Handover in Multihop Cellular Networks

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ABSTRACT

This article introduces various handover scenarios in multihop cellular networks. In addition, this article presents handover schemes where relay stations are located either inside a cell or on the boundary between two adjacent cells and investigates the effects of the deployment position of relay stations to handover performance. The simulation results show that multihop cellular networks for both deployment scenarios can achieve 90 percent throughput increase over single-hop cellular networks. The results also show that the overall throughput of the multihop cellular networks with relay stations inside a cell is higher than for those with relay stations on the boundary between two adjacent cells, whereas the opposite is observed for the throughput of cell-boundary users. The intercell handover latency in multihop cellular networks is increased by 20 ~ 56 percent compared with that in single-hop cellular networks because of the increased number of handovers and signaling overhead. However, by deploying relay stations on the boundary between two adjacent cells, the service-interruption time caused by inter-cell handover is reduced by 80 percent compared with that of single-hop cellular networks.

INTRODUCTION

Recently, multihop or relay networks have been widely considered as supplementary technology in next-generation wireless systems such as fourth generation (4G), Third Generation Partnership Project Long-Term Evolution (3GPP LTE), and IEEE 802.16m to increase the cell radius or combat the shadowing effect, which is mainly caused by large obstacles between transceivers [1–5]. The application of the multihop concept to cellular networks, however, raises many technical issues, such as the best positions for the base station (BS) and relay stations (RSs); the number of RSs; spectrum allocation and multiplexing between the BS and RSs; scheduling; and handover [1, 2]. Especially, the introduction of RS in cellular networks creates additional handover scenarios and increases the number of handovers. In conventional cellular systems, handover occurs only when a mobile station (MS) moves to different cells or different sectors of the same cell, whereas additional handovers occur in a multihop cellular network (MCN) between the BS and the RSs or between two different RSs. These additional MCN handovers can cause serious ping-pong problems and increase signaling overhead.

Unfortunately, only a few research articles have studied handover issues in relay networks [6–8]. Reference [6] proposes a relay-assisted vertical handover scheme for hybrid cellular and wireless local area network (WLAN) systems. In this scheme, an active MS, which has an active connection, uses non-active MSs as relay stations in handover regions when a handover request is rejected or delayed for an unacceptable period of time. Reference [7] categorizes and evaluates the performance of different types of handovers in multihop radio-access networks (MRANs). In [7], the multihop handover schemes are categorized into forced handover and route optimization-based handover, according to the handover initiation method. In addition, the signaling mechanisms for these handover scenarios are proposed, and handover delay and signaling overhead are also investigated. Reference [8] proposes relay-assisted handover with geo-locating information in a hybrid ad hoc cellular system. An MS is assumed to be able to establish direct connections with nearby MSs to form a temporary wireless relay network, and the MS-to-MS interface is based on a WLAN protocol like the integrated cellular and ad hoc relaying (i-CAR) system proposed in [2]. The relay-assisted handover in [8] uses relaying technology to avoid unnecessary handovers and call drop caused by abrupt channel degradation.

Although these works studied relay-handover problems, the main interest of using the multihop concepts is not in cellular networks but in ad hoc networks. Recently, the handover schemes in MCNs have been defined in the baseline document for the draft standard of IEEE 802.16j [9]. Media-access-control (MAC)-layer handover procedures in IEEE 802.16j are almost the same as handover procedures in IEEE 802.16e, except that an RS relays handover-associated messages between an MS and a BS. However, scanning procedures in IEEE 802.16j are more complicated than those in IEEE 802.16e. IEEE 802.16j defines two different types of RS such as transparent-mode RS and non-transparent-mode RS, which support the one-hop relay and the two-hop relay, respectively. Only a non-transparent-mode RS broadcasts its own preamble, time-aligned with its

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serving BS preamble. Therefore, a non-transparent-mode RS is included in a neighbor list for handover scanning and broadcasts a different neighbor advertisement message that is suitable for its service area [9]. On the other hand, a transparent-mode RS is excluded from a neighbor list, and a neighbor advertisement message is broadcasted by a BS. IEEE 802.16j also defines a mobile RS handover to support an RS migration from a serving BS to another BS. However, few technical contributions in IEEE 802.16j have studied the effect of relay-deployment structures to the design of handover algorithms and the handover performance of the cellular systems because IEEE 802.16j must be backward-compatible with the IEEE 802.16e systems, and consequently, the main interesting points are to design handover-signaling procedures and amend the current mobile-broadband wireless access (MBWA) specification [10].

This article investigates handover schemes for two different RS deployment structures, where an RS is located either inside a cell or on the boundary between two adjacent cells. Detailed cell planning, spectrum allocation, frame structure, and handover signaling for MCNs are also explained. The performance of the handover schemes in an MCN is compared with a single-hop cellular network (SCN) in terms of the average throughput of all users and the cell-boundary users, the handover latency, and the signaling overhead.

HANDOVER SCENARIOS IN MCNS

This section describes all possible handover scenarios in MCNs regardless of the RS deployment structure. Handovers in MCNs can occur when an MS moves between different BSs, between different RSs, or between a BS and an RS. Figure 1 depicts diverse handover scenarios in MCNs. This article classifies each handover scenario into intracell handover and intercell handover with the inter-sector or softer handover excluded. The detailed handover scenarios are explained in the following sections.

INTRACELL HANDOVER

Scenario 1 (Intracell RS-RS Handover) — In this scenario, an MS performs handover between two different RSs in the same cell. In Fig. 1, MS1 moving from RS1b to RS1a in cell 1 illustrates handover scenario 1. The BS easily can control the handover process because both the serving RS and the target RS are under their own control, and inter-BS information or signaling is not required. To prevent packet loss during the handover process, automatic retransmission request (ARQ) status should be consistent between a serving RS and a target RS. In this scenario, transfer of the ARQ status to the target RS is not required during handover if the ARQ function is located in the BS. In addition, the current layer 3 (L3) address can be used after the handover.

Scenario 2 (Intracell BS-RS Handover) — In scenario 2, an MS changes its communication node from a BS to the RS of the same cell, or vice versa, which is the handover of MS2 in Fig. 1. In this case, the BS easily can control the handover process as in scenario 1, and the ARQ status transfer and the L3 address renewal are not required.

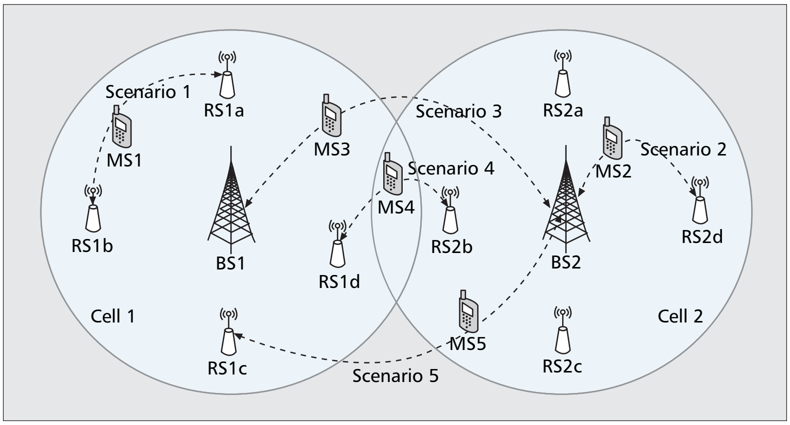

Figure 1. *Handover scenarios in multihop cellular networks.*

INTERCELL HANDOVER

Scenario 3 (Intercell BS-BS Handover) — Scenario 3 is exactly the same as the inter-BS handover in the conventional cellular systems. The ARQ status should be transferred during the handover process if the ARQ is controlled by the BS, and the L3 address is also reassigned when the subnet is changed by the handover.

Scenario 4 (Intercell RS-RS Handover) — In scenario 4, an MS performs handover from an RS to the RS of different cells, which is the handover of MS4 in Fig. 1. This scenario can cause relatively larger signaling overhead than other scenarios because it requires inter-BS signaling and RS-BS signaling in both cells. In addition, the channel quality of the MS in this handover region can be seriously attenuated by the intercell interference from the adjacent BSs and RSs. The ARQ status and the L3 address management are similar to those of scenario 3.

Scenario 5 (Intercell BS-RS Handover) — In scenario 5, an MS moves from a BS to the RS of different cells, or vice versa, which is the handover of MS5 in Fig. 1. Inter-BS signaling is also required in this scenario, and the ARQ status and the L3 address management are the same as scenario 3 except for additional signaling between the RS and the BS.

HANDOVERS FOR THE DIFFERENT MCN STRUCTURES

The design principle and performance of handovers depend highly on the RS deployment structure in the MCN. This section describes the detailed handover operation and signaling according to the RS deployment structures. This section focuses especially on the intercell RS-RS or BS-RS handover schemes for different RS deployment structures because these handovers are the most complicated scenarios among the available handover scenarios in MCNs and occur more frequently than intercell BS-BS handovers

The frequency-reuse factor (FRF) of the MCN is basically assumed to be one, which means that all BSs and RSs share the same spectrum band. However, fractional frequency reuse schemes can be used to mitigate inter-cell interference.

if the RSs are densely deployed on the cell-boundary region. This article considers the fixed multihop systems where RSs are fixed like a BS. In addition, it is assumed that the handover decision is made by BSs to increase the handover efficiency and reduce the cost of RSs. The following sections describe two different RS deployment structures and the detailed intercell handover schemes under the described RS deployment structures.

RELAY-DEPLOYMENT STRUCTURES

Cell Structure — The cell structure of an MCN can be varied according to the deployment method of RSs. This article considers two kinds of RS deployment methods as shown in Fig. 2a and Fig. 2b. As shown in Fig. 2a and Fig. 2b, RSs are located inside a cell in MCN structure 1 (MCN 1), while RSs are located on the boundary between two adjacent cells in MCN structure 2 (MCN 2). This article considers these two structures because MCN 1 is most widely used in the previous works [1–3], whereas MCN 2 is much preferable to intercell RS-RS handover. Most of the previous work [1–3] assumes that RSs are located inside a cell and controlled by the BS to increase the cell coverage or high-data-rate region, as in MCN 1. Meanwhile, RSs are supposed to be synchronized with the adjacent two BSs and controlled by the BSs in MCN 2; for example, RS1 is synchronized with BS0 and BS1 in Fig. 2b and shares the radio resources and control information with BS0 and BS1. The frequency-reuse factor (FRF) of the MCN is basically assumed to be one, which means that all BSs and RSs share the same spectrum band. However, fractional frequency reuse schemes [10, 11] can be used to mitigate intercell interference.

Multiplexing and Frame Structure — Because BSs and RSs are assumed to use the same frequency bands, the resources of BSs and RSs should be coordinated for multiplexing. Time-division multiplexing (TDM) and frequency-division multiplexing (FDM) mainly were used in the latest works [1, 2]. This article mainly considers TDM between BS and RSs; whereas, FDM also can be used without significant modification of the considered frame structure. Figure 2c depicts an example of TDM-based frame structure for an MCN, which is compatible with the non-transparent-mode frame structure of IEEE 802.16j [9] except that an RS can transmit its preamble. In this frame structure, the duplexing between downlink (DL) and uplink (UL) is based on time-division duplexing (TDD). Each frame in the DL transmission begins with a preamble followed by a frame-control header (FCH), a DL map (DL-MAP), and possibly a UL map (UL-MAP). BSs and RSs transmit their own preamble signal in a preamble region. An FCH is a control header to inform the transmission scheme and length of MAP. The DL-MAP and UL-MAP include DL and UL channel-usage information, respectively. The R-MAP, which indicates the DL and UL relay channel usage, is located following the UL-MAP or defined as an extension of the MAP. For the frame synchronization among a BS, RSs, and MSs in a cell, RSs and MSs must receive control information such as the FCH, DL-MAP, and UL-MAP regardless of channel quality. Therefore, the FCH, DL-MAP, and UL-MAP would be transmitted using low-order modulation with lower code rate. The frame structure following the MAP consists of a DL sub-frame period and UL sub-frame period. The DL sub-frame includes at least one DL access zone for the BS to its subordinate MS or RS transmissions, and optionally, includes a transparent zone for the RS to its subordinate MS transmissions. The UL sub-frame includes the UL access zone and UL relay zone. The MS can transmit UL control or data information to the BS or RS during the UL access zone; meanwhile the RS can transmit UL control or data information to the BS or another RS during the UL relay zone. The ranging channel in the UL access zone is shared by the RS and MS. In each frame, a relay receive/transmit transition gap (R-RTG) is inserted between the DL access zone and the DL transparent zone and between the UL access zone and the UL relay zone. In MCN 2, the same DL and UL sub-frame for an RS are allocated by the adjacent two BSs.

INTERCELL HANDOVER SCHEMES IN MCN

Handover Scenarios — Although intracell handover scenarios are almost the same for both deployment schemes, intercell handover scenarios can be quite different. Figure 3a shows the point of handover executions and the related handover scenarios of two different RS deployment structures. As seen in this figure, MS1 located in MCN 1, moves from cell 1 to cell 2, and accordingly, performs three handovers, namely, intracell BS-RS handover, intercell RS-RS handover, and intracell BS-RS handover. However, MS2 located in MCN 2 moves from cell 2 to cell 3 and performs only two handovers, namely, intracell BS-RS handover and intercell BS-RS handover. In this case, MS2 can perform the intercell handover without switching the current serving RS, which is quite different from the previously defined handover scenario 4 or 5. Thus, this type of handover is newly defined as the advanced handover scenario 5 or advanced intercell BS-RS handover, whereas the MS handover procedure in IEEE 802.16j falls under handover scenario 4. The detailed intercell handover procedures and signaling in MCN 1 and 2 are compared in the following section.

Received-Signal-Strength Measurement and Handover Decision — The received-signal-strength (RSS) measurement process can cause packet-loss or packet-transmission delay because an MS cannot receive data packets from the serving BS during the RSS measurement for the neighbor BSs. To minimize the packet-loss or the transmission delay during measurement, puncturing has been used in conventional code-division multiple-access systems. In mobile WiMAX systems based on IEEE 802.16e standardization [10], an MS requests a measurement period during which a BS does not send any data packets to the MS to prevent the packet loss. In an MCN, the RSS measurement overhead

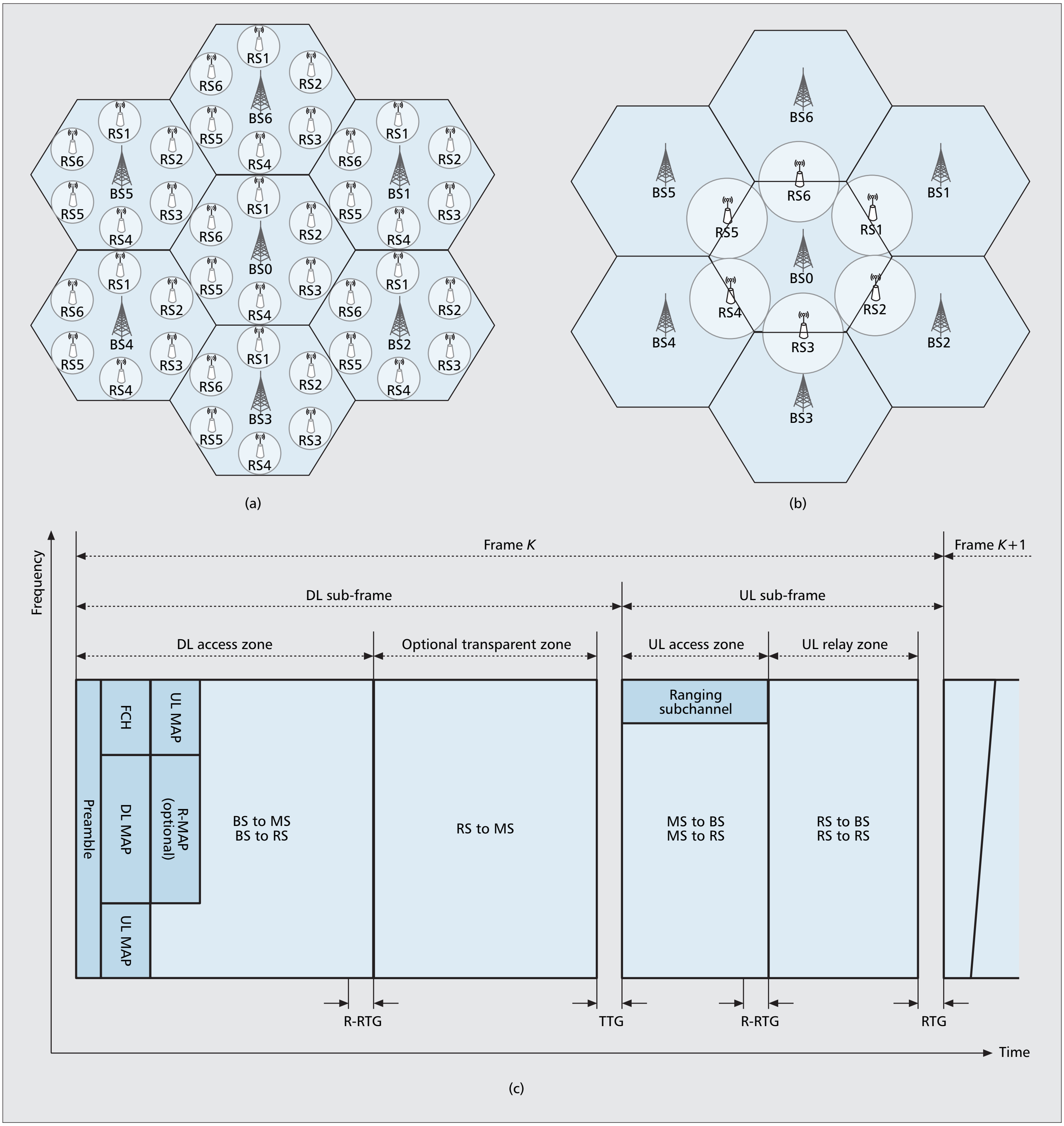

Figure 2. *The cell and frame structures for multihop cellular networks: a) multihop cellular network structure 1; b) multihop cellular network structure 2; c) an example of frame structure for multihop cellular networks.*

increases because an MS should measure the RSS of the neighbor RSs, as well as the neighbor BSs. Therefore, packet-loss or packet-transmission delay caused by handover can be increased in an MCN compared to an SCN. In IEEE 802.16j, a non-transparent-mode RS can make its own neighbor list based on its service area; accordingly, an MS should receive neighbor lists from a serving BS and an RS for precise measurement. In the advanced handover scenario 5, an RS can generate its own neighbor list, or a serving BS can make a neighbor list for RSs and forward the list to each RS. Regardless of the signaling procedures for RSS measurement, the MCN 2 can reduce the measurement overhead compared with the MCN 1 because the number of RSs in the measurement list is smaller than it is in the MCN 1. In Fig. 3a, MS2 measures the RSS of BS2, RS3, and BS3, while MS1 measures the RSS of BS1, RS1, RS2, and BS2. The handover decision is based on the RSS measurement result. When the serving BS receives the measurement report from the MS or the RS, it determines the handover execution and direction based on the RSS and the resource availability in the target BS or RS. The detailed handover decision criteria in cellular networks are well defined in [12].

Handover Procedures and Signaling — Once a BS determines the handover execution and direction, an MS performs handover with the directed BS or RS. Figure 3b and Fig. 3c illustrate the overall handover procedures and signaling of intercell handovers in MCN 1 and 2, respectively. In the case of the MS handover procedures in IEEE 802.16j, an RS simply relays handover-associated messages between an MS and a serving BS as shown in Fig. 3b. However, the handover procedures described in Fig. 3b can be simplified by the advanced BS-RS handover. This section explains the difference of handover procedures and signaling between MCN 1 and MCN 2 for each step. The handover procedure consists of several steps such as measurement, handover decision, handover ranging, association, and resource allocation. In the measurement step, the signaling process is exactly the same in MCN 1 and 2, as seen in Fig. 3b and Fig. 3c. However, the advanced intercell BS-RS handover in MCN 2 can reduce the measurement overhead as described in the previous section. After the measurement step, a serving BS determines the handover execution and direction based on the measurement report and then sends a handover request (`Handover_REQ`) message to a target BS or RS to check the resource availability for a handover user. As illustrated in Fig. 3b, the `Handover_REQ` message is forwarded from the serving BS to RS2 by a two-hop in MCN 1, while it is transmitted to BS3 by a one-hop in MCN 2. Therefore, the advanced intercell BS-RS handover can reduce the signaling overhead in this step. After the serving BS receives a handover response (`Handover_RSP`) message from the target BS or RS, it sends a `Handover_Direction` message to the serving RS and the target BS or RS as shown in Fig. 3b and Fig. 3c. When an MS in MCN 1 receives the `Handover_Direction` message from the serving BS, it starts the handover ranging and association procedure. In this step, the advanced intercell BS-RS handover can significantly reduce handover delay because a serving RS is not changed in this handover scenario, and consequently, the MS is not required to do handover ranging as illustrated in Fig. 3c. After the ranging procedure, the MS performs an association procedure. As seen in Fig. 3b, MS1 sends an `Association_REQ` message to RS2, and RS2 forwards this message to BS2 because an RS in an MCN is unlikely to have an association function to reduce the cost. BS2 registers MS1 after receiving the `Association_REQ` message from RS2 and sends an `Association_RSP` message to RS2 with a new ID for MS1. After receiving the `Association_RSP` message from the target RS, MS1 sends a `Handover_Complete` message to the serving RS and resumes data receiving and transmission with the target RS. On the other hand, MS2 in Fig. 3c is not required to send an `Association_REQ` message by itself. Instead,

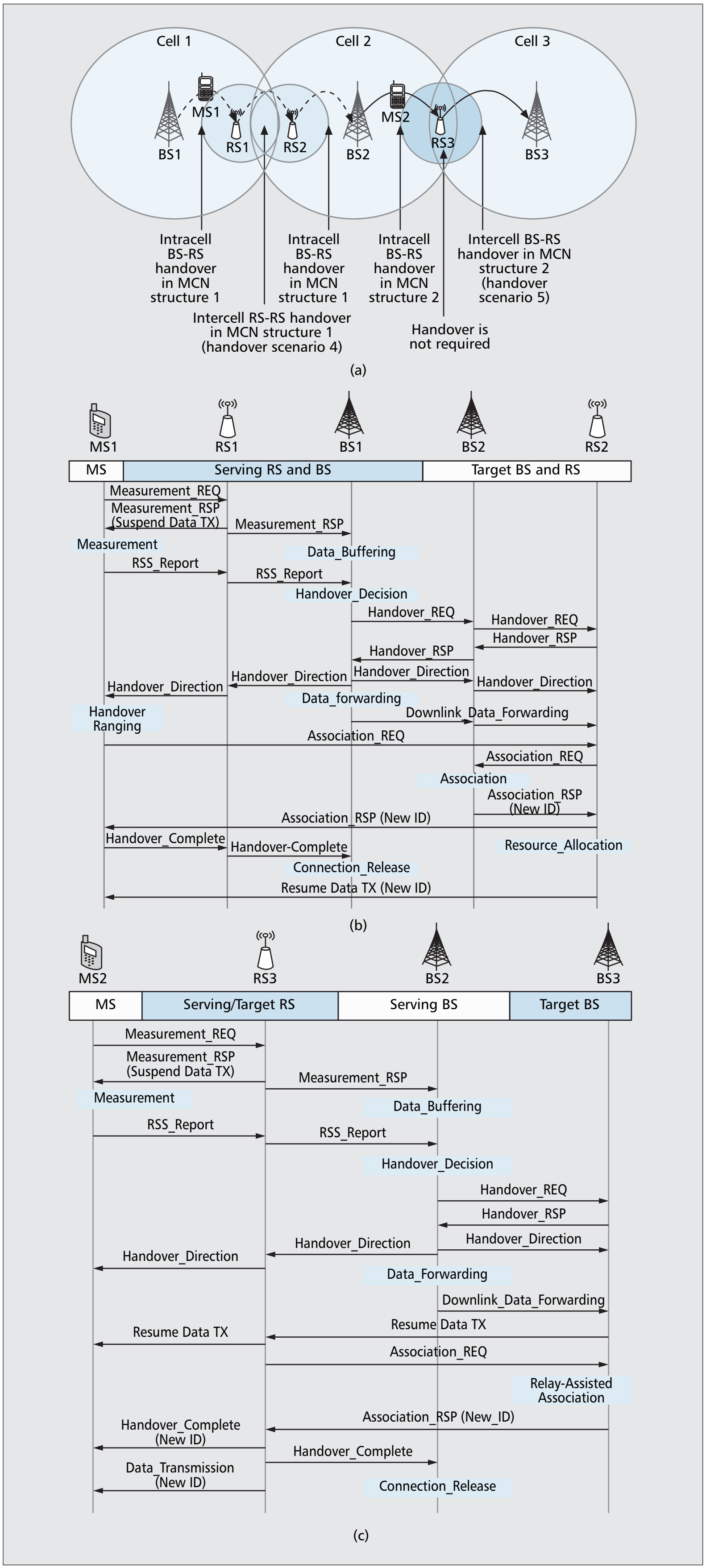

Figure 3. *Comparison of handover scenarios and signaling in two multihop deployment structures: a) the point of handover execution and related handover scenarios; b) intercell RS-RS handover signaling in MCN 1; c) advanced intercell BS-RS handover signaling in MCN 2.*

RS3 sends an `Association_REQ` message to the target BS because the MS is already registered in RS3. BS3 registers MS2 and sends an `Association_RSP` message to RS3 with a new ID for MS2. As shown in Fig. 3b, once the data transmission is interrupted by handover, it will not be resumed until the ranging and association procedures are completed in MCN 1. On the other hand, the data transmission can resume before association procedures in MCN 2 as illustrated in Fig. 3c because the MS does not change the current serving RS.

> *The service-interruption time can be defined as the duration from suspending data transmission to resuming data transmission, triggered by the RSS measurement and handover completion, respectively.*

HANDOVER LATENCY AND SERVICE-INTERRUPTION TIME

To compare the efficiency of the handover schemes in the SCN, MCN 1, and MCN 2, the handover latency and service-interruption time are investigated in this section. In this article, the handover latency is defined as the duration between the time when the measurement procedure starts and the time when the `Handover_Complete` message is transmitted to a serving BS. To analyze the handover latency, the following parameters are defined:

T_{measure}: Average time to measure the RSS for a BS or RS

T_{rng_BS}: Average handover ranging time between an MS and a BS

T_{rng_RS}: Average handover ranging time between an MS and an RS

T_{assoc}: Average association processing time

T_{BS_proc}: Average processing time to determine handover or allocate resources in a BS

T_{RS_proc}: Average processing time to allocate resources in an RS

$T_{\text{signaling}}$: Average time to generate and transmit a control message between two different nodes

$T_{\text{neighbor}BS}$: Total number of neighbor BSs required to be periodically measured

$T_{\text{neighbor}RS}$: Total number of neighbor RSs required to be periodically measured

The handover latency can be calculated from the handover procedure and signaling sequences. To clarify an understanding, the handover procedure and signaling sequence with latency parameters are illustrated in Fig. 4. A link between an MS and a serving node or target node, or between a serving node and a target node, can be one hop or two hop. Based on Fig. 4, the handover latency for each handover scenario can be derived as follows:

$$L_{\text{scenario1}} = (N_{\text{neighbor}BS} + N_{\text{neighbor}RS}) \times T_{\text{measure}} + 2 \times T_{\text{signaling}} + T_{BS\_proc} + 2 \times T_{\text{signaling}} \quad (1)$$

$$L_{\text{scenario2}} = (N_{\text{neighbor}BS} + N_{\text{neighbor}RS}) \times T_{\text{measure}} + T_{\text{signaling}} + T_{BS\_proc} + T_{\text{signaling}} \quad (2)$$

$$L_{\text{scenario3}} = (N_{\text{neighbor}BS} + N_{\text{neighbor}RS}) \times T_{\text{measure}} + T_{\text{signaling}} + T_{BS\_proc} + 2 \times T_{\text{signaling}} + T_{\text{signaling}} + T_{rng\_BS} + 2 \times T_{\text{signaling}} + T_{\text{assoc}} + T_{\text{signaling}} \quad (3)$$

$$L_{\text{scenario4}} = (N_{\text{neighbor}BS} + N_{\text{neighbor}RS}) \times T_{\text{measure}} + 2 \times T_{\text{signaling}} + T_{BS\_proc} + 2 \times T_{\text{signaling}} + 2 \times T_{\text{signaling}} + T_{rng\_RS} + 4 \times T_{\text{signaling}} + T_{\text{assoc}} + 2 \times T_{\text{signaling}} \quad (4)$$

$$L_{\text{scenario5}} = (N_{\text{neighbor}BS} + N_{\text{neighbor}RS}) \times T_{\text{measure}} + 2 \times T_{\text{signaling}} + T_{BS\_proc} + 2 \times T_{\text{signaling}} + 2 \times T_{\text{signaling}} + T_{rng\_BS} + 2 \times T_{\text{signaling}} + T_{\text{assoc}} + 2 \times T_{\text{signaling}} \quad (5)$$

where $L_{\text{scenario}K}$ means the handover latency of scenario K. In handover scenario 1 and scenario 2, the handover procedure consists of measurement and handover decision steps. Therefore, the handover latencies of scenario 1 and 2 are defined as the duration between step 1 and step 5, excluding step 4, illustrated in Fig. 4. In scenarios 1 and 2, step 4 can be shortened because the BS, where the handover MS is currently associated, knows the resource availability of a target RS. The only difference is that the signaling time of scenario 1 is twice as much as scenario 2 because the link between an MS and a serving node or target node is a two-hop in scenario 1. In the intercell handover scenarios of MCN 1, the handover procedures and signaling include all of the steps illustrated in Fig. 4. Therefore, the handover latency of scenario 3, 4, and 5 in MCN 1 is the duration between step 1 and step 9 as defined in Eqs. 3, 4, and 5, respectively. The signaling times, which are dependent on the number of hops between the signal transmitter and receiver, are different among the scenarios. In addition, the handover ranging times are also different from one another because a handover target node is a BS in scenario 3 and 4, while the target node is an RS in scenario 5. In MCN 2, the handover latencies of scenario 3 and 4 are exactly the same as those in MCN 1. However, the handover latency of scenario 5 can be significantly reduced because a handover ranging is not required in MCN 2. The handover latency of scenario 5 in MCN 2 is defined as follows:

$$L_{\text{scenario5}\_new} = (N_{\text{neighbor}BS} + N_{\text{neighbor}RS}) \times T_{\text{measure}} + 2 \times T_{\text{signaling}} + T_{BS\_proc} + 2 \times T_{\text{signaling}} + 2 \times T_{\text{signaling}} + 2 \times T_{\text{signaling}} + T_{\text{assoc}} + T_{\text{signaling}} \quad (6)$$

The service-interruption time caused by handover is another important performance metric of handover schemes. The service-interruption time can be defined as the duration from suspending data transmission to resuming data transmission, triggered by the RSS measurement and handover completion, respectively. In intracell handover scenarios, the service interruption occurs only during the measurement procedure if the puncturing or addition finger in the receiving module of an MS is not considered. However, in intercell handover scenarios, the service interruption can occur during the measurement and handover execution procedures. The service-interruption times of each scenario in MCN 1 are almost the same as its handover latency. However, the service-interruption time of handover scenario 5 in MCN 2 is significantly shorter than the handover latency because the data transmission can be resumed before the associa-

Although power and bandwidth are not optimized in this simulation, the fraction of time and bandwidth for the RS-MS DL and the BS-MS DL should be optimized because inappropriate design can significantly degrade the throughput.

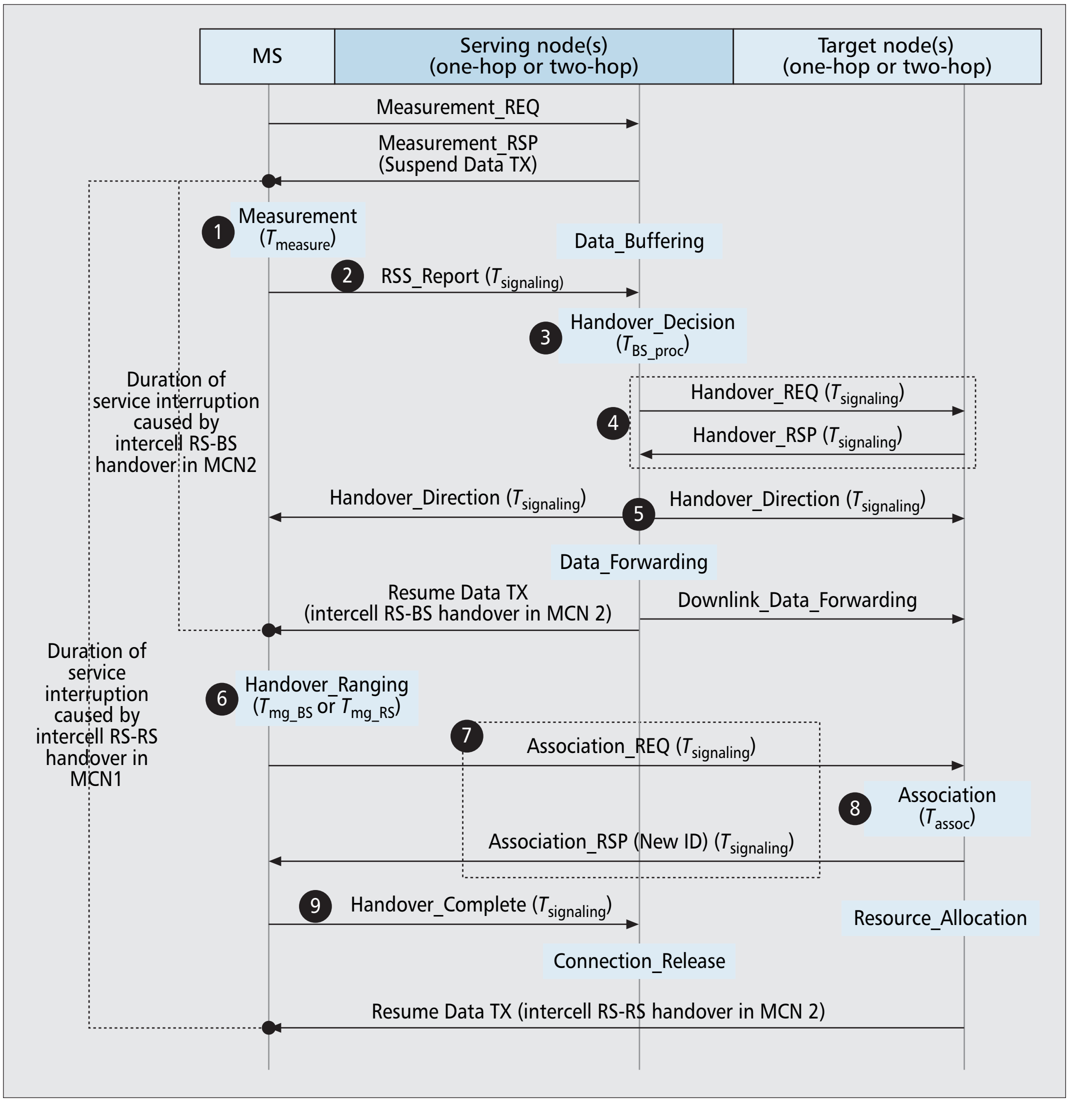

Figure 4. *Handover steps with latency parameters.*

tion procedure, and an additional time for resource allocation is not required as illustrated in Fig. 4. Therefore, the service interruption time of handover scenario 5 in MCN 2 is defined as follows:

$$D_{scenario5\_new} = L_{scenario5\_new} - (2 \times T_{signaling} + T_{assoc} + T_{signaling}) \qquad (7)$$

PERFORMANCE ANALYSIS

This section compares the handover performance of the MCN and the SCN in terms of overall cell throughput, cell-boundary users' throughput, and cell-center users' throughput. The number of handovers, handover delay, service-interruption time, and signaling overhead caused by handovers are also investigated for the MCN and the SCN.

SIMULATION MODEL

The performance of MCN 1, MCN 2, and the SCN are compared by computer simulation, based on IEEE 802.16e orthogonal frequency-division multiple-access (OFDMA) DL systems using MATLAB. MSs are uniformly distributed in a cell, which is divided into six sectors of 60 degrees each. BSs use different frequencies in each sector with directional antennas. To model the interference from other BSs and RSs in different cells, 18 adjacent cells are deployed around one cell. In the SCN, each cell has one BS, and each BS serves all the users in the cell by allocating time or frequency in each OFDMA frame. In MCN 1, each cell has one BS and six RSs; in MCN 2, each cell has one BS and shares six RSs with adjacent cells, as in Figs. 2a and 2b. The RSs use the same frequency, and all other RSs can be a source of interference. A BS and an RSs in a cell are not interfering with each other because TDM is used in a proposed frame structure.

The system model uses non-line-of-sight (NLOS) 3GPP universal mobile telecommunications system (UMTS) channel models [13], as well as a line-of-sight (LOS) channel model for the simulation. The propagation from a BS to an MS is modeled as an urban macrocell-NLOS; the propagation from an RS to an MS is modeled as an urban microcell-NLOS; and the propagation from a BS to an RS is modeled as a LOS channel model. In an SCN, constant transmission power and bandwidth are allocated to each user regardless of channel gains, although optimizing power and bandwidth allocation can increase the performance of each handover scenario. In MCN 1 and 2, BSs and RSs also allocate constant power and bandwidth to each user. Although power and bandwidth are not optimized in this simulation, the fraction of time and bandwidth for the RS-MS DL and the BS-MS DL should be optimized because inappropriate design can significantly degrade the throughput. Assume that α is the fraction of time used for the BS-MS link or the BS-RS link in the proposed frame structure, and $1 - \alpha$ is the fraction for the RS-MS link. In the time slot for the DL fraction from the BS, β denotes the fraction of frequency used for the BS-RS link, and $1 - \beta$ is used for the BS-MS link. For the best performance of MCN, the number of MSs associated with BSs and RSs should be optimized in accordance with α and β. However, this simulation assumes that MSs determine their association with BSs or RSs by comparing signal-to-interference and noise ratio (SINR) from BSs and RSs, and therefore, the number of MSs associated with RSs is fixed.

To evaluate the handover latency and service-interruption time, T_{measure}, T_{signal}, T_{BS_proc}, and T_{RS_proc} are assumed to be 5 msec because a typical frame size of an IEEE 802.16e system is 5 msec. T_{rng} and T_{assoc} are assumed to be 20 msec and 50 msec, respectively. The value of T_{assoc} is relatively large because it requires additional backbone network communication.

SIMULATION RESULTS AND DISCUSSION

Figure 5a illustrates the DL throughput normalized by that of the SCN with $\alpha = 0.65$ and $\beta = 0.54$. Though α and β should be optimized to get the best performance in MCN 2, one representative example is given here. The extensive simulations show that the performance is relatively insensitive to the choice of α and β if they are chosen in a reasonable range. The first three bars show that the overall throughput of both MCN structures increases by 90 percent compared to that of the SCN. The overall throughput difference between these structures is closely related to the number of deployed RSs. The system throughput can be increased by deploying more RSs as in MCN 1. However, this also increases the overall system complexity, as well as handover delays. The second three bars show the average throughput of users who are in a cell-boundary region, and the throughput is normalized by the total throughput of the SCN. In this simulation, users who have the lower 40 percent throughput in the SCN are considered to be in a cell-boundary region, and other users who have the higher 60 percent throughput in the SCN are considered to be in a cell-center region. The throughput of cell-boundary users is significantly improved by deploying RSs. For these lower 40 percent of users, MCN 2 supports higher data rates than MCN 1 because MSs associated with RSs in MCN 1 have more adjacent RSs than those in MCN 2, and the MSs suffer from stronger interference. The last three bars show

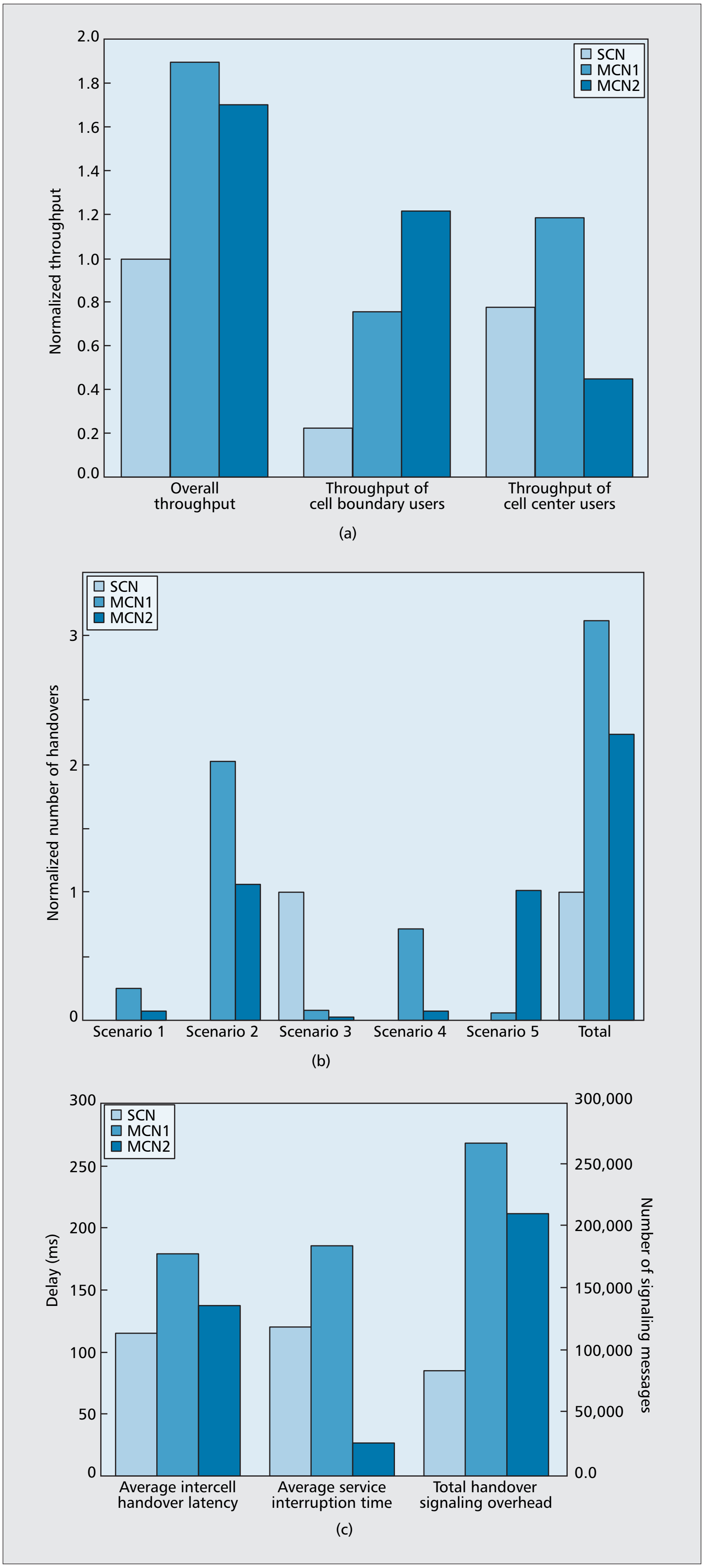

Figure 5. *A performance comparison of SCN, MCN 1, and MCN 2: a) the downlink throughput normalized by the throughput of SCN; b) the number of handovers normalized by the number of handovers in SCN; c) comparisons of handover latency, service interruption time, and control overhead.*

Parameter	Value
Cell	19 cells (6 sectors with directional antennas)
Carrier frequency	1.9 GHz
Power constraint of BS	30 dBm
Power constraint of RS	20 dBm
Cell radius	1 km
Distance between a BS and a RS in MCN 1	800 m
T_{measure}	5 ms
T_{rng_BS} and T_{rng_RS}	20 ms
T_{assoc}	50 ms
T_{BS_proc} and T_{RS_proc}	5 ms
$T_{\text{signaling}}$	5 ms
$N_{\text{neighbor}BS}$ in SCN, MCN 1, and MCN 2	3
$N_{\text{neighbor}RS}$ in SCN	0
$N_{\text{neighbor}RS}$ in MCN 1	5
$N_{\text{neighbor}RS}$ in MCN 2	4

Table 1. *Simulation parameters.*

the average throughput of users who have the higher 60 percent throughput in the SCN, and the throughput is normalized by the total throughput of the SCN. The throughput of MCN 1 is larger than that of MCN 2 because RSs in a cell can also support some of the MSs close to the BS and further increase the throughput of those users, while RSs at the cell-boundary would not support these good users. The throughput of MCN 2 is smaller than that of the SCN in this case because the fraction is used for the BS-RS link, and the throughput of the BS-MS link for good users decreases.

Figure 5b shows the number of handovers normalized by that of the SCN for each scenario. A handover number is counted for a thousand users in 19 cells. The initial moving direction of each user is randomly selected and maintained as the selected direction during the simulation time. The overall handover numbers in MCN 1 and MCN 2 are increased by three times and two times of the one in the SCN, respectively, due to the introduction of RSs in a cell. The handover number of scenario 2 in MCN 1 is larger than in MCN 2 because the number of RSs in a cell is larger in MCN 1. The handover number of scenario 5 is larger in MCN 2 compared with the one in MCN 1 because the condition of handover scenario 4 is changed to the handover scenario 5 by the advanced intercell BS-RS handover scheme in MCN 2.

Figure 5c shows the simulation results, which compare the average intercell handover latency, the average service-interruption time caused by intercell handover, and the total handover signaling overhead in MCN 1, MCN 2, and the SCN. Because the intracell RS-RS or RS-BS handover never occurred in the SCN, only the intercell handover latency is evaluated for fair comparison. As seen in the first set of bars of Fig. 5c, the average intercell handover latency of MCN 1 and MCN 2 is larger than in the SCN because the introduction of RSs accompanies the additional signaling for handover. However, the average intercell handover latency in MCN 2 is reduced by 24 percent compared with that in MCN 1 because the handover ranging is not required, and the additional signaling also is reduced in the advanced intercell BS-RS handover. The second set of bars of Fig. 5c shows the average service-interruption time caused by intercell handover. In MCN 1 and the SCN, the data transmission is suspended before the RSS measurement and resumed right after the handover completion. Therefore, the average service-interruption time in MCN 1 and the SCN is almost the same as the average intercell handover latency. However, the average service-interruption time is significantly reduced in MCN 2. The reason is that an MS in MCN 2 is not required to change the current serving RS and consequently, resumes data receiving or transmission right after the handover decision without ranging in the handover scenario 5. The third set of bars of Fig. 5c shows the total signaling overhead caused by handovers. In this simulation, the signaling overhead means the total number of control messages that are exchanged among an MS, RS, and a BS during the handover procedures. The total signaling overhead in an MCN is increased to 250 percent ~ 320 percent compared with the overhead in the SCN because the signaling messages are usually transmitted by multihop. However, in MCN 2, the signaling overhead is reduced by 21 percent compared with MCN 1 because the number of RSs in MCN 2 is relatively smaller than it is in MCN 1 and consequently, the number of signaling messages also is decreased.

CONCLUSIONS

As discussed in the previous sections, several design principles can affect the performance of handover schemes in an MCN. The location and number of RSs in a cell for an MCN have the most direct affect on the performance of handover in terms of throughput and handover latency. MCN 1 can improve the overall cell throughput with an appropriate handover scheme. MCN 2 simplifies the handover process and reduces handover signaling overhead and handover latency compared with MCN 1. Especially, the service-interruption time is significantly reduced in MCN 2, even compared with the SCN. However, there exists a clear tradeoff between this simplification and the throughput loss of cell-center users as seen in Fig. 5a. If the handover efficiency and the throughput of cell-boundary users are important, MCN 2 is preferred; whereas, MCN 1 is preferred if improving the service of high-rate users is more important. In addition, MCN 2 involves complicated network management issues such as synchronization, data routing, and RS authentication even it has many benefits for handover performance. Therefore, further study is required to design an adaptive or hybrid MCN structure to improve both the handover efficiency and the throughput of cell-edge and cell-boundary users and to resolve the network issues. In a hybrid or adaptive MCN, RSs may be deployed as an MCN 1 type, whereas those controlled by the adjacent two BSs, like MCN 2 or mobile RSs, can be considered to adopt the MCN 2 structure without complicated network management issues. In addition, fractional frequency reuse or cooperative diversity schemes also can be considered with MCN 2 to improve the overall throughput without a sacrifice of handover efficiency.

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