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On the Use of Ad Hoc Cooperation for Seamless Vertical Handoff and Its Performance Evaluation

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Abstract In heterogeneous network environments, it is very important for users to provide seamless services while satisfying quality-of-service, regardless of the connected access network. In this paper, we apply a concept of ad hoc cooperation for the vertical handoff in the heterogeneous network. For the seamless vertical handoff of mobile nodes, a neighbor ad hoc node assists some parts of the handoff procedures requiring large latency, such as authentication and IP registration procedures. Details of the vertical handover operation using the ad hoc cooperation are presented and its performance is evaluated. Numerical results show that the proposed vertical handoff procedure decreases the service disruption time and the probability of packet loss, compared with the conventional handoff methods that do not consider the cooperation of ad hoc node.

Keywords Vertical handoff · mobility management · ad hoc cooperation.

1 Introduction

Future wireless network will consist of various wireless technologies existing currently, such as GSM, CDMA2000, WCDMA, WiMAX and WiFi, and mobile users will be provided any kind of services anytime and anywhere via any radio interface while guaranteeing the end-to-end quality of service (QoS). Such heterogeneous network environment makes mobile nodes (MN) undergo a vertical handoff as it changes its service connection between different types of access network (AN). In case that an MN hands off within the same AN (i.e., horizontal handoff), it may perform only layer 2

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(L2) handoff procedures such as L2 detachment and L2 attachment. However, in the vertical handoff, the MN should perform not only L2 handoff procedures, but also connection setup procedures such as authentication and L3 (IP) registration with a new AN. Since the authentication and IP registration processes basically consume much more time than the L2 detachment and attachment processes, the vertical handoff induces longer handoff latency and service disruption time. Therefore, it is an important issue to provide seamless services during the vertical handoff [1]-[3].

To make the vertical handoff seamless, conventional handoff schemes generally utilize a fast handoff mechanism on the IP level. It uses a pre-registration or post-registration technique, which reduces the handoff latency as it separates L2 and L3 handoffs and performs the L3 handoff earlier or later than the L2 handoff [4]. These techniques can reduce the handoff time on the L3 level efficiently, but they basically assume an interworking agreement between two different ANs involved in the MN's vertical handoff. That is to say, they require an additional interworking architecture and pre-defined signalling procedures between two heterogeneous ANs to apply them for the vertical handoff. However, these requirements might not be feasible in the future network environment consisting of various kinds of ANs because it is practically difficult to establish interworking agreements between all heterogeneous ANs. Therefore, it is necessary to develop a common and unified interworking solution applicable to various kinds of AN regardless of any specific interworking architecture and pre-defined signalling procedure for providing ubiquitous and seamless services in the heterogeneous network environments.

Another characteristic of the future wireless network is a peer-to-peer communication between MNs by a revolutionary paradigm of mobile ad hoc network (MANET) technologies [5]. The MANET technologies, such as neighbor discovery, routing, and distributed scheduling algorithms, enable MNs to communicate each other without any infrastructure. The standards, such as Bluetooth and IEEE 802.11 ad hoc mode, define the function of peer-to-peer communication. The ad hoc network not only organizes a community network through the direct communication between MNs, but also integrate with the typical infrastructure network. Various ad hoc integrated network architectures already have been presented, such as unified cellular and ad hoc networks (UCAN), multihop cellular network (MCN), integrated cellular and ad hoc relaying (iCAR), and opportunity-driven multiple access (ODMA) [6]-[9].

To complete the vertical handoff, the MN should generate, transmit and receive a number of signaling messages. Nevertheless, the MN suffers from the poor channel quality with both its serving and target ANs during the overall vertical handoff period. These conditions cause the MN to consume more radio resources and processing power, so the vertical handoff can be a big burden to MN. To overcome the difficulties of vertical handoff, in this paper, a new concept for vertical handoff is proposed, which uses an ad hoc node for seamless vertical handoff instead of the typical interworking solutions between heterogeneous networks. An MN that wants vertical handoff requests an ad hoc node to take over some handoff procedures that require large latency, such as authentication and registration procedures, and to process them instead of the requested MN before the handoff completion. Since the ad hoc node is used to assist vertical handoff in the proposed scheme, it has the advantage that there is no need for there to exchange interworking signaling messages directly between two ANs involved in handoff. In addition, because the ad hoc cooperation reduces the amount of signaling procedures that the MN should perform during the vertical handoff, the MN can reduce its processing overhead and connect with the new AN more quickly. To make the concept of ad hoc cooperative vertical handoff concrete, details of the vertical handover procedures are explained and its performance is evaluated with respect to the total handoff time, service disruption time, and the QoS of transmitted packets.

The rest of this paper is organized as follows. In Section 2, the standards and literature related to the vertical handoff are introduced. In Section 3, the network architecture and operation procedure of the proposed vertical handoff using the ad hoc cooperation are explained and some practical issues are stated. In Section 4, the performances of the proposed vertical handoff scheme are evaluated. In Section 5, analysis results are presented. Finally, Section 6 concludes this paper.

2 Related Work

For offering seamless roaming to mobile devices on the Internet, the IETF's mobile IP working group has proposed so-called low latency handoff schemes, which are distinguished as *Pre-Registration* and *Post-Registration handoff* [4].

In pre-registration handoff, the network assists the MN in performing an L3 handoff before the L2 handoff is completed. Fig. 1 presents the operation procedure of the pre-registration handoff scheme. First of all, a *Router Solicitation* is sent from an old foreign agent (oFA) to a new foreign agent (nFA) and a *Router Advertisement* is returned from the nFA to the oFA. The oFA should solicit and cache advertisements from the nFA in advance of the pre-registration handoff in order not to delay the handoff. A mobile-initiated handoff occurs when an L2 trigger is received at the MN. This L2 trigger notifies that the MN will shortly move to the nFA and contains information such as the nFA's IP address identifier. As a consequence of the L2 trigger, a *Proxy Router Solicitation* is generated by the MN. A *Proxy Router Advertisement* is sent by the oFA as a result of the MN's solicitation message. Then, the *(Regional) Registration Request* to the nFA is sent via the oFA and is relayed to the home agent (HA) by the nFA, which can verify the HA information within the message received from the MN. Finally, the *(Regional) Registration Reply* is sent by the HA to the nFA, and is delivered to the MN, via the oFA if the L2 handoff is not completed, or to the MN directly if the L2 handoff is finished. If the handoff trigger occurs, the MN performs the detachment process with the old AN (oAN) and the attachment process with the new AN (nAN). After finishing the authentication process, the MN finally performs the re-registration procedure.

In post-registration handoff, the L3 registration occurs after the L2 handoff has been completed. [10]. A handoff occurs when the MN moves from the oFA, where the MN performed a mobile IP (MIP) registration, to the nFA. Instead of making a new MIP registration with the nFA, the MN delays it while maintaining connectivity using the bi-directional edge tunnel (BET) between the oFA and the nFA. The sequence of messages for post-registration handoff is depicted in Fig. 2. An FA becomes aware that a handoff is about to occur at L2 through the use of an L2 trigger. The FA receiving the trigger sends a *Handoff Request* to the other FA. The FA receiving the handoff request sends a *Handoff Reply* to the other FA. This establishes a BET. When the L2 handoff occurs and the MN is no longer connected to the oFA, the oFA begins forwarding the MN packets to the nFA through the BET, and then the nFA delivers these packets to the MN. If the MN attaches to the nAN and completes the authentication process, it decides to initiate the MIP registration process with the nFA by using *Agent Solicitation* and *Agent Advertisement*. Once the registration process is ended by the exchange of a

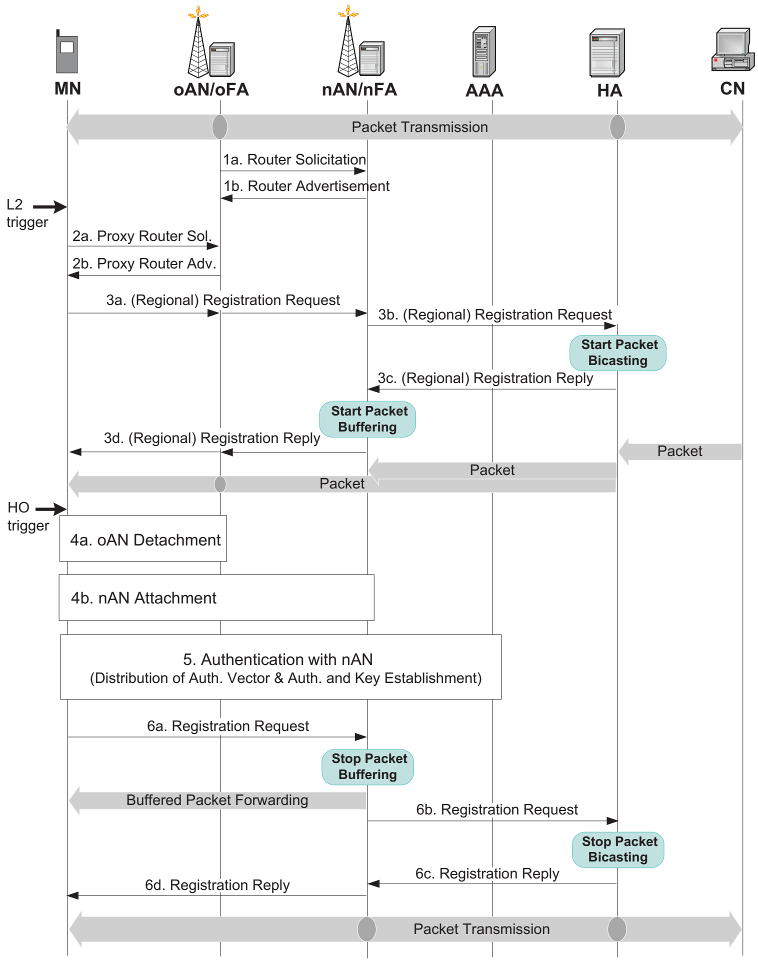

Fig. 1 Operation procedure of pre-registration handoff.

(Regional) Registration Request and a *(Regional) Registration Reply* with the HA, the nFA takes over the role of the oFA.

Unified cellular and ad-hoc network (UCAN) architecture has been proposed as an enhanced network architecture [6]. In UCAN, a mobile client has both 3G cellular link and IEEE 802.11-based peer-to-peer links. The 3G base station forwards packets for destination clients with poor channel quality to proxy clients with better channel quality. The proxy clients then use IEEE 802.11 ad-hoc links to forward the packets to the appropriate destinations, thereby improving cell coverage and throughput. With the UCAN architecture, novel greedy and on-demand protocols are proposed for efficient proxy discovery.

The approach of *integrated cellular and ad hoc relaying* (iCAR) used special pre-installed ad hoc relay stations to deliver traffic between cells [8]. The integration of cellular infrastructure and modern *ad hoc* relay-technology is proposed. The key device in this architecture is the ad hoc relay stations (ARSs). A number of ARSs are pre-

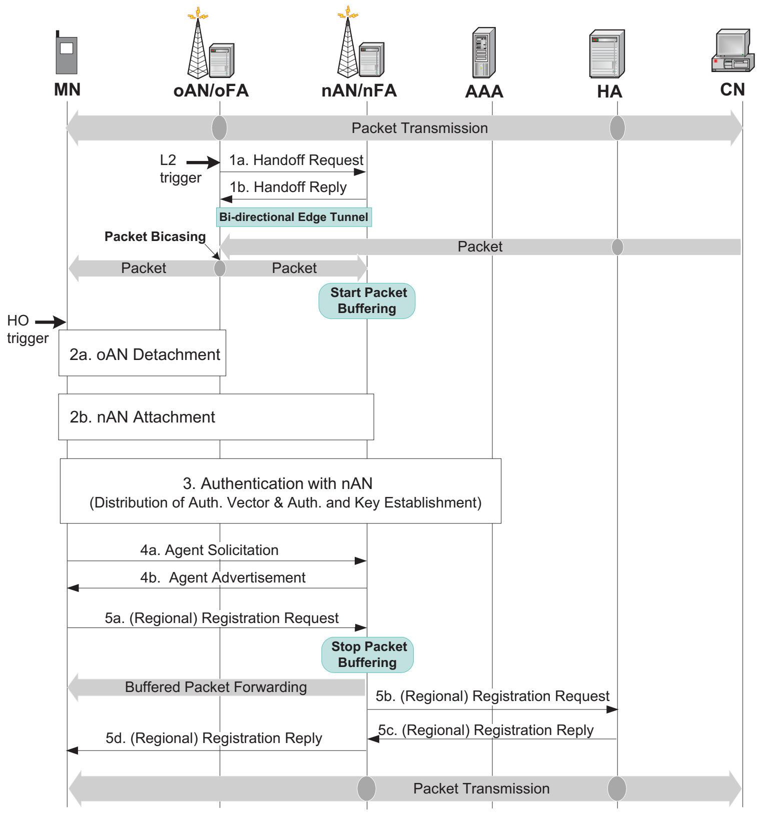

Fig. 2 Operation procedure of post-registration handoff.

installed at strategic locations of the system and they act just like an active router without mobility. In this system, the MN under handoff can access to the nearest ARS to perform the handoff procedure, and this ARS forwards the handoff signaling messages to its new AN.

An *ad hoc assisted handoff* (AAHO) is proposed in the IEEE 802.11 system [11]. In AAHO, a single additional ad hoc hop is used by a mobile station to obtain the range extension together with good channel quality or to achieve the fast roaming to neighbor access point while maintaining its real-time voice connection. The IEEE 802.11 system is an originally distributed system enabling ad hoc communications, so this AAHO scheme is so natural to realize the handoff using ad hoc nodes.

3 Vertical Handoff Using Ad Hoc Cooperation

In this section, we present the considered heterogeneous network architecture using ad hoc cooperation, explain the detailed procedure of proposed vertical handoff, and discuss implementation issues taking into account practical environments.

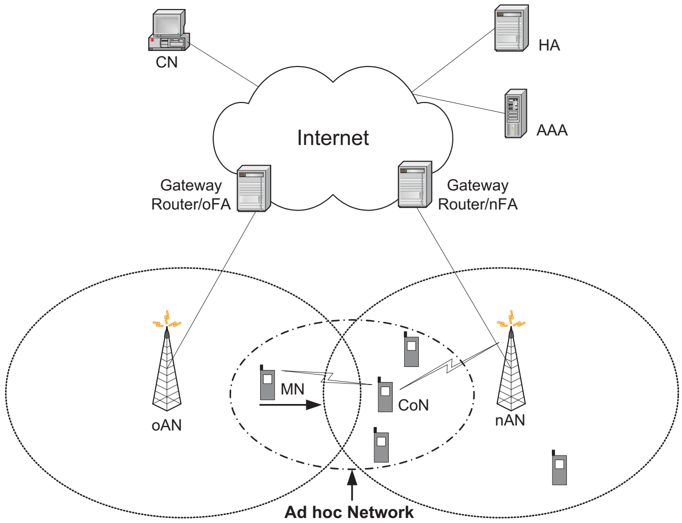

Fig. 3 Ad hoc cooperative heterogeneous networks architecture.

3.1 Network Architecture

Fig. 3 illustrates a considered heterogeneous network architecture using ad hoc cooperation. There are two ANs that have different access technologies each other. Each AN is connected to Internet via its gateway router. Each FA is assumed to be located together with the gateway router and manages the mobility within the same AN. The HA manages the mobility between the different ANs, the AAA (authentication, authorization and accounting) server takes charge of the authentication for the MN, and the correspondent node (CN) sends packets to the MN by checking the MN's current location information registered at the HA and the FA. Compared to existing network architectures, there is no additional interworking unit between two heterogeneous ANs.

In this architecture, we assume that an MN can directly communicate with their neighbor nodes through the predetermined access technology and frequency channel. These neighbor nodes can be any wireless communication entity existing within the MN's coverage. For example, another mobile node or fixed/empowered access point can communicate directly with the MN via Bluetooth or 802.11-based WiFi technology. An MN that hands off from one AN to another AN selects a neighbor node suitable to help its vertical handoff process. Here, we denote this selected appropriate node as a cooperation node (CoN) and for the reliable cooperation the CoN should observe the following conditions:

- The CoN should be connected to the nAN currently or should be capable of connecting with the nAN directly.
- The CoN should have good communication quality with both MN and nAN. Thus, a CoN is selected among nodes located in the joint coverage of MN and nAN.
- The CoN can be either a fixed node or mobile node, but the CoN should be selected to have low mobility as much as possible in order to maintain the connection with the MN and nAN during the handoff period.

3.2 Handoff Procedures

The basic idea of the proposed vertical handoff is to use cooperative ad hoc nodes instead of backbone signaling between heterogeneous ANs. On the basis of this ad hoc cooperation, the pre-registration and pre-authentication processes are performed before the L2 handoff. This can reduce the handoff time and the service disruption time effectively. In addition, packet buffering and bicasting mechanisms are applied to each network agent such as FA and HA. These mechanisms significantly decrease packet loss during the service disruption period and so the QoS of transmitted packets can be guaranteed.

Basically the proposed handoff procedure uses the existing registration and authentication messages defined at the standards [4], [12]. Besides these messages, three signaling messages related to the CoN are newly defined as follows.

- *Cooperation Request* is issued by an MN after it finds a suitable CoN. This message is sent to the CoN via the ad hoc channel to request to process pre-authentication and pre-registration for MN's fast handoff. It delivers the information of MN's identity and IP address.
- *Cooperation Reply* is a response message of cooperation request and is sent from the CoN to the MN. It delivers the address information of AAA and FA used in the CoN's AN.
- *Attachment Confirm* is generated by the nAN when an MN attached to the nAN. This message informs the MN of the results of pre-authentication and pre-registration, as it delivers MN's new IP address and security key available in the nAN.

Fig. 4 illustrates the detailed signaling procedure of the proposed vertical handoff. The overall handoff procedures consist of seven steps.

Step 1) If an L2 trigger is generated by MN's link layer, the MN starts the CoN discovery process. During this process it finds a CoN suitable to the pre-processing for the fast vertical handoff. However, if the MN does not find any CoN during the predetermined discovery time, it gives up finding a CoN and directly executes the typical hard handoff procedure.[1] There exist various neighbor discovery protocols in the ad hoc network [13], [14]. In this paper, we assume an effective discovery protocol is applied for finding an appropriate CoN and focus mainly on the handoff protocol.

Step 2) If the MN selects a proper CoN, it sends a *Cooperation Request* message. This message requests the CoN to assist pre-authentication and pre-registration with the nAN by delivering the identity number and IP address of the MN. If the CoN receives the *Cooperation Request* message, it responds to the MN through a *Cooperation Reply* message, which contains the addresses of the AAA and nFA for the MN to execute the pre-authentication and pre-registration processes.

Step 3) After the MN confirms the *Cooperation Reply* message, it starts pre-authentication process with nAN and AAA server through the CoN's cooperation. For this pre-authentication, the standard authentication procedure specified at the nAN can be used without change [15]. The MN has only to notify the nAN that this is a pre-authentication executed before attachment process. After the successful pre-authentication, the nAN memorizes the results of authentication for the MN.

[1] In practice, the probability that a stable CoN can be found depends on several factors such as the number of neighbor nodes, the type of access technology used for discovery protocol, the discovery time duration, and the transmission power of MN [13].

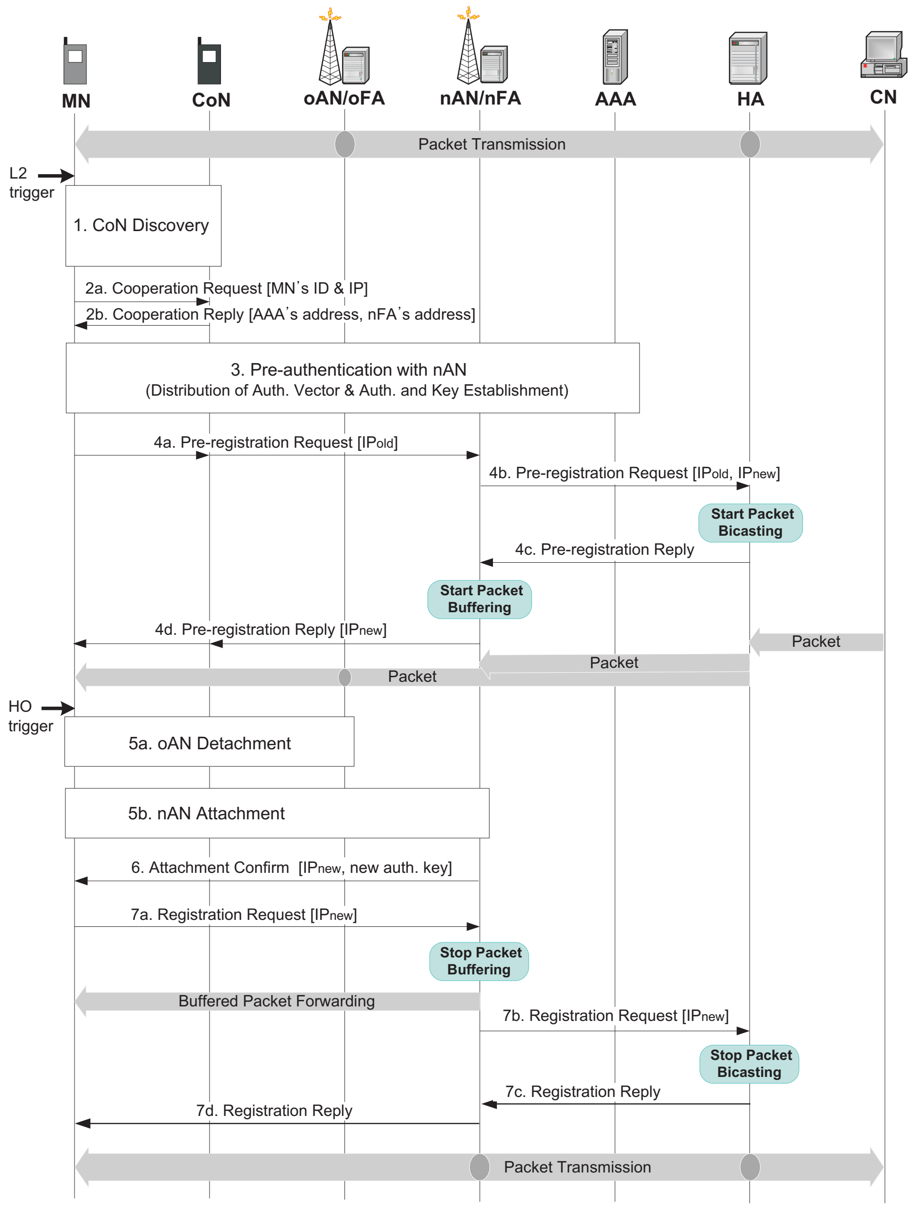

Fig. 4 Signaling procedure of proposed vertical handoff.

Step 4) After the end of pre-authentication, the MN performs the pre-registration with nFA and HA. This process basically follows the procedure of MIP-based pre-registration handoff, but the signaling messages are tunnelled via the CoN. The MN sends the pre-registration request message including the its current IP address (i.e, IP_{old}) to the nFA. If the nFA receives this request message, it assigns a new IP address that will be used in the nAN (i.e., IP_{new}) and forwards two IP addresses to the HA. If the HA confirms IP_{old} and IP_{new}, it starts to bicast packets destined for the MN by using two IP addresses. At this time, packets are delivered to both oAN and nAN. Thereafter, the HA sends the pre-registration reply to the nFA. If the nFA receives this reply message, it starts to buffer the MN's packet of which destination address is IP_{new}. Lastly, the nFA transmits the MN the pre-registration reply message via the nAN and CoN.

Step 5) Regardless of the end of MN's pre-processing, the MN may begin L2 detachment process with the oAN and L2 attachment process with the nAN, respectively, if an L2 handoff trigger occurs. This is because the MN can receive the pre-registration reply message via the link with CoN after the link with the oAN is disconnected. The detachment and attachment processes observes the standard procedures defined in each AN.

Step 6) If the nAN recognizes the new attachment of MN, it sends the MN a *Attachment Confirm* message that reports the MN's new IP address (IP_{new}) and authentication key, which make it possible to skip new authentication and registration processes in the nAN. If the MN does not receives the *Attachment Confirm* message from the nAN even though it attaches with the nAN, it judges the relay process failed and then attempts directly the authentication and registration precesses in the nAN.

Step 7) If the MN confirms the IP_{new}, it carries out the registration again with the nFA and HA, to inform of the handoff completion and to deactivate the buffering and bicasting functions in the FA and HA. If the FA and HA receive the registration request message from the MN, they stop the packet buffering and bicasting, respectively. Here, the FA forwards the buffered packets destined for the MN. After the registration reply message is sent to the MN, the overall vertical handoff procedure is completed.

By using these handoff procedures, the MN can connect with the nAN by only L2 detachment and attachment processes without new authentication and registration if the MN and CoN completes the pre-processing successfully. In addition, the packet loss that might occur during the AN detachment and attachment processes can be prevented by the packet bicasting and buffering mechanisms. These cooperative and efficient handoff mechanisms make it possible to minimize handoff time and packet loss during the vertical handoff.

3.3 Implementation Issues

The proposed vertical handoff scheme based on the cooperative ad hoc node has some advantages compared with the conventional handoff schemes based on interworking signaling. First, the vertical handoff generally requires a large number of signaling procedures because the MN changes its access network. Hence, the ad hoc cooperation is very helpful to the MN and it can lighten the load of MN undergoing vertical handoff. Second, it is difficult for the MN to maintain good channel quality with both ANs involved in the handoff according to its location and mobility. However, if the CoN is used, the channel quality between MN and new AN can be improved. Third, the ad hoc cooperation concept does not require additional interworking units or direct signaling procedures between two heterogeneous networks. It just requires a peer-to-peer communication between MN and CoN. This concept is more useful in the nextgeneration heterogeneous network environments where various kinds of ANs exist and so it is difficult to make a common handoff solution among all different ANs.

On the other hand, there are some requirements and implementation issues for the operation of the proposed vertical handoff. The following should be considered for the realization of seamless handoff.

- The proposed scheme requires that the MN should discover a CoN as a suitable neighbor node to assist MN's handoff. In order to find an appropriate CoN, the MN broadcasts the identity information of its target AN and only available neighbor nodes that can connect to the MN's target AN are allowed to transmit a response message to the MN. Moreover, the neighbor node informs the MN of its mobility level and channel quality with the serving AN through the response message. Based on these effective information, the MN selects an appropriate CoN that has a low mobility and a good channel quality with its serving AN for the reliable cooperation. This additional discovery process may have an influence on the entire vertical handoff performance, so we need a fast neighbor discovery scheme, which makes the MN find a suitable CoN while decreasing the discovery time efficiently [14].
- Secure peer-to-peer communication between MN and CoN is important. The MN should confirm whether the CoN is secure or not before sending the cooperation request because an illegal CoN may abuse the information of MN. There are several security solutions such as secure routing and secure key management in ad hoc networks [16], [17]. Therefore, the proposed handoff scheme can employ one of the current security solutions of the ad hoc networking to find a secure CoN and cooperate with the CoN.
- Ping-pong problem can happen if the MN does not hand off after it request the CoN to assist some vertical handoff processes. In this case, the pre-processing of CoN is useless. Therefore, we need to use an accurate handoff decision algorithm to minimize the ping-pong effect. Nevertheless, if the ping-pong effect occurs, we can resolve it by the timer pre-defined in each entity [18]. If the MN is not attached with the nAN within the defined time, the nAN judges that the MN cancelled the handoff and then gives up to transmit the attachment confirm message for the MN. In the same manner, the FA and HA stop their buffering and bicasting functions after the predefined timer is expired.

4 Performance Evaluations

We evaluate the performances of the proposed vertical handoff scheme with respect to total handoff time, service disruption time, and packet loss and discard probabilities, and compare it with the conventional MIP, pre-registration and post-registration handoff schemes. Following parameters are defined for the performance analysis:

- d_{x_y}: average number of hops between x and y.
- R_i: random variable of service time at router i, which follows exponential distribution with λ_i.[2]
- s_r: average size of a signaling message for registration update.
- s_c: average size of a signaling message for cooperation with ad hoc node.

[2] In detail, the service time in the router includes queueing delay, route lookup delay, and packet processing delay. Generally the queueing delay is majority and is modelled by the exponential distribution, and the other delay terms have very small constant values [19].

- B_w: bandwidth of wired link.
- B_{wl}: bandwidth of wireless link.
- L_w: constant delay of one-hop wired link (propagation and link layer delays).
- L_{wl}: constant delay of wireless link (propagation and link layer delays).
- $T_{discovery}$: average time needed for CoN discovery process.
- T_{detach}: average time needed for L2 detachment process.
- T_{attach}: average time needed for L2 attachment process.
- T_{auth}: average time needed for authentication process.

Using above parameters, we define the transmission delay of signaling message on the wired link and wireless link. Let $T_w(s, d_{x\_y})$ be the transmission delay of a message of size s sent from x to y via wired links, which is defined as

$$\begin{aligned} T_w(s, d_{x\_y}) &= \sum_{i=1}^{d_{x\_y}} \left(\frac{s}{B_w} + L_w + R_i \right) \\ &= d_{x\_y} \times \left(\frac{s}{B_w} + L_w \right) + \sum_{i=1}^{d_{x\_y}} \frac{1}{\lambda_i}. \end{aligned} \tag{1}$$

Moreover, let $T_{wl}(s)$ be the transmission delay of a message of size s sent from an MN via wireless link, which is given by

$$T_{wl}(s) = \frac{s}{B_{wl}} + L_{wl}. \tag{2}$$

4.1 Total Handoff Time

Total handoff time is defined as the time duration required to complete all handoff signaling procedures from the beginning of L2 trigger to the end of handoff signaling [20]. Since L2 detachment, L2 attachment and authentication are common processes in all handoff schemes, they consume the identical time. Only the registration process consumes different time in each scheme. Let T_{reg} be a time required for registration. It becomes the sum of delays consumed for transmitting all registration update messages. By analyzing the registration signaling, we can describe T_{reg} in each handoff scheme as follows.

$$T_{reg}(\text{MIP}) = \frac{T_{ad}}{2} + 4T_{wl}(s_r) + 4T_w(s_r, d_{MN\_nFA} - 1) + 2T_w(s_r, d_{nFA\_HA}) \tag{3}$$

$$\begin{aligned} T_{reg}(\text{Pre}) = {} & 6T_{wl}(s_r) + 4T_w(s_r, d_{MN\_oFA} - 1) + 2T_w(s_r, d_{MN\_nFA} - 1) \\ & + 4T_w(s_r, d_{nFA\_HA}) + 4T_w(s_r, d_{oFA\_nFA}) \end{aligned} \tag{4}$$

$$\begin{aligned} T_{reg}(\text{Post}) = {} & 4T_{wl}(s_r) + 4T_w(s_r, d_{MN\_nFA} - 1) + 2T_w(s_r, d_{nFA\_HA}) \\ & + 2T_w(s_r, d_{oFA\_nFA}) \end{aligned} \tag{5}$$

$$\begin{aligned} T_{reg}(\text{Prop}) = {} & 7T_{wl}(s_r) + 2T_w(s_r, d_{CoN\_nFA} - 1) + 3T_w(s_r, d_{MN\_nFA} - 1) \\ & + 4T_w(s_r, d_{nFA\_HA}) \end{aligned} \tag{6}$$

In the case of MIP-based hard handoff, the discovery time is required when an MN moves into a new network area. This kind of discovery is indicated by receiving an agent advertisement from the new network. Hence, the average discovery time is equal

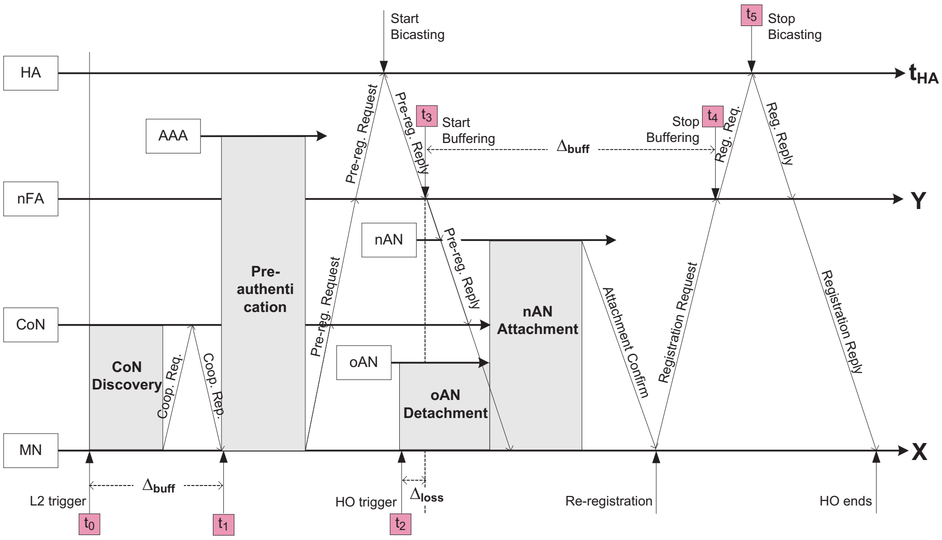

Fig. 5 Timing analysis for the proposed vertical handoff.

to $T_{ad}/2$ where T_{ad} is the advertisement period. Therefore, the total handoff time of each scheme is given by

$$T_{HO}(\text{MIP}) = T_{detach} + T_{attach} + T_{auth} + T_{reg}(\text{MIP}) \quad (7)$$
$$T_{HO}(\text{Pre}) = T_{detach} + T_{attach} + T_{auth} + T_{reg}(\text{Pre}) \quad (8)$$
$$T_{HO}(\text{Post}) = T_{detach} + T_{attach} + T_{auth} + T_{reg}(\text{Post}) \quad (9)$$
$$T_{HO}(\text{Prop}) = T_{discovery} + 2T_{wl}(s_c) + T_{detach} + T_{attach} + T_{auth} + T_{reg}(\text{Prop}) \quad (10)$$

where the term of $2T_{wl}(s_c)$ in the proposed scheme is caused by the cooperation signaling with the CoN.

4.2 Service Disruption Time

Fig. 5 shows an analytical timing model of the proposed handoff scheme. We define five time instants, as follows.

$$t_1 = t_0 + T_{discovery} + 2T_{wl}(s_c) \quad (11)$$
$$t_2 = t_0 + t_{HO} \quad (12)$$
$$t_3 = t_1 + T_{auth} + 2T_{wl}(s_r) + T_w(s_r, d_{CoN\_nFA} - 1) + 2T_w(s_r, d_{nFA\_HA}) \quad (13)$$
$$t_4 = t_2 + T_{detach} + T_{attach} + 2T_{wl}(s_r) + T_w(s_r, d_{MN\_nFA} - 1) \quad (14)$$
$$t_5 = t_4 + T_w(s_r, d_{nFA\_HA}). \quad (15)$$

where t_0 is a time when the L2 trigger occurs in MN and t_{HO} is a time interval between L2 trigger and handoff trigger. We assume that the MN does not receives packets from its connected AN while it finds the CoN and the ongoing packets are buffered at the AN during this period. Also the packet buffering operates at the FA during the vertical handoff period. Considering there are two packet buffering durations, as shown in Fig. 5, the buffering duration is given by

$$\begin{aligned} \Delta_{buff}(\text{Prop}) &= t_1 - t_0 + t_4 - \max\{t_2, t_3\} \\ &= T_{discovery} + 2T_{wl}(s_c) + t_4 - \max\{t_2, t_3\}. \end{aligned} \quad (16)$$

In spite of the buffering function, packets might be lost if the MN is detached from the oAN before the buffering function starts in the nFA. Thus, this packet loss duration is described as

$$\Delta_{loss}(\text{Prop}) = \max\{0, t_3 - t_2\}. \quad (17)$$

Here we define the service disruption time as the time duration during which the MN cannot receive ongoing downlink packets directly due to the packet loss or buffering. So, it becomes the sum of packet loss and buffering durations. Finally, the service disruption time of the proposed handoff scheme is calculated as

$$\begin{aligned} T_{disrupt}(\text{Prop}) &= \Delta_{loss}(\text{Prop}) + \Delta_{buff}(\text{Prop}) \\ &= T_{discovery} + 2T_{wl}(s_c) + t_4 - \max\{t_2, t_3\} + \max\{0, t_3 - t_2\} \\ &= T_{discovery} + 2T_{wl}(s_c) + t_4 - t_2 \\ &= T_{discovery} + 2T_{wl}(s_c) + T_{detach} + T_{attach} + 2T_{wl}(s_r) \\ &\quad + T_w(s_r, d_{MN\_nFA} - 1). \end{aligned} \quad (18)$$

In the case of the other handoff schemes, the service disruption time is obtained by the same analytic approach. Figs. 6 and 7 show the analytical timing model of the pre-registration and post-registration handoff schemes. By referring to [21] and the timing models, the disruption time is given as

$$T_{disrupt}(\text{MIP}) = T_{HO}(\text{MIP}) \quad (19)$$

$$T_{disrupt}(\text{Pre}) = T_{detach} + T_{attach} + T_{auth} + T_{wl}(s_r) + T_w(s_r, d_{MN\_nFA} - 1) \quad (20)$$

$$T_{disrupt}(\text{Post}) = T_{detach} + T_{attach} + T_{auth} + 3T_{wl}(s_r) + 3T_w(s_r, d_{MN\_nFA} - 1) \quad (21)$$

Note that the disruption time of MIP is equal to its total handoff time because it is a hard handoff without the buffering or bicasting mechanisms. Furthermore, compared to the conventional schemes, we can see that the propose scheme has no T_{auth} term because it performs the pre-authentication via the CoN, even though it contains the discovery time for CoN.

4.3 Packet Loss and Discard Probabilities

To evaluate packet loss and discard probabilities, we assume that the HA periodically transmits voice over IP (VoIP) packets with a constant bit rate destined for the MN every time $t_{HA} = k \cdot T_P$ where k is a positive integer and T_P is the time interval of packet generation [22]. Let X be a random variable of the time when the MN receives a packet transmitted from the HA at time t_{HA} and Y be a random variable of the time when the FA receives a packet transmitted from the HA at time t_{HA}. Two random variables, X and Y, are expressed as

$$X = t_{HA} + T_{wl}(s_c) + T_w(s_c, d_{MN\_HA} - 1) \quad (22)$$

$$Y = t_{HA} + T_w(s_c, d_{FA\_HA}). \quad (23)$$

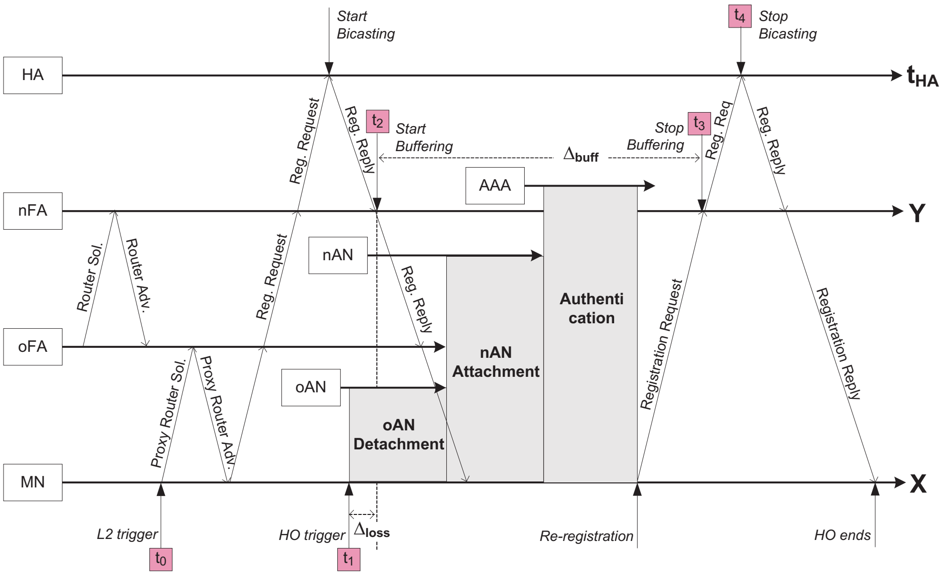

Fig. 6 Timing analysis for the pre-registration handoff.

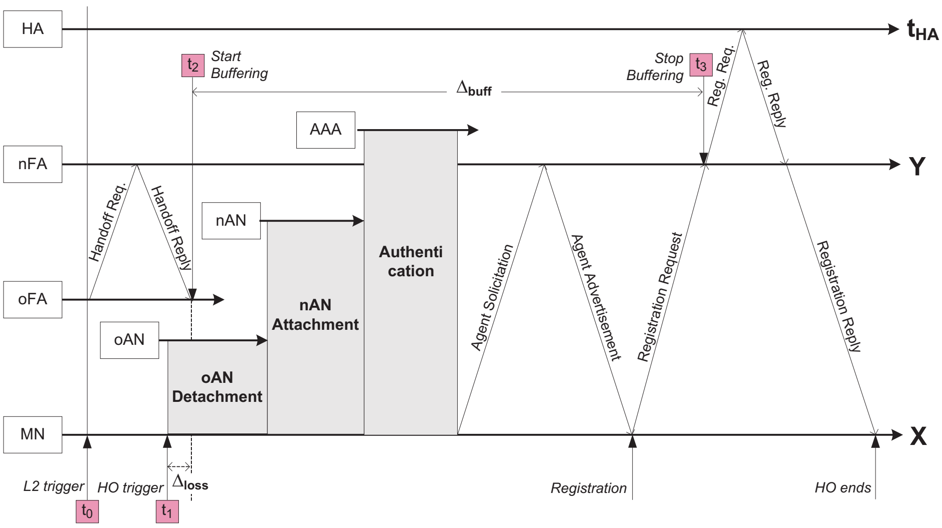

Fig. 7 Timing analysis for the post-registration handoff.

From a viewpoint of routing path of packet transmission, each transmitted packet during the handoff period belongs to exactly one of the following classes.

- Class 0: packets routed via the oFA and directly forwarded to the MN.
- Class 1: packets routed via the oFA and buffered during the CoN discovery period. Buffered packets may be lost due to the buffer overflow.
- Class 2: packets routed via the oFA and directly forwarded to the MN after the discovery process.

– Class 3: packets routed via the oFA but lost because the packet buffering is not activated although the MN is detached from the oAN.
– Class 4: packets routed via the nFA and buffered until the MN completes the registration with the nFA. Buffered packets may be lost due to the buffer overflow at the FA.
– Class 5: packets routed via the nFA and directly forwarded to the MN.

In the network, the packet is lost when the connection detached and the buffering function is not working or when the buffer overflow occurs due to the limited buffer size even though the buffering function is working. According to the above classifications, therefore, the packet loss can occur in the classes 1, 3 and 4. We can calculate each probability that a transmitted packet arrives in the class 1, 3 or 4, as follows.

$$P_{loss}\{\text{class 1}\} = P\{t_0 < X < t_1 - \tau\} \tag{24}$$

$$P_{loss}\{\text{class 3}\} = P\{X > t_2 \ \& \ Y < t_3\} \tag{25}$$

$$P_{loss}\{\text{class 4}\} = P\{t_{HA} + \tau < t_5 \ \& \ \max\{t_2, t_3\} < Y < t_4 \ \& \ Y + \tau < t_4\} \tag{26}$$

where τ is a buffer size in time, defined as $\tau = \text{BufferSize} \times T_P$. Therefore, the total probability that a transmitted packet is lost becomes $P_{loss} = \sum_{i=1,3,4} P_{loss}\{\text{class i}\}$. Considering all packets generated periodically at the time $t_{HA} = kT_P$ during the handoff period, the average packet loss probability is obtained by

$$P\{\text{packet is lost}\} = \frac{\sum_{k=0}^{N-1} P_{loss}\{t_{HA} = kT_P\}}{N}. \tag{27}$$

where N is the total number of packets generated during the whole handoff period.

VoIP packets are discarded by a receiver if their propagation delay exceeds an allowable maximum end-to-end delay corresponding to its QoS level. The packet discard probability is defined as the probability that the received packet violates the end-to-end delay constraint and so it includes the packet loss probability. When δ denotes the maximum end-to-end delay constraint for VoIP packets, the packet discard probability of the proposed scheme is calculated as

$$P_{discard} = P_{loss} + \sum_{i=0,1,2,4,5} P\{\text{class i} \ \& \ \text{delay} > \delta\} \tag{28}$$

$$P\{\text{class 0} \ \& \ \text{delay} > \delta\} = P\{t_{HA} < t_5 \ \& \ X < t_0 \ \& \ D_1 > \delta\} \tag{29}$$

$$P\{\text{class 1} \ \& \ \text{delay} > \delta\} = (1 - P_{loss}\{\text{class 1}\}) \times P\{t_0 < x < t_1 \ \& \ D_2 > \delta\} \tag{30}$$

$$P\{\text{class 2} \ \& \ \text{delay} > \delta\} = P\{t_{HA} < t_5 \ \& \ t_1 < X < t_2 \ \& \ D_1 > \delta\} \tag{31}$$

$$P\{\text{class 4} \ \& \ \text{delay} > \delta\} = (1 - P_{loss}\{\text{class 3}\}) \times P\{t_{HA} < t_5 \ \& \ \max\{t_2, t_3\} < Y < t_4 \ \& \ D_3 > \delta\} \tag{32}$$

$$P\{\text{class 5} \ \& \ \text{delay} > \delta\} = P\{Y > t_4 \ \& \ D_1 > \delta\} \tag{33}$$

There are three different types of propagation delay. Each delay term are given by $D_1 = X - t_{HA}$, $D_2 = D_1 + D_{buff1}$ and $D_3 = D_1 + D_{buff2}$ where two buffering delay are defined as $D_{buff1} = t_1 - X$ and $D_{buff2} = t_4 - Y$, respectively. Considering all packets transmitted during the whole handoff period, the average packet discard probability is obtained by

$$P\{\text{packet is discarded}\} = \frac{\sum_{k=0}^{N-1} P_{discard}\{t_{HA} = kT_P\}}{N}. \tag{34}$$

Table 1 Parameter setting for the proposed vertical handoff.

Parameter	Value
s_r	48 bytes
s_c	64 bytes
B_w	100 Mbps
B_{wl}	2 Mbps
L_w	1 ms
L_{wl}	3 ms
$T_{discovery}$	50∼100 ms
T_{detach}	8 ms (WLAN detachment [23])
T_{attach}	192 ms (UMTS attachment [24])
T_{auth}	100 ms (802.1x authentication [12])
T_{ad}	500 ms
t_{HO}	300 ms
T_P	20 ms

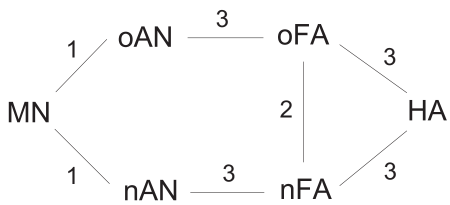

Fig. 8 Relative distances by hops in simulated network.

In the same way, the packet loss and discard probabilities of the conventional pre-registration and post-registration schemes could be evaluated.[3]

5 Results and Discussions

The parameter settings for the performance evaluation are listed in Table 1 and the number of hops between two entities, d_{x_y}, is represented in Fig. 8. As an example scenario, we consider the vertical handoff between the IEEE 802.11-based WLAN system and the UMTS system [25]. We assume that the size of each signaling message and the time of each process used equally in all handoff schemes have constant values according to the considered system specification. We vary $T_{discovery}$ from 50 ms to 100 ms, taking into account the bandwidth of wireless link (B_{wl}) and the size of messages needed for cooperation (s_c). Moreover, we do not consider an abrupt detachment after L2 trigger occurs and there are enough time for the CoN to process pre-authentication and pre-registration. VoIP packets are assumed to be generated every 20 ms during the entire handoff period.

Fig. 9 shows the total handoff time versus average service time ($1/\lambda$) in each router. The total handoff time increases as the service time in each router increases because the delay consumed for transmitting signaling messages in the wired backhaul network increases. The MIP-based handoff scheme shows the longest total handoff time because it basically follows a hard handoff procedure. Compared to the pre-/post-registration

[3] Here, the analysis for the conventional schemes is not described due to the same numerical development process.

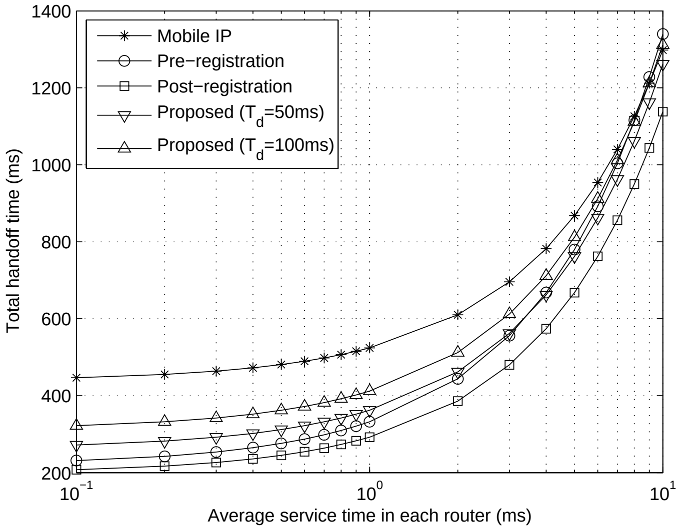

Fig. 9 Total handoff time vs. average service time in each router.

handoff schemes, the proposed scheme has longer handoff time because it has more signaling process to complete the vertical handoff than the other scheme. Especially, the discovery time to select the CoN has an effect on the total handoff time of the proposed handoff scheme. As the discovery time is allowed more, the total handoff time becomes longer. However, the difference between the proposed scheme and the conventional schemes decreases as the service time in each router increases. This is because the conventional schemes need more exchange of signaling messages between network nodes for the handoff so that it is affected more by the network signaling delay.

Fig. 10 shows the average service disruption time versus average service time in each router. The service disruption time of the proposed scheme is shorter than that of the conventional schemes, because it performs not only the pre-authentication process before attaching to the nAN, but also the pre-registration process with the nAN/nFA through the direct link using the CoN. On the other hand, the conventional schemes have a relatively long service disruption time because they exchange the signaling messages through the backhaul link (which consists of many routers), and perform the authentication process after attaching to the nAN. However, as the discovery time increases, the disruption time of the proposed scheme increases because the disruption time is directly affected by the CoN discovery time. The analysis result shows that the discovery time allowed less than 100 ms makes the disruption time of the proposed scheme shorter than the conventional scheme.

Fig. 11 shows the average packet loss probability according to the change of buffer size in the FA when the service time in each router is set to 2 ms. The MIP-based hard handoff scheme has a constant packet loss probability irrespective of the increase of buffer size because it does not use the packet bicasting and buffering mechanisms. As the buffer size increases, the packet loss of three schemes decreases because the packet loss occurs due to the buffer overflow. The proposed handoff scheme shows the smallest packet loss probability compared with the conventional schemes. This is because the

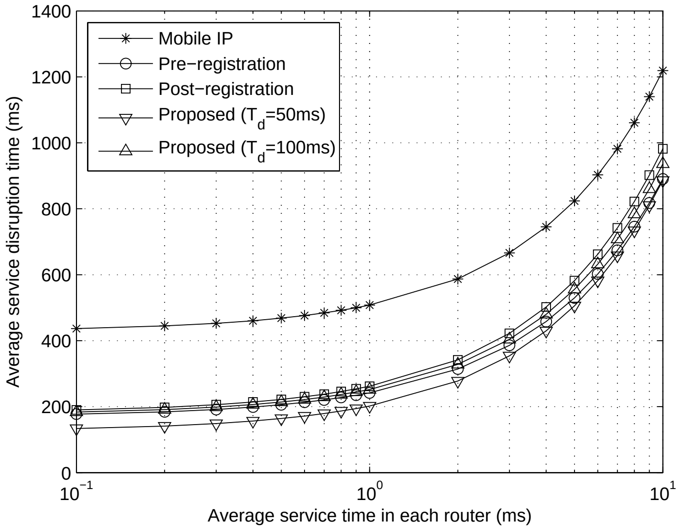

Fig. 10 Average service disruption time vs. average service time in each router.

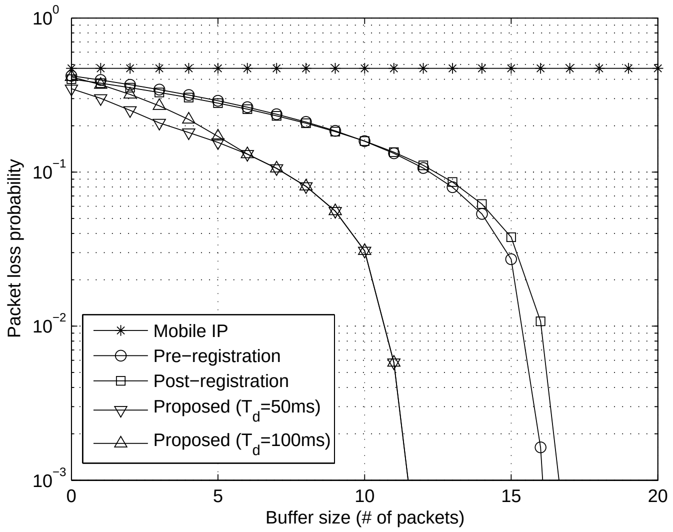

Fig. 11 Average packet loss probability vs. buffer size.

proposed scheme reduces the packet buffering period (i.e., service disruption time) as much as possible through the pre-authentication and pre-registration processes. In the proposed scheme, the transmitted packets are buffered during the CoN discovery time, so the packet loss increases as the discovery time increases. However, if the buffer size is greater than a certain value to cover this discovery time, we can see that the packet loss probability of the proposed scheme is the same regardless of the discovery time.

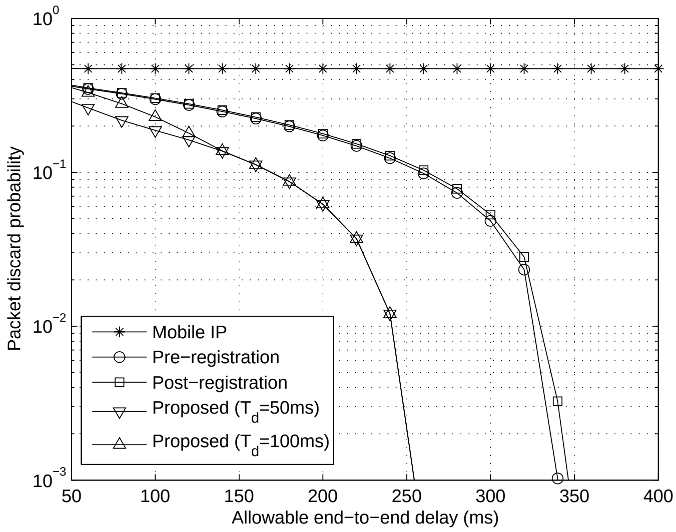

Fig. 12 Average packet discard probability vs. allowable maximum end-to-end delay.

Fig. 12 shows the average packet discard probability according to the allowable maximum end-to-end delay when the buffer size is infinite and the service time in each router is 2 ms. A VoIP packet is discarded if its end-to-end propagation delay exceeds the allowable maximum end-to-end delay that corresponds to the VoIP QoS. Therefore, the packet discard probability is decreased as the allowable maximum end-to-end delay is increased. The packet discard probability exhibits the similar aspect to the packet loss probability. The proposed handoff scheme has the lowest probability of packet discard because its service disruption time is shorter than the other schemes. Similarly, we can see that the packet discard probability is not affected by the CoN discovery time if the allowed end-to-end delay is longer than about 140 ms.

6 Conclusions

In this paper, we applied a concept of ad hoc cooperation for the seamless vertical handoff in the heterogeneous network. Although this cooperation concept requires additional operations of ad hoc node, it can reduce the service disruption time and packet loss during the vertical handoff period, so fast and seamless handoff is achieved. Numerical analysis verified that the proposed vertical handoff procedure reduces the service disruption time and the probabilities of packet loss and discard effectively compared to the conventional handoff scheme. If some practical issues for implementation are resolved, we expect that the concept of vertical handoff using ad hoc cooperation can be applied as an effective interworking solution for the fourth generation heterogeneous networks.

References

1. N. Nasser, A. Hasswa, and H. Hassanein, "Handoffs in fourth generation heterogeneous networks," *IEEE Communications Magazine*, vol. 44, issue 10, pp. 96-103, Oct. 2006.
2. Sadia Hussain, Zara Hamid, Naveed S. Khattak, "Mobility management challenges and issues in 4G heterogeneous networks," *ACM international conference on Integrated internet ad hoc and sensor networks*, vol. 138, no. 14, May 2006.
3. J. McNair and Fang Zhu, "Vertical handoffs in fourth-generation multinetwork environments,", *IEEE Wireless Commun.*, vol. 11, no. 3, pp. 8-15, June 2004.
4. K. El Malki, et al., *IETF draft*, "Low latency Handoff in Mobile IPv4", May 2001.
5. C.K. Toh, "Ad hoc mobile wireless networks, protocols, and systems," Prentice-Hall, 2002.
6. H. Luo et al., "UCAN: A Unified Cellular and Ad-Hoc Network Architecture," *in Proceedings of the 9th Mobicom*, pp. 353-367, ACM Press, Sept. 2003.
7. Y. Lin and Y. Hsu, "Multi-Hop Cellular: A New Architecture for Wireless Communications," *Proc. IEEE INFOCOM 2000*, vol. 3, pp. 1273-1282, Mar. 2000.
8. W. Hu et al., "Integrated Cellular and Ad Hoc Relaying Systems: iCAR," *IEEE J. Select. Areas Commun.*, vol. 19, pp. 2105-2115, Oct. 2001.
9. 3GPP, "Opportunity driven multiple access," *3G TR 25.924*, v. 1.0.0, Dec. 1999.
10. O. Casals, Ll. Cerda, G. Willems, C. Blondia, N. Van den Wijngaert, "Performance evaluation of the post-registration method, a low latency handoff in MIPv4," *IEEE ICC 2003*, vol.1, pp. 522-526, May 2003.
11. Ming He, et al. "Ad hoc assisted handoff for real-time voice in IEEE 802.11 infrastructure WLANs," *IEEE WCNC 2004*, vol. 1, pp. 201-206, Mar. 2004.
12. *IEEE Std 802.1X-2004*, "IEEE Standard for Local and metropolitan area networks Port-Based Network Access Control," pp. 1-169, 2004.
13. D. Angelosante, E. Biglieri, M. Lops, "A Simple Algorithm for Neighbor Discovery in Wireless Networks," *IEEE Int. Conf. on Acoustics, Speech and Signal Processing*, vol. 3, pp. 15-20, Apr. 2007.
14. Byungjoo Park, Eunsang Hwang, H. Latchman, "An efficient fast neighbor discovery (EFND) scheme to reduce handover latency in mobile IPv6," *Int. Conf. Advanced Communication Technology*, vol. 2, pp. 20-22, Feb. 2006.
15. Jyh-Cheng Chen, Yu-Ping Wang, "Extensible authentication protocol (EAP) and IEEE 802.1x: tutorial and empirical experience," *IEEE Communications Magazine*, vol. 43, issue 12, pp. 26-32, Dec. 2005.
16. X. Zhang, S. Chen, Ravi Sandhu, "Enhancing data authenticity and integrity in P2P systems," *IEEE Internet Computing*, vol. 9, issue 6, pp. 42-49, Nov.-Dec. 2005.
17. Hao Yang, Haiyun Luo, Fan Ye, Songwu Lu, Lixia Zhang, "Security in mobile ad hoc networks: challenges and solutions," *IEEE Wireless Communications*, vol. 11, issue 1, pp. 38-47, Feb. 2004.
18. C. Guo, et al., "A Seamless and Proactive End-to-End Mobility Solution for Roaming Across Heterogeneous Wireless Networks," *IEEE J. Select. Areas Commun.*, vol. 22, pp. 834-848, June 2004.
19. B. Kao, H. Garcia-Molina, and D. Barbara, "Aggressive transmissions of short messages over redundant paths," *IEEE Trans. on Parallel and Distributed Systems*, vol. 5, pp. 102-109, Jan. 1994.
20. Sang-Jo Yoo, David Cypher, Nada Golmie, "Predictive Handover Mechanism based on Required Time Estimation in Heterogeneous Wireless Networks," *IEEE Milcom*, pp. 1-7, Nov. 2008.
21. H. H. Choi, O. Song, D. H. Cho, "Seamless Handoff Scheme Based on Pre-registration and Pre-authentication for UMTS-WLAN Interworking," *Wireless Personal Communications*, vol. 41 , issue 3, pp. 345-364, May 2007.
22. C. Blondia et al, "Performance analysis of optimized smooth handoff in mobile IP," *5th ACM MSWiM 2002*, pp. 22-29, 2002.
23. IEEE 802.11, *Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications*, Standard, IEEE, Aug. 1999.
24. *Technical Specification Group Services and System Aspects; General Packet Radio Service (GPRS); Service description; Stage 2*, Rel.6, 3GPP TS 23.060, v6.3.0, Dec. 2003.
25. Y. Nkansah-Gyekye, J. I. Agbinya, "Vertical Handoff Decision Algorithm for UMTS-WLAN," *Int. Conf. on Wireless Broadband and Ultra Wideband Communications*, vol. 1, pp. 27-30, Aug. 2007.