Mobility Management in Mobile Hotspots with Heterogeneous Multihop Wireless Links

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ABSTRACT

In this article we study two representative mobility management schemes for mobile hotspots with heterogeneous multihop wireless links: the NEMO basic support protocol at the network layer and the SIP-based network mobility support protocol at the application layer. We evaluate their salient features and quantify their handoff latency. It is shown that the SIP-based network mobility support protocol can easily be deployed and reduce the tunneling overhead incurred in the NEMO basic support protocol. However, it increases handoff latency due to longer message length. We also discuss several open research issues for seamless mobility support in mobile hotspots.

INTRODUCTION

Third-generation (3G) cellular systems are being deployed on a large scale around the world, and standardization efforts for fourth-generation (4G) cellular systems are continuing. On the other hand, broadband wireless networking, called Wibro, commenced in Korea in June 2006 [1]. With the advances of these wireless communication technologies, the extension of WiFi hotspots to moving vehicles such as subways, trains, and buses is gaining significant attention. The hotspot service in a mobile platform is referred to as *mobile hotspot* [2]. Mobile hotspots enable ubiquitous and seamless Internet services while on-board a vehicle, and therefore it is regarded as a novel approach to realize always best connected (ABC) services in future wireless/mobile networks.

Figure 1 illustrates a typical network architecture for mobile hotspots with heterogeneous multihop wireless links. A number of mobile nodes (MNs) are connected to an access point (AP) of a wireless local area network (WLAN). A wireless wide area network (WWAN) is employed to bridge the mobile hotspots to a wireline Internet; the bridging is via a connection between the AP of the WLAN and the base station (BS) of the WWAN. The WWAN can be an IP-based cellular system or an IEEE 802.16 Worldwide Interoperability for Microwave Access (WiMAX) network. Packets sent from a correspondent node (CN) to an MN are first routed to the BS through the Internet, and then transmitted to the MN over the interconnected WWAN-WLAN link. A WLAN supports higher data rates than a WWAN but has smaller service coverage area than the WWAN. By integrating these two technologies, WWAN provides extended service coverage to the vehicle, and WLAN accommodates more users without excessive usage of the WWAN resources. The aggregate traffic at the AP is transmitted to the BS through an antenna mounted on top of the vehicle. Compared with generic wireless systems (e.g., cellular systems), where there are direct communications between the MNs and the BS, this setup provides a better communication paradigm. In addition, since the AP has better knowledge of the location of the vehicle, handoff management can be effective and efficient [3].

Various research on mobile hotspots has been conducted in the literature, including mobility management [4, 5], quality of service (QoS) support [6], link layer transmission technique [2], and gateway architecture [7]. In this article we focus on mobility management for mobile hotspots. Seamless mobility management is a key aspect for the success of mobile Internet services. A number of protocols, such as Mobile IPv4 (MIPv4), MIPv6, and Hierarchical MIPv6 (HMIPv6), have been proposed. These mobility management protocols focus on terminal mobility, where an MN changes its attachment to the Internet. Thus, they are not suitable for mobility management in mobile hotspots due to excessive binding update traffic. The Internet Engineering Task Force (IETF) has subsequently introduced a network mobility (NEMO) basic support protocol [4]. However, since the NEMO basic support protocol is a network layer solution, it has some limitations in deployment and implementa-

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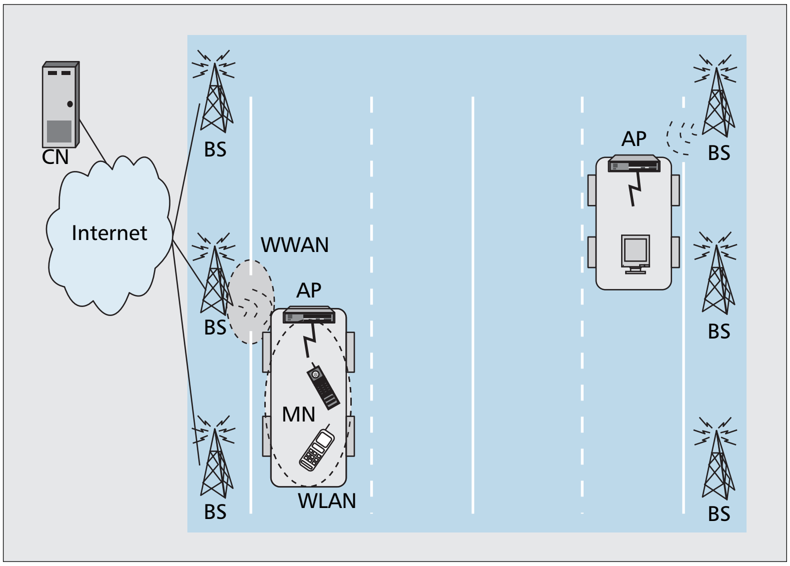
tion. To overcome the drawbacks of the NEMO basic support protocol, a Session Initiation Protocol (SIP)-based network mobility support protocol has recently been reported in [5].

In this article we study the location update and packet delivery (or session establishment) procedures in the NEMO basic support protocol and the SIP-based network mobility support protocol. We evaluate their salient features qualitatively and analyze the handoff latency. In addition, we identify some open research issues in mobility management for mobile hotspots.



■ **Figure 1.** *Mobile hotspot architecture.*

Mobility Management in Mobile Hotspots

We describe the location registration and packet delivery (or session establishment) procedures in mobility management schemes for mobile hotspots. Since the NEMO basic support protocol presumes no route optimization due to security and incompatibility issues [4], no route optimization (i.e., binding update to a CN) is considered.

Network Mobility Basic Support Protocol

The NEMO basic support protocol provides a mobility management solution at the network layer. In the architecture for the NEMO basic support protocol a mobile router (MR) collocated with the AP plays an important role in location registration procedures since it provides collective Internet connectivity to a group of MNs within a vehicle. The NEMO basic support protocol defines the operations of the MR and home agent (HA), whereas other nodes (i.e., CNs and MNs) perform the same operations as MIPv6.

To facilitate the establishment of a location registration procedure, the concept of a mobile network prefix (MNP) is introduced. The MNP is an IPv6 prefix delegated to an MR and advertised to all MNs within the vehicle. Each MN then configures its care-of address (CoA) based on the MNP, and the CoA is not changed while the MN resides under the coverage of the MR. Therefore, the MN does not need to update its location even though the vehicle moves to another location, which can significantly reduce the location update traffic incurred by handoffs. Figure 2 shows the details of the location update procedure, which has the following steps:

Step 1: When an MR moves to a foreign network, the MR configures a CoA (*CoA_MR*) of the egress link.

Step 2: The MR sends a binding update (BU) message that contains its new CoA and MNP (*MNP_MR*) to its HA. The MNP is used by the MR's HA to intercept packets destined for an MN in the vehicle, which will be elaborated on later.

Step 3: When an MN connects to the MR, the MN configures its CoA (*CoA_MN*) based on the MR's MNP. In other words, the MN configures its CoA by concatenating the MNP and its network interface identifier (i.e., medium access control [MAC] address in the extended unique identifier [EUI] 64 format).

Step 4: After completing address configuration, the MN sends a BU message to its HA, and then the MN's HA maintains a binding between the MN's home address (*HoA_MN*) and the MN's CoA (*CoA_MN*). Finally, the HA sends a binding acknowledgment (BACK) message to the MN.

For incoming packets to an MN, the HA performs packet tunneling. However, unlike MIPv6, outgoing packets originated from an MN are also tunneled via the MR's HA. This is because the NEMO basic support protocol does not use the home address option, which remedies the ingress filtering problem in MIPv6. As shown in Fig. 3, we focus on incoming packets, and the packet delivery procedure is as follows:

Step 1: If a CN sends packets to the MN's HoA, they are intercepted by the MN's HA.

Step 2: As the MN's CoA is derived from the MR's MNP, the packets are routed toward the MR's home network and intercepted by the MR's HA.

Step 3: Since the MR's HA maintains a binding between the MR's MNP and its CoA, the MR's HA can forward the packets to the MR's CoA.

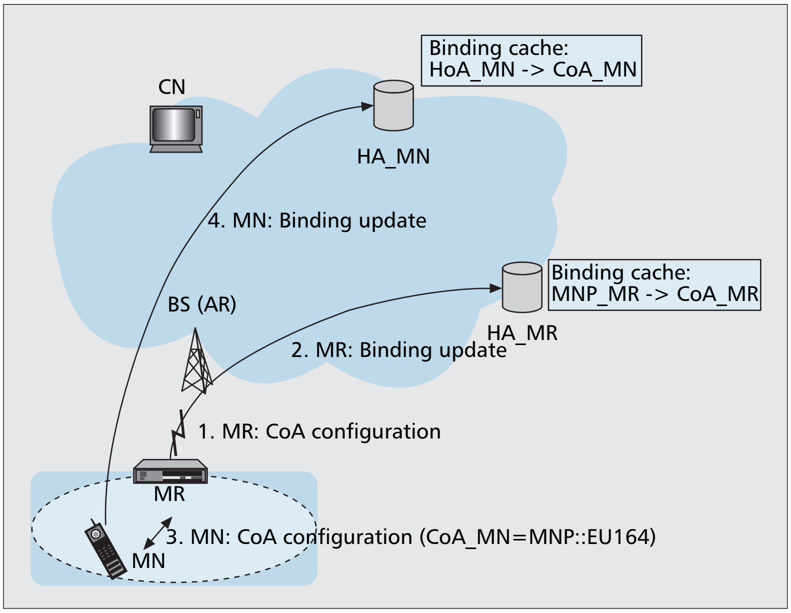
Step 4: The packets in turn are decapsulated at the MR and forwarded to the MN.

SIP-Based Network Mobility Support Protocol

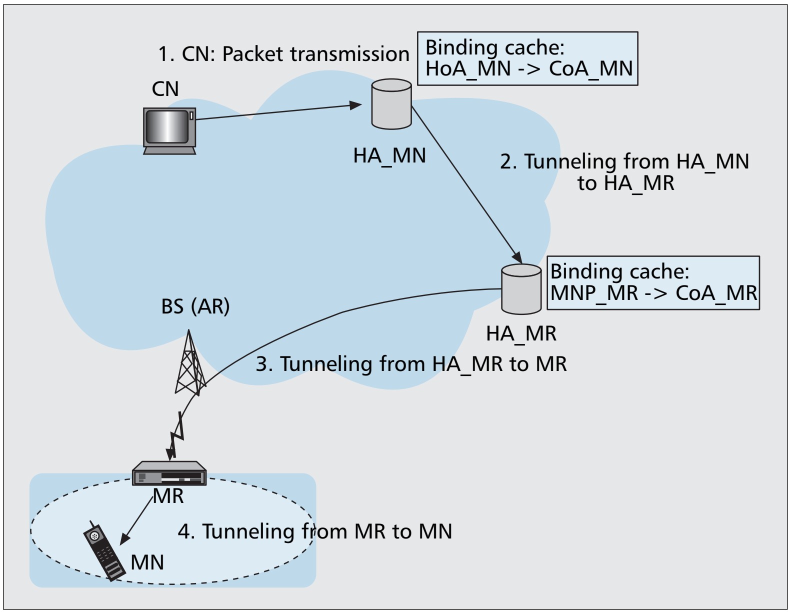
SIP is an application layer protocol originally designed for session management, but it can also be utilized to provide terminal, service, and personal mobility [9]. The SIP-based network mobility protocol supports network mobility through SIP. The architecture of the SIP-based network mobility support protocol is shown in Fig. 4. The home SIP server and network mobility server (NMS) correspond to the HA and MR in the NEMO basic support protocol, respectively. The home SIP server accepts registrations from MNs and records their current locations in order to provide location information to other SIP servers or user agents (UAs). On the other hand, the NMS is a gateway attached to the AP and performs message translation for network mobility support. When a vehicle moves from the coverage of one subnet to another, the NMS ensures that all existing sessions are continuous, and all MNs (or SIP clients) attached to the vehicle should be globally reachable all the time. The location update procedure in the SIP-based network mobility support protocol can be explained as follows:

Step 1: When an NMS moves to a foreign network, the NMS configures a new CoA (*CoA_NMS*).

Step 2: The NMS then sends a REGISTER message to its home SIP server with its new CoA in the `Contact` field and its SIP universal resource identifier (URI), *SIP_NMS*.



■ **Figure 2.** *Binding update procedure of the NEMO basic support protocol.*



■ **Figure 3.** *Packet delivery procedure of the NEMO basic support protocol.*

As a result, the home SIP server maintains routing information for the NMS.

Step 3: After entering the coverage of the NMS, a SIP UA *UA*1 (i.e., an MN) obtains a new contact address *SIP_UA*1, which is derived from the NMS domain name. For instance, if the NMS domain name is mobile.sip.com, the contact address of UA1 can be UA1@mobile.sip.com.

Step 4: For location registration, UA1sends a REGISTER message, which includes UA1's contact address in the Contact field. Note that the From field in the REGISTER message is the home SIP URI of UA1 for keeping its global reachability.

Step 5: The NMS receiving the REGISTER message from UA1 changes the message accordingly. That is, the Contact field is updated from the contact address of UA1 to that of the NMS (i.e., *SIP_NMS*).

Step 6: The NMS sends the updated REGISTER message to the home SIP server of UA1, and then the home SIP server maintains the binding information between the home SIP URI (*HomeURI_UA*1) of UA1 and the NMS's contact address for session establishment.

Unlike the NEMO basic support protocol, the SIP-based network mobility support protocol has an explicit session establishment procedure. For session establishment, we consider both an incoming session and an outgoing session. The establishment procedure for an incoming session is shown in Fig. 5a, and its detailed description is as follows:

Step 1: UA2 sends an INVITE message to the home SIP server of UA1 for session establishment.

Step 2: By the location registration procedure, the contact address of the NMS, *SIP_NMS*, is registered in the home SIP server of *UA*1. Therefore, the INVITE message is redirected to the home SIP server of the NMS.

Step 3: The NMS's home SIP server maintains an up-to-date CoA of the NMS and thus can forward the INVITE message to the current location of the NMS.

Step 4: When the NMS receives the INVITE message, it updates the message accordingly for transparent network mobility support. In other words, the Contact field is changed from *SIP_NMS* to *SIP_UA*1, and it is forwarded to UA1. UA1 then accepts the invitation.

Step 5: After acceptance, UA1 replies with 200 OK.

Step 6: The 200 OK message is also updated at the NMS and then delivered to UA2.

The establishment procedure for an outgoing session can be described as follows (Fig. 5b):

Step 1: *UA*1 sends an INVITE message to the NMS, and the NMS translates the Contact field in the message. That is, the NMS changes the Contact field from *SIP_UA*1 to *SIP_NMS*.

Step 2: After message translation, the NMS forwards the INVITE message to the home SIP server of UA2.

Step 3: After lookup at the home SIP server of UA2, the INVITE message is forwarded to UA2.

Step 4: When a 200 OK message is delivered to the NMS, the Contact field in the message is translated to *SIP_UA*1 and the message is forwarded to UA1.

EVALUATION

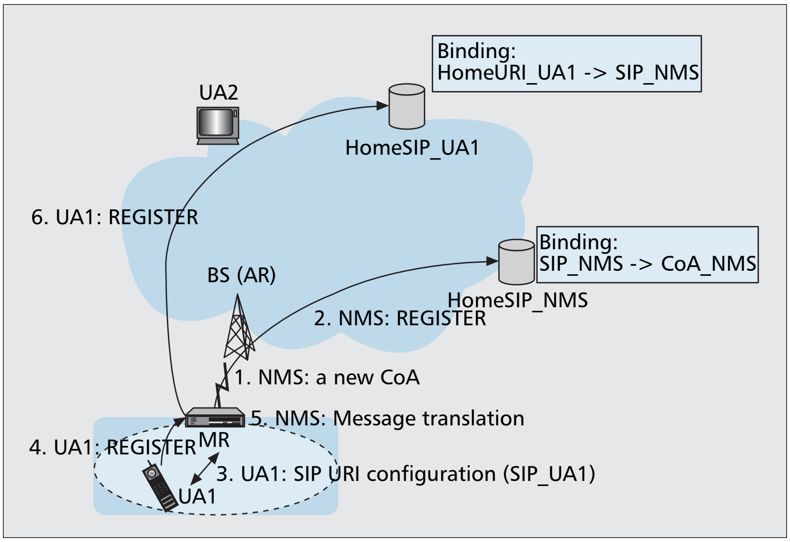
We evaluate the NEMO basic support protocol and the SIP-based network mobility support protocol in terms of deployment/implementation, system bottleneck, usability, high mobility support, overhead, and nested mobile hotspot support.

With regard to deployment and implementation, the NEMO basic support protocol requires the installation of an MR at the vehicle. In addition, the HA should be upgraded to support MNP-based tunneling. The MR and HA are network layer devices; hence, the network infrastructure should be modified for the NEMO basic support protocol. On the other hand, the SIP-based network mobility support protocol only needs an NMS at the vehicle, which is an application server; no modification is needed for other SIP servers. Typically, an application server is easier to deploy and modify than a network device. Consequently, the SIP-based network mobility support protocol is a better choice for easy implementation and deployment.

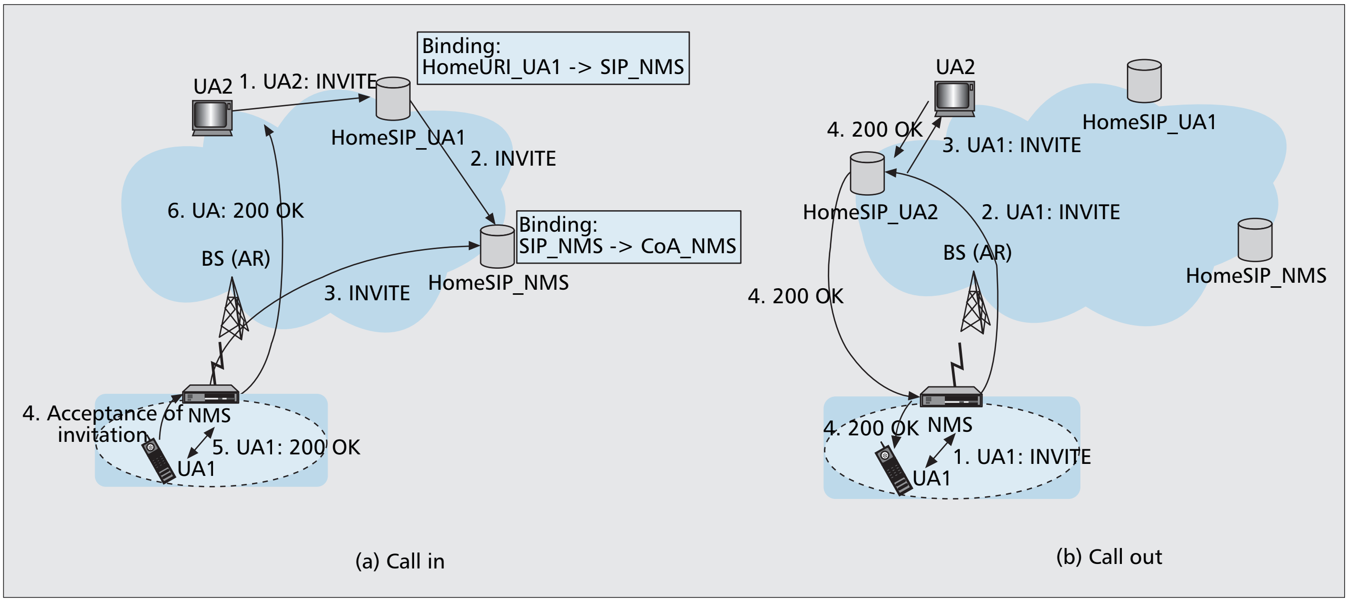
To improve system availability and provide fault tolerance, it is important to eliminate a single bottleneck point. In the NEMO basic support protocol the HA and MR can be bottlenecks because they are in charge of tunneling for all incoming and outgoing packets. On the contrary, in the SIP-based network mobility support protocol, session establishment and packet delivery are separated; therefore, SIP servers are not bottlenecks for packet delivery. Only the NMS can be a single bottleneck point because it performs message translations for SIP messages.

One advantage of a network layer mobility solution is that it can be applied to any kind of application. In other words, since mobility is provided at the network layer, applications can be mobility-unaware. On the other hand, the SIP-based network mobility support protocol uses an application layer signaling protocol, SIP. Hence, it can be useful only when SIP is employed as a signaling protocol. Multimedia applications (e.g., voice over IP [VoIP]) require an explicit session establishment procedure; thus, the SIP-based network mobility support protocol is a more attractive solution for multimedia applications in mobile hotspots.

For mobile hotspots deployed in transportation systems, signaling traffic under high velocity should be minimized. In the NEMO basic support protocol route optimization is not specified. Hence, an MN performs a binding update procedure only when it first attaches to the MR. On the other hand, the SIP-based network mobility support protocol leads to high signaling traffic due to an invitation procedure for every MR handoff. In addition, since the message length of



■ **Figure 4.** *Location update procedure of the SIP-based network mobility support protocol.*



■ **Figure 5.** *Packet delivery procedure of the SIP-based network mobility support protocol.*

The SIP-based network mobility support protocol supports route optimization by sending INVITE messages to correspondent UAs. Therefore, there is no tunneling overhead, but there is an increase in packet delivery latency due to nested mobile hotspots exist.

the SIP-based network mobility support protocol is much longer than that of the NEMO basic support protocol, the SIP-based network mobility support protocol has larger handoff latency, which will be quantitatively analyzed in the next section.

In the NEMO basic support protocol, packets should be tunneled at both the HAs (of the MN and MR) and the MR since route optimization is not supported, which results in high tunneling overhead. In the SIP-based network mobility support protocol no tunneling overhead occurs; however, it has message translation overhead at the NMS that affects the session establishment time. Furthermore, explicit session establishment leads to increased packet delivery latency.

Finally, mobile hotspots can be configured as a form of nested networks. For instance, a personal area network (PAN), which is also a kind of mobile hotspot, can be attached to an AP in a vehicle. For nested mobile hotspot support, the NEMO basic support protocol has a serious drawback: all packets have to traverse all HAs involved (the so-called pinball routing problem); thus, the packet delivery latency can be drastically increased. On the other hand, the SIP-based network mobility support protocol supports route optimization by sending INVITE messages to correspondent UAs. Therefore, there is no tunneling overhead, but there is an increase in packet delivery latency due to nested mobile hotspots.

Handoff Latency Analysis

In this section we quantify the handoff latency in the NEMO basic support protocol and the SIP-based network mobility support protocol. Handoff latency is defined as the time until a location update procedure is completed when a vehicle moves to the coverage of a new subnet. For the NEMO basic support protocol and the SIP-based network mobility support protocol, the MN (or UA) performs a location update procedure only when it first attaches to the AP. Therefore, we consider the location update procedure by the MR or NMS. In addition, we consider only location update to the HA (or home SIP server) because no binding updates to CNs are supported in the NEMO basic support protocol. Before performing location update procedures, a CoA should be configured. For CoA configuration, the MR or NMS sends a Router Solicitation (RSol) message to the access router (AR) collocated with the BS. Then a Router Advertisement (RAdv) message is returned to the MR or NMS, and a CoA is configured by an IPv6 stateless auto-configuration scheme.

Since the bandwidth of a wired link is sufficiently large and the delay is relatively stable, we focus on the latency over a wireless channel. We consider a Rayleigh fading channel, and a two-state Markov channel model is used to approximate the error process at the frame level over the fading channel [10]. The discrete-time two-state Markov channel model has a *good* (g) state and a *bad* (b) state: frame error probability is 1 in the *bad* state and 0 in the *good* state. When the velocity and carrier frequency are given, the average transmission error probability and state transition probabilities can be obtained from [10].

We assume that a truncated ARQ scheme is used at the data link layer, where a sender retransmits a frame until the frame is successfully delivered, or drops the frame if the retry limit L (including the first transmission) is reached. Let p_{XY} be the state transition probability from state $X \in \{b, g\}$ to state $Y \in \{b, g\}$ and π_X be the stationary probability in state $X \in \{b, g\}$. Also, let q_k be the probability a message consisting of k frames is lost over a wireless link. Then q_k is given by $q_k = 1 - (1 - \pi_b p_{bb}^{L-1})^k$. For RSol, BU, INVITE, and 200 OK messages, an end-to-end retransmission mechanism using a backoff timer is specified. Therefore, the average transmission latency can be computed from

$$L_X = \frac{1}{1-q_k^N}\sum_{i=1}^{N} q_k^{i-1}(1-q_k)\cdot\left(\sum_{j=1}^{i-1}\theta(j)+T(k)\right) \quad (1)$$

where $X \in \{RSol, BU, INVITE, 200OK\}$ and N is the end-to-end retransmission limit for X. $\theta(j)$ is the retransmission timer at the jth retransmission, and it is given by $2^{j-1} T_{Init}$ where T_{Init} is the initial retransmission timer and its value is defined in [8, 9]. $T(k)$ is the average transmission time when a message consisting of k frames is successfully delivered. Then $T(k)$ is given by

$$T(k) = k \times \left(\pi_g \cdot D + \pi_p p_{bg} \sum_{i=2}^{L} p_{bb}^{i-2} \cdot iD\right), \quad (2)$$

where D is the time slot duration (i.e., 5 ms). For RAdvt and BACK messages, the sender does not perform end-to-end retransmissions, and only link layer retransmission by ARQ is supported. Therefore, the transmission latency for these messages is

$$L_Y = T(k), \quad (3)$$

where $Y \in \{RAdv, BACK\}$.

Consequently, the handoff latency for the NEMO basic support protocol and the SIP-based network mobility support protocol can be obtained respectively from

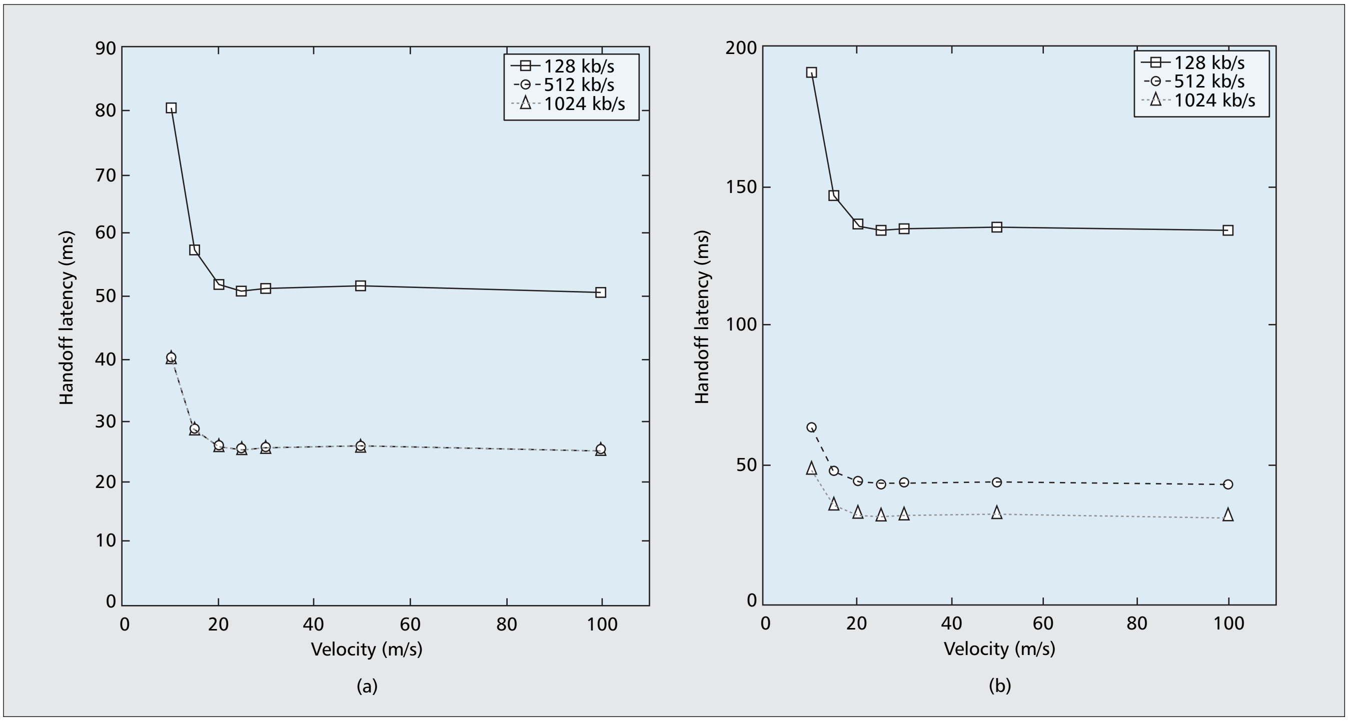
$$H_{NEMO} = L_{RSol} + L_{RAdv} + L_{BU} + L_{BACK}$$

and

$$H_{SIP} = L_{RSol} + L_{RAdv} + L_{INVITE} + L_{200OK}.$$

As shown in Fig. 6, the NEMO basic support protocol outperforms the SIP-based network mobility support protocol in terms of handoff latency. When the wireless link bandwidth is limited, the NEMO basic support protocol can provide much lower handoff latency than the SIP-based network mobility support protocol. However, if the wireless link bandwidth is sufficiently large, SIP messages can be delivered with a small number of frames; thus, the SIP-based network mobility support protocol exhibits comparable handoff latency to the NEMO basic support protocol.

From Fig. 6, it can be observed that the handoff latency is small when the velocity (v) is high. This is because when v increases, the



■ **Figure 6.** *Handoff latency comparison: a) the NEMO basic support protocol; b) the SIP network mobility support protocol.*

Doppler frequency increases (i.e., the wireless link's coherence time decreases), which in turn reduces the burstiness of the transmission errors in the wireless link. Since there is a finite number of retransmission attempts over the wireless link, the frame loss rate decreases as v increases. Consequently, the low frame loss rate at high velocity can reduce handoff latency.

Figure 6 also demonstrates the effect of wireless link bandwidth. As wireless link bandwidth increases, the frame size (in bytes) for a time slot increases and the number of frames for an IP/SIP message decreases. Therefore, the handoff latency can be reduced when the wireless link bandwidth is high. The effect of wireless link bandwidth is more obvious for the SIP-based network mobility support protocol. This is because the message size of the SIP-based network mobility support protocol is much larger than that of the NEMO basic support protocol. In particular, a NEMO basic support protocol message can be delivered by a single frame when the wireless link bandwidth is larger than 512 kb/s. Hence, the handoff latency cannot be further reduced even though the wireless link bandwidth increases.

Open Research Issues

The NEMO basic support protocol and the SIP-based network mobility support protocol provide the primitives for mobility management in mobile hotspots. However, several issues remain open.

Fast and smooth handoff: Since a vehicle in mobile hotspots may move at a very high speed, fast and smooth handoff should be supported. At the link layer, an information raining scheme is introduced in [2], where multiple link layer frames are disseminated to a group of BSs to minimize packet losses in high-speed environments. On the other hand, fast handover for MIPv6 [11] is a network layer solution with the assistance of the link layer for reducing handoff latency and packet loss. To minimize packet loss during handoff and achieve seamless handoff, a cross-layer approach may be a solution. In addition, TCP and UDP performance analysis due to handoff is also an interesting research issue.

System availability and fault tolerance: For successful deployment of mobile hotspots, system availability and fault tolerance are critical. In the IETF NEMO working group, a multihoming issue is being actively discussed. By installing multiple interfaces on the vehicle, availability and fault tolerance can be substantially improved. For multihoming in mobile hotspots, how to optimally distribute packets to multiple interfaces (for downlink/uplink traffic), and how to quickly detect and recover a failure are open issues.

Security: Wireless communications are vulnerable to external attacks because they rely on an open and shared medium. For secure wireless communications in mobile hotspots, a key distribution mechanism has been reported in [12]. However, how to authenticate an MN within a vehicle in heterogeneous wireless networks where different wireless access technologies are integrated is an important issue.

Multimedia support: Multimedia streaming is expected to be a promising application in mobile hotspots. To support multimedia applications in mobile hotspots, efficient resource management needs to be devised. Also, since the WWAN-WLAN integrated link in mobile hotspots has different characteristics than traditional wireless systems, a new transport protocol for multimedia transmission should be developed.

Since the WWAN-WLAN integrated link in mobile hotspots has different characteristics compared with the traditional wireless systems, a new transport protocol for multimedia transmission should be developed.

CONCLUSION

In this article we have studied two mobility management schemes in mobile hotspots with heterogeneous multihop wireless links: the NEMO basic support protocol and SIP-based network mobility support protocol. The SIP-based network mobility support protocol has advantages in easy deployment, no tunneling overhead, and nested mobile hotspot support. However, since SIP message length is much larger than that of the NEMO basic support protocol, the SIP-based network mobility support protocol leads to longer handoff latency over a wireless fading channel. We have also identified open research issues that should be considered for the successful deployment of mobile hotspots.

ACKNOWLEDGMENT

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BIOGRAPHIES

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