Relay Assisted Soft Handover in Multihop Cellular Networks

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ABSTRACT
This paper proposes a relay assisted soft handover in multihop cellular networks. In the relay assisted soft handover, a handover ranging is not required and an association process can be significantly simplified because it is unnecessary to change a serving node during handover process. In the proposed scheme, the handover latency and the service-interruption time caused by handover are reduced by 24% and 86%, respectively, while the capacity loss is only 5.33% compared to a hard handover in multihop cellular networks.

Keywords
Handover, Soft handover, Multihop cellular networks, Handover latency, Service-interruption time.

1. INTRODUCTION
Recently, multihop or relay technologies have been widely considered as supplementary technology in the next generation wireless systems in order to increase the cell radius or cover the shadowing region [1]-[3]. However, application of multihop technologies to cellular networks raises many possible technical issues such as spectrum allocation and multiplexing between a base station (BS) and relay stations (RSs); scheduling; and handover. Especially, the introduction of RS in cellular networks makes additional handover scenarios, and increases the number of handover and signaling overhead. Handover schemes can be divided into intra-cell handovers and inter-cell handovers according to the associated handover regions. Inter-cell handovers cause much larger handover delay and service interruption than intra-cell handovers. Soft handover technologies have been used to mitigate the problems of inter-cell handovers in CDMA systems while it has not been considered in OFDM systems; i.e., IEEE 802.16e, WiMAX or 3GPP LTE [4],[5]. Moreover, the introduction of relay in cellular networks makes worse the problems of inter-cell handovers. A few papers have studied handover issues in relay networks [6],[7]. Reference [6] categorizes the multihop handover schemes according to handover initiation methods, and evaluates the performance of different types of handovers. Reference [7] proposes a relay assisted handover to avoid call drops caused by abrupt channel degradation in hybrid ad hoc cellular systems. However, these works have addressed relay-handover issues only in ad hoc networks. Recently, many technical contributions of IEEE 802.16j deal with handover issues in multihop cellular networks (MCNs) [8]. Unfortunately, most of contributions are based on hard handover and consequently have a limitation to mitigate the inter-cell handover problems in multihop cellular networks.

2. SYSTEM MODEL
To provide a relay assisted soft handover, we consider a new RS deployment structure, called Structure 1, where RSs are placed on the cell boundary between adjacent cells as RS1 in Fig. 1. In Structure 1, RSs are supposed to be synchronized and controlled by adjacent BSs. On the other hand, in the typical MCN structure, RSs are placed inside cells like RS2 and RS3 in Fig. 1, and controlled by a BS. This structure is called Structure 2 in this paper. BSs and RSs are assumed to use same frequency bands and to be coordinated by time division multiplexing. In addition, the frame structure defined in IEEE 802.16j [8] is used in the proposed handover scheme. The channel response for handover decision is assumed to be characterized by path loss and slow log-normal shadowing terms. Fast multipath fading is not considered because a handover decision is usually based on the averaged signal strength for certain duration to prevent ping-pong effects.

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Figure 1. The cell structure for multihop cellular networks
Thus, the channel response between the \( i \)-th MS and the \( m \)-th BS or RS, \( H_{m,i}(d) \), is defined as [9]

\[
H_{m,i}(d)_{(db)} = \eta_{m,i}(d)_{(db)} + \xi_{m,i}(d)_{(db)},
\]

where \( \eta_{m,i}(d) \) and \( \xi_{m,i}(d) \) represent the path loss and slow log-normal fading measured in decibels, respectively.

### 3. RELAY ASSISTED SOFT HANDOVER

#### 3.1 Basic Idea

Application of the multihop concept to cellular networks increases the number of handovers and decreases the handover efficiency. For example, MS2 performs inter-cell hard handover with switching a current serving node from RS2 to RS3 when it moves from cell 2 to cell 3 in Fig. 1. In this case, the handover procedures and signaling are more complicated than in a single-hop cellular network (SCN) because handover procedures are performed via multihop among a MS, RSs, and BSs. To resolve these problems, we propose a relay assisted soft handover (RASH). RASH can be provided by placing RSs like in Structure 1 without supplementary techniques to provide soft handover such as RAKE receivers. Let us suppose that MS1 is currently associated with BS1 and receives data from RS1 in Fig. 1. If a received-signal-strength (RSS) from MS1 becomes larger than from BS1, MS1 performs an inter-cell handover without changing a current serving RS. Note that BS1, which is located on the boundary between BS1 and BS2 and has direct connections with each BS, can assist an inter-cell handover process. It can be remarkably advantageous to simplify inter-cell handover procedures and signaling in MCN. An inter-cell handover in Structure 2 is called a relay assisted hard handover (RAHO) for a comparative study.

#### 3.2 Handover Procedures and Signaling

Figure 2 illustrates the general inter-cell handover procedures and signaling in MCN. All steps are mandatory in RAHO while steps 1, 4, 6, and 7 can be omitted or simplified in RASH. Eight handover steps illustrated in Fig. 2 can be classified into three processes such as measurement, decision, and execution.

In measurement process, a MS periodically measures downlink signal strengths from neighbor BSs or RSs. The measurement process is exactly same in RASH and RAHO. However, Structure 1 can reduce the measurement time because the number of neighbor RSs to be measured is smaller than in Structure 2. After a measurement, a serving BS determines a handover execution and chooses a target node based on the reported measurement results. It is assumed that the handover decision is made by BSs to increase the handover efficiency and reduce the cost of RSs. To decide a handover execution, the difference between the channel responses received at the \( i \)-th MS from two BSs or RSs, \( \Delta_{h_{m_1},h_{m_2}}(d) \), is defined as:

\[
\Delta_{h_{m_1},h_{m_2}}(d)_{(db)} = H_{m_1}(d) - H_{m_2}(d)
\]

\[
= \Delta_{h_{m_1},h_{m_2}}(d) + \Delta_{h_{m_1},h_{m_2}}(d)
\]

where \( \Delta_{h_{m_1},h_{m_2}}(d) \) and \( \Delta_{h_{m_1},h_{m_2}}(d) \) are path loss and long-term channel response differences at the \( i \)-th MS from two BSs or RSs. Compared \( \Delta_{h_{m_1},h_{m_2}}(d) \) with predetermined thresholds, each handover scheme determines a handover execution as follows:

**RASH:** if \( \Delta_{h_{m_1},h_{m_2}}(d) \geq \delta_1 \), an MS performs a handover from BS\( m_1 \) to BS\( m_2 \), where \( \delta_1 \) is a predetermined inter-cell handover threshold. \( \delta_1 \) can be relatively higher than the threshold for RAHO because MSs in handover regions receive only robust control messages from a BS in RASH. It can reduce the total number of inter-cell handovers and ping-pong effect on the cell boundary.

**RAHO:** if \( \left( \Delta_{h_{m_1},h_{m_2}}(d) \geq \delta_2 \right) \land \left( \Delta_{h_{m_1},h_{m_2}}(d) \geq \delta_3 \right) \), an MS performs a handover from RS\( m_1 \) to RS\( m_2 \), where \( \delta_2 \) and \( \delta_3 \) are a predetermined inter-cell handover threshold and a minimum signal strength to prevent an outage, respectively.

Once a handover direction is determined, the serving BS checks whether or not a target node can accept a handover call as step 4 in Fig. 2. In RASH, this step is not required because the handover MS does not change its current serving BS. If the target node can afford a handover call, a handover execution process is started. RASH can significantly simplify the handover execution processes. Most of all, a handover ranging, which is a main cause of handover delay, is not required in RASH because the MS is already synchronized with the serving RS. In RASH, an association process can also be simplified by the RS assistance because the RS can perform an association without registration-information from the MS. Another principal difference between RASH and RAHO is the amount of handover signaling overheads. In RAHO, a serving RS and a target BS can not directly communicate each other and consequently the handover control messages are transmitted by two or more hops. On the other hand, the handover control messages are transmitted by one or two hops in RASH because a serving RS can communicate with the serving and the target BSs. It can significantly reduce the handover signaling overhead.

### 4. PERFORMANCE ANALYSIS

#### 4.1 Handover Efficiency Analysis

In this paper, the handover latency is defined as the duration from step 1 to step 8 in Fig. 2. All steps are required in RAHO meanwhile steps 4 and 6 are unnecessary in RASH. Therefore, the handover latency of RASH (\( L_{\text{RASH}} \)) and RAHO (\( L_{\text{RAHO}} \)) can be defined as follows:

\[
L_{\text{RASH}} = N_{\text{NBR}} \times T_{\text{measure}} + 2 \times T_i + T_p + 2 \times T_i + 2 \times T_a + 2 \times T_s + T_s
\]

\[
L_{\text{RAHO}} = N_{\text{NBR}} \times T_{\text{measure}} + 2 \times T_s + T_p + 4 \times T_s + 2 \times T_a + 4 \times T_s + 2 \times T_s
\]

where \( N_{\text{NBR}} \), \( T_{\text{measure}} \), \( T_{\text{ping}} \), \( T_{\text{asc}} \), \( T_{\text{p}} \), and \( T_{\text{i}} \) denote the total number of neighbor BSs and RSs to be measured, the average time to measure a RSS from a BS or RS, the average handover ranging...
time, the average association time, the average processing time for a handover decision in a BS, and the average time to generate and transmit a control message, respectively.

The service interruption time can be defined as the duration from the suspending to the resuming data transmissions. In RAHO, the service-interruption time is almost the same as the handover latency as illustrated in Fig. 2. However, the service-interruption time in RASH, $D_{RASH}$, is much shorter because data transmissions can be resumed before an association procedure. Therefore, $D_{RASH}$ is defined as:

$$D_{RASH} = L_{RASH} - (T_{asc} + 2 \times T_s + T_r).$$ (5)

The handover latency and the service-interruption time are compared by simulations. Table I shows the specific simulation parameters and their values. Figure 3 (a) compares the average inter-cell handover latency, the average service-interruption time, and the total handover signaling overhead in hard handover in SCN, RAHO, and RASH. The average handover latency in MCN is larger than in SCN as shown in the first bar charts because the introduction of RSs yields additional handover signaling. However, the handover latency of RASH is reduced by 24\% compared to RAHO because the handover procedures are simplified as described earlier. The second bar charts show the average service-interruption time caused by inter-cell handover. The service-interruption time is significantly reduced in RASH because handover ranging is not required and the data transmissions are resumed right after a handover decision. The third bar charts compare the total number of control messages used in each handover schemes. While the signaling overhead in RASH is larger than in SCN, it is reduced by 21\% compared to RAHO.

### 4.2 Capacity Analysis

The average cell capacity can be varied due to repositioning of relay stations for supporting RASH. In this subsection, the average cell capacities of MCN Structures 1 and 2 are compared. The average received signal-to-interference-ratio (SINR) values vary according to relay positions in MCN. In [10], the average received SINR values according to relay positions are already analyzed. From the SINR values combining with Shannon's well-known formula, the average cell capacity (bps) can be derived as:

$$C_{av} = \lambda_{BS} \cdot B \cdot \log_2 (1 + \Gamma_{BS}) + \lambda_{RS} \cdot B \cdot \log_2 (1 + \Gamma_{RS}).$$ (6)

where $B$, $\lambda_{BS}$, $\lambda_{RS}$, $\Gamma_{BS}$, and $\Gamma_{RS}$ denote the system bandwidth, the bandwidth allocation ratio to BS transmissions, and the bandwidth allocation ratio to RS transmissions ($\lambda_{BS} + \lambda_{RS} = 1$), and the average SINR values in BS and RS regions, respectively. Figure 3(b) shows a numerical example of the average relay cell capacities of MCN Structures 1 and 2. Structure 1 has 5.33\% capacity loss compared to Structure 2 at the full load because the average received signal power strength in Structure 1 is lower than in Structure 2.

### 5. CONCLUDING REMARKS

As studied in the previous sections, RASH guarantees much shorter handover latency and service-interruption time than RAHO while RAHO has better cell throughput than RASH. However, RASH will be more favorable in future multihop cellular networks because the capacity loss can be overcome by the improved handover efficiency such as reduced handover-signaling overhead and short service-interruption time. The proposed scheme can be applied to IEEE 802.16j (WiMAX) or 3GPP LTE systems.

### Table 1. Simulation parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Cell</td>
<td>19 cells</td>
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<tr>
<td>Bandwidth</td>
<td>xx MHz</td>
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<tr>
<td>Power constraint of BS</td>
<td>30 dBm</td>
</tr>
<tr>
<td>Power constraint of RS</td>
<td>20 dBm</td>
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<tr>
<td>Cell radius</td>
<td>1 km</td>
</tr>
<tr>
<td>Distance from BS to RS</td>
<td>800 m</td>
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<tr>
<td>$T_{measure}$</td>
<td>5 msec</td>
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<tr>
<td>$T_{rng}$</td>
<td>20 msec</td>
</tr>
<tr>
<td>$T_{asc}$</td>
<td>50 msec</td>
</tr>
<tr>
<td>$T_s$</td>
<td>5 msec</td>
</tr>
<tr>
<td>$T_r$</td>
<td>5 msec</td>
</tr>
<tr>
<td>$N_{NBKR}$ in SCN, RAHO, RASH</td>
<td>3, 8, 7</td>
</tr>
</tbody>
</table>

![Figure 2. Inter-cell handover procedure in MCN](image-url)
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7. REFERENCES