

AN OPTIMIZED VERTICAL INTER-MAP HANDOVER SCHEME FOR HMIPv6 IN HETEROGENEOUS WIRELESS NETWORKS

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ABSTRACT. *An optimized fast vertical inter-mobility anchor point (MAP) handover scheme for Hierarchical Mobile IPv6 (HMIPv6) is proposed for heterogeneous wireless access networks. Two existing non-optimized vertical handover schemes – the simple vertical inter-MAP handover for HMIPv6 (SVH6) and fast vertical inter-MAP handover for HMIPv6 (FVH6) – assisted by existing hierarchical handover and fast handover strategies are described. In order to improve handover latency, handover preparation time, packet loss of these two non-optimized schemes, an optimized fast vertical inter-MAP handover for HMIPv6 (OFVH6) scheme is proposed. In the proposed OFVH6, the IEEE 802.21 Media Independent Handover (MIH) is adopted to optimize and enhance the two non-optimized vertical handover schemes. The Media Independent Information Service in IEEE 802.21 MIH is extended by including new network layer (L3) information to provide domain prefixes of heterogeneous neighboring MAPs, which can eliminate the heterogeneous neighboring MAP discovery phase in the FVH6. Analysis, computer simulations and practical experiments are used to evaluate and compare performance. The proposed OFVH6 is shown to outperform the two existing non-optimized schemes in terms of handover latency, handover preparation time, and packet loss, although the OFVH6 requires additional functionality and a network entity.*

Keywords: Hierarchical Mobile IPv6, Fast handover, Vertical handover, IEEE 802.21 MIH

1. Introduction. The Hierarchical Mobile IPv6 (HMIPv6) has been standardized and investigated [1-6], in order to reduce wireless signaling overhead while the mobile node is moving within a local mobility management domain. Meanwhile, researchers have attempted to integrate diverse heterogeneous wireless access networks, such as wireless wide area network (WWAN), e.g., third-generation (3G); wireless metropolitan area network (WMAN), i.e., IEEE 802.16e; wireless local area network (WLAN), i.e., IEEE 802.11 a/b/g [7-11], to provide ubiquitous wireless communications at high data rates and a large variety of services with variable bandwidth and quality of service (QoS) requirements, across a wide range of propagation environments and mobility conditions. This integration of heterogeneous wireless access networks can be linked with many technical challenges, including IP mobility, vertical handover, fast handover, security, common authentication, unified accounting/billing, consistent QoS, and service provisioning.

In this paper, an optimized fast vertical inter-mobility anchor point (MAP) handover scheme for HMIPv6 is proposed for heterogeneous wireless access networks. Two existing non-optimized vertical handover schemes – the simple vertical inter-MAP handover for HMIPv6 (SVH6) and fast vertical inter-MAP handover for HMIPv6 (FVH6) – assisted by existing hierarchical handover and fast handover strategies are described. In the SVH6,

as shown in [2], global mobility management is performed for the vertical handover between heterogeneous access networks and local mobility management is performed for the horizontal handover within each access network. However, the SVH6 has an inevitable network layer (L3) handover latency caused by several latencies. Therefore, as shown in [4-6], the FVH6 supports the fast handover strategy of [12-14] to reduce the vertical handover latency of the SVH6. However, the FVH6 requires the heterogeneous neighboring MAP discovery phase (RtSolPr/PrRtAdv exchange) after the link layer triggering, which can increase the handover preparation time. In addition, neither the SVH6 nor the FVH6 considered how heterogeneous neighboring MAPs could map the domain prefix with the corresponding L2 identifier.

In order to improve these two non-optimized schemes in terms of handover latency, handover preparation time, packet loss, an optimized fast vertical inter-MAP handover for HMIPv6 (OFVH6) scheme is proposed. In the proposed OFVH6, the IEEE 802.21 Media Independent Handover (MIH) of [15-17] is used to optimize and enhance two non-optimized vertical handover schemes. The Media Independent Information Service (MIIS) in the IEEE 802.21 MIH is extended by including new L3 information to provide domain prefixes of heterogeneous neighboring MAPs. This can eliminate the heterogeneous neighboring MAP discovery phase in the existing FVH6, which can increase the probability of predictive behavior for the OFVH6 and thus can reduce handover latency. Performance evaluation and comparison are carried out using the analysis for handover latency, handover preparation time, functional requirements and involved entities, computer simulations for the probability of predictive behavior, and practical experiments for packet loss measurement in a real-time audio streaming service. Through performance evaluation and comparison, the proposed OFVH6 is shown to outperform the two existing non-optimized schemes in terms of handover latency, handover preparation time and packet loss, although the OFVH6 requires additional functionality and a network entity.

The paper is organized as follows. In Section 2, existing non-optimized vertical inter-MAP handover schemes for HMIPv6 are described. In Section 3, an optimized fast vertical inter-MAP handover for HMIPv6 scheme is proposed. In Section 4, performance evaluation and comparison are given by analysis, computer simulation, and practical experiment. Finally, concluding remarks are provided in Section 5.

2. Existing Non-optimized Vertical Inter-MAP Handover Schemes for HMIPv6. As shown in Figure 1, 3G and IEEE 802.16e coexistence network is considered as an example of heterogeneous wireless access networks. This paper assumes that the mobile node (MN) initiates the communication at the IEEE 802.16e network and then performs the vertical handover to the 3G network. For each heterogeneous access network, the gateway and the serving GPRS support node (SGSN) act as a mobility anchor point (MAP) which performs the local mobility management within each access network. These two MAPs are called MAP₁₆ for IEEE 802.16e network and the MAP_{3G} for 3G network, respectively. The local mobility within the MAP domain for each access network can be hidden from home agent (HA) and correspondent nodes (CNs). Meanwhile, the global mobility management is required for the mobility between MAPs for heterogeneous access networks. That is, the global mobility management is performed for vertical handover between heterogeneous access networks whereas the local mobility management is performed for horizontal handover within each access network. In this paper, vertical inter-MAP handover schemes for HMIPv6 are considered for heterogeneous wireless access networks. First of all, two existing non-optimized vertical handover schemes assisted by existing hierarchical handover and fast handover strategies are described.

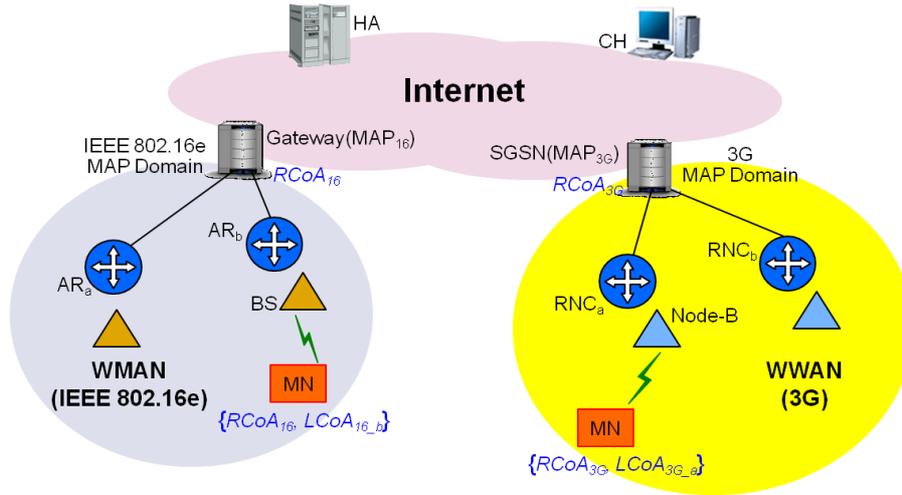


FIGURE 1. Vertical handover scenario for 3G and IEEE 802.16e coexistence networks

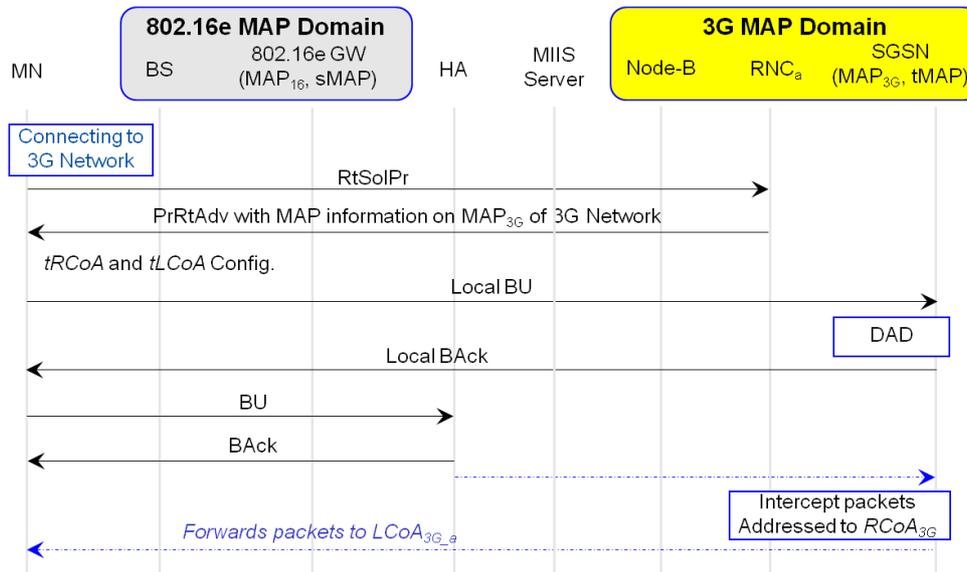


FIGURE 2. Operation procedure for SVH6

2.1. **Simple vertical inter-MAP handover for HMIPv6 (SVH6).** The SVH6 is based on only the HMIPv6 in [2]. The signaling procedure for the SVH6 in 3G and IEEE 802.16e coexistence networks is shown in Figure 2. The MN entering the MAP domain (MAP_{3G}) of 3G network from the MAP domain (MAP_{16}) of IEEE 802.16e network receives a Router Advertisement message containing information on MAP_{3G} from its access router, RNC_a . Because of the vertical handover to the MAP_{3G} from the MAP_{16} , it needs to configure two care-of addresses (CoAs): $\{RCoA_{3G}, LCoA_{3G_a}\}$. $RCoA_{3G}$ is the address based on the prefix received in the MAP option on the MAP_{3G} of the 3G network. $LCoA_{3G_a}$ is the on-link CoA configured using the prefix advertised by its access router, RNC_a . After forming two CoAs, the MN sends a Local Binding Update (LBU) to the MAP_{3G} in order to establish a binding between $RCoA_{3G}$ and $LCoA_{3G_a}$. The LBU includes the $RCoA_{3G}$ in the Home Address Option (HAO). The $LCoA_{3G_a}$ is used as the source address of the LBU. This LBU binds $RCoA_{3G}$ (similar to a Home Address) to its $LCoA_{3G_a}$. The MAP_{3G} (acting as a HA) in 3G network performs the duplicated address detection (DAD) for $RCoA_{3G}$ on its link and then returns a Binding

Acknowledgement to the MN. After check uniqueness of RCoA_{3G}, the MAP_{3G} stores this information in its Binding Cache to be able to forward packets to their final destination when received from the different HAs and CNs. The MAP_{3G} acts as a HA for the RCoA_{3G}. Thus, packets addressed to the RCoA_{3G} are intercepted by the MAP_{3G} in 3G network, using proxy Neighbour Advertisement, and then encapsulated and routed to LCoA_{3G_a}. After registering with the MAP_{3G} for RCoA_{3G} and LCoA_{3G_a}, the MN registers its target RCoA_{3G} with its HA by sending a BU that specifies the binding between Home Address (HoA) and RCoA_{3G} as in MIPv6. The MN's HoA is used in the HAO and the RCoA_{3G} is used as the CoA in the source address field. The MN may also send a similar BU (i.e., that specifies the binding between the HoA and RCoA_{3G}) to its current CNs.

2.2. Fast vertical inter-MAP handover for HMIPv6 (FVH6). The SVH6 has an inevitable L3 handover latency caused mainly by movement detection latency, CoA configuration latency and authorizing global/local binding latency. That is, the SVH6 scheme could not start before L2 handover is completed and thus it may induce unacceptable latency for real-time Internet services. To resolve this problem, the Fast Handover MIPv6 (FMIPv6) in [12-14] can be supported for SVH6 to reduce vertical handover latency as shown in [4-6], which is called the FVH6. When the vertical handover from IEEE 802.16e network to 3G network occurs, the MN can get L2 triggering information from 3G network. Then, the MN sends a Router Solicitation for Proxy (RtSolPr) to its serving MAP (sMAP) in IEEE 802.16e network to get information on target MAP (tMAP) in 3G network. Note that sMAP and tMAP can be MAP_{3G} and MAP₁₆, respectively, in Figure 1. In response, the sMAP of IEEE 802.16e network sends a Proxy Router Advertisement (PrRtAdv) message containing information on the tMAP of 3G network to the MN. With the information provided in the PrRtAdv message, the MN formulates a target LCoA (TLCoA) and a target RCoA (TRCoA). Note that tRCoA and tLCoA can be RCoA_{3G} and LCoA_{3G_a}, respectively, in Figure 1. Then, the MN sends a Fast Binding Update (FBU) message to the sMAP, when a link-specific handover event occurs. After receiving FBU, the sMAP in IEEE 802.16e network sends a Handover Initiation (HI) message to the tMAP to establish tunnel between two heterogeneous access networks and determine whether tRCoA and tLCoA are acceptable to the tMAP in 3G network. In response to the HI message, the tMAP determines whether tRCoA and tLCoA supplied in the HI message are valid for use. After the tMAP considers tRCoA and tLCoA acceptable for use, it sends a Handover Acknowledgement (Hack) message to the sMAP. Then, the sMAP sends a Fast Binding Acknowledgement (FBack) to the MN. The result of the FBU and FBack processing is that the sMAP in IEEE 802.16e network begins tunneling the MN's packets addressed to serving RCoA (sRCoA) and serving LCoA (sLCoA) to tRCoA and tLCoA, the tMAP in 3G network begins buffering copies of incoming packets from the sMAP. Such a tunnel remains active until the MN completes the binding update with its HA and correspondents. Then, L2 handover procedure is completed and a "link up" indication is obtained on 3G network. The MN sends a Fast Neighbor Advertisement (FNA) immediately after attaching to the tMAP and then the tMAP forwards arriving and buffered packets to the MN right away. Note that the proposed FVH6 scheme has two behaviors. The first one is that the MN sends an FBU and receives an FBack on the sMAP domain, which is called the "predictive" behavior. In the predictive behavior, all signaling message for the handover preparation can be processed before L2 disconnection. However, there can be no sufficient time to process all signaling messages before the L2 disconnection. That is, the MN sends an FBU from the tMAP domain. In this case, the FVH6 should be operated by "reactive" behavior. Figure 3 shows the "predictive" behavior for the FVH6.

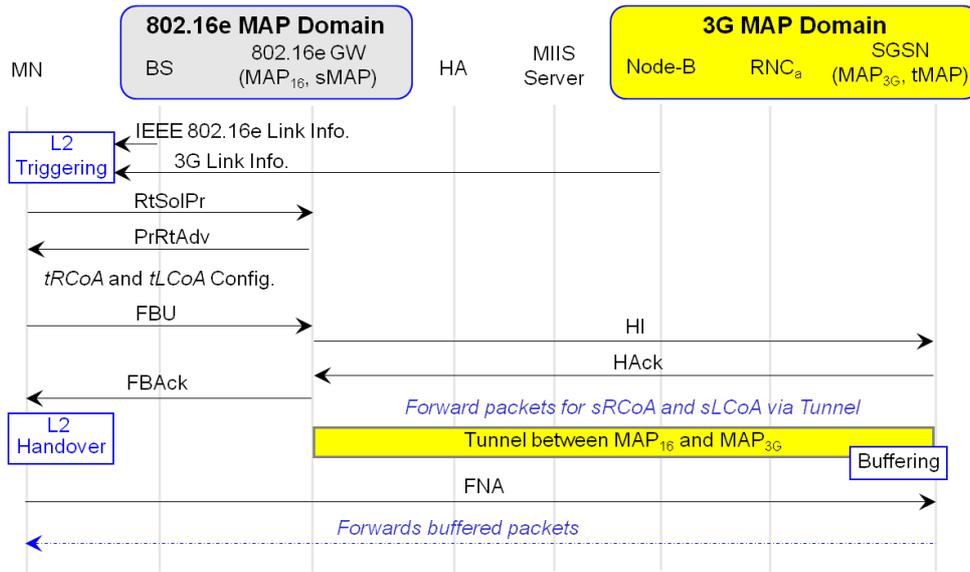


FIGURE 3. Operation procedure for FVH6

3. Optimized Fast Vertical Inter-MAP Handover Scheme for HMIPv6 (OFV H6). The FVH6 requires the heterogeneous neighboring MAP discovery phase (RtSolPr/PrRtAdv construction and exchange) after the L2 triggering, which can increase the handover preparation time. In addition, both SVH6 and FVH6 did not consider how heterogeneous neighboring MAPs can map the domain prefix with the corresponding L2 identifier. In this section, therefore, an optimized fast vertical inter-MAP handover for HMIPv6 (OFVH6) scheme is proposed in order to improve both SVH6 and FVH6 in terms of handover latency, handover preparation time, packet loss. The OFVH6 is developed by applying the IEEE 802.21 Media Independent Handover (MIH) of [15-17]. The MIH is known to enable transparent service continuity while a mobile device switches between heterogeneous access network technologies, which can provide general solutions for the vertical handover in heterogeneous access networks.

The provisioning of L3 information of heterogeneous neighboring MAPs is included newly in the existing IEEE 802.21 Media Independent Information Service (MIIS). In addition to existing Information Element (IE) with static L2 information, a new IE with L3 information called the “Domain Prefix” is defined to provide domain prefixes of heterogeneous neighboring MAPs. According to the MIIS specification, the MN can get this information including “Domain Prefix” by requesting the IE from the IS server. The IS server can be located inside or outside MAPs, which can be determined by the network operator. It also allows the heterogeneous neighboring MAP information to be delivered to the MN by using pre-defined vertical handover information (VHI). The VHI containing IEs with L3 information as well as static L2 information is produced and stored in the IS server. Note that the VHI maintained by the IS server will be similar to the mapping table maintained by the MAPs for resolving L2 identifiers of corresponding heterogeneous domain prefixes. So, this could eliminate the need for MAPs to exchange heterogeneous neighboring MAP information mapping table and thus resolve the heterogeneous neighboring MAP discovery issue in FVH6. Much before the L2 trigger, the VHI is delivered to the MN through primitives of IEEE 802.21 MIIS specification. In addition, it is assumed that the MN stores and maintains the obtained VHI for all handovers. Then, using the L3 information of corresponding heterogeneous neighboring MAPs, the MN knows domain prefixes of the tMAP and formulates tLCoA and tRCoA prior to handover. This

reduces the heterogeneous neighboring MAP discovery time in the FVH6. Thus, during the handover procedure, the configuration procedure time for tLCoA and tRCoA, which is related with the heterogeneous neighboring MAP discovery, can be decreased. Since several signalling messages such as RtSolPr and PrRtAdv is reduced during the handover preparation phase, the overall handover preparation time can be reduced. Thus, the adverse impacts of the long handover preparation time in the FVH6 can be resolved. Furthermore, the OFVH6 can use the IEEE 802.21 MIES to get the L2 trigger; and therefore, quickly detect any L3 movement and perform handover preparation before an L2 handover.

The MN with MIH sends a “MIH Information” request message to its sMAP in IEEE 802.16e network to get the VHI on tMAP in 3G network. In response, the sMAP with MIH in IEEE 802.16e network sends an “MIH Information” reply message containing the VHI on the tMAP of 3G network to the MN. Note that the “MIH Information” request and reply messages are done much before the L2 trigger (i.e., “MIH Link Going Down”), unlike the existing FVH6 in which RtSolPr and PrRtAdv messages only occur after L2 triggers (when the MN senses the signal strength of the link in existing access network is becoming too weak). Later, when the signal strength of the BS of IEEE 802.16e network that the MN is connected with becomes weak, the MIES will be informed by the MAC layer of the MN. The MIES will scope and filter this link layer information against the rules set by the OFVH6, and then produce a “MIH Link Going Down” event indication message, and sends it to L3 layer where the OFVH6 scheme is working. Upon receiving this notification, the MN selects the 3G network to handover to. Since the MN knows the radio link information such as MAC address and channel range of Node-B in the tMAP (i.e., 3G network) using the VHI received beforehand, the time to discover them is eliminated.

After selecting the 3G network, the MN can utilize the Media Independent Command Service (MICS), and generate a link switch command using “MIH Link Switch” request primitive. Then the MN uses “Domain Prefix” in the VHI to formulate the tLCoA and the tRCoA. Note that tRCoA and tLCoA can be RCoA_{3G} and LCoA_{3G_a}, respectively, as shown in Figure 1. Therefore, the MN does not need the heterogeneous neighboring MAP discovery, which is required for the FVH6. Then, the MN sends an FBU message to the sMAP. After receiving FBU, the sMAP in IEEE 802.16e network sends a HI message to the tMAP to establish tunnel between two heterogeneous access networks and determine whether tRCoA and tLCoA are acceptable to the tMAP in 3G network. In response to the HI message, the tMAP determines whether tRCoA and tLCoA supplied in the HI message are valid for use. After the tMAP considers tRCoA and tLCoA acceptable for use, it sends a Hack message to the sMAP. Then, the sMAP sends a FBack message to the MN. After the receiving the FBack message on the sMAP’s domain and necessary L2 authentication and association procedure, an “MIH Link Up” primitive notification will be sent to inform the OFVH6 scheme in the L3 that the L2 connection in tMAP is established. The result of the FBU and FBack processing is that the sMAP in IEEE 802.16e network begins tunneling the MN’s packets for sRCoA and sLCoA to tRCoA and tLCoA, the tMAP in 3G network begins buffering copies of incoming packets from the sMAP. Such a tunnel remains active until the MN completes the binding update with the HA and CNs. After an “MIH Link Up” primitive notification is obtained in the tMAP domain of 3G network, the MN sends immediately the FNA message to the tMAP. Then the tMAP forwards arriving and buffered packets to the MN right away. Once the traffic starts to flow from the tMAP, the MN with MIH generates a “MIH Link Switch” reply primitive. As shown in FVH6, the OFVH6 has also two scenarios, “predictive” and “reactive” behaviors. Figure 4 shows the “predictive” behavior for the OFVH6.

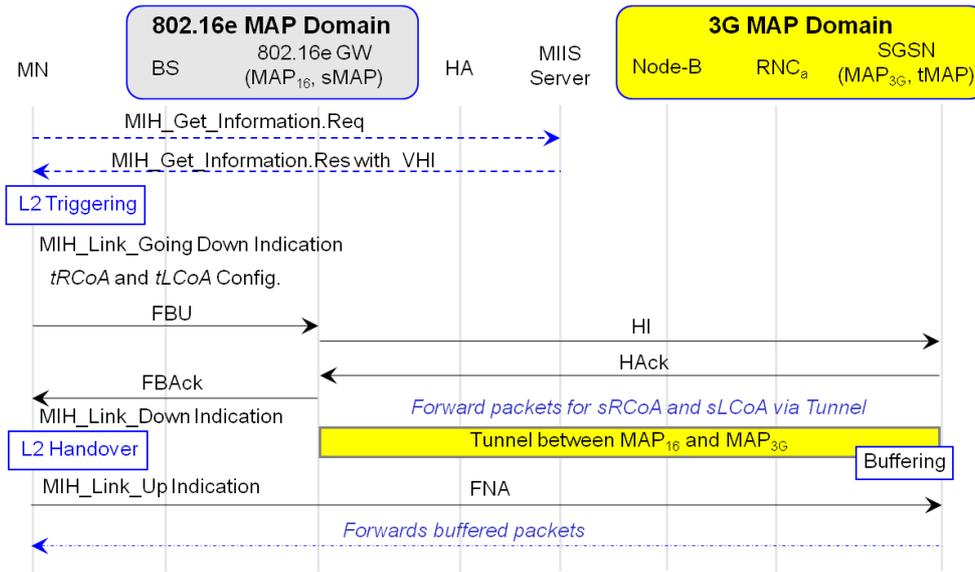


FIGURE 4. Operation procedure for OFVH6

4. Performance Evaluation and Comparison. In this section, to verify the superiority of the proposed OFVH6, performance evaluation and comparison are carried out using the analysis for handover latency, handover preparation time, functional requirements, and involved entities, computer simulations for the probability of predictive behavior, and practical experiments to measure packet loss in a real-time audio streaming service.

4.1. Analytical evaluation and computer simulation. To present analytical results for estimating handover latency and handover preparation time, following parameters are defined:

- T_{L2D} : Time from L2 triggering to L2 handover start, which is hard to estimate because it might be highly variable according to MN's moving speed, a sudden degradation of L2 quality, an L2 handover decision rule, etc.
- T_{L2H} : Time required for L2 handover.
- T_{MD} : Time required for movement detection.
- T_{CoA} : Time required for CoA configuration.
- T_{DAD} : Time required for DAD operation of RCoA.
- $T_{LBU-LBAck}$: Time required for exchange LBU and LBAck messages between MN and tMAP.
- $T_{BU-BAck}$: Time required for exchange BU and BAck messages between MN and HA via sMAP.
- T_{FNA} : Time required for FNA to reach tMAP.
- $T_{RtSolPr-PrRtAdv}$: Time required for exchange of RtSolPr and PrRtAdv messages for heterogeneous neighboring MAP discovery between MN and sMAP.
- $T_{FBU-FBAck}$: Time required for exchange of FBU and FBack messages between MN and tMAP.
- $T_{HI-HAck}$: Time required for exchange of HI and HAck messages between sMAP and tMAP.
- $T_{FNA(R)}$: Time required for FNA including FBU to reach tMAP (only for reactive behavior).
- $T_{FBU-FBAck(R)}$: Time required for exchange of FBU and FBack messages between sMAP and tMAP (only for reactive behavior).

- $T_{HP_{SVH6}}$: Handover preparation time for SVH6.
- $T_{HP_{FVH6}}$: Handover preparation time for FVH6.
- $T_{HP_{OFVH6}}$: Handover preparation time for OFVH6.

Analytical results of handover latency and handover preparation time are shown in Table 1 and Table 2. Table 1 shows that the handover latency of the FVH6 is much smaller than that of the SVH6. Since the FNA message is a simple one-way message to announce the MN's attachment that allows the tMAP to consider MN to be reachable, T_{FNA} requires only several tens milliseconds at most. This means that the FVH6 can reduce remarkably the handover latency of the SVH6. Meanwhile, the handover latency of the OFVH6 is shown to be comparable with that of FVH6 if both schemes are operated actually in the "predictive" behavior. However, as shown in Table 2, the handover preparation time, $T_{HP_{OFVH6}}$, of the OFVH6 is shorter than $T_{HP_{FVH6}}$ of the FVH6 since the heterogeneous neighboring MAP discovery phase is eliminated. Actually, the time from L2 triggering to L2 handover start, defined by T_{L2D} , is hard to be estimated because it might be highly variable according to MN's moving speed, a sudden degradation of L2 quality, an L2 handover decision rule, etc. If the handover preparation time $T_{HP_{FVH6}}$ or $T_{HP_{OFVH6}}$ is longer than T_{L2D} , the MN loses its connectivity to the sMAP and thus the "reactive" behavior is operated. Thus, the probability of predictive behavior decreases as the handover preparation time increases, which cause the handover latency to increase as shown in Table 1. Therefore, the probability of predictive behavior of OFVH6 can be higher than the FVH6 because $T_{HP_{OFVH6}}$ is shorter than $T_{HP_{FVH6}}$.

The probability of predictive behavior for FVH6 and OFVH6 is compared by computer simulations. Simulations are performed by randomly varying set values as shown in Table 3. As mentioned before, T_{L2D} might be highly variable; its simulated value is set with a relatively wide range. Because the heterogeneous neighboring MAP discovery phase is eliminated in the OFVH6, simulated values of $T_{HP_{OFVH6}}$ are shorter than those of $T_{HP_{FVH6}}$ and consider three cases for diverse simulations. To make a clearer comparison, simulations of 30 runs are performed using randomly varying set values, and each single simulation occurs 100 handovers. As shown in Figure 5, for all cases, the OFVH6 is shown to outperform the FVH6.

4.2. Practical experiment for packet loss measurement. To demonstrate the practical usefulness of the proposed OFVH6, experiments are performed to measure packet loss for a real-time audio streaming service. The testbed for experiments has two MAP,

TABLE 1. Handover latency

| Schemes | | Predictive behavior | Reactive behavior |
|---------------|------------|--|---|
| Non-optimized | SVH6 [2] | $T_{L2H} + T_{MD} + T_{CoA} + T_{DAD} + T_{LBU-LBAck} + T_{BU-BAck}$ | |
| | FVH6 [4-6] | $T_{L2H} + T_{FNA}$ | $T_{L2H} + T_{FNA(R)} + T_{FBU-FBAck(R)}$ |
| Optimized | OFVH6 | $T_{L2H} + T_{FNA}$ | $T_{L2H} + T_{FNA(R)} + T_{FBU-FBAck(R)}$ |

TABLE 2. Handover preparation time

| Schemes | | Handover preparation time |
|---------------|--------------------------------|---|
| Non-optimized | SVH6 ($T_{HP_{SVH6}}$) [2] | . |
| | FVH6 ($T_{HP_{FVH6}}$) [4-6] | $T_{RtSolPr-PrRtAdv} + T_{CoA} + T_{FBU-FBAck} + T_{HI-HAck}$ |
| Optimized | OFVH6 ($T_{HP_{OFVH6}}$) | $T_{CoA} + T_{FBU-FBAck} + T_{HI-HAck}$ |

TABLE 3. Randomly varying set values for simulations

| Parameters | Set values (Uniform over) |
|--------------------------|---------------------------|
| T_{L2D} | 50ms ~ 100ms |
| $T_{HP_{FVH}}$ | 70ms ~ 90ms |
| $T_{HP_{OFVH}}$ (Case 1) | 60ms ~ 80ms |
| $T_{HP_{OFVH}}$ (Case 2) | 50ms ~ 70ms |
| $T_{HP_{OFVH}}$ (Case 3) | 40ms ~ 60ms |

TABLE 4. Functional requirements and Involved entities

| Schemes | Functional requirements | Involved entities |
|---------------|-------------------------|--|
| Non-optimized | SVH6 [2] | HMIPv6 only MN, tMAP, HA, AR in tMAP domain |
| | FVH6 [4-6] | HMIPv6, FMIPv6 MN, tMAP, sMAP, BSs in sMAP and tMAP domains |
| Optimized | OFVH6 | HMIPv6, FMIPv6, MIH MN, tMAP, sMAP, MIIS server |

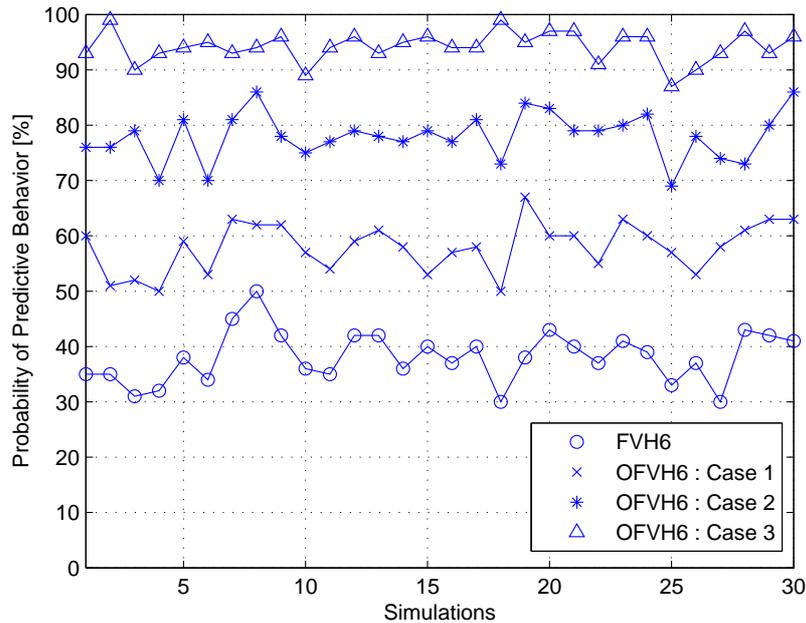


FIGURE 5. Simulation result: Probability of predictive behavior

sMAP and tMAP, and a single MN communicating with a CN over 3G (High Speed Down-link Packet Access, HSDPA) and IEEE 802.16e (WiMAX) coexistence network. For this testbed, the traffic is generated by the audio streaming server that plays a role of the CN. Then a single MN RTP/UDP streaming service between two MAPs is experimented for the proposed OFVH6 and the existing FVH6 in [4-6]. To make a clearer, 50 handovers are performed and then lost packets are measured. As shown in Figure 6, experiments show that the proposed OFVH6 can minimize packet loss more than the existing FVH6. One possible explanation for this is that the probability of predictive behavior for the

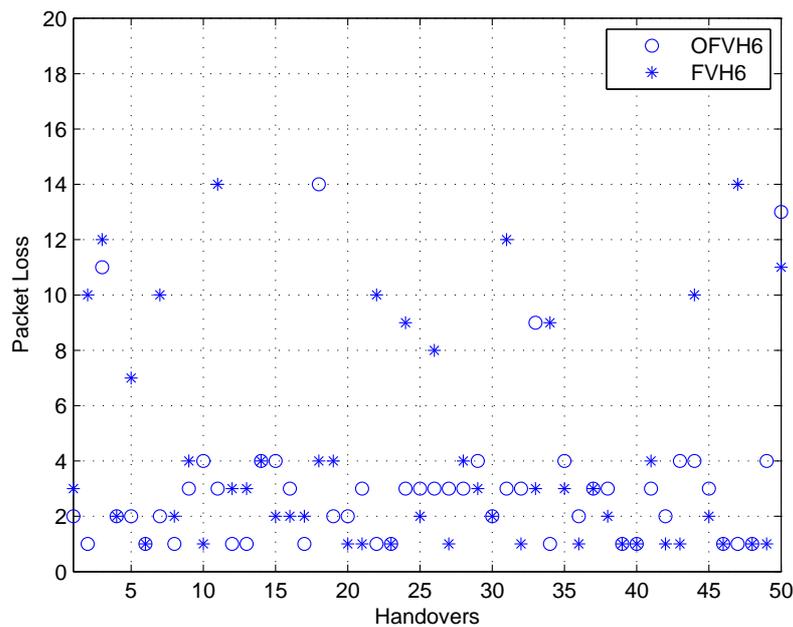


FIGURE 6. Experiment result: Packet loss

OFVH6 is higher than the FVH6. The packet loss could be appreciable for real-time and throughput-sensitive Internet services such as multimedia streaming, VoIP and IPTV [18,19]. Hence, minimizing packet loss is an important issue in the practical environment.

4.3. Functional requirements and involved entities. The proposed OFVH6 and existing non-optimized schemes are compared in terms of functional requirements and involved entities for overall vertical handover procedure as shown in Table 4. The SVH6 can be performed by HMIPv6 functionality only. On the other hand, the FVH6 require FMIPv6 functionality as well as HMIPv6 functionality. The OFVH6 requires HMIPv6, FMIPv6 functionalities as well as IEEE 802.21 MIH functionality. The terminology of involved entities means that how many network entities are involved for overall vertical handover procedure. In SVH6, MN, tMAP, HA and access router in tMAP domain are involved. In FVH6, MN, tMAP, sMAP, base stations in sMAP and tMAP domains are involved. In OFVH6, MN, tMAP, sMAP, MIIS server are involved. Although the SVH6 does not require any additional functionality and network entities, its handover latency is much larger than FVH6 as well as OFVH6. The FVH6 requires only FMIPv6 as an additional functionality and base stations in sMAP and tMAP domains as additional network entities. In addition, its handover latency is much smaller than the SVH6 and comparable with the OFVH6. The OFVH6 requires both FMIPv6 and IEEE 802.21 MIH as an additional functionality, and the MIIS server as an additional network entity.

5. Concluding Remarks. This paper has proposed an optimized fast vertical inter-MAP handover scheme for HMIPv6, called the OFVH6, for heterogeneous wireless access networks to improve the two existing non-optimized schemes, SVH6 and FVH6. The proposed OFVH6 has used IEEE 802.21 MIH to optimize and enhance the two existing non-optimized schemes. The MIIS in IEEE 802.21 MIH has been extended by including new L3 information to provide domain prefixes of heterogeneous neighboring MAPs, which can eliminate the heterogeneous neighboring MAP discovery phase in the existing FVH6. To verify the superiority of the proposed OFVH6, handover latency, handover preparation

time, functional requirements, and involved entities have been evaluated and compared, computer simulations for the probability of predictive behavior have been carried out, and practical experiments to measure packet loss have been performed using a real-time audio streaming service. Performance evaluation and comparison have shown that the proposed OFVH6 can outperform existing the two non-optimized schemes in terms of handover latency, handover preparation time, and packet loss, although the OFVH6 requires additional functionality and a network entity. Hence, the proposed OFVH6 could be useful for various real-time and throughput-sensitive Internet services such as multi-media streaming, VoIP and IPTV.

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