probability $P_{di}$ that an accepted new call is eventually forced into termination is more important than the loss probability. We will use the dropping probability $P_{di}$ instead of the blocking probability from now on. $P_{hi}$ is the handover probability of calls of MS$_i$s in a cell of layer-*i*.

$$P_{di} \approx \frac{P_{hi} P_{b0} P_{bi}}{1 - P_{hi}\left(1 - P_{bi}\right)} \tag{13}$$

### 4.3 Numerical Results

We evaluate the performance of the dynamic hierarchical cellular system, and present numerical results. The system has cellular layer-0 and layer-1 for simplicity. We assume that new arrival rates are all identical for all cells in the same cellular layer, and that there is a rate of $\sigma$ fast-moving new calls per slow-moving new calls in the same region. When the mean speed of an MS$_1$ is 120km/h, the length of one side of layer-1 cell $l_1$ is 600m.

Fig.6~Fig.7 shows the variation of the dropping probability $P_{di}$ with the new call arrival rate $\lambda_{n0}$. The figures show that the dropping probability $P_{di}$ increases with an increase in the $\lambda_{n0}$ or with an increase in the mean speed of an MS$_1$. The figures also show the dropping probability $P_{d0}$ increases more slowly with an increase in $\sigma$ than the dropping probability $P_{d1}$. When the traffic into the macro-cell increases, the macro-cell cannot provide enough channels and the micro-cells provide channels instead of the macro-cell. Therefore, the figures show that the macro-cell size can little affect the dropping probability $P_{d1}$ at high$\sigma$. The independent in the figures refers to the reference system where the two layers are kept completely independent without overflow and take-back. We can observe from the figures that the dropping probability is reduced by the overflow and take-back scheme in comparison with the independent case.

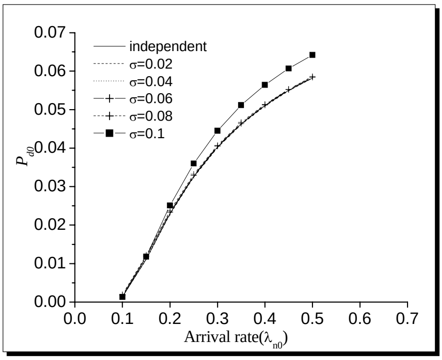


Fig. 6. Probability $P_{d0}$ when the speed of an $MS_1$ is 120km/h

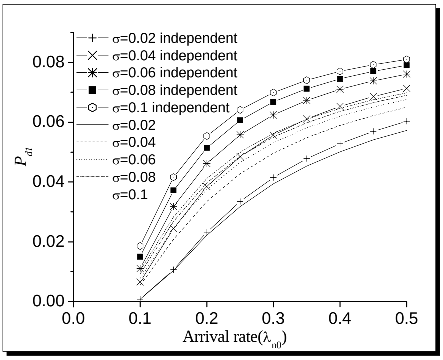


Fig. 7. Probability $P_{d1}$ when the speed of an $MS_1$ is 120km/h

## 5. CONCLUSIONS

In this paper, we have designed speed-sensitive handover protocols over IEEE 802.16 Multi-Relay Networks and have proposed a dynamic hierarchical cellular system for the speed-sensitive handover. We have shown that the failure probability $P_l$ increases with an increase in the mean speed of MSs, while larger macro-cell size decreases the probability $P_l$. Thus, the optimal cell size for a macro-cell is dynamically adjusted depending on the distributions of the mean speed in order to decrease the probability $P_l$. Consequently, there can be none or one or more types of macro-cells according to the distributions of the mean speeds. In the hierarchical cellular system, the speed-dependent non-preferred cell can provide a secondary resource. Therefore, we adopt overflow and take-back schemes in order to increase channel utilization. We calculate the dropping probability of new and handover calls due to the shortage of channels in the system.

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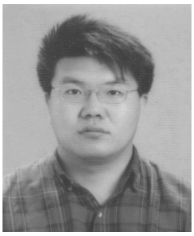

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