Wireless Netw (2013) 19:1375–1386
DOI 10.1007/s11276-012-0539-8

Performance analysis of IP mobility with multiple care-of addresses in heterogeneous wireless networks

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Published online: 10 January 2013

Abstract This paper aims to suggest a host-based localized mobility management scheme which provides similar user experiences and seamless mobility of real time communications. The proposed scheme supports multiple care-of addresses and fast handover mechanism with a single unitary virtual interface among heterogeneous radio access technologies without network changes. We verify that the proposed scheme has significant vertical handover performance gains to support real time communication traffics through the experiment over the real network experimental environment consists of WiFi and 3GPP2 networks.

Keywords Vertical handover · IP mobility · Multiple care of address · Virtual interface · Heterogeneous wireless network

1 Introduction

Recently, Telecommunication networks have been evolved into a unified single IP Network, which is appropriate for creation and provision of converged services. Telecommunication operators with diversified radio access technology (RAT) environments consider how to converge their heterogeneous wireless networks [1]. Integration of heterogeneous systems with seamless mobility service is referred as a key feature of real technical step-up of next generation wireless network. The core of this integration is provided by the multimode or reconfigurable devices [2]. An always best connected service of a multimode device and IP mobility technology are regarded as the necessities of the next generation mobile network architecture. Seamless mobility based on MIPv6 is suggested in the mobile network architecture [3]. A mobility management scheme based on session initiation protocol (SIP) for a session-oriented service such as voice telephony is researched [4]. While in [5], a joint SIP and mobile IP (MIP) approach is researched to reduce handover latency of SIP-based mobility management and to support IP mobility. IP mobility should be supported to provide seamless mobility in a carrier grade unified single IP network. Internet engineering task force (IETF) has suggested various IP mobility schemes such as mobile IP (MIP), hierarchical mobile IP (HMIP), Fast handover mobile IP (FMIP), proxy mobile IP (PMIP), and dual stack mobile IP (DSMIP) [6–9]. Multiple care-of address (MCoA) registration mechanism is also suggested [10]. 3GPP has defined evolved packet core (EPC) architecture to integrate legacy 3GPP, LTE (Long-Term Evolution), and non-3GPP access networks [11–14]. The IEEE 802.21 standard shows media independent framework for seamless, inter-technology handover [15, 16].

This paper aims a suggestion of localized mobility management (LMM) scheme which is as a transitional period solution till whole deployment of EPC architecture or as a practical solution for convergence legacy wireless networks efficiently without any network changes. The proposed scheme supports IP mobility and seamless

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handover with a single unitary virtual interface and multiple care-of addresses during a handover movement in a localized mobility management domain. The rest of the paper is organized as follows. We describe the architecture and functions of the proposed scheme in Sect. 2. We describe the vertical handover performance analysis of the scheme in Sect. 3 and present the feasibility of the scheme through the results of vertical handover experiment over the test-bed with WiFi and 3GPP2 data networks in Sect. 4. Section 5 and 6 describe discussions of experiment results and final conclusions respectively.

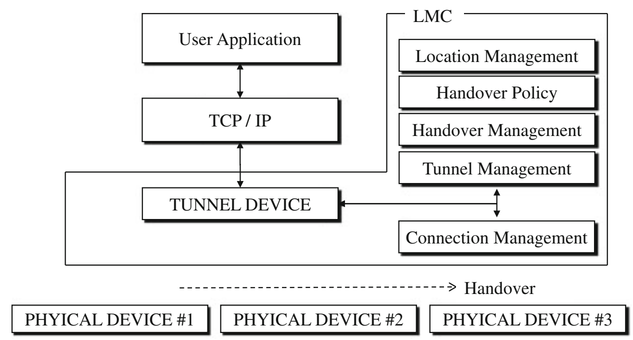


Fig. 1 Functional architecture of LMC

2 Proposed scheme

2.1 Overview of the LMM architecture

The architecture of the LMM is an overlay and client–server model in a unified single IP network with heterogeneous access environments such as WiFi, mobile WiMAX, 3GPP, and 3GPP2 etc. Therefore, the scheme does not require any changes of existing IP core or radio access nodes and uses them transparently. The main components of the architecture are localized mobility server (LMS), localized mobility client (LMC) and tunnel gateway (TGW). LMS is located in IP core network. LMC is located in MN. TGW which is fully responsible for IP tunneling process is located in IP core and is managed by LMS. The end points of an IP tunnel are MN and TGW, therefore IP tunneled packets are transferred between MN and TGW. LMS deals with control signals of location and handover management. The scheme supports scalability by separating the processing of tunneled packets and control signals.

2.2 Functional description of LMM scheme

When MN enters an area of the LMM domain network for the first time, LMC is downloaded and installed in the MN automatically with a subscriber enrollment. LMC consists of several functional blocks which are location management, handover policy, handover management, tunnel management, connection management and tunnel device. Figure 1 shows the functional architecture of LMC.

Location management block executes location registration through IP binding update. In the case of binding update expiration, location management block requests elimination of the correspondent tunnel and carries out initialization. Handover policy block selects a serving interface among available interfaces and decides interface switching. This block maintains policies related with user preferences and conditions of interfaces. Handover management block monitors handover-related events according to handover policies. On the occasion of an event occurring, handover management block requests a tunnel creation to the tunnel management block and requests binding update to the location management block. Tunnel management block performs creation and elimination of IP tunnels. Tunnel device is a virtual interface as a unitary interface, which stands for various physical devices in MN. Tunnel device performs IP tunneling process. Connection management block controls a correspondent physical RAT device.

The LMC is responsible for deciding a serving interface appropriate to the present location and receives an allocated care-of address (CoA) related with a correspondent IP domain. The MN maintains home of address (HoA) which the MN holds on in initial enrollment phase. This address is used for uniquely identifying the MN. LMC requests a creation of IP tunnel as HoA over CoA through a decided serving physical interface. LMS makes up a tunnel from MN to TGW so as to meet the request of the tunnel creation. After the tunnel is created, LMC executes a location registration using binding update through the tunnel. Then the MN is ready to communicate.

The operation process of LMS is shown in Fig. 2. LMS manages IP mobility of MN using a tunnel and its binding information. The process of LMS is related with three types of MN's request messages. One is a message of tunnel creation request or a message of candidate tunnel information for recognition before tunnel creation. Another is a message of initial location registration or a message of location update or a message of invalid tunnel deletion request. The other is a message of a security channel creation request over existing IP tunnel. The required information in order to create IP tunnel are HoA of MN, CoA or network address translation (NAT) address of MN, Port or NAT port of MN, IP address of corresponding tunnel end point of LMS, and tunnel state such as READY, STANDBY and ACTIVE. LMS supports NAT traversal for the environment, which uses a private IP address as a CoA, like WiFi and 3GPP/3GPP2 networks. LMS transfers the information of the NAT address and the port received from LMC to TGW. And then TGW creates a UDP tunnel instead of IP tunnel. LMS supports a UDP tunnel of full cone NAT and port-restricted cone NAT [17].

In order to support soft vertical handover, LMS prepares a standby tunnel for connecting a candidate network besides an active tunnel connected with a serving network. In relation to the standby tunnel, LMS maintains only the tunnel information but does not perform a packet tunneling process until the standby tunnel is converted to an active tunnel. The 'create tunnel' means creation of an active tunnel, and the 'prepare tunnel' means creation of information of standby tunnel. If life time in binding update message is default, location registration will be updated or kept up. When binding update information is different from existing information of binding cache entry, it is regarded as a location update. When the information is same as that of binding cache entry, it is regarded as location sustenance. If a life time in binding update message is zero, the existed tunnel will be deleted. This case is arisen at the time of tunnel switching from standby tunnel to active tunnel when MN moves to a candidate network. At this time, a vertical handover is executed and an elimination of invalid active tunnel connected with previous serving network is executed.

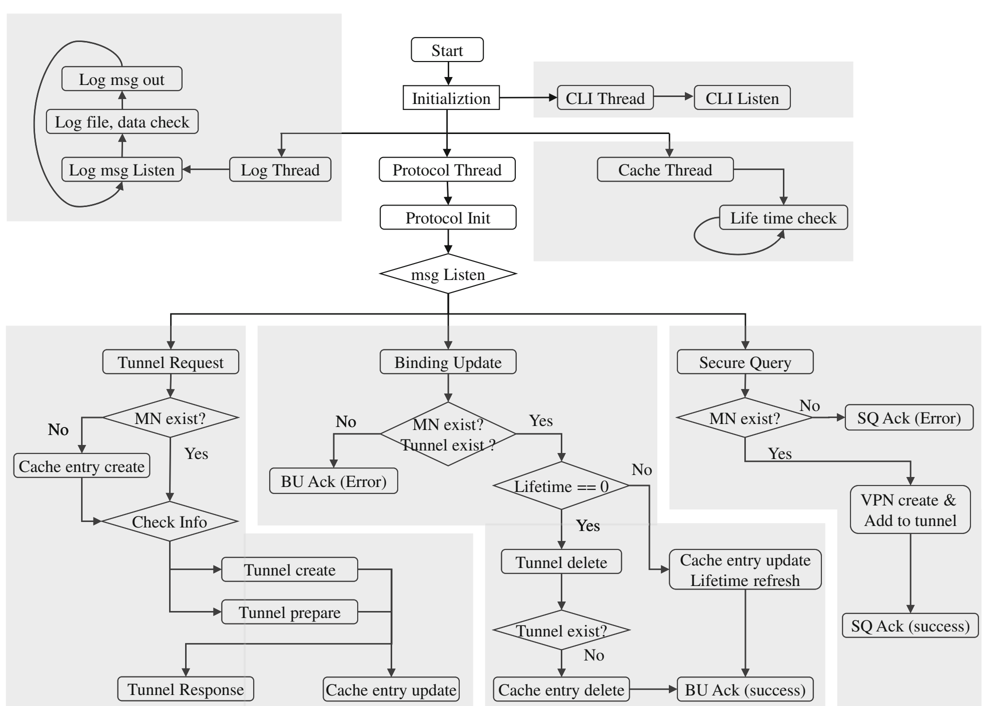
The 'secure query' of Fig. 2 enables a secure channel via password authenticated key exchange (PAK)—IPSEC over an active tunnel. The secure channel mode is operated when virtual private network (VPN) services are required.

2.3 Message flows of LMM scheme

Figure 3 shows the state changes of tunnel when MN moves through heterogeneous networks, WiFi and 3GPP2. We assume that MN moves from point #1 to point #5. The case shows that the MN moves from the coverage of WiFi #1 to WiFi #2 via 3GPP2 EVDO. It is presumed that overlapped coverage exist between WiFi #1 and EVDO and between WiFi #2 and EVDO. We also presume that the access priority of WiFi is set higher than that of EVDO. In the point #1, LMC accesses AP #1 of WiFi #1 and creates an active tunnel. In the point #2, as signal strength of AP #1 gets weaker and is below the threshold, LMC decides to access base transceiver station (BTS) of EVDO, creates an active tunnel, and converts the prior active tunnel connected with AP #1 of WiFi to a standby tunnel. LMC decides to change the tunnel state of WiFi #1 to READY because the MN is not able to access AP #1 of WiFi #1 in point #3. The EVDO interface still keeps up ACTIVE state. In the point #4, as signal strength of AP #2 gets stronger and is beyond the threshold, LMC decides to access AP #2 of WiFi #2, creates an active tunnel, and converts the prior EVDO active tunnel to STANDBY. In the point #5, the state of the EVDO interface is converted to READY because of losing the access of the EVDO network. The interface can have one of the five states at a time. The states are DISABLE, READY, INIT, STANDBY and ACTIVE.

During the movement of MN through heterogeneous networks, the MN performs soft vertical handover using an active tunnel and a standby tunnel correspondent of a serving network and a candidate network respectively. The procedure of vertical handover is shown in Fig. 4. When LMC accesses a network through link #1, layer 2

Fig. 2 Functional procedure of LMS



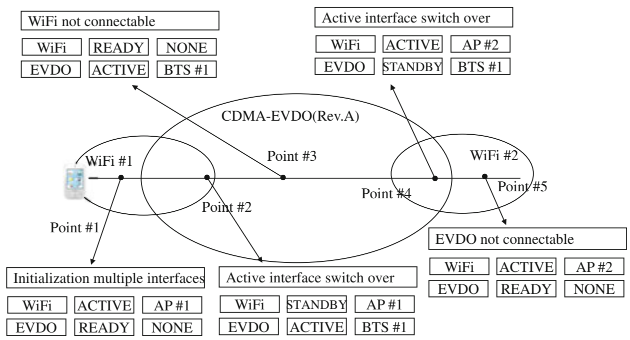


Fig. 3 Tunnel states of interfaces in LMC

connection is built and CoA #1 is allocated in the MN. LMC requests a tunnel through the serving network of link #1. LMS authenticates the MN via AAA function (the flows related to AAA are omitted in Fig. 4) and requests a tunnel creation to TGW. After creation of tunnel #1, LMC performs a location registration by sending a binding update message through tunnel #1. The MN communicates over tunnel #1 of serving network link #1. After LMC detects link #2, LMC access a candidate network via link #2. Layer 2 connection is built and CoA #2 is allocated. LMC exchanges the information of standby tunnel #2 to LMS. At this time, authentication is fulfilled through a candidate network. Consequently, LMC maintains active tunnel #1 and the information of standby tunnel #2. This state corresponds to point #2 and point #4 in Fig. 3. When the signal strength of link #1 is below the predefined threshold, LMC decides to switch to standby tunnel #2 of link #2. After LMC decides handover, LMC requests the creation of tunnel #2 to LMS via a candidate network. LMS creates tunnel #2 and activates tunneling function through committing to TGW. LMC performs a location registration by sending a binding update message to LMS over tunnel #2. After completion of binding update, the state of tunnel #2 is converted from STANDBY to ACTIVE and packets are transferred through the tunnel #2. LMC sends a binding update message with zero life time to LMS through tunnel #1 as a request of tunnel #1 deletion and then TGW eliminates the tunnel #1. The state of link #1 turns STANDBY or READY according to the condition of link accessible state.

3 Analysis

3.1 Qualitative analysis

Table 1 shows the summarization of a qualitative analysis between various existing well-known IP mobility schemes and the proposed IP mobility scheme. The proposed scheme has several distinguished characteristics to improve the vertical handover performance.

(A) The scheme embeds a virtual interface as a unitary interface with implementation of a tunnel device which supports multi-homing corresponding to various RAT interfaces for user data transmissions. This virtual interface enforces vertical handover performance for keeping continuity of sessions.

(B) The scheme embeds a link layer event listener which detects MN's movements quickly through events of link state changes with implementation of a handover management block. This listener provides a room to prepare standby tunnel over a candidate interface in advance for soft handover. The link layer event listener enforces handover performance for rapid movement detections. On the other hand, the scheme has disadvantage of power consumption. Because of always multiple interfaces on to detect a movement into candidate network and to maintain a standby tunnel, more power consumption occurs.

(C) The scheme supports separation of control and data channels. This scheme enforces to solve a scalability issue. All binding information of MNs in this LMM mobility domain are kept and managed by LMS and all tunneling processes are performed by TGW. Therefore the scheme can provide scalability more liberal compared to the existing IP mobility schemes because the scheme is able to think independently, to separate processing of user data and control data. On the other hand, more protocol overhead and management overhead between LMS and TGW exist. If these overheads are not well managed, there is the possibility of a bad effect on handover latency.

3.2 Quantitative analysis

We provide a simple analytical model in Fig. 5 referred by a basic model and assumptions for quantitative performance analysis of handovers suggested in [6].

A mobility agent of the proposed scheme is LMS. The location of LMS is same as the location of MAP in HMIP and of LMA in PMIP. We assume that duplication address detection (DAD) is optimized (TDAD is zero). Therefore we eliminate all delays affected by DAD. The notations used in Fig. 5 are shown in Table 2. We inspect closely control signal delays of each scheme for analysis of handover performance.

The handover control signal delay of MIPv6 is represented as Eq. (1). T_{MD} means the delay of movement detection. T_{REG}^{MIPv6} means the delay of HA registration.

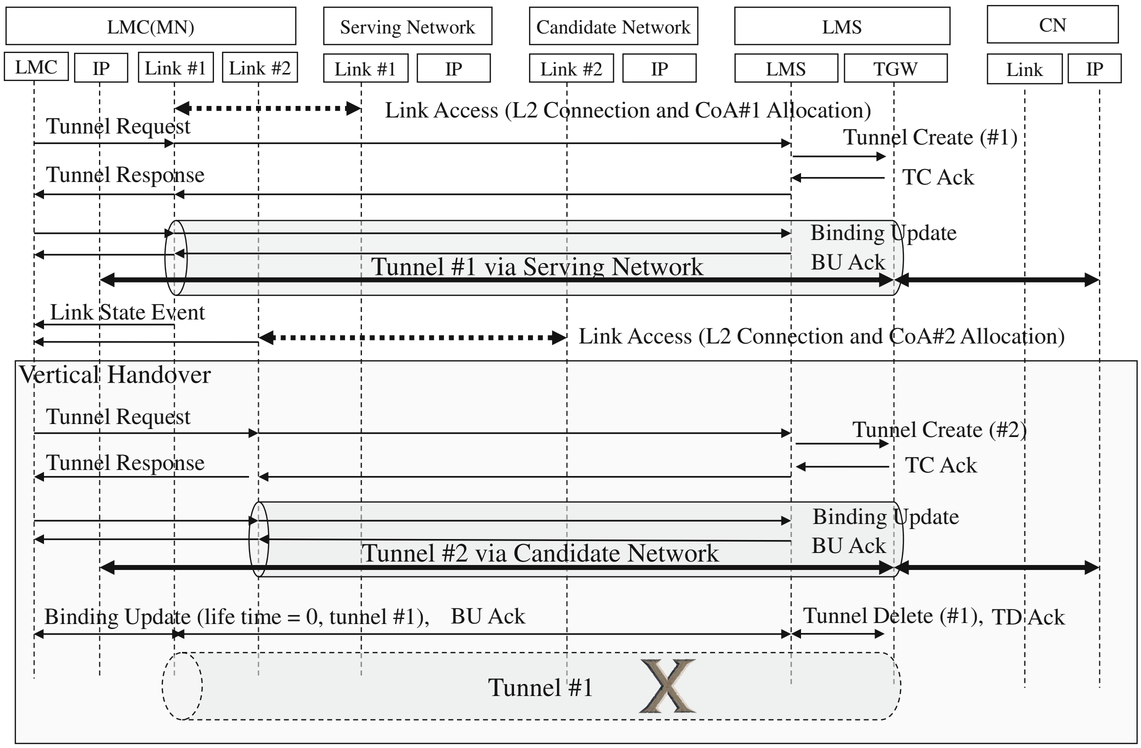


Fig. 4 Control message flows

Table 1 Comparison between the proposed and well-known IP mobility schemes

Protocols and criteria	MIPv6	HMIPv6	FMIPv6	PMIPv6	Proposed
Operating layer	Network layer	Network layer	Network layer	Network layer	Network layer
Mobility scope	Global	Local	Global/(local)	Local	Local
Location management	Yes	Yes	No	Yes	Yes
Handover management	Yes (limited)	Yes	Yes	Yes	Yes
Required infrastructure	HA	HA, MAP	HA, enhanced AR	LMA, MAG	LMS, TGW
Channel separation	–	–	–	–	Separated
MN modification	Yes	Yes	Yes	–	Yes (w/virtual IF)
Handover latency	Bad	Moderate	Good	Good	Good
Route optimization	Yes	Yes	–	–	–
Movement detection	Required	Required	Required	Not required (performed by layer 2)	Not required (performed by layer 2)

$$\begin{aligned} D_{HO}^{MIPv6} &= T_{MD} + T_{DAD} + T_{AAA} + T_{REG}^{MIPv6}, \\ T_{AAA} &= 2 \times 2t_a, T_{REG}^{MIPv6} = 2(t_{mr} + t_{ra} + t_{ah}), \\ D_{HO}^{MIPv6} &= T_{MD} + 4t_a + 2(t_{mr} + t_{ra} + t_{ah}) \end{aligned} \quad (1)$$

The handover control signal delay of HMIPv6 is represented as Eq. (2). T_{REG}^{HMIPv6} means MAP registration delay.

$$\begin{aligned} D_{HO}^{HMIPv6} &= T_{MD} + T_{DAD} + T_{AAA} + T_{REG}^{HMIPv6}, \\ T_{AAA} &= 2 \times 2t_a, T_{REG}^{HMIPv6} = 2(t_{mr} + t_{ra} + t_{am}) \\ D_{HO}^{HMIPv6} &= T_{MD} + 4t_a + 2(t_{mr} + t_{ra} + t_{am}) \end{aligned} \quad (2)$$

The handover control signal delay of FMIPv6 predictive mode is represented as Eq. (3). T_{MD} means the delay of router solicitation for neighbor AR in FMIP. T_{REG}^{FMIPv6} consists of the delay of fast binding update, handover initiation delay, the delay of fast neighbor advertisement, and HA registration delay.

$$\begin{aligned} D_{HO}^{FMIPv6} &= T_{MD} + T_{DAD} + T_{AAA} + T_{REG}^{FMIPv6}, \\ T_{MD} &= 2(t_{mr} + t_{ra}), T_{AAA} = 2 \times 2t_a, \\ T_{REG}^{FMIPv6} &= 2(t_{mr} + t_{ra} + t_{a'}) + t_{a'} + (t_{mr} + t_{ra}) \\ &\quad + 2(t_{mr} + t_{ra} + t_{ah}), \\ D_{HO}^{FMIPv6} &= 7(t_{mr} + t_{ra}) + 4t_a + 3t_{a'} + 2t_{ah} \end{aligned} \quad (3)$$

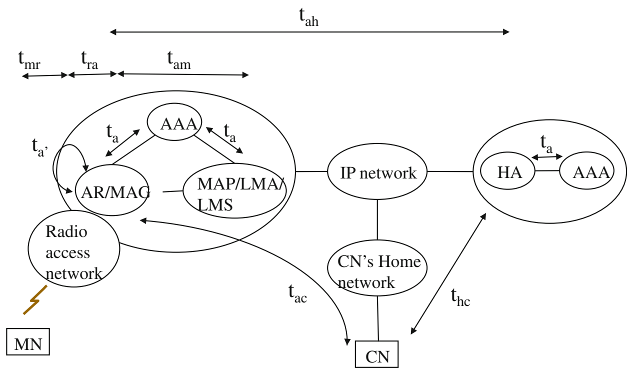


Fig. 5 Simple analytical model

Table 2 Notations of the analytical model

Notations	Meanings
t_{mr}	The delay between the MN and access point
t_{ra}	The delay between the AP and AR/MAG
t_{am}	The delay between the AR/MAG and MAP/LMA/LMS
t_{ah}	The delay between the AR/MAG and HA
t_{ac}	The delay between the AR/MAG and CN
t_{hc}	The delay between the HA and CN
t_a	The delay between mobility agents and AAA
$t_{a'}$	The delay between AR/MAG and its neighbor (candidate) AR/MAG
T_{MD}	The mean value of movement detection TMD = (MinInt + MaxInt)/4, MinInt = MinRtrAdvInterval, MaxInt = MaxRtrAdvInterval
T_{AAA}	The delay involved in performing the AAA procedure, TAAA = 4ta (= 2 × 2ta)
T_{REG}	The location registration delay
D_{HO}	The handover latency

The handover control signal delay of PMIPv6 is represented as Eq. (4). T_{REG}^{PMIPv6} means the LMA registration delay from new MAG. $t_{mr} + t_{ra}$ is the packet transfer delay from MAG to MN.

$$\begin{aligned} D_{HO}^{PMIPv6} &= T_{AAA} + T_{REG}^{PMIPv6} + t_{mr} + t_{ra}, \\ T_{AAA} &= 2 \times 2t_a, T_{REG}^{PMIPv6} = 2t_{am}, \\ D_{HO}^{PMIPv6} &= 4t_a + 2t_{am} + t_{mr} + t_{ra} \end{aligned} \tag{4}$$

The handover control signal delay of the proposed LMM scheme is represented as Eq. (5). T_{MD} of the scheme means the delay of router solicitation or CCOA allocation. T_{REG}^{LMM} means the sum of tunnel creation delay and binding update delay.

$$\begin{aligned} D_{HO}^{LMM} &= T_{MD} + T_{DAD} + T_{AAA} + T_{REG}^{LMM}, \\ T_{MD} &= 2(t_{mr} + t_{ra}), T_{AAA} = 2 \times 2t_a, \\ T_{REG}^{LMM} &= 4(t_{mr} + t_{ra} + t_{am}), \\ D_{HO}^{LMM} &= 6(t_{mr} + t_{ra}) + 4(t_{am} + t_a) \end{aligned} \tag{5}$$

In the case of Eqs. (1), (2), and (4), handover delay of user data plane and control signal delay of handover is same. However, in the case of Eqs. (3) and (5), there is a difference, because some control signaling is executed for handover preparation before handover execution. In the Eq. (3), control signal delay of handover is relatively long because of the inclusion of control signaling delay for packet buffering in order to reduce packet loss. However, it is expected that shorter handover latency in user data plane. In Eq. (5), handover is prepared by using control signaling over a standby tunnel during packets are transmitted through a previous active tunnel. Therefore experienced handover latency in user data plane is expected dramatically reduced. It seems that handover control latency of PMIP is shortest for seeking Eqs. (1) to (5). However, in the case of Eqs. (3) and (5), from the experienced handover latency in user data plane point of view, we need to inspect sequence numbers of packets and elapsed time between the last packet received before handover and the first packet received after handover through experiment.

3.3 Condition of seamless vertical handover

We seek for the seamless mobility condition of the LMM scheme in this section. Figure 6 shows the condition of seamless mobility based on elapsed time which means a duration between the time of the last packet received before handover and the time of the first packet received after handover.

α is a duration between the time of LMC request of a tunnel creation (TC) to LMS and the time of the LMC reception of a create tunnel ack (TCAck) after LMC allocates a CoA through link #2 of a candidate network. γ is duration between the time of binding update (BU) and the time of binding update ack (BUAck). When LMC receives a BUAck message, the tunnel is switched-over and vertical handover is accomplished. γ is regarded as tunnel switching-over latency for vertical handover. τ means elapsed time between the time of receiving the last packet over link #1 and the time of receiving the first packet over link #2. β is duration from the time of a tunnel creation request over link #2 to the time of a tunnel of link #1 elimination by means of a normal control or an abnormal cut-off of communication caused by deterioration of link #1 signal strength. The normal condition of seamless vertical

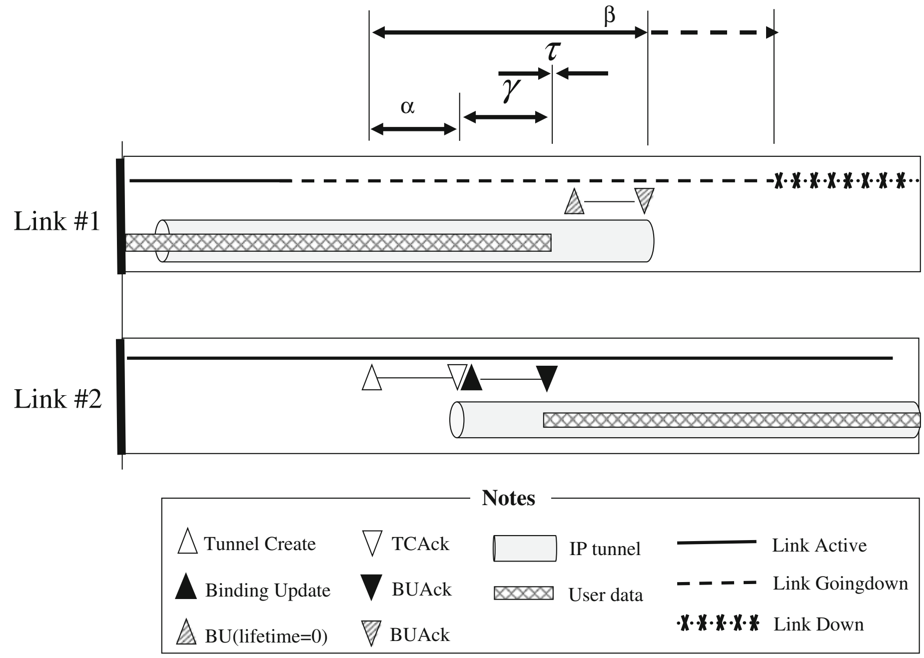


Fig. 6 Seamless vertical handover condition

handover is represented in Eq. (6). It is premised that receive strengths of link #1 and link #2 are changed linearly.

$$(\beta - \alpha) \geq (\gamma + \tau), \text{ assuming } \tau \approx 0 \quad (6)$$

4 Experimentation

In this section, we introduce evaluation scenarios and present handover performance evaluations of the proposed LMM scheme based on a testbed.

4.1 Testbed

The testbed consists of CDMA 1xEVDO Rev.A, which has wide area coverage described in [18, 19] and WiFi (IEEE 802.11 g standard compliance), which has local area coverage. The test-bed is as same as the operator's real network except for the transmission power of CDMA 1xEVDO Rev.A BTS. WiFi AP is embedded in a cradle of a voice IP telephone, which is provided commercially to the subscribers of the operator currently. We use a handheld PC as MN. EVDO and WiFi in the testbed are operated with different sub-networks from IP domain point of view.

4.2 Evaluation scenarios

In the testbed, the MN uses IPv4 HoA and IPv4 CoA. In relation to CoA, the operator uses DHCP and allocates IPv4 common CoA (CCoA) to the MN. For convenience of vertical handover performance evaluation, LMC is already installed in the MN and a traffic generator is set up in the correspondent node (CN). CN generates packets of 100 byte and 700 byte UDP payloads with 10 ms intervals on the supposition of VoIP and VoD real time traffics respectively. The generated traffics are rates far more aggressive than those used in actual real time interactive services. We set the WiFi access priority higher in the vertical handover policy. Then we let the MN access the WiFi inside of the WiFi coverage and access the EVDO outside of the WiFi coverage. We measure 30 vertical handover observations when the MN moves form the WiFi area to the EVDO area and vice versa. The measured objects are two. The one is the binding update latency (γ in Fig. 6) which is tunnel switching-over latency. The other is vertical handover latency, which is user data elapsed time (τ in Fig. 6) between the time of the last packet reception before handover execution and time of the first packet reception after handover execution. We arrange four categories of experimentation scenarios based on combination of UDP payload sizes and handover directions. They are shown in Table 3.

4.3 Evaluation of the handover performance

When Received Signal Strength Indication (RSSI) of WiFi is lower than the predefined threshold (the value is -57 in the experiment), handover to EVDO is executed. In order to avoid ping-pong states caused by unstable state of WiFi link at the coverage edge, handover is executed only when the RSSI below the threshold is detected several times consecutively. When the RSSI beyond the predefined threshold (the value is -47 in the experiment) is monitored, handover to WIFI is executed. We set up the threshold of WiFi RSSI differently as two steps according to the handover directions. We inspect handover latency of each scenario with repeated practices. A dashed line (+) is represented vertical handover latency (τ) and a solid line (o) is tunnel switching-over latency (γ). Figure 7(a) shows the graph of 30 observations measured in scenario. The mean value of τ is 98.967 ms and 95 % confidence interval of τ is from 41.489 to 156.444 ms. The average value of packet loss is 0.300 packets and 95 % confidence interval of packet loss is from 0.126 to 0.474 packets. Figure 7(b) shows the graph of scenario. The mean value of τ is 10.900 ms and 95 % confidence interval of τ is from −24.430 to 45.230 ms. The average value of packet loss is 0.167 packets and 95 % confidence interval of packet loss is from 0.025 to 0.308 packets. Figure 7(c) shows the graph of scenario. The mean value of τ is 123.033 ms and 95 % confidence interval of τ is from 59.503 to 186.564 ms. The average value of packet loss is 0.333 packets and 95 % confidence interval of packet loss is from 0.192 to 0.537 packets. The graph of scenario is shown in Fig. 7(d). The mean value of τ is 80.100 ms and 95 % confidence interval of τ is from 9.804 to 150.396 ms. The average value of packet loss is 0.333 packets and 95 % confidence interval of packet loss is from 0.154 to 0.512 packets. Table 4 summarizes the average values of τ and the packet loss of each scenario.

Figure 8 shows statistics and analysis of variance (ANOVA) for γ of (a), (b), (c), and (d) scenarios. (a) and (c) represent handover scenarios to EVDO. The mean value of γ of (a) is 56.50 ms and the value of (c) is 63.30 ms. (b) and (d) represent handover scenarios to WiFi. The mean value of γ of (b) is 7.47 ms and the value of (d) is 7.63 ms. According to the analysis, it is estimated that each γ of two directions is

Table 3 Performance evaluation scenarios

Scenarios	Conditions
(a)	100 bytes payload, 10 ms interval, WiFi to EVDO
(b)	100 bytes payload, 10 ms interval, EVDO to WiFi
(c)	700 bytes payload, 10 ms interval, WiFi to EVDO
(d)	700 bytes payload, 10 ms interval, EVDO to WiFi

Table 4 Average values of experiment results

Scenarios		Mean value	Confidence interval (95 %)
(a)	τ	98.967	41.489–156.444
	Packet loss	0.300	0.126–0.474
(b)	τ	10.900	−24.430–45.230
	Packet loss	0.167	0.025–0.308
(c)	τ	123.033	59.503–186.564
	Packet loss	0.333	0.192–0.537
(d)	τ	80.100	9.804–150.396
	Packet loss	0.333	0.154–0.512

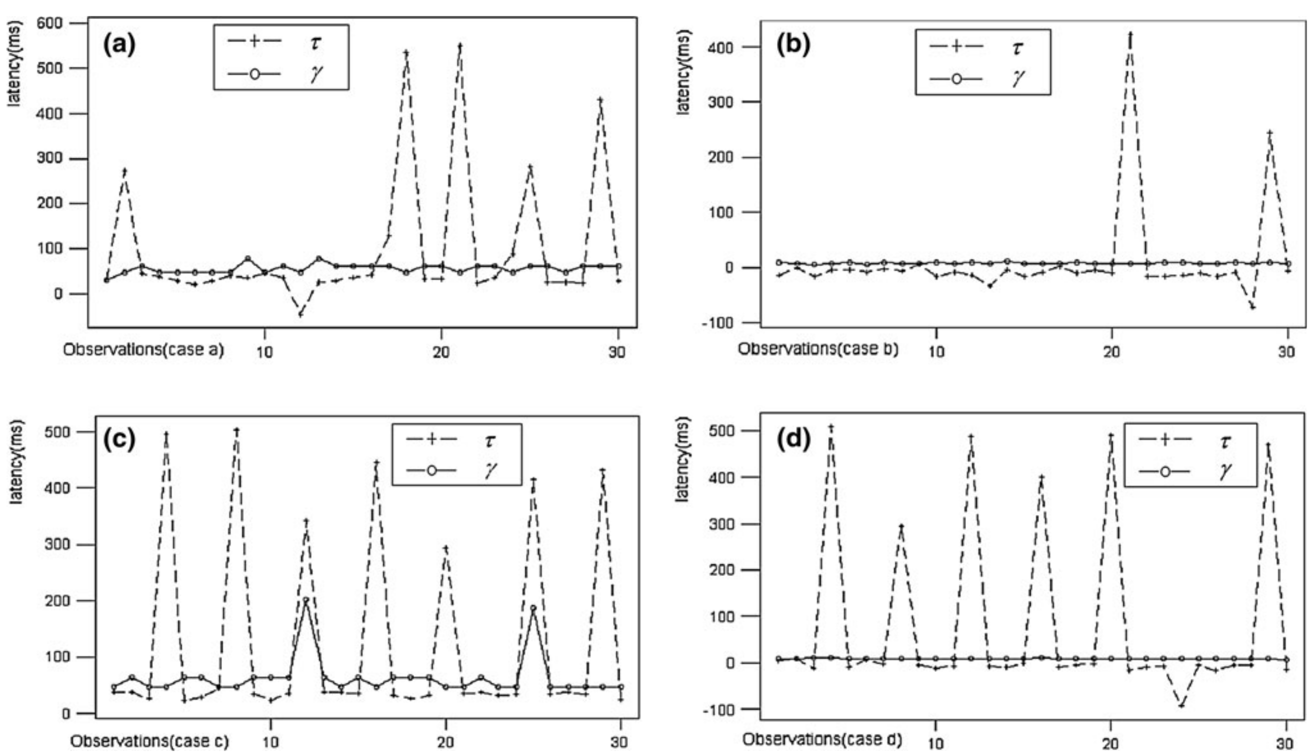


Fig. 7 Handover latencies of scenario

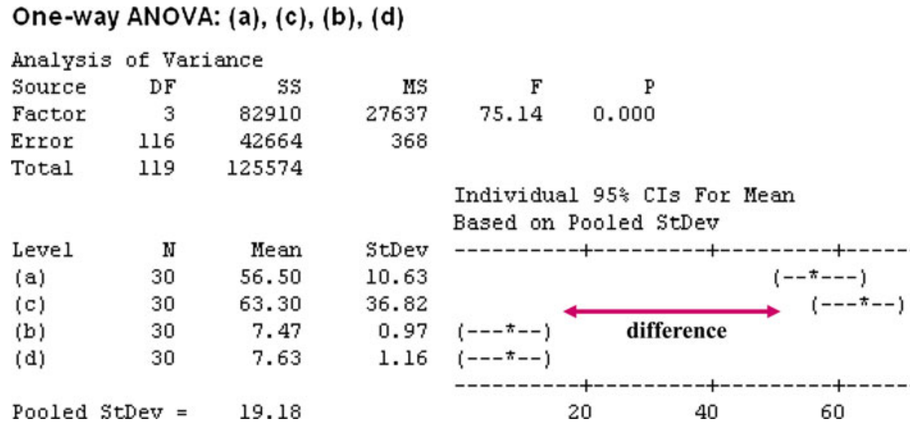


Fig. 8 Switching-over latencies for handover

Table 5 Electric current consumption changes

Cases	Before WiFi AP scan	WiFi AP scan	Active tunnel on WiFi
(A) (Initial access to WiFi AP)	145 mA	292 mA (N = 10, SD = 18.6)	211 mA (N = 10, SD = 16.7)
(B) (EVDO to WiFi handover)	338 mA	541 mA (N = 10, SD = 29.4)	447 mA (N = 10, SD = 42.7)

Table 6 Referred handover latencies

Cases	IP mobility scheme	Handover latency	Remark
Horizontal handover in WiFi	MIPv6	About 3,000 ms	[19]
	HMIPv6	Above 2,000 ms	
	FMIPv6	Above 200 ms	
	PMIPv6	About 200 ms	
Horizontal handover in 3GPP2	MIPv6	Above 3,000 ms	[20]
Vertical handover between UMTS and WiFi	None	Average 4,130 ms (WiFi to UMTS) Average 5,430 ms (UMTS to WiFi)	[21]

different because the significance probability (P value) is smaller than the significance level (significance level is 0.05 in the analysis). The γ value of EVDO direction handover tends to be longer than that of WiFi direction. The reason is that binding update occurs over the candidate network.

4.4 Evaluation of the power consumption

Measured results of the MN's average electric current consumption are presented in Table 5. In this measurement, we measure 10 observations (N = 10) of electric current consumptions for the two cases. The first case (A) is a case of measuring the current consumptions when the MN turns on the WiFi interface and accesses to the WiFi AP initially in the standing state of MN. In the second case (B), the current consumptions are measured when the MN moves and performs handover EVDO to WiFi. In both cases, the current consumption of WiFi AP scan rises to a maximum, and we confirm that the WiFi interface on the active tunnel is formed, there is considerable current consumption. It is expected that periodic frequent AP scan turned on the WiFi interface consumes a lot of electric power.

5 Discussions

In this section, we discuss the results of the presented handover performance.

In [19], it is presented the measured values of horizontal handover latency of the well-known IP mobility schemes (MIPv6, HMIPv6, FMIPv6, and PMIPv6) in which the proposed scheme compared to. Ping data, which has 64 byte packet size and 10 ms sending interval, is used as user traffics, and WiFi access network is used in the experiment environment. In the results, the handover latency of MIPv6 is about 3,000 ms, the latency of HMIPv6 is above 2,000 ms, that of FMIPv6 is above 200 ms, and that of PMIPv6 is about 200 ms. Handover performances of FMIP and PMIP are presented as a similar degree. The horizontal handover latency test result in a 3GPP2 emulated network using MIPv6 is presented in [20]. The measured handover latency is above 3,000 ms even if upper layer control signals (SIP, AKA, and context transfer) are preceded from old network and optimized. The handover latency is measured by checking the control signals. It is found that most parts of the latency come from re-establishment and reconfiguration related with MAC layer access. In [21], UMTS and WiFi actual vertical handover latency measurements are presented. The experiment does not use any IP mobility schemes and only use a certain low complexity RSSI-based algorithm. The measurement results of vertical handover latency presented average 4,130 ms (with standard deviation 1,760 ms) in WiFi to UMTS direction and average 5,430 ms (with standard deviation 3,300 ms) in UMTS to WiFi direction respectively. When compared with the results presented in the above references, our proposed scheme has a FMIP or PMIP level of horizontal handover performance at least in an environment of vertical handover between 3GPP2 and WiFi. This result is due to the features of the proposed scheme described in Sect. 3.1. Table 6 shows the handover latencies presented by the references.

Table 7 Compare to user receptiveness latency

T test		μ of τ (ms)	H_0 vs H_1	T	*P* value
(a)	τ	99.0	$\mu = 150$ vs $\mu < 150$ ms	−1.82	0.040 (H_1)
(b)	τ	10.9	$\mu = 150$ vs $\mu < 150$ ms	−8.29	0.000 (H_1)
(c)	τ	123	$\mu = 150$ vs $\mu < 150$ ms	−0.87	0.196 (H_0)
			$\mu = 150$ vs $\mu \neq 150$ ms	−0.87	0.392 (H_0)
			$\mu = 150$ vs $\mu > 150$ ms	−0.87	0.804 (H_0)
(d)	τ	80.1	$\mu = 150$ vs $\mu < 150$ ms	−2.03	0.026 (H_1)

In relation to handover with IP mobility, handover delay or cuts above 150 ms would generally cause user perceptible quality degradation in real time communications such as VoIP and video streams. A streaming application can withstand a delay of 400 ms [20]. Analysis of τ of the scheme is shown in Table 7.

The significance level is 0.05 in this analysis. (a), (b), and (d) scenarios have the mean value of τ (μ) within 150 ms. The mean value of τ in scenario (c) is estimated same as 150 ms from the analysis. Therefore, it is referred that the mean value of τ is bound of 150 ms in all scenarios. Although handover latencies occur up to about 500 ms in some observations, the LMM scheme is expected that users have little recognition of quality degradation of real time communications averagely. There is the existence of relatively high deviation values of τ and the existence of relatively high gap between τ and γ from Fig. 7(a)–(d). Figure 8 shows the deviations of γ value of each scenario are not much. This implies that the variation of data transmission delay of wireless interface tends to affect the handover latency rather than tunnel switching-over latency itself. Figure 9(a) shows the difference of τ of (a) and (b) scenarios and Fig. 9(b) shows that of (c) and (d) scenarios. From the analysis of Fig. 9(a), it is estimated that τ values of two scenarios have difference distinctly in 0.95 confidence level. It is referred that the handover latency of EVDO to WiFi direction is far lower than that of inverse direction. However, it is estimated that τ values of two scenarios (c) and (d) have no difference in 0.95

(a) One-way ANOVA: (a), (b)

```
Analysis of Variance
Source     DF       SS       MS       F      P
Factor      1   116336   116336    7.24  0.009
Error      58   932252    16073
Total      59  1048588
                                 Individual 95% CIs For Mean
                                 Based on Pooled StDev
Level       N     Mean    StDev  --------+---------+---------+--------
(a)        30     99.0    153.9                    (--------*--------)
(b)        30     10.9     91.9   (--------*--------)
                                 --------+---------+---------+--------
Pooled StDev =    126.8                  0        50       100
```

(b) One-way ANOVA: (c), (d)

```
Analysis of Variance
Source     DF       SS       MS       F      P
Factor      1    27649    27649    0.86  0.358
Error      58  1867240    32194
Total      59  1894889
                                 Individual 95% CIs For Mean
                                 Based on Pooled StDev
Level       N     Mean    StDev  --------+---------+---------+--------
(c)        30    123.0    170.1          (------------*------------)
(d)        30     80.1    188.3   (------------*------------)
                                 --------+---------+---------+--------
Pooled StDev =    179.4                 50       100       150
```

Fig. 9 Handover latency difference (*a*)–(*d*) confidence level from the analysis of Fig. 9(b). It means that delay variations of two interfaces are increased as the user data sizes are increased. There is a peculiar finding, which is an existence of negative values of τ. Most occasions of negative τ are from scenario (b) and (d) as the case of EVDO to WiFi direction handover. The main reason of negative τ comes from high difference of transmission delay of both interfaces. The difference of transmission delay comes from bandwidth difference. From an analogical inference based on this phenomenon, the bi-casting scheme addressed in [22] has a possibility to cause the problem of packet duplications when handover occurs from a high speed interface to a low speed interface in heterogeneous networks. From this reason, a sophisticated packet reordering mechanism or an application is needed when vertical handover is performed between RATs with high bandwidth difference.

6 Conclusion

This paper verifies that vertical handover performance of host-based localized mobility management scheme, which provides the soft handover mechanism with a single unitary virtual interface and multiple care-of addresses during a handover moment. Conclusively, the paper presents that the LMM scheme can support real time communication traffics through the analysis of experiment results. The experiment is performed in the testbed similar to a real network environment. In addition, the analysis demonstrates that the variation of transmission delay of a wireless interface tends to affect the handover latency rather than IP tunnel switching-over latency itself in soft vertical handover.

However the proposed scheme has the disadvantage of a lot of power consumption always maintained multiple radio. Accordingly, the research of network driven handover policy realization is needed in order to reduce power consumption while maintaining less handover latency of the level of this scheme. We consider following main research directions. These are how to determine the exact location using GPS, how to apply media independent handover of IEEE 802.21 or access network discovery and selection function of 3GPP, and how to interact with the network management system to reflect the location and access coverage of the base stations and access points in real-time. One more research direction is how to extend to a distributed mobility control scheme based on the separation of control and data channels, which is one of features of the proposed scheme.

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