Wireless Pers Commun (2010) 52:593–613
DOI 10.1007/s11277-008-9627-6

# A Robust Seamless Handover Scheme for the Support of Multimedia Services in Heterogeneous Emerging Wireless Networks

**Hayoung Oh · Kibaek Yoo · Jongkeun Na · Chong-kwon Kim**

**Abstract** With the rapid development of wireless technologies and numerous types of mobile devices, the need to support seamless multimedia services in Mobile and Ubiquitous Computing (MUC) is growing. To support the seamless handover, several mobility protocols such as Mobile IPv6 (MIPv6) (Johnson et al., Mobility Support in IPv6, IETF, RFC 3775, 2004) and fast handover for the MIPv6 (FMIPv6) (Koodli et al. Past handovers for mobile IPv6 (FMIPv6), IETF, RFC 4068, 2005) were developed. However, MIPv6 depreciates the Quality-of-Service (QoS) especially in multimedia service applications because of the long handover latency and packet loss problem. To solve these problems in the MIPv6, FMIPv6 is proposed in the Internet Engineering Task Force (IETF). However, FMIPv6 is not robust for the multimedia services in heterogeneous emerging wireless networks when the MN may move to another visited network in contrast with its anticipation. In MUC, the possibility of service failure is more increased because mobile users can frequently change the access networks according to their mobility in heterogeneous wireless access networks such as 3Generation (3G), Wireless Fidelity (Wi-Fi), Worldwide Interoperability for Microwave Access (WiMax) and Bluetooth co-existed. In this paper, we propose a robust seamless handover scheme for the multimedia services in heterogeneous emerging wireless networks. The proposed scheme reduces the handover latency and handover initiation time when handover may fail through the management of tentative Care-of Addresses (CoAs) that does not require Duplicate Address Detection (DAD). Through performance evaluation, we show that

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our scheme provides more robust handover mechanism than other scheme such as FMIPv6 for the multimedia services in heterogeneous emerging wireless networks.

**Keywords** Robust seamless handover · Multimedia services · Heterogeneous emerging wireless networks · Mobile and Ubiquitous Computing (MUC) · Tentative CoAs

## 1 Introduction

In recent years, with the proliferation of wireless technologies and electronics devices, there is a fast growing interest in Mobile and Ubiquitous Computing (MUC) [1,2]. In MUC, end users increasingly use mobile devices such as cell phones, PDAs and other handhelds for the seamless interactive and intelligent services. One of the main challenges in MUC is to support a seamless multimedia streaming service such as Internet Protocol Television (IPTV) and Voice over Internet Protocol (VoIP) [3] by supporting fast and robust handover between heterogeneous wireless access networks. Further the core network of the heterogeneous wireless access networks is evolving into all-IP based network. Accordingly, Mobile IPv6 (MIPv6) [4] has become a global mobility solution of Internet Engineering Task Force (IETF) that provides host mobility management. However, the long handover latency and packet loss problem in MIPv6 depreciates the Quality-of-Service (QoS) especially in multimedia service applications. To reduce the handover latency and solve the packet loss problem in the MIPv6, fast handover for the MIPv6 (FMIPv6) [5] is proposed in the IETF. FMIPv6 tries to reduce the address resolution time through the address pre-configuration. It reduces the packet loss and handover latency by providing fast IP connectivity as soon as a new link is established. However, FMIPv6 is not robust for ubiquitous multimedia streaming. In FMIPv6, a Mobile Node (MN) is previously configured with only one new Care-of Addresses (CoA) before it is attached to the new link. This address pre-configuration is useless when the MN may move to another visited network in contrast with its anticipation. In this case, FMIPv6 follows the handover procedure of MIPv6 so that the handover latency increases undesirably. Some work has already tried to improve MIPv6 and FMIPv6. To achieve fast handover in IPv6 mobility, Gogo et al. [6] proposed the L3-driven fast handover mechanism using the abstract link layer information and primitives. They are independent of the link layer (L2) protocols and devices [7]. Through the L2 primitives, the network layer (L3) can know a sign of the L2 handover and L3 can prepare for the L3 handover in advance. As a result, the total handover delay is dramatically reduced. L2 handover means that the MN switches AP (Access Point) from pAP (previous Access Point) to nAP (new Access Point) and L3 handover means that the MN switches AR (Access Router) from pAR (previous Access Router) to nAR (new Access Router). To present an enhanced handover mechanism, Hsief et al. [8] also utilized the additional primitives and parameters by newly adding them to the media independent handover (MIH) services defined in the IEEE 802.21 [9]. The proposed scheme can reduce handover latency by removing the router discovery time and design the network cost-effectively by reducing coverage overlap between adjacent cells. However, these schemes still do not satisfy the delay of the seamless multimedia services and consider the handover delay under imperfect prediction of the MN and out-of sequence problem. To eliminate Duplicate Address Detection (DAD) delay, Leu and Mark [10] and Campbell et al. [11] proposed a fast handover mechanism using fast neighbor discovery and DAD for fast moving MNs. They modified Neighbor Cache with look up algorithm for a quicker DAD checking speed. Therefore it solves the shortcomings of conventional DAD when a router has more than two links. However, it also does not consider the handover delay under imperfect prediction of the MN and out-of sequence problem. Optimistic DAD (oDAD) [12] eliminates DAD delay based on the premise that DAD is far more likely to succeed than fail. To do this, an optimistic MN modifies the standard IPv6 operation rules of [13] and [14] while keeping backward interoperability. However, although this optimistic approach reduces handover latency in noncollision case, if the address collision occurs, it can incur some penalty to both optimistic MN and rightful owner of the address. Therefore, oDAD cannot be the unique solution for the DAD problem. Furthermore, since it is a complete end-to-end approach, only MN can initiate the registration process with the new optimistic address [15]. Also, it does not consider the handover delay under imperfect prediction of the MN and out-of sequence problem. To realize the fast vertical handover, Ishibashi et al. [16] provides the virtual MAC address scheme. That is, to reduce the L3 handover, the virtual MAC address becomes a unique identifier for a MN within the Mobile Ethernet. However, this scheme has limits to implement and needs the additional layer in each MN and also does not consider the handover delay under imperfect prediction and out-of sequence problem. To support the seamless handover between the specific heterogeneous emerging wireless networks such as cellular and wireless local area networks [17] or IEEE 802.16e broadband wireless access system [18] or UMTS-WLAN [19] or WiBro System [20] or 802.11 [21], they provides details on the use of the framework or algorithms for the seamless handover. Shenoy et al. [17] have introduced a framework that can be used for integrating cellular and WLANs. The main features of this framework are its hierarchical and distributed architecture, which provides scalable solution to seamlessly roam across a number of WLANs and cellular networks while supporting call continuity through predictive handoff, QoS mapping, intersystem message translation, and provision in the WLAN for user-subscribed services. Lee et al. [18] presented fast handover algorithm for IEEE 802.16e. According to existing IEEE 802.16e standard, handover procedure consists of network topology acquisition, scanning, initial ranging, authorization, and registration. These procedure causes waste of channel resource. Therefore, they reduced the process of handover for fast and optimized handover. Choi et al. [19] introduced a practical UMTS-WLAN interworking architecture based on 3GPP standards and proposed a seamless handoff method which guarantees low delay and low packet loss during UMTS-WLAN handoff. For low handoff delay, the proposed handoff scheme performs pre-registration and pre-authentication processes before L2 handover. Moreover, it uses packet buffering and forwarding functions in order to reduce packet loss during the handoff period. Shim et al. [20] proposed an effective fast handover mechanism for IPv6 based WiBro system by employing the packet buffering and tunneling mechanism. As a result, the proposed scheme reduces the handover latency, packet loss and eliminates the out-of order problem by integrating L2 and L3 handovers efficiently. Sampraku et al. [21] presents an effective and simple solution in IEEE 802.11 wireless LANs (WLANs) using IP tunneling mechanism. However, these handover schemes are only applied to the specific heterogeneous emerging wireless networks. Furthermore, it does not consider the handover delay under imperfect prediction of the MN. In this paper, we propose a robust seamless handover scheme for the multimedia services in heterogeneous emerging wireless networks. Unlike FMIPv6 that uses one tentative CoA at a MN handover, the proposed scheme exploits multiple tentative CoAs to prevent a fast handover from being failed in a visited network for which there is no provisional CoA in case of FMIPv6. By making a fast handover possible in any situations, the scheme definitely reduces the handover latency in average. Furthermore, the proposed scheme minimizes the handover initiation time by proactively managing the tentative CoAs available among the neighboring access routers. In our scheme, each AR maintains a set of unused IP addresses in its access networks by periodically performing DAD. Each of neighboring ARs allocates a few of unused IP addresses to be used as tentative CoAs to the other AR, and notify its allocation to the other AR by sending Router Advertisement (RA). Thus, each AR collects a set of tentative CoAs to be temporarily used in other neighboring access networks. In our scheme, AR provides the tentative address list which contains tentative CoAs for each neighboring access network with the MN before handover. As a result, at handover the MN can use a tentative CoA to be instantly used without DAD in new visited network for fast IP connectivity. Our main contribution is indeed a mechanism that definitely reduces the handover latency in average and analyzes the effect of perfect handover prediction and imperfect handover prediction in heterogeneous emerging wireless networks. Through performance evaluation, we show that our scheme provides a more robust handover mechanism than other scheme such as FMIPv6 for multimedia streaming services. The rest of this paper is organized as follows. We start in Sect. 2 by giving the general system architecture for the proposed scheme. A robust seamless handover scheme for the multimedia services in heterogeneous emerging wireless networks is described in Sects. 3, and 4. Section 5 presents the analysis and performance results. Finally, we conclude the paper in Sect. 6.

## 2 System Architecture

In MUC, generally several heterogeneous wireless networks are coexisted as shown in Fig. 1. The internet is a backbone connecting the home network and several heterogeneous visited

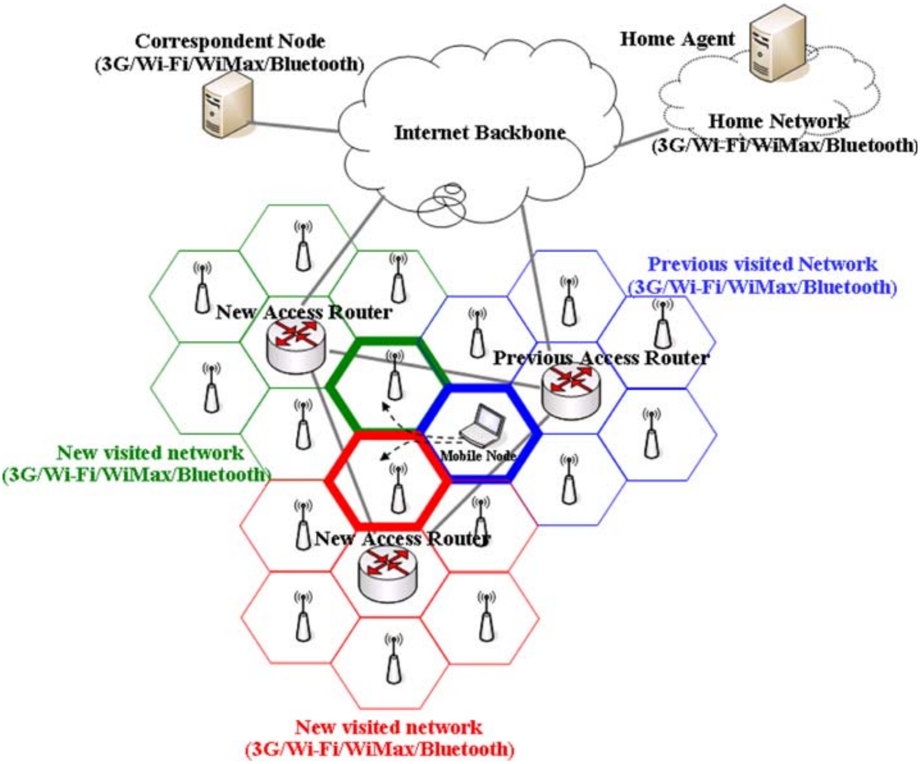


**Fig. 1** Architecture with heterogeneous wireless access networks in MUC

networks such as 3G, Wi-Fi, WiMax and Bluetooth [3]. The home network is where a MN has its global IPv6 address (home address). IPv6 address is 128 bits and it consists of the prefix of AR (64 bits) and MAC address of MN (64 bits). Home address is a unicast routable address assigned to the MN, used as the permanent address of the MN. Standard IP routing mechanisms will deliver packets destined for a MNs home address [4]. A domain of visited network is comprised of several ARs and wireless APs which a MN can make a connection with [15]. We assume that each AR has an interface which is connected with a distinct set of APs and the same network prefix cannot be assigned to the interface of a different AR. That is, ARs are distinguished with its own prefix each other. In general, a MN can send and receive packets to Home Agent (HA) or Correspondent Node (CN) with CoA. HA is a router in the MNs home network with which the MN has registered its CoA. While the MN is away from home network, HA intercepts packets destined to the MNs home address, encapsulates them, and tunnels them to the MNs registered CoA. The association between a MNs home address and CoA is known as a binding for the MN. While away from home network, a MN registers its new CoA with a home address. The MN performs this binding registration by sending a Binding Update message to the HA. The HA replies to the MN by returning a Binding Acknowledgement message. CN is a peer node with which a MN is communicating. The CN may be either mobile or stationary. CoA is a unicast routable address associated with a MN while visiting a new visited network. CoA is composed of the prefix of nAR in a new visited network and the MAC address of the MN. CoA is made after DAD. DAD corresponds to the most part of handover latency as it requires time in the order of seconds to detect whether the MNs new CoA is duplicated or not [12].

## 3 A Robust Seamless Handover Scheme

In this section, we detail a robust seamless handover scheme with the temporal reuse of tentative CoAs for the multimedia services in heterogeneous emerging wireless networks, along with the architectural view depicted in Fig. 2. The proposed scheme introduces the tentative address management that is performed proactively by ARs. Based on that, the handover procedure is composed of the movement detection using L2 trigger, L3 handover through fast IP connectivity with tentative CoA, and binding updates.

### 3.1 Tentative Address Management (TAM)

Each AR such as nAR and pAR manages the tentative address pool containing the unused IP addresses that can be used as temporal CoA by a visiting MN. We denote those addresses to tentative CoAs. The AR makes sure that the tentative CoAs registered in the pool are currently not used by other MNs by performing DAD for each tentative address periodically. Basically let us assume that each AR maintains tentative CoAs as many as the number of neighbor ARs. A tentative CoA is deleted from the pool if it is proved as being used by another node through DAD. If the number of tentative CoAs is smaller than the number of neighbor ARs, then the router adds new tentative CoAs into the pool by searching available IP addresses. We assume that each router can periodically send and receive the modified Neighbor Router Advertisement (mNRA) including the non-overlapping several tentative CoAs to each other. As a result, each router can manage available tentative CoAs about the access networks of one-hop neighbor. In general, NRA contains router information [5]. We modified the reserved field in NRA to include the several tentative CoAs. Each router informs modified Proxy Router Advertisement (mPrRtAdv) containing several tentative CoAs about

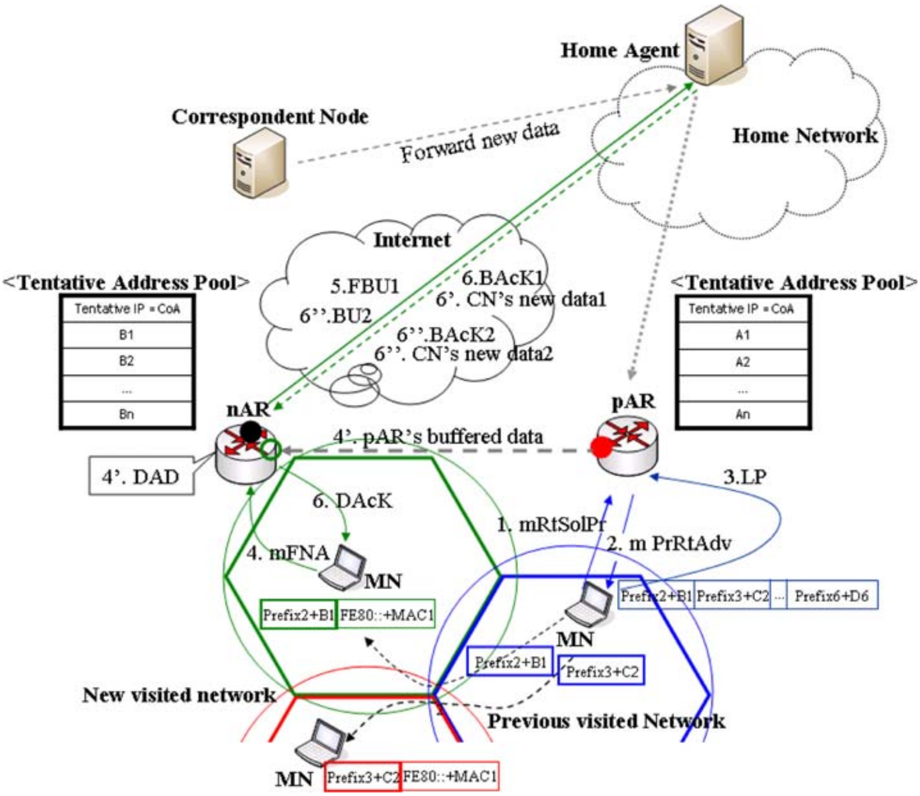


**Fig. 2** Architectural view for a robust seamless handover scheme with tentative CoAs in MUC

neighboring access networks to the MN before it moves to one of visited networks. As shown in Fig. 2, when the MN moves to one of the new visited networks from the previous visited network, the corresponding tentative CoA of new visited network is used by the MN for fast IP connectivity. The fast IP connectivity enable the MN to perform binding update using the tentative CoA i.e. FBU1 and BAcK1 in Fig. 2. After the MN acquires its original CoA containing its own MAC address by performing DAD, it replaces the fast IP connectivity using tentative CoA to its normal IP connectivity using the original CoA (see Sects. 4.2 and 4.3). Recycling of tentative CoAs is possible because these tentative CoAs are temporally used by MNs to reduce handover delay until the MN completes binding updates using its new original CoA, i.e BU2 and BAcK2 in Fig. 2.

## 4 Handover Procedure

In general, a handover procedure can be divided into two components: a link layer handover (L2 handover) and a network layer handover (L3 handover). In the L2 handover, the link layer of the MN changes the access point (AP) to which it is connected. That is, the term L2 handover denotes its support for roaming at the link layer level and effects as the hint of the MNs movement. The L2 handover precedes the L3 handover even though the L3 handover is independent of the L2 handover. For independence between L2 handover and L3 handover, IEEE 802 has been developing standards to enable interoperable handover between heterogeneous networks [22,23]. In special, IEEE 802.21 specification defines Media Independent Handover (MIH) primitives to provide the link layer intelligence and other related network information to the upper layers to optimize handovers between heterogeneous media [20]. One of the primitive categories is event service. It is used for the hint of L3 handover. Events provides the condition of the L2 data links to the L3 layer or reflects the response of the L3 layer. The representative event primitives includes link going down, link down, link up, etc. (see Sect. 4.1). L3 handover occurs when the network point-of-attachment of the MN changes after an inter-network movement (inter-network or intra-foreign-network movement) [24]. Inter-network or intra-foreign-network movement means the MN changes from oAR to nAR. When L3 handover happens, the MNs ongoing transmissions are disrupted and IP-connectivity via its home IP address and old CoAs is lost because the nAR can not recognize the MNs old CoAs. Therefore, to support the seamless handover, the L3 handover consists of the two phases. In the first phase, a new CoAs is generated and DAD is executed when a MN moves to the new visited network. In the second phase, the new CoA is registered with the HA through the binding update.

Figure 3 shows the handover procedure of the proposed scheme for Interactive Multimedia and Intelligent Service (IMIS) in MUC and Fig. 4 shows the modified representative mes-

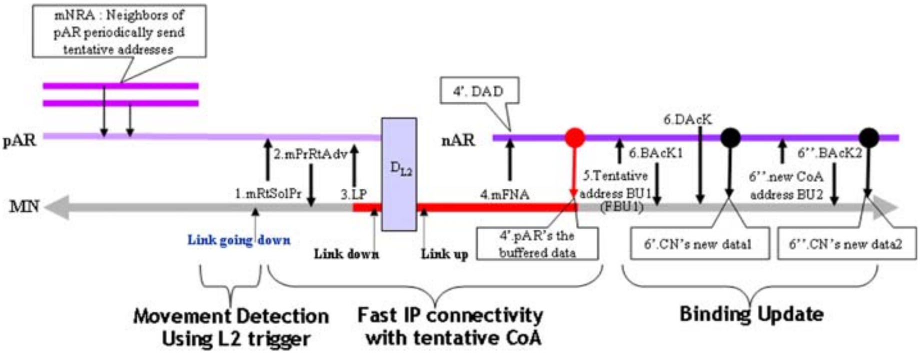


**Fig. 3** A robust seamless handover scheme for IMIS in MUC

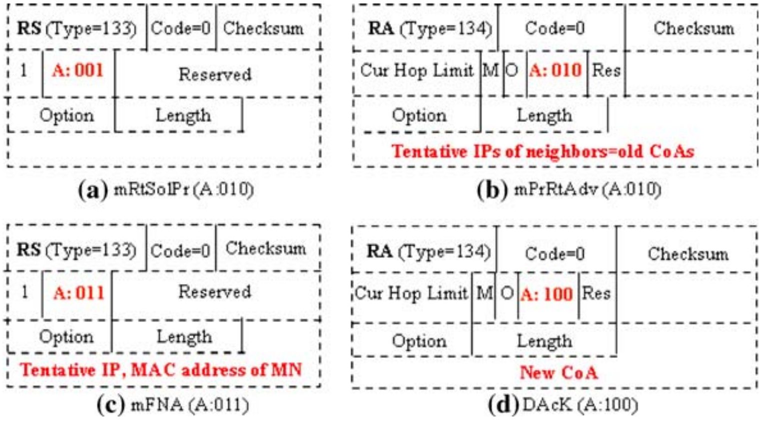


**Fig. 4** The modified representative message format for a robust seamless handover scheme

sage formats. For comparison, we annotate the differences in handover procedure between FMIPv6 and our scheme. (1) modified Router Solicitation for Proxy (mRtSolPr): a MN initiates the handover procedure by sending mRtSolPr to pAR when link going down is triggered. mRtSolPr is used for the MN to inform pAR of MNs movement to one of new visited networks and ask the tentative address list containing the unused IP addresses that can be used as temporal CoA by a visiting MN. In FMIPv6, a MN initiates the handover procedure by sending RtSolPr to nAR. It is used for the MN to ask the nARs prefix which will be used to make a new original CoA. (2) modified Proxy Router Advertisement (mPrRtAdv): when pAR receives mRtSolPr from the MN, it sends mPrRtAdv containing several tentative CoAs about one-hop neighbors to the MN. In FMIPv6, when pAR receives RtSolPr from a MN, it sends PrRtAdv containing the prefix of nAR where a MN will handover. (3) Last Packet (LP): The MN sends the LP message when the calculated RSSI of received beacon is less than the link going down and greater than the link down. It makes to pAR stop forwarding ongoing packets to the MN because the MN is about to handover. pAR receives the LP from the MN and checks the last packet in the red circle buffer of Fig. 3. In FMIPv6, instead of the LP, the MN exchanges FBU and FBAcK with pAR involving in the signaling [5] with nAR to get the prefix information of nAR. After having sent FBU, pAR stops forwarding packets to the MN. This causes a long packet delay and handover delay because the MN can not receive the packets after FBU. (4) modified Fast Neighbor Advertisement (mFNA): the MN sends mFNA including a tentative CoA for fast IP connectivity and the unique MAC address of the MN for making its original CoA to nAR as soon as it handovers. As a result, nAR simultaneously performs DAD of the original CoA of the MN while forwarding the buffered packets to the MN using the tentative CoA. Although the MN moves to the other place in contrast with the anticipation, the MN can send new mFNA without the additional DAD by choosing a corresponding tentative CoA in the tentative address list. In FMIPv6, the MN sends FNA including the CoA made at handover initiation between pAR and nAR in advance. In that case, if MN moves into the other place to which the CoA is not applicable (i.e., MN cannot use the CoA directly), the fast IP connectivity becomes impossible so that MN has to make a new CoA for the visited network as in MIPv6. (5) Binding Update (BU): nAR performs FBU1 for a tentative CoA in a new visited network before BU2. Because BU2 is possible after the MN makes the original CoA including its own MAC address through DAD. After FBU1, the packets directed from HA or CN may be delivered earlier than the buffered packets from pAR. This may cause an out-of sequence problem. To solve this problem, each router uses the separate two buffers. One is for the packets relayed from pAR during the MNs handover and the other is for the packets forwarded directly from HA or CN, the two buffering points are depicted as the red and black circles in Fig. 3. In FMIPv6, nAR performs one binding update with new CoA if the handover succeeds. However, it does not take care of the out-of sequence problem. (6) DAD Acknowledgement (DAcK): DAcK is a signaling message newly introduced in the proposed scheme. The MN gets its original CoA through DAcK after DAD of nAR, it also continues to perform normal binding update, BU2, while communicating with CN via the tentative CoA.

### 4.1 Movement Detection Using L2 Trigger

The primary aim of movement detection is for the MN to prepare L3 handover. Our scheme uses the L2 triggers as used in FMIPv6 to trigger L3 handover initiation in advance [9,25]. As stated above, L2 handover means that the MN switches the AP from pAP to nAP. For exmaple, when L2 of the MN senses the weakening of the signal strength from pAP, it recognizes its mobility from pAP to nAP. And it informs its mobility of L3 of the MN through L2 triggers. As a result, the MN prepares L3 handover which means that the MN switches the AR from pAR to nAR. We consider three kinds of L2 triggers. These are link going down, link down and link up. Link going down means that a link down event will be occurred in the near future, so L3 of the MN must initiate the handover procedure. Link down indicates that the link of pAP cannot be used for data transmission any more. Link up is provided to L3 of the MN when a new link of nAP is connected. Each L2 triggers are occurred when the calculated RSSI (Receive Signal Strength Indicator) of received beacon is smaller than the predefined RSSI threshold [26].

### 4.2 Fast IP Connectivity with Tentative CoA

Handover latency means an elapsed time period from the time instant a MN receives the last packet from its pAR until the time instant the MN receives the first packet from its nAR. To compare the handover latency in handover schemes, we illustrate the overall handover procedures of MIPv6, FMIPv6 and our proposed scheme in Fig. 5. As represented by the red bold lines in Fig. 5, the handover latency of our proposed scheme is shorter than that in other schemes because managing tentative CoAs allow the MN to receive packets as soon as it handovers to a new access network. In case of using a tentative CoA, DAD of the original CoA is independently progressed while maintaining the fast IP connectivity to which the tentative CoA is applied. Thus, it does not affect the handover latency. Comparing with MIPv6, the handover latency of our proposed scheme can be reduced at least 1sec of DAD. In addition, the proposed scheme reduces packet latency because the MN can receive the packet from pAR until the MN sends the LP message to pAR. In FMIPv6, the MN is pre-configured with one corresponding CoA at handover initiation before it is attached to a new access network. If the MN moves to another access network for which the MN does not have a preconfigured CoA, the fast IP connectivity fails because the acquired CoA is useless in the access network. Thus, in the unexpected case, the handover latency of FMIPv6 may become longer than

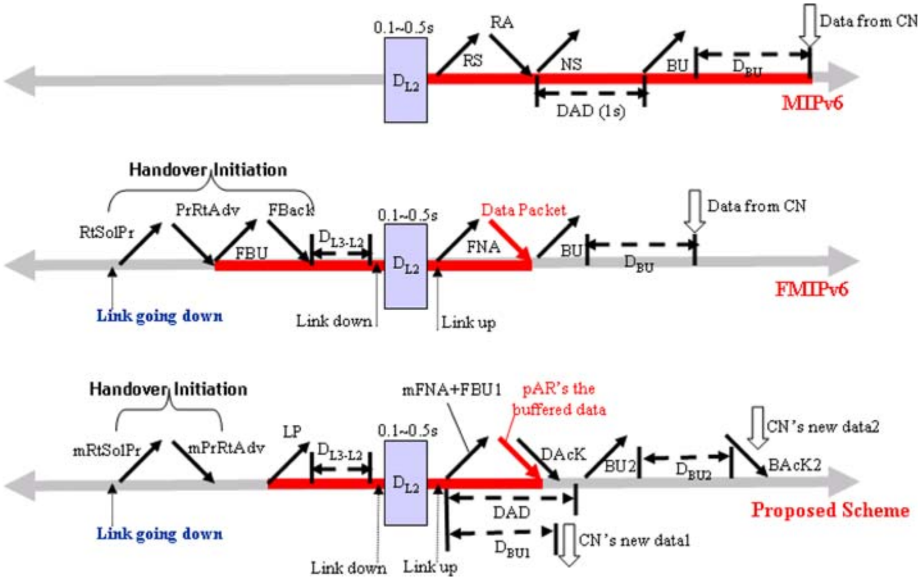


**Fig. 5** Handover procedure of MIPv6, FMIPv6, proposed scheme

even MIPv6. In contrast, our proposed scheme using tentative CoA is very robust because it can still provide the fast IP connectivity by choosing one of tentative CoAs dedicated to the visited network. In Sect. 5, we detail on the effect of imperfect handover prediction of FMIPv6.

### 4.3 Binding Updates

In MIPv6, CN communicates with the MN using global IP of the MN via HA before direct binding update between MN and CN. And HA maintains the binding cache composed of CoA of MN and global IP of the MN. Therefore, the MN should inform a new CoA to HA when the MN moves to a new visited network. After binding updates, CN and HA can send packets to the MN. In our scheme, two binding updates occur. One is a binding update with the tentative CoA and the other is that with the original CoA composed of the prefix of router and the unique MAC address of the MN. In this case, as simultaneously progressed while maintaining the fast IP connectivity using tentative CoA, the second binding update with the original CoA does not affect the handover latency in Fig. 5.

## 5 Performance Evaluation

To evaluate the performance of FMIPv6 and our proposed scheme, simulation was performed with various parameters such as coverage of AR, beacon interval, traffic type, link delay and so on. Figure 6 shows a network topology used in our simulation. In this simulation

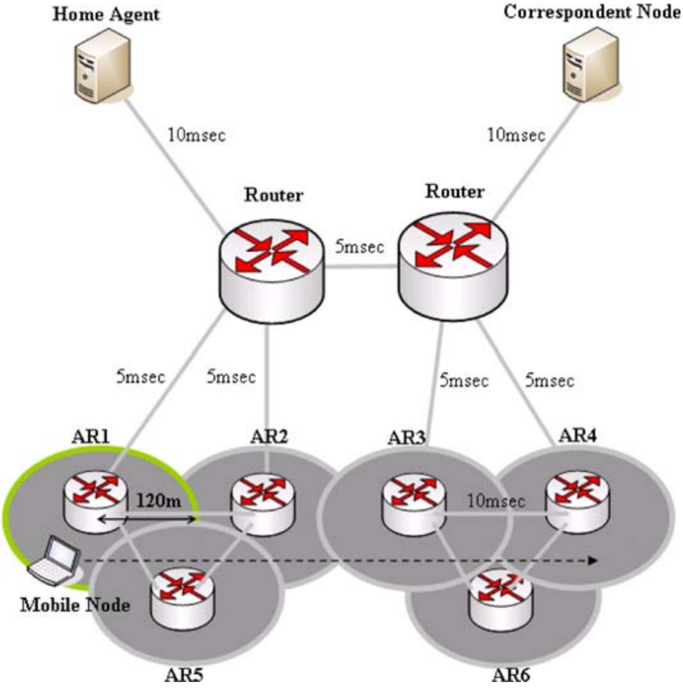


**Fig. 6** Simulation network topology

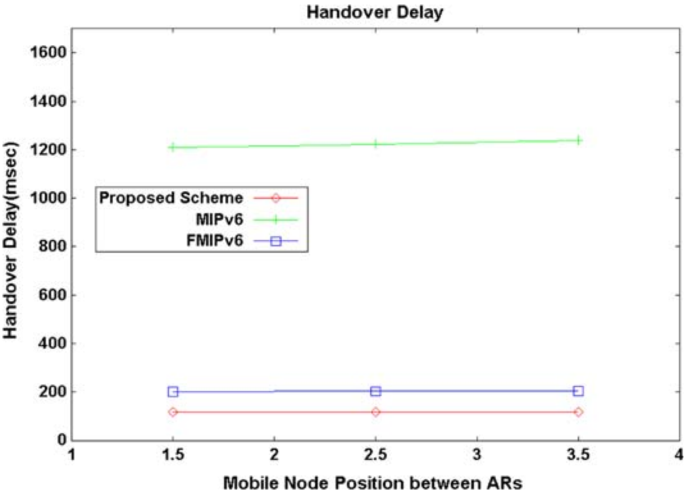


**Fig. 7** Handover delay with mobile node position

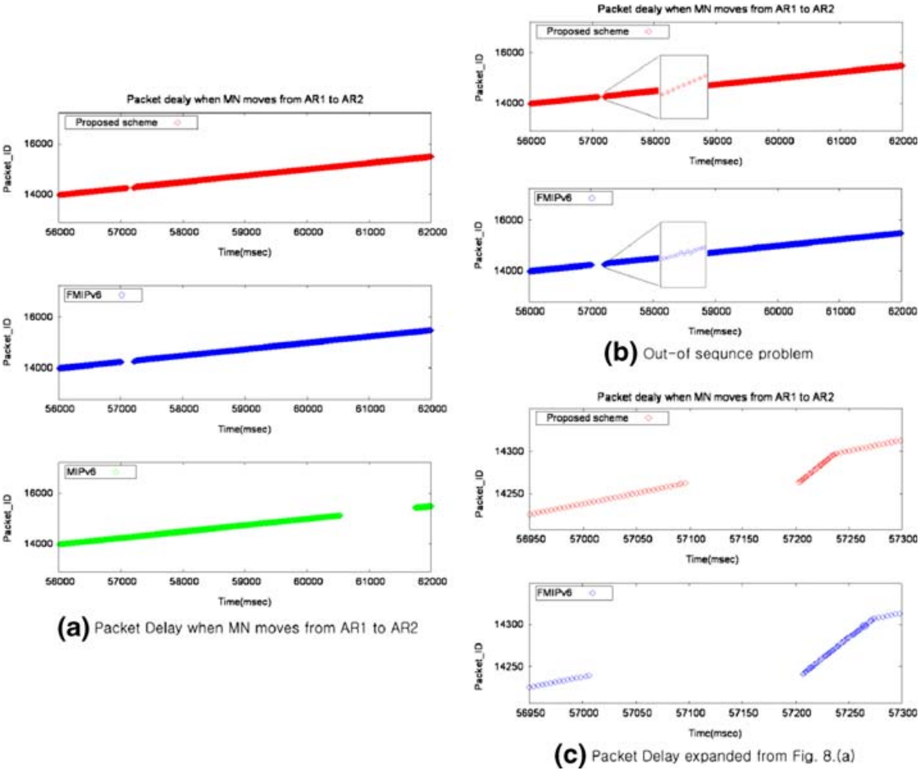
topology, we use several entities, including HA, CN, AR, and MN. We use 2 Mbps CBR/UDP multimedia traffic that constantly is sent from CN to MN. Link delay is assigned to 5 ms for MN-AR links and AR-Router links, 10 ms for Router- CN/HA links and AR-AR links, as shown in Fig. 6. Link delay contains propagation delay, processing delay and queuing delay. The velocity in which MN is moving across the network is 2 m/s.

### 5.1 Handover Delay Under Perfect Prediction

Figure 7 shows handover delay of MIPv6, FMIPv6 and the proposed scheme when the MN moves from AR1 to AR4. Handover delay shows better performance according to the order of our proposed scheme, FMIPv6 and MIPv6. Comparing to other schemes, handover delay of the proposed scheme is prominently reduced and that is improved than the previous work [27]. The reason is directly from that the MN can receive the packets from pAR until the MN sends LP (Last Packet) to pAR and also can receive packets as soon as moving to new visited networks by using tentative CoAs. Figure 8a shows the packet delay when the MN moves from AR1 to AR2. Each point means the trace of packet IDs received from CN to MN. We can see that the packet delay of the proposed scheme is smaller than other schemes. Figure 8b shows how the proposed scheme solves the out-of sequence problem. And Fig. 8c shows the proposed scheme receives the packets as much as possible from pAR before the MN moves to a new visited network.

### 5.2 Handover Delay Under Imperfect Prediction

To compare our proposed scheme with FMIPv6 in the existence of imperfect handover prediction, we utilize several mobility models such as Random Walk Model, City Section Model and Linear Walk Model [28]. First of all, we analyze and simulate FMIPv6 and our scheme by using Random Walk Model. It is useful to understand mobility patterns according to direction and speed. Figure 9a shows that Random Walk Model has total nine states with the combination of each $x$ and $y$ states and each state means the direction (i.e. north, south, east, west, north-east, north-west, south-east, south-west and stay) and speed. The numeric

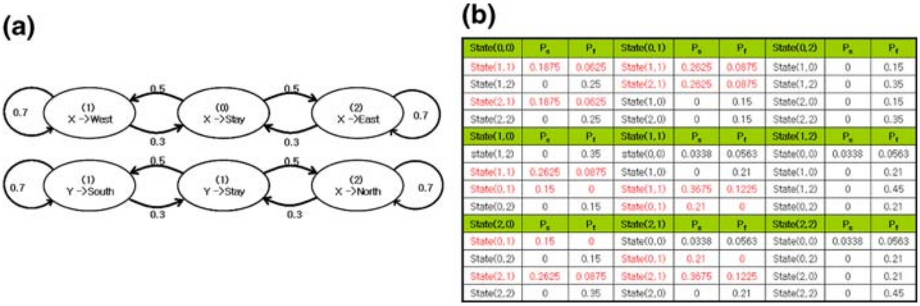


(a) Packet Delay when MN moves from AR1 to AR2

(b) Out-of sequnce problem

(c) Packet Delay expanded from Fig. 8.(a)

**Fig. 8** When MN moves from AR1 to AR2 **a** packet delay of proposed scheme, MIPv6, and FMIPv6, **b** out-of sequence problem, **c** packet delay expanded from (**a**)



| State(0,0) | $P_s$ | $P_f$ | State(0,1) | $P_s$ | $P_f$ | State(0,2) | $P_s$ | $P_f$ |
|---|---|---|---|---|---|---|---|---|
| State(1,1) | 0.1875 | 0.0625 | State(1,1) | 0.2625 | 0.0875 | State(1,0) | 0 | 0.15 |
| State(1,2) | 0 | 0.25 | State(2,1) | 0.2625 | 0.0875 | State(1,2) | 0 | 0.35 |
| State(2,1) | 0.1875 | 0.0625 | State(1,0) | 0 | 0.15 | State(2,0) | 0 | 0.15 |
| State(2,2) | 0 | 0.25 | State(2,0) | 0 | 0.15 | State(2,2) | 0 | 0.35 |
| State(1,0) | $P_s$ | $P_f$ | State(1,1) | $P_s$ | $P_f$ | State(1,2) | $P_s$ | $P_f$ |
| state(1,2) | 0 | 0.35 | state(0,0) | 0.0338 | 0.0563 | State(0,0) | 0.0338 | 0.0563 |
| State(1,1) | 0.2625 | 0.0875 | State(1,0) | 0 | 0.21 | State(1,0) | 0 | 0.21 |
| State(0,1) | 0.15 | 0 | State(1,1) | 0.3675 | 0.1225 | State(1,2) | 0 | 0.45 |
| State(0,2) | 0 | 0.15 | State(0,1) | 0.21 | 0 | State(0,2) | 0 | 0.21 |
| State(2,0) | $P_s$ | $P_f$ | State(2,1) | $P_s$ | $P_f$ | State(2,2) | $P_s$ | $P_f$ |
| State(0,1) | 0.15 | 0 | State(0,0) | 0.0338 | 0.0563 | State(0,0) | 0.0338 | 0.0563 |
| State(0,2) | 0 | 0.15 | State(0,1) | 0.21 | 0 | State(0,2) | 0 | 0.21 |
| State(2,1) | 0.2625 | 0.0875 | State(2,1) | 0.3675 | 0.1225 | State(2,0) | 0 | 0.21 |
| State(2,2) | 0 | 0.35 | State(2,0) | 0 | 0.21 | State(2,2) | 0 | 0.45 |

**Fig. 9** In Random Walk Model, **a** flow chart of the probabilistic version of Random Walk Model, **b** Prob. of $P_s$ and $P_f$ according to the MNs initial state

number of the arrow means the transition probability. Each state changes to the next state according to the transition probability. In this paper, we only consider the direction of MN to simplify the analysis.

We randomly locate the MN in a part of the overlapping area shadowed with black triangle as shown in Fig. 10a. This area is common part out of link going down range of each visited networks. The MN randomly chooses one of initial nine states with the same

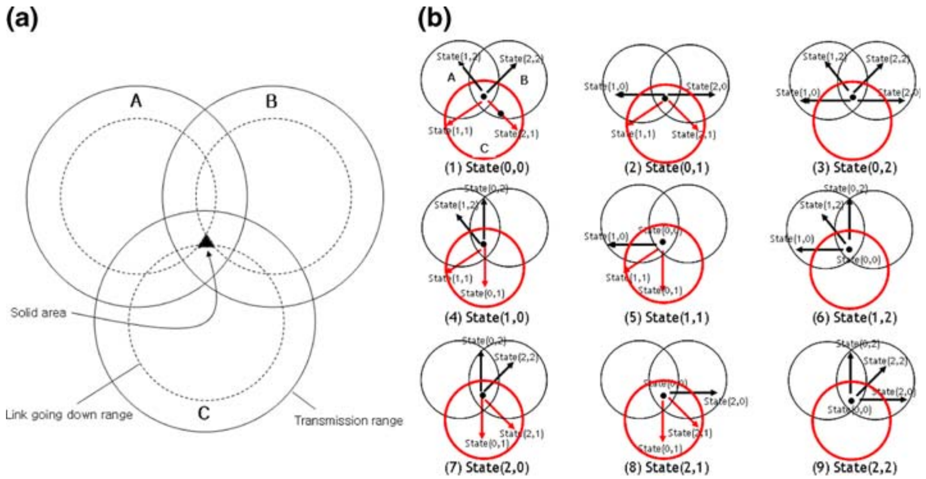


**Fig. 10** In Random Walk Model, **a** MNs initial location within solid area, **b** MNs four next state according to MNs each initial state

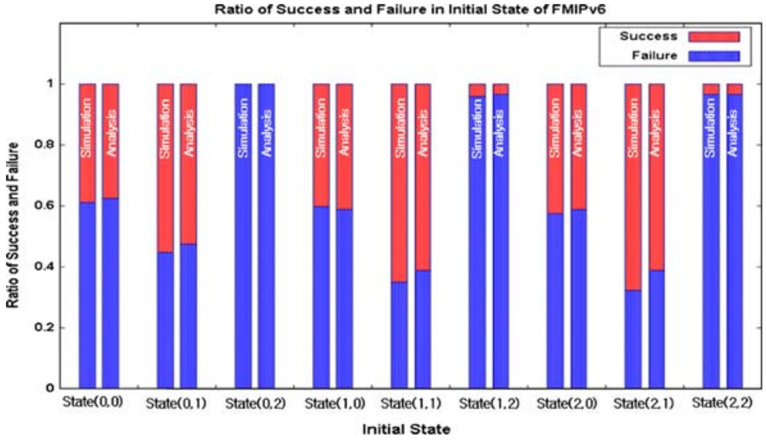


**Fig. 11** In Random Walk Model, result of simulations and analysis

probability. And then changes to one of four next states as in Fig. 10b. We assume that Area A is pAR of the MN and the MN predicts to move to Area C at once. In this case, let us say that the handover succeeds as the MN really handovers to Area C and otherwise it fails. We first analyze the handover success probability ($P_s$) and the handover failure probability ($P_f$) according to the MNs initial state based on the transition probability as shown in Fig. 9a. And then we simulate the random walk procedure with sample size 10,000 to verify the result of analysis. Figure 9b shows the analysis result of $P_s$ and $P_f$. $P_s$ can be calculated when the MN moves to one of the following states: State(1,1), State(0,1) and State(2,1) in Area C. $P_f$ can be calculated when the MN handovers to other areas except Area C. Figure 11 shows the results of simulation and analysis. It shows that the analysis results nearly match the simulation. The small difference is due to unpredictable mobility patterns of State(1,1), State(2,1) that are sometimes success or failure. The detailed analysis of handover delay in case of perfect handover prediction and imperfect handover prediction can be found in Appendix 1.

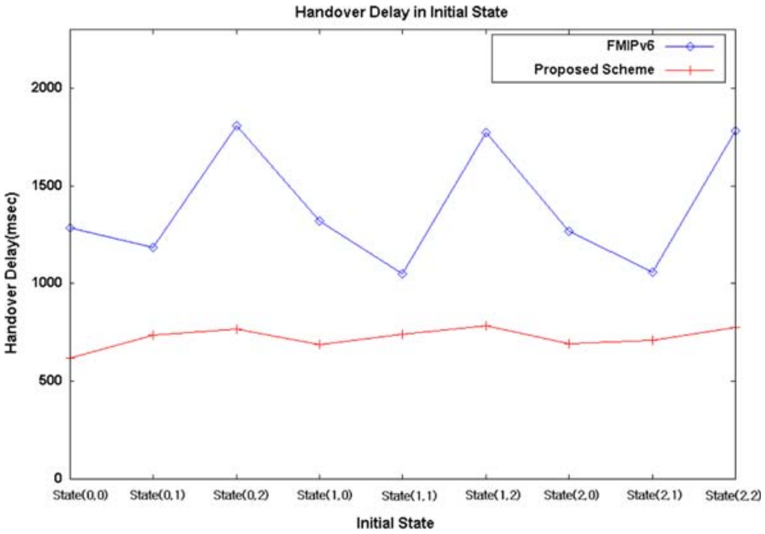


**Fig. 12** In Random Walk Model, handover delay in initial state of FMIPv6 and our proposed scheme

Figure 12 shows the handover delay of FMIPv6 and our proposed scheme according to the initial state. Initial states are possible locations where the MN can be located. As expected, our scheme provides shorter handover delay than FMIPv6 because it is more robust in case of handover failure situations in dynamic mobility environment. Figure 13a shows the total probability of success and failure of FMIPv6 and proposed scheme according to Random Walk Model, City Section Model and Linear Model. Figure 13b shows handover delay of FMIPv6 and our proposed scheme. In City Section Model, with the values defined in Fig. 9a, a MN may take a step in any of the four possible directions (i.e. north, south, east, west) as long as it continues to move (i.e. no pause time). In Linear Model, with the values defined in Fig. 9a, a MN may take a step in any of the two possible directions (i.e. north, south) as long as it continues to move. In these cases, the handover delay of FMIPv6 is still longer than the proposed scheme. As stated above, In FMIPv6, the MN is pre-configured with one new CoA before handover. As a result, the failure probability of FMIPv6 handover increases under imperfect handover prediction. However, in our proposed scheme, the handover failure does not occur because the MN can use the pre-allocated tentative CoAs in all neighboring access networks at handover.

## 6 Conclusion

With the remarkable development of wireless technologies, the need to support seamless multimedia services in MUC is growing. To support the seamless handover, several handover schemes such as MIPv6 and FMIPv6 and micromobility protocols [29–31] were developed. However, these schemes especially do not satisfy the Quality-of-Service (QoS) in multimedia service applications because of the long handover latency and packet loss problem and handover failure and out-of sequence problem. In MUC, the possibility of service failure is more increased because mobile users can frequently change the access networks according to their mobility in heterogeneous wireless access networks such as 3G, Wi-Fi, WiMax and

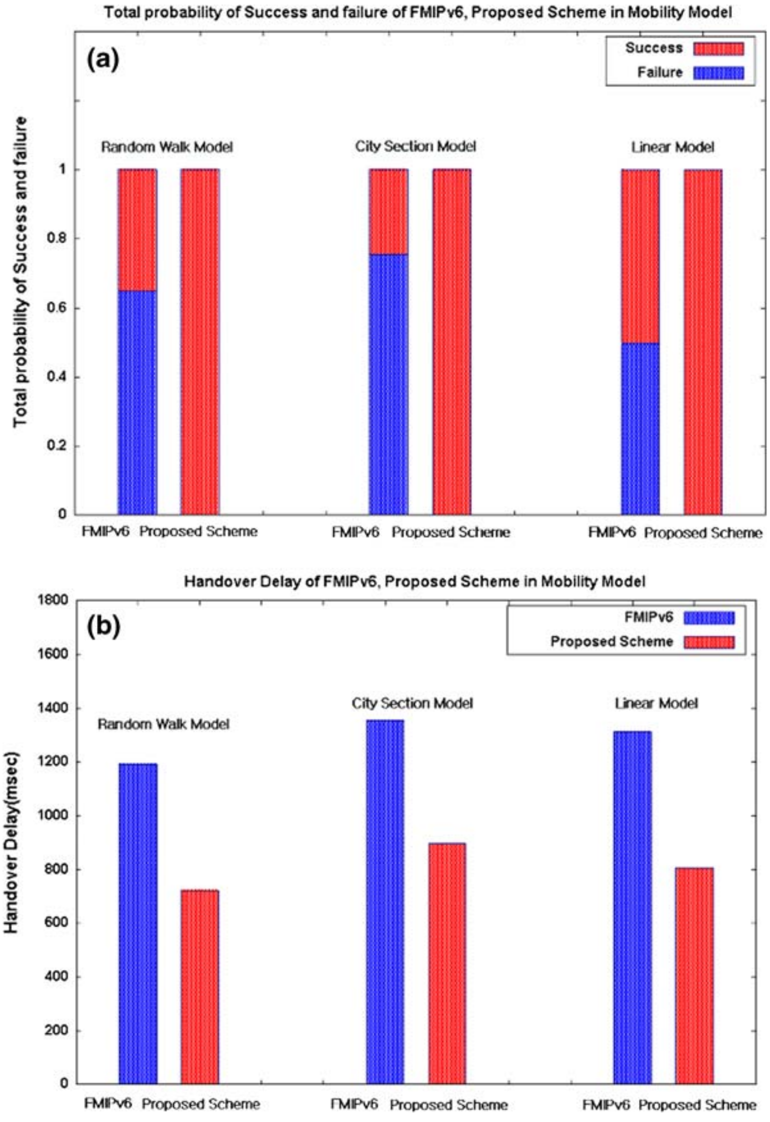


**Fig. 13** According to Random Walk Model, City Section Model, Linear Model, **a** the total probability of success and failure of FMIPv6 and proposed scheme, **b** handover delay of FMIPv6 and proposed scheme

Bluetooth co-existed. In this paper, we propose a robust seamless handover scheme with tentative CoA for the multimedia services in heterogeneous emerging wireless networks. It reduces the handover latency, handover initiation time when handover may fail through the temporal reuse of tentative CoA that does not require DAD. Through performance evaluation based on Random Walk, City Section and Linear Mobility Models, we show that our proposed scheme provides more robust handover mechanism than other scheme such as FMIPv6 for a seamless multimedia streaming in MUC.

**Acknowledgments** "This research was supported by the MKE (The Ministry of Knowledge Economy), Korea, under the ITRC (Information Technology Research Center) support program supervised by the IITA (Institute for Information Technology Advancement)" (IITA-2008-C1090-0803-0004) and "This work was supported by the IT R&D program of MKE/IITA [2007-F-038-02, Fundamental Technologies for the Future Internet]" and "This study was supported by the Seoul Research and Business Development, Program, Seoul, Korea" and "This work was supported by the Brain Korea 21 Project in 2008."

## Appendix 1

We analyze total handover delay of FMIPv6 and the proposed scheme both perfect handover prediction and imperfect handover prediction considering Ps and Pf in Random Walk Model. In FMIPv6, the latency of handover success and handover failure is not equal because a MN predicts one of the new visited networks to make a new CoA in advance. If the MN moves to another visited network different from MNs anticipation, handover fails. Therefore, in case of handover failure, FMIPv6 comes back to MIPv6 procedure like followings.

$$T^{Success}_{FMIPv6} = t_{FBU} + t_{FBAck} + t_{D_{L2-L3}} + t_{D_{L2}} + t_{FNA}$$

$$T^{Failure}_{FMIPv6} = \left(t_{FBU} + t_{FBAck} + t_{D_{L2-L3}} + t_{D_{L2}} + t_{FNA} + t_{NAAcK} + T^{Success}_{MIPv6}\right).$$

In the proposed scheme, the latency of handover success and handover failure is equal because the case of handover failure is not exist. Even though the MN moves to one of the unpredicted visited networks, the MN can simultaneously communicate using tentative address as temporal CoA while making a new CoA via DAD. Therefore, handover delay of the proposed scheme is like followings.

$$T^{Success}_{ProposedScheme} = T^{Failure}_{ProposedScheme} = t_{LP} + t_{D_{L2-L3}} + t_{D_{L2}} + t_{mFNA}.$$

To analyze the delay of handover failure, we calculated Ps and Pf based on Random Walk Model as shown Fig. 9b. The total probability of handover success, Ps, can be expressed by the summation of Ps when state $i$ and $j$ is one of 0, 1 and 2 states.

$$p'_s = \sum_i \sum_j (P_s)/9 = \sum_i \sum_j \left(State^{Success}_{ij}\right)/9$$

$$p'_f = (1 - p_s) = 1 - \left(\sum_i \sum_j \left(State^{Success}_{ij}\right)/9\right).$$

As a result, considering $P_s$ and $P_f$ in Random Walk Model, total handover delay of FMIPv6 and the proposed scheme can be expressed like followings. As you can see, total handover delay of the proposed scheme is shorter than that of FMIPv6.

$$T_{TotalHandoverDelayofFMIPv6} = P_s * T^{Success}_{FMIPv6} + P_f * T^{Failure}_{FMIPv6}$$

$$= \sum_i \sum_j \left( State_{ij}^{Success} \right) /9 * \left( t_{FBU} + t_{FBAck} + t_{D_{L2-L3}} + t_{D_{L2}} + t_{FNA} \right)$$

$$+ \left( 1 - \sum_i \sum_j \left( State_{ij}^{Success} \right) /9 \right)$$

$$* \left( t_{FBU} + t_{FBAck} + t_{D_{L2-L3}} + t_{D_{L2}} + t_{FNA} + t_{NAAcK} + T_{MIPv6}^{Success} \right)$$

$$T_{Total Handover Delay of Proposed Scheme} = P_s * T_{Proposed Scheme}^{Success} + P_f * T_{Proposed Scheme}^{Failure}$$

$$= \sum_i \sum_j \left( State_{ij}^{Success} \right) /9 * \left( t_{LP} + t_{D_{L2-L3}} + t_{D_{L2}} + t_{mFNA} \right)$$

## Appendix 2

In this sub-section we introduce the terminology used to explain proposed scheme.

- MUC: Mobile and Ubiquitous Computing
- 3G: 3Generation
- Wi-Fi: Wireless Fidelity
- WiMax: Worldwide Interoperability for Microwave Access
- IMIS: Interactive Multimedia and Intelligent Service
- DAD: Duplicate Address Detection
- IPTV: Internet Protocol Television
- VoIP: Voice over Internet Protocol
- AP: Access Point
- L2 handover: a link layer handover
- L3 handover: a network layer handover
- WLANs: IEEE 802.11 wireless LANs
- MIH: Media Independent Handover
- CoAs: Care-of Addresses
- MIPv6: Mobile IPv6

- FMIPv6: Fast handover for the MIPv6
- IETF: Internet Engineering Task Force
- RA: Router Advertisement
- HA: Home Agent
- CN: Correspondent Node
- pAR: previous Access Router
- nAR: new Access Router
- RtSolPr: Proxy Router Solicitation
- PrRtAdv: Proxy Router Advertisement
- NRA: Neighbor Router Advertisement
- MN: Mobile Node
- mNRA: modified Neighbor Router Advertisement
- mRtSolPr: modified Router Solicitation for Proxy
- mPrRtAdv: modified Proxy Router Advertisement
- LP: Last Packet
- mFNA: modified Fast Neighbor Advertisement
- BU: Binding Update
- DAcK: DAD Acknowledgement
- RSSI (Receive Signal Strength Indicator).

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