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Improving Handover Performance between LTE and CMDA2000 for Seamless Communication

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高性能なスマートフォンの登場や，動画配信などの Web アプリケーションの普及に伴い，モバイルデータトラヒックは急速に増加しており，モバイル通信事業者は多くの利用者を収容可能な高速な無線アクセスの導入を検討している．新しい無線アクセス導入時に継続して通信サービスを提供するには，新旧の無線アクセス間でスムーズにハンドオーバできることが望ましい．しかし，新旧無線アクセス間に互換性がなく，無線レベルでの十分な相互動作がない場合，スムーズなハンドオーバ実現には，IP ネットワークによって新旧無線アクセスを統合し，ネットワークベースの移動管理方式を用いるのが有効である．そこで，本稿では異なる標準に基づく無線アクセスであり，ネットワークベースの移動管理方式が採用された LTE と CDMA2000 の間のハンドオーバ手順を分析し，ハンドオーバ中の通信中断をより短くするための改良方法を提案する．実機 PC によるテストベッド上での性能評価では，ノード配置がハンドオーバ性能に与える影響を明らかにし，提案手法によりシームレスなハンドオーバが実現されることを示す．

Improving Handover Performance between LTE and CMDA2000 for Seamless Communication

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The increase in demand for content-rich mobile data communications encourages Mobile Network Operators (MNOs) to deploy broadband radio access technologies (RATs). A network-based mobility management is a promising approach for MNOs and their users to migrate from an existing RAT to a new RAT. In particular, when these RATs belong to other standards, the network-based mobility management is of great importance because of insufficient radio-based interwork between the RATs. This paper focuses on the handover procedures between 3GPP LTE and 3GPP2 CDMA2000. While the handover procedures have been developed in 3GPP and 3GPP2, the performance difference for the handover directions remains to be revealed. This paper analyzes the standard handover procedures and proposes modifications to the handover procedures to realize seamless mobility, that is, shorter disruption of the mobile node's communications during the handover. We show performance results in an experimental testbed using actual PCs. We reveal the performance difference of handover procedures affected by node deployments and our proposed modification still improves the handover performance.

1. Introduction

Content-rich IP-based applications and high performance mobile devices such as smart phones require broadband radio access services. This encourages Mobile Network Operators (MNOs) to deploy more broadband Radio Access Technologies (RATs). 3GPP has developed Long Term Evolution [1], which is a beyond third generation (3G) mobile broadband standard and successor to UMTS. When deploying a new RAT, such as, LTE, MNOs need to use it with the existing RATs concurrently in order to provide users with seamless radio access services.

Interconnectivity of IP-based network architectures enables migration of the existing and new RATs. System Architecture Evolution (SAE) [2] in 3GPP has standardized Evolved Packet Core (EPC) as an IP-based network architecture for LTE. EPC also supports interwork between multiple RATs, which include LTE, other 3GPP RATs (e.g., UMTS and GERAN), and non-3GPP RATs (e.g., CDMA2000, WiMAX and WiFi).

One of the important interwork functions of IP-based network architectures is mobility management between multiple RATs. In particular, when these RATs have been developed in other standard organizations, the mobility management enabling the mobile nodes (MNs) to make handover between the new and the existing RATs is of great importance because of insufficient radio-based interwork capability between these RATs. In the SAE standard, Proxy Mobile IPv6 (PMIPv6) [3], which is network-based mobility management standardized in IETF, is specified as the mobility management protocol between LTE and non-3GPP RATs.

This paper focuses on the handover procedures between 3GPP LTE and 3GPP2 CDMA2000. While the handover procedures between LTE and CDMA2000 have been developed in 3GPP [4] and 3GPP2 [5], the handover performance issues of both directions, which are handover from LTE to CDMA2000 and from CDMA2000 to LTE, remains to be revealed. This paper analyzes the standard handover procedures and then proposes a modification to these procedures to realize seamless mobility, that is, shorter disruption of the MN's communication.

We show performance results of handover procedures in terms of multiple node deployment scenarios. In these scenarios, we suppose that MNO deploys the EPC nodes regarding to a new RAT in a phased manner. We investigate the performance difference affected by the scenarios. The handover performance is evaluated using an experimental testbed where the EPC functions are implemented in actual PCs.

This paper is organized as follows. Section II shows related work. Section III describes an overview of the standard handover procedures and proposes modified handover procedures

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for seamless communication. Section IV evaluates the handover performance for the node deployment scenarios using the experimental testbed. Section V concludes this paper.

2. Related Work

A. Racz, *et al.* [6] investigated data forwarding during inter-LTE handover, and propose a re-ordering scheme using a priority queue to solve out-of-order packets caused by data forwarding. After the high priority queue which the forwarded traffic joins becomes empty, other traffic begins to be transmitted. However, this approach cannot recognize the end of data forwarding correctly because empty queue does not necessarily mean the end of data forwarding. To recognize the end of data forwarding for communication quality, we apply this approach to the handover between multiple RATs which belong to other standards.

K. Kim, *et al.* [7] argue TCP performance during handover between LTE and CDMA2000, focusing on the difference of the data rates. They propose an enhanced TCP congestion control during handover and evaluate its performance with simulation results. While the difference of data rates between the two RATs is important for handover performance, seamless mobility, that is, shorter disruption of communication during handover is also important. In particular, when radio-based interwork is insufficient between different RATs, network-based mobility management will work for seamless mobility. Therefore, while we also argue handover procedure between LTE and CDMA2000, we evaluate the handover performance focusing on network-based mobility management.

3. Handover Procedures and Proposed Modifications

3.1 Handover Procedures between LTE and CDMA2000

We give an overview of EPC architecture and the standard handover procedures between LTE and CDMA2000. Fig. 1 shows EPC including CDMA2000 nodes. The EPC consists of Packet Data Network Gateway (P-GW), Serving Gateway (S-GW), Mobility Management Entity (MME), and eNodeB. In terms of PMIPv6, P-GW and S-GW play a role of Local Mobility Anchor (LMA) and Mobile Access Gateway for LTE (LTE MAG), respectively. eNodeB is Base Station of LTE (LTE BS). CDMA2000 nodes are HRPD Serving Gateway, which is a MAG for CDMA2000 (CDMA MAG) and a BS/Packet Control Function for CDMA2000 (CDMA BS/PCF). CDMA BS is called as Access Network (AN) in the CDMA2000 standard. LMA is a home agent for MNs that move between LTE and CDMA2000. LTE MAG and CDMA MAG are access routers to MNs that are attached via LTE and CDMA BSs, respectively. MME manages signaling of EPC domain while PCF manages signaling and data transmission for CDMA2000. MME and PCF exchange signaling messages for interwork between LTE and CDMA2000.

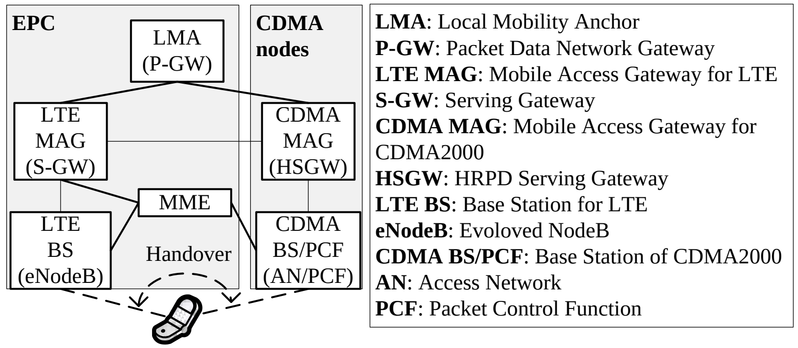

Fig. 1 SAE architecture including CDMA2000 nodes.

Fig. 2 shows the standard handover procedure from LTE to CDMA2000. At first, MN's context is registered at CDMA MAG before the handover, which reduces signaling overhead after the handover (Steps 1 to 3). LTE MAG and LTE BS create a forwarding tunnel from LTE BS to CDMA MAG via LTE MAG (Steps 4 and 5). Then, LTE BS transfers downlink traffic to CDMA MAG through the forwarding tunnel. CDMA MAG buffers the forwarded traffic until MN attaches to CDMA MAG. Then, LTE BS requests MN to move to CDMA2000 (Steps 6 and 7).

After MN is attached to the CDMA MAG, the buffered downlink traffic at CDMA MAG is released (Step 8). CDMA MAG sends PMIPv6 Proxy Binding Update (PBU) to LMA, and then LMA switches downlink traffic to CDMA MAG (Step 9). CDMA MAG buffers the traffic from LMA until the traffic from LTE MAG is released. LMA sends PMIPv6 Proxy Binding Acknowledgement (PBA) to CDMA MAG, and then CDMA MAG notifies completion of handover to PCF (Steps 10 and 11). Finally, CDMA MAG releases the buffered downlink traffic from LMA when the MAG judges completion of data forwarding.

The standard handover procedure from CDMA2000 to LTE is shown in Fig. 3. First, MN transmits request of context setup to LTE MAG via CDMA BS/PCF and MME (Steps 1 and 2). LTE MAG sends PBU, and then LMA switches downlink traffic to LTE MAG. LTE MAG buffers the downlink traffic until MN moves to LTE (Step 3). Then, LMA sends PBA to LTE MAG (Step 4). In Steps 5 and 6, completion of handover preparations is notified to MN and MME by exchanging signaling messages. Then, MME requests MN to move to LTE (Step 7).

After switching to LTE, MN exchanges signaling messages with LTE BS and MME in order to attach to LTE MAG (Steps 8 and 9). MME notifies MN's attachment to LTE MAG and LTE MAG releases the buffered downlink traffic (Step 10). Finally, LTE MAG replies to MME (Step 11).

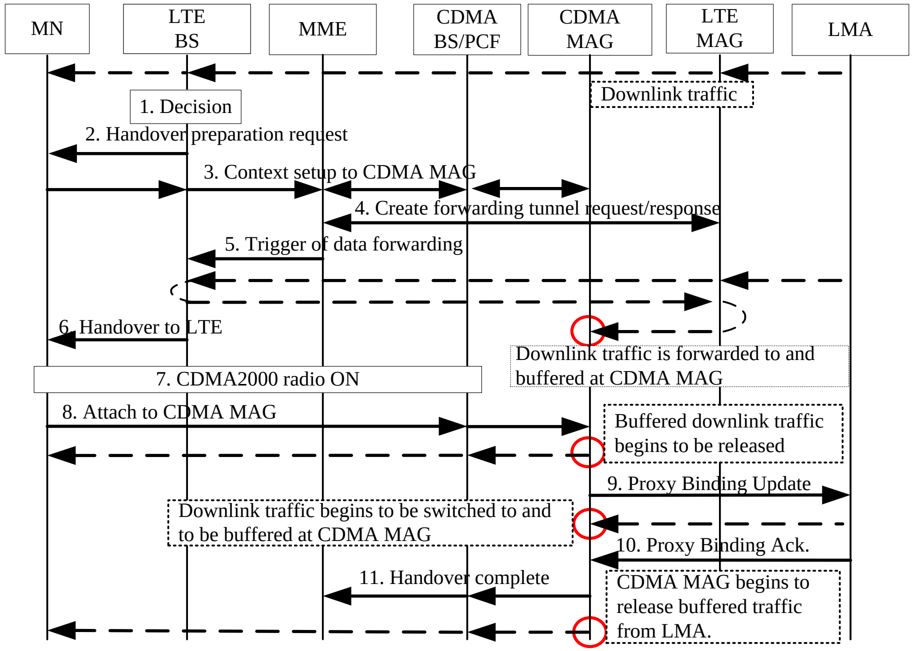

Fig. 2 Standard handover procedure from LTE to CDMA2000.

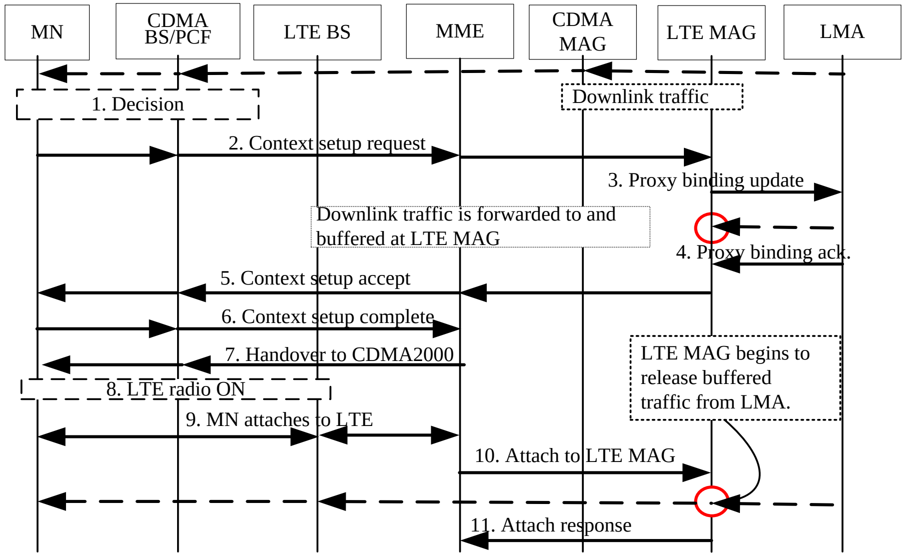

Fig. 3 Standard handover procedure from CDMA2000 to LTE.

3.2 Analysis of Handover Procedures

This subsection analyzes the handover performance of the standard procedures. In both directions, downlink traffic is forwarded to the target MAG to avoid packet losses during the handover. In the handover from LTE to CDMA2000, downlink traffic is transmitted to the target MAG via the forwarding tunnel from LTE BS just before LTE BS requests MN to move to CDMA2000. Therefore, the disruption time during handover can be minimized. On the other hand, in handover from CDMA2000 to LTE, once LMA switches downlink traffic to the target MAG, MN moves to LTE after exchanging signaling messages via multiple nodes (MME, PCF and MN). This may cause longer disruption of communication than that in the reverse direction.

While data forwarding reduces the disruption time during handover, the target MAG needs to handle the downlink traffic from two directions, that is, one is from the source MAG through the forwarding tunnel and the other is from LMA. To avoid out-of-order packets, the target MAG continues to buffer the traffic from LMA until the release of all the traffic from the source MAG finishes. However, the target MAG cannot recognize the end of data forwarding from the source MAG. Therefore, in preventing out-of-order packets, the target

MAG is required to postpone release of the forwarding traffic from LMA for a sufficient period, e.g., until the pre-defined timer has expired. When the timer value is too long, it causes unacceptable disruption time of MN's communication.

3.3 Proposed Modifications to Handover Procedures

From the analysis of the standard handover procedures, two problems are identified, the longer disruption time in handover from CDMA2000 to LTE, and long delay or out-of-order packets in data forwarding. To solve these problems, we propose two modifications to the handover procedures; data forwarding and end-marker emulation approaches. In the modified procedures, signaling messages are based on 3GPP and IETF standards to minimize the impact on the current procedures.

To shorten the disruption time in the handover procedure from CDMA2000 to LTE, a data forwarding approach is applied between two MAGs. This approach aims to reduce the preparation period for MNs to make a handover after downlink traffic is switched to the target MAG.

The proposed handover procedure with data forwarding is shown in Fig. 4. This procedure corresponds to the original standard handover procedure shown in Fig. 3. Steps 1 to 6 are the same as the standard procedure of Fig. 3, except that PBU and PBA in Steps 4 and 5 are skipped. After Step 6, the forwarding tunnel from CDMA MAG to LTE MAG is established by exchanging signaling messages. In Step A1, MME requests LTE MAG to create a forwarding tunnel between LTE MAG and CDMA MAG using the 3GPP signaling message. This is similar to the message of Step 4 in the handover from LTE to CDMA2000 shown in Fig. 2. Then, LTE MAG creates the forwarding tunnel and notifies the tunnel information by sending Handover Initiate message to CDMA MAG (Step A2). Handover Initiate is specified in IETF Fast Handovers for Proxy Mobile IPv6 (PFMIPv6) [8]. CDMA MAG forwards downlink traffic to LTE MAG and LTE MAG buffers it. CDMA MAG replies PFMIPv6 Handover Acknowledgement to LTE MAG and LTE MAG replies to MME (Steps A3 and A4). Steps 7 to 10 are similar to the standard procedure.

After Step 10, LTE MAG releases the buffered traffic from CDMA MAG. Then, LTE MAG exchanges PBU and PBA with LMA (Steps B1 and B2). LMA switches downlink traffic to LTE MAG after receiving PBU and LTE MAG buffers it. This downlink traffic from LMA is released after all the downlink traffic from CDMA MAG is transmitted.

The end-marker emulation approach is applied to avoid the waiting time when data forwarding is applied. To notify the end of data forwarding to the target MAG, our proposal uses PFMIPv6 messages to fit to the PMIPv6-based specification.

The proposed modification is shown in Fig. 5. This modification can be applied to handover procedures with data forwarding shown in Fig. 2 and Fig. 4. After the target MAG and LMA exchange PBU and PBA, LMA sends PMIPv6 Binding Revocation Indication (BRI) message to the source MAG (Step C1). BRI is specified in IETF [9] to terminate a MN's session and to release the associated resources. BRI is used to notify the source MAG to finish data forwarding. The source MAG transmits Handover Initiate with indication of forwarding completion to the target MAG (Step C2). Then, the target MAG recognizes the end of data forwarding and begins to release the downlink traffic from LMA. The target MAG replies Handover Acknowledgement to the source MAG, and then the source MAG sends Binding Revocation Acknowledgement to LMA (Steps C3 and C4).

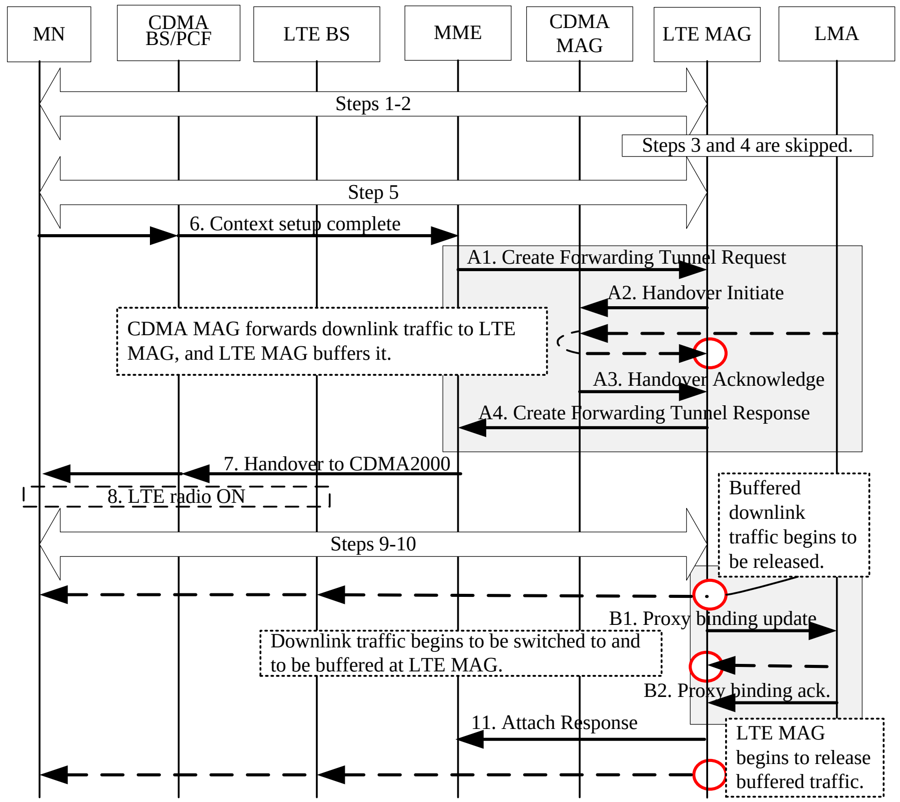

Fig. 4 Modified handover procedure from CDMA2000 to LTE with data forwarding. The procedures with grey squares are modifications.

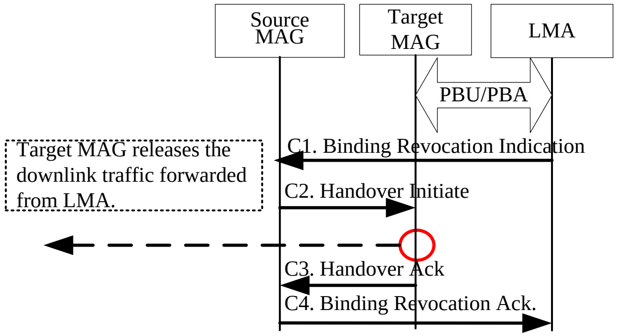

Fig. 5 End-marker emulation procedure.

4. Performance Evaluation

4.1 Experimental Environment and Scenarios

The handover performance is evaluated in an experimental testbed where actual PCs implement the functions of EPC and are interconnected. Table 1 shows the specifications of nodes. Network delay between nodes is controlled by a network emulator dummynet [10]. Both LTE and CDMA2000 are emulated by WiFi. In this experiment, handover performance is evaluated by moving MN between two WiFi access points which correspond to LTE BS and CDMA BS, respectively. During the handover, UDP packets are transmitted from Corresponding Node (CN) to MN using iperf traffic generator [11]. The data rate is 1Mbps and packet size is 1250Bytes. All results are obtained by 10 times and averaged.

We introduce four node deployment scenarios with the case where MNO deploys the new RAT (LTE). In this case, the existing RAT (CDMA2000) was already been deployed in the entire area, whereas the new RAT is deployed in a phased manner. Each phase corresponds with the individual scenario specifying the node deployments, as follows.

-Phase A: MNO deploys LTE only in the urban area. MAG, MME, and BSs for LTE are newly installed in the urban area.

-Phase B: MNO begins to provide LTE service in the rural area. However, only LTE BSs are deployed there. MNs in the rural area still use LTE MAG and MME in the urban area.

-Phase C: After Phase B, a separate LTE MAG is installed in the rural area. MME is still located only in the urban area.

-Phase D: Finally, MME is also deployed in the rural area.

Through all phases, CDMA2000 (the existing RAT) nodes are located in the entire areas. We evaluate handover performance of MN in the urban area in Phase A, while handover performance in the rural area is evaluated in Phases B, C, and D. To realize the above deployment scenarios, the network topology shown in Fig. 6 is constructed. The node deployments in each phase are shown in Fig. 7. This experiment uses the delay parameters shown in Table 2.

For the performance evaluation, the communication disruption time during handover between two RATs is measured as shown in Fig. 8. The entire disruption time, $T_{disruption}$, is defined as the interval time from the receipt of the last packet before the handover to the first data packet after the handover. Time for switching radio accesses is denoted as T_{radio_switch}, which is the period from the arrival time of the last signaling message before the handover to the first signaling packet after the handover. In the experiment testbed, radio accesses are emulated by WiFi so that T_{radio_switch} depends on WiFi specification. To evaluate the disruption time caused by signaling overhead of handover procedures, $T_{overhead}$ is defined as $T_{disruption}$-T_{radio_switch}. This paper uses $T_{overhead}$ as the performance metric to evaluate each handover procedures.

Table 1 Specification of nodes in experimental testbed.

	Mobile Node	Other nodes
Terminal	Panasonic CF-R9JWACDR	Dell PowerEdge R300
OS	Fedora core 10	CentOS 5.3
CPU	Intel Core 7 820UM	Intel Xeon L5410
Network I/F	IEEE 802.11a	Gigabit Ether NIC

Vol.2010-MBL-55 No.12
2010/9/3

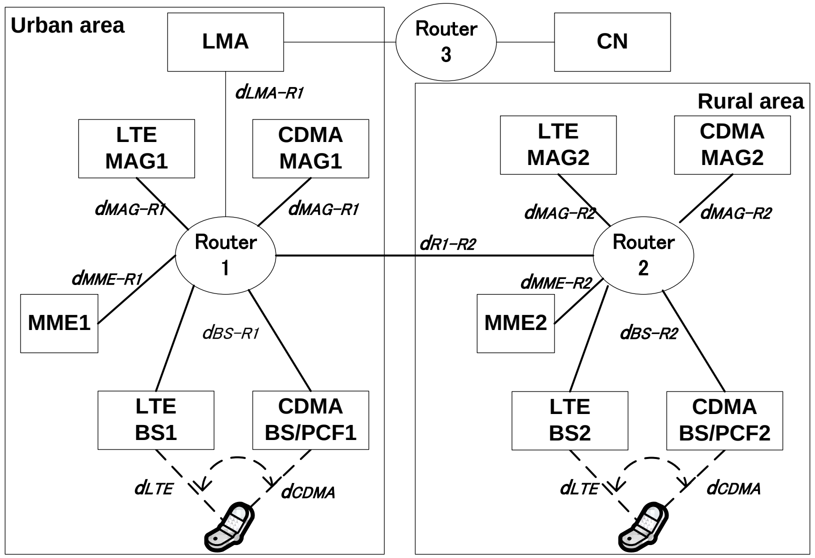

Fig. 6 Network topology and one-way delay between nodes.

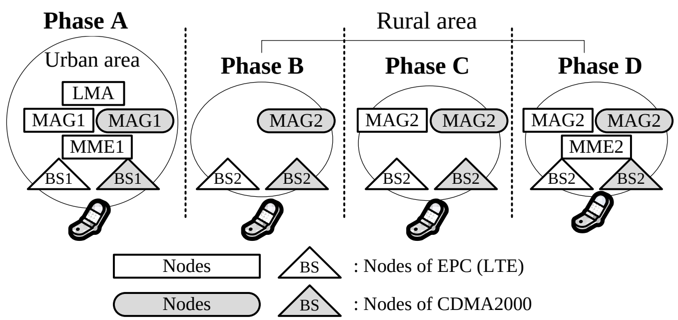

Fig. 7 Node deployments in each phase.

Table 2 Delay parameters in each phase.

Parameters	Delay (msec)	Parameters	Delay (msec)
$d_{R1\text{-}R2}$	0.030	$d_{BS\text{-}R}1/d_{BS\text{-}R2}$	0.010
$d_{LMA\text{-}R1}$	0.002	d_{LTE}	0.020
$d_{MAG\text{-}R1}/d_{MAG\text{-}R2}$	0.002	d_{CDMA}	0.050
$d_{MME\text{-}R1}/d_{MME\text{-}R2}$	0.002		

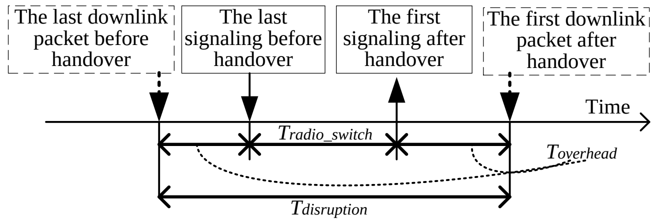

Fig. 8 The communication disruption time during handover.

4.2 Experimental Environment and Scenarios

Fig. 9 shows the disruption time caused by signaling overhead during handover in both the handover directions, that is, handover from LTE to CDMA and handover from CDMA to LTE. Now, we call the former handover Hand-down, and the latter one Hand-up. In the Hand-up procedure, both of the standard and the proposal are shown.

In the Hand-down procedure, all the disruption time of signaling overhead is comparable even when the deployment phases change. This means that the performance in the Hand-down procedure is independent of the node deployments. On the other hand, in the standard Hand-up procedure, results in Phases B and C are higher than those in Phases A and D. In Phases B and C, MME and/or LTE MAG are located only in the area that is far away from the location of MN and BSs. This node deployment causes signaling and transmission delay between nodes involved in MME and LTE MAG so that the disruption time caused by signaling overhead is higher than the other phases. In Phases A and D, all nodes are located nearby MN except LMA. Thus, the location of LMA does not affect the disruption time in this experiment.

Comparing the results between the standard and proposed Hand-up procedures, the disruption time of the proposal is lower than that of the standard procedure in every phase. Particularly, in Phases A and D, the disruption time is reduced by half in the proposed procedure. As described in Section 3B, this is because the data forwarding approach in the proposal decreases the delay for MN to move to LTE since downlink traffic is forwarded to LTE MAG.

Comparing the Hand-down and Hand-up procedures, the disruption time of Hand-down is the lowest in each phase. However, the results of the proposed Hand-up procedure in Phases A and D are almost the same as the Hand-down procedure. From this result, we confirm that the proposal reduces the disruption time when the nodes other than LMA are located in the same area.

Next, we investigate the effect of the end-marker emulation approach when data forwarding is applied. Fig. 10 shows the interval between path switching in LMA and completion of data forwarding through forwarding tunnel. In this experiment, after receiving PBA, the target MAG measures the interval time until the last data packet via the forwarding tunnel arrives.

In the Hand-down procedure, the result of Phase B is four times the other phases. In Phase B, the target CDMA MAG is far away from the source LTE MAG. Thus, the long delay between the two MAGs causes these results. This characteristic applies to the proposed Hand-down procedure, that is, there is longer interval time in Phase B. Comparing the Hand-down and Hand-up procedures, the Hand-down procedure requires more interval time than the Hand-up procedure. This is because in the Hand-down procedure, downlink packets are forwarded in more hops, that is, traffic is forwarded through LTE BS, LTE MAG, and the target MAG.

When the end-marker emulation approach is applied, the target MAG can release the buffered packet just after the completion of data forwarding independent of the node deployments. If the target MAG applies an expiration timer to release the buffered traffic, the timer needs to be set at the maximum value in all the node deployments, that is, the value of Phase B in this experiment. In this case, the target MAG waits for data forwarding to finish in the other node deployments until the timer has expired. This causes unnecessary disruption time for MN after the handover procedure.

Through the experiment, we confirm that the handover performance depends on the node deployments. In particular, when some network nodes are located in the area far from MN, the disruption time becomes higher than other cases. The proposed modification with data forwarding and end-marker emulation approaches reduces the disruption time so that MN can communicate seamlessly when handover occurs.

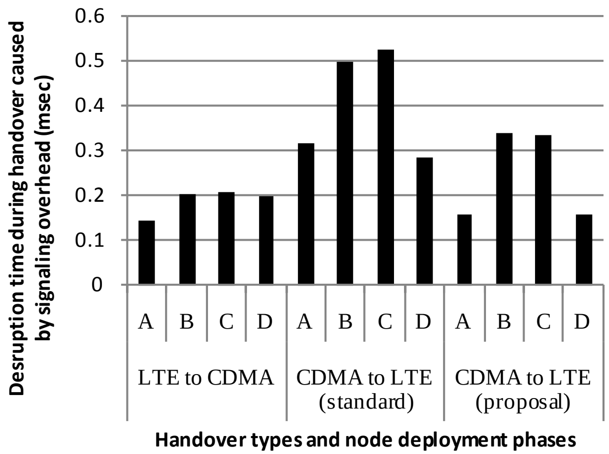

Fig. 9 Disruption time caused by signaling overhead during handover with handover types and node deployment phases.

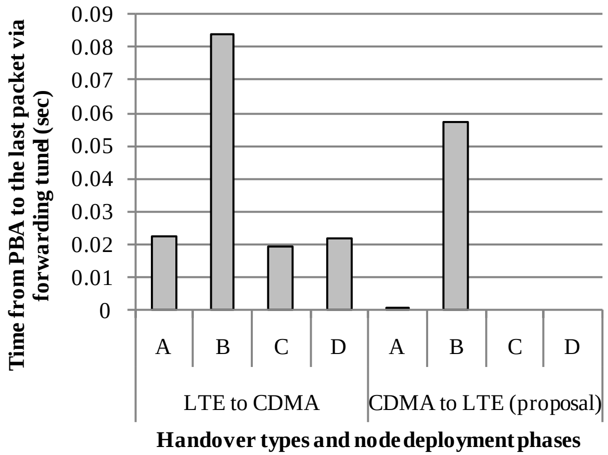

Fig. 10 Time from receipt of PBA to receipt of the last packet via forwarding tunnel at the target MAG.

Vol.2010-MBL-55 No.12
2010/9/3

5. Conclusion

This paper focused on the handover procedures between LTE and CDMA2000 that are standardized in different organizations. We proposed a modified handover procedures using network-based mobility management to achieve shorter disruption of communication during handover. The proposed modification applies data forwarding and end-marker emulation approaches to the standard handover procedures. The handover performance was evaluated using an experimental testbed using actual PCs taking account of a node deployment scenario. From the experimental results, it is confirmed that the handover performance depends on the node deployments. The proposed modification reduces the disruption time in the handover procedure and realizes seamless communications for MNs that move between LTE and CDMA2000 in both directions.

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