Mobility Support for IP-Based Networks

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ABSTRACT

IP-based wireless networks will become the core of next-generation mobile networks. Mobility support plays an important role in all IP-based wireless networks for providing multimedia applications. In this article we address various major issues in mobility support for IP-based networks. Existing technology, including Mobile IP, Mobile IPv6, and other related techniques, are discussed. The issues of mobility support for wireless LANs, wireless WANs, 2–3G cellular networks, and next-generation heterogeneous mobile networks are also addressed in this article.

INTRODUCTION

The explosive growth of Internet applications combined with widespread availability of small hosts in the form of laptop and palmtop computers has created an increasing demand for mobility support for moving hosts. Mobile wireless networks have evolved to be integrated with IP-based infrastructure for multimedia applications where mobility support has become a key issue. This article aims to provide an overview of various major technical issues of mobility support for different IP-based networks including Mobile IP, Mobile IPv6, and IP mobility support in wireless local area networks (LANs) and wireless wide area networks (WANs). It also discusses recent developments in mobility support for cellular networks and next-generation heterogeneous IP-based mobile networks.

The rest of the article is organized as follows. We provide an overview of Mobile IP, Mobile IPv6, and other related technical issues. We also present IP mobility support for wireless LANs and WANs. IP mobility support for second- and third-generation (2–3G) cellular networks and next-generation heterogeneous mobile networks is addressed. Finally, we draw the conclusions of this article.

MOBILE IP

The original versions of IP do not support host mobility in the Internet. In traditional IP, a node's point of attachment to the networks remains unchanged over time, and an IP address identifies a particular network location. Mobile IP (i.e., Mobile IPv4) was designed to provide a way to support host mobility. A standard Mobile IP proposed by the Internet Engineering Task Force (IETF) [1–3] over IP version 4 (IPv4) consists of the following functional entities:

- Mobile node (MN): A host or router that can travel around the Internet while maintaining any ongoing communication session. In this article the terms mobile node and mobile host (MH) are used interchangeably.
- Home agent (HA): A router that maintains a list of registered MNs. It is used to forward MN-addressed packets to the appropriate visiting network when MNs are away from home.
- Foreign agent (FA): A router with an interface in an MN's visiting network, which assists the MN in informing its HA of its current care-of address.
- Care-of address (CoA): A local IP address that identifies the MN's current location.
- Collocated CoA: An externally obtained local IP address temporarily assigned to the MN.
- Correspondent node (CN): A peer host with which an MN communicates.
- Home address: A permanent IP address that is assigned to an MN.
- Tunnel: The path taken by an encapsulated data packet. It leads packets from the HA to the FA.

Mobile IP uses two IP addresses: the fixed (permanent) home address and the CoA for the mobility of an MN. The operation of Mobile IP is based on the cooperation of the three major processes: agent discovery, registration, and tunneling.

1. Agent discovery: A process by which an MN determines its new attachment point or IP address as it moves within the wireless/IP network. When an MN is connected to its home network, it works exactly as a traditional node in a fixed place. When an MN detects its movement to a foreign network, it obtains a CoA by directly reading it from an agent advertisement from its associated FA or a collocated CoA by contacting Dynamic Host Configuration Protocol (DHCP) on the local network.

2. Registration: A process performed as an MN enters and remains in a foreign network. This process involves requesting services for the

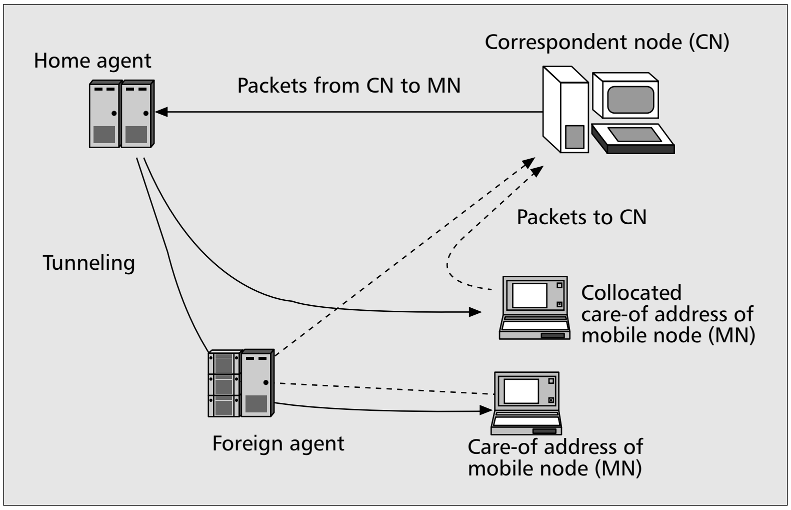

Figure 1. *Triangle routing in Mobile IP.*

MN from the associated FA and informing the associated HA of its new CoA. The MN informs the HA directly if it obtains a new collocated CoA. Registration consists of an exchange of two messages, a registration request and a registration reply, between the MN and its HA. This process enables the HA to associate each new CoA to the MN's home address. This process is also called *binding update*.

3. Tunneling: A process by which Mobile IP tunnels data packets, whether it is away from its home network or not. In the tunneling process, the HA encapsulates the data packets by using an IP-within-IP approach. In the IP-within-IP approach, the HA inserts a new IP header, the MN's CoA, in front of the IP header of a data packet addressed to the MN's home address. When using an FA CoA, when an FA receives the encapsulated data packet, it merely has to eliminate the tunnel header and deliver the rest to the MN. If a collocated CoA is used, the HA sends the encapsulated data packet to the MN directly, and the MN does the decapsulation itself.

ROUTING IN MOBILE IP

Mobile IP uses triangle routing (i.e., tunnel) as shown in Fig. 1. In triangle routing, data packets sent from the CN (a fixed terminal) to the MN is sent to the MN's HA first using standard IP routing. The HA encapsulates the data packets and tunnels the data packets to the MN's CoA. At the associated FA, the data packets are detunneled and sent to the MN. Although triangle routing is simple and easy to use, it is inefficient since it takes a route from a CN to an HA and then to an MN. The overhead of the HA could be a system performance bottleneck due to large data traffic passing through.

Optimized routing is proposed to solve the performance problem with triangle routing in Mobile IP. In optimized routing, the MN informs the CN of its CoA that has been tunneled to the MN directly without any assistance from the HA. Mobile IP with optimized routing allows every CN to cache and use binding copies between the associated HA and the MN. The update of the binding copy can be sent to the required nodes, which may keep it in their caches for direct routing to an MN. Although it seems that overall quality of service (QoS) could be improved with optimized routing, the operation of optimized routing is quite complicated, and the overhead incurred by caching can be large. Cached bindings are possibly inconsistent since they are maintained in a distributed fashion. Security management could be the main obstacle to optimized routing. In a hostile environment, an intruder could easily cut off all communications to an MN by sending a bogus registration if the MN's CoA is known. How to manage authentication and security for optimized routing remains open.

MOBILE IPV6

The current IPv4 has only a 32-bit address size, which is not enough to support the addressing needed on the Internet. Since 1994, the IEFT has been working on IP version 6 (IPv6) to solve the limitations inherent in IPv4 in terms of addressing, routing, mobility support, and QoS provisioning. In IPv6, 128-bit addressing is used instead of the 32-bit addressing in IPv4. The increased IP address size allows the Internet to support more levels of addressing hierarchy, a much greater number of addressable nodes, and simpler auto-configuration of addresses. IPv6 is considered as the core protocol for next-generation IP networks [4, 5].

The network entities of IPv6 for mobility support, Mobile IPv6 [2, 3] are similar to those in Mobile IPv4, except that Mobile IPv6 does not have the concept of an FA. Mobile IPv6, unlike Mobile IPv4, uses an extensible packet header including both home address and CoA, along with the authentication header to simplify routing to the MN and perform route optimization in a secure manner. While discovery of a CoA is still required, an MN uses the stateless address auto-configuration and neighbor discovery functions defined in IPv6 to acquire a collocated CoA of a foreign network in Mobile IPv6. Mobile IPv6 also uses the IP-within-IP tunneling approach to deliver data packets to an MN. If a CN knows the MN's CoA, the CN could send data packets to the MN directly (i.e., source routing) using an IPv6 routing header. Otherwise, the data packets are routed to the associated HA, and then tunneled to the MN's CoA (i.e., tunneling).

Although Mobile IPv6 has almost the same terminologies as Mobile IPv4 except for the absence of the FA, security management makes a big difference between them. In Mobile IPv6 all nodes are expected to implement strong authentication and encryption functions. Mobile IPv6 uses both tunneling and source routing to deliver data packets to destination MNs, as shown in Fig. 2, while tunneling is the only option for Mobile IPv4. With careful security management, optimized routing could be a solution for Mobile IPv6.

HIERARCHICAL MOBILE IPV6

In mobile networks, a rapidly moving MN can cause many binding updates to be sent. The increased number of MNs will also cause increased signaling traffic due to mobility support. To improve the efficiency of mobility management, an interesting scheme called Hierarchical Mobile IPv6 has been proposed [6] (Fig. 3). The basic idea is to use regional registration to reduce the overall registration signaling overhead and improve the QoS in handovers for mobile communications. With Hierarchical Mobile IPv6, the concept of a mobile anchor point (MAP) is also introduced. An MAP handles mobility management for MNs within a network domain, including registration and handover. The MAP functions like a local HA. It receives data packets on behalf of MNs and tunnels the packets to the MNs' CoAs. An MN is assigned two CoAs, a regional one and a local one. The regional CoA is local to the MAP's covered region. The local CoA is the same as an MN's Mobile IPv6 CoA; it is the address local to the node's link. An MN communicates with its correspondent nodes via its regional CoA. It only sends binding updates to CNs (assuming route optimization) when the MN moves outside the MAP region. Otherwise, it only sends a binding update to the MAP to update its regional CoA (local CoA binding). All packets received by CNs will have the MN's regional CoA as the source address; they will thus respond directly to this address. The MAP, on detecting packets sent to this CoA, will encapsulate and forward these packets to the MN at its local CoA.

With the new addressing, hierarchical extensions, and security management, Mobile IPv6 could make MNs available for peer-to-peer (P2P) services, a promising information service (e.g., easier file sharing), since Mobile IPv6 lets MNs have static addresses even as they move around. Without static addressing, MNs have to communicate through a server, which violates the P2P technology's specifications.

Security Requirements

In Mobile IP and Mobile IPv6, registration of the CoA naturally requires authentication [7]. The registration in an HA must be initiated by the right MN and not by some other malicious node pretending to be the MN. A malicious node could cause the HA to alter its routing table with erroneous CoA information, and the MN would be unreachable to all incoming communications from the Internet. To secure the registration process, authentication is mandatory and performed by all HAs, MNs, and FAs for Mobile IP and Mobile IPv6. An algorithm used for the authentication is known as keyed Message Digest 5 (MD5).

Generally, the mobility of MNs in IP-based networks is supported by dynamic network architectures and location management. The security consideration due to mobility for IP-based networks arises significantly.

For traditional secure access of services from remote location, such as Point-to-Point Protocol (PPP) connections, authentication, authorization and accounting (AAA) exist. The concept of AAA was introduced by the IETF to support secure roaming of MNs in the wireless Internet. The AAA extensions try to meet security requirements in a systematic way.

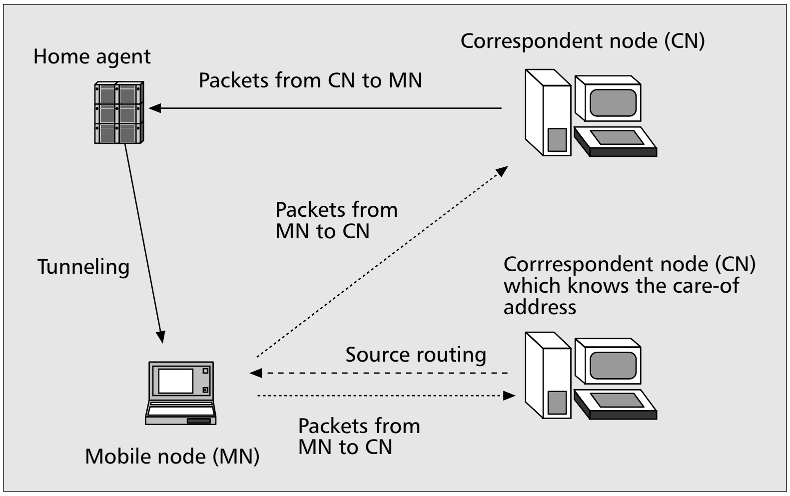

Figure 2. *Mobile IPv6 routing.*

IP Mobility Support with Wireless LANs

Wi-Fi Technology

Wi-Fi is a technology currently dominating all wireless LANs [8]. Wi-Fi is an abbreviation for wireless fidelity. The term Wi-Fi has been used in general to refer to any type of 802.11 network, whether 802.11a, 802.11b, 802.11g, and so on. The term has been promulgated by theWi-Fi Alliance. Any products tested and approved as Wi-Fi Certified® by the Wi-Fi Alliance are certified as interoperable with each other, even if they are from different manufacturers. This feature of Wi-Fi technology allows device-level multivendor interoperability to support mobility. A user with a Wi-Fi Certified product can use any brand of access point with any other brand of client hardware that is also certified. Typically, any Wi-Fi products using the same radio frequency (e.g., 2.4 GHz for 802.11b or 802.11g, 5 GHz for 802.11a) will work with one another, even if not Wi-Fi Certified.

Initially, networks are designed to extend enterprise networks. Nowadays, it is a requirement to extend Wi-Fi broadband access to many public places such as universities, hotels, and conference centers. Mobile IP can be a good solution for providing roaming services to Wi-Fi networks, in which Wi-Fi is viewed as a visited network. In this section we address IP mobility support for wireless LANs, including Wi-Fi and Bluetooth.

DHCP-Based Mobility Support in Wireless LANs

Traditional IP addresses an entire wireless LAN as a single subnet, where IP addresses of all hosts have the same address prefix. Over a wireless LAN, mobility support is implemented through use of dynamic IP address allocation provided by DHCP. When an MN remains in a wireless LAN that could be considered a foreign network (or subnet), it requests an IP address (i.e., CoA) for some period of time. The server returns an available IP address from a pool of addresses. If the IP address is

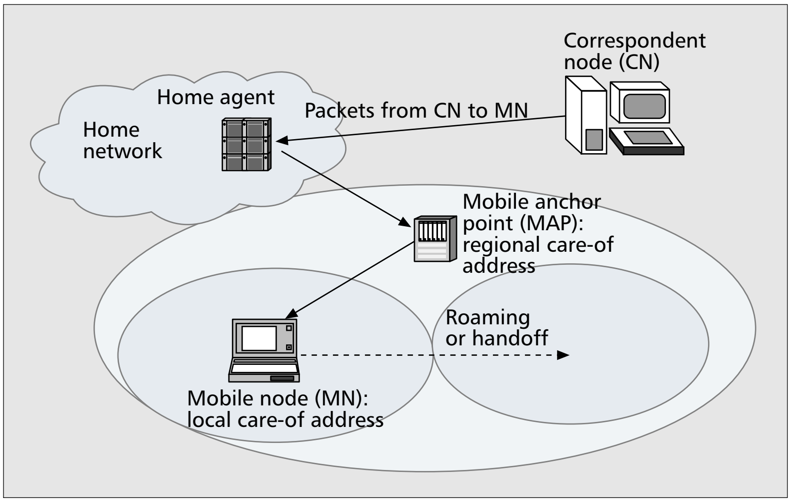

Figure 3. *Hierarchical Mobile IPv6.*

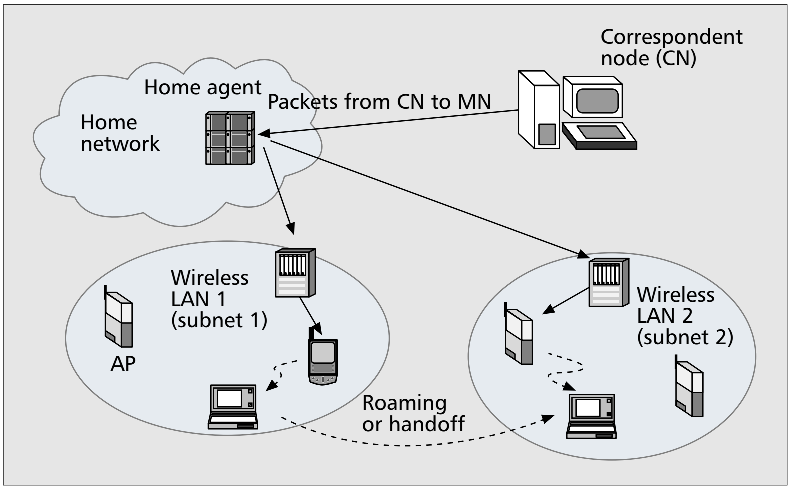

Figure 4. *Mobile IP mobility support for wireless LANs.*

configured successfully, the MN can communicate within the wireless LAN. DHCP-based mobility support is simple to implement. However, it cannot provide for the MN roaming across different wireless LANs since the network connection can be achieved only within wireless LAN boundaries. For multimedia applications to MNs, it is important to implement multiple IP subnets across a common wireless LAN in order to make network management easier, facilitate location-dependent services, and decrease the spread of broadcast packets throughout the network.

Therefore, with multiple subnets MNs must be able to seamlessly roam from one subnet to another while traversing a network. Wireless LAN access points provide support for roaming at the data link layer (International Standards Organization open systems interconnection [ISO/OSI] layer 2). Users automatically associate and reassociate with different access points as they move through a network. As MNs roam across subnets, though, there must be a mechanism at the IP/network layer (ISO/OSI layer 3) to ensure that a user device configured with a specific IP address can continue communications within the applications.

The Solutions with Mobile IP

Both Mobile IPv4 and Mobile IPv6 provide solutions to the problem by taking a wireless LAN as a subnet that may include several access points (APs), as shown in Fig. 4. To implement Mobile IPv4 or Mobile IPv6, two major components are needed: a Mobile IP server and Mobile IP client software. The Mobile IP server will fully implement the Mobile IP HA functionality, providing mobility management for MNs. The Mobile IP server can generally also keep track of where, when, and for how long users utilize the roaming services. That data can then become the basis for accounting and billing. The registration of an MN's CoA when the MN moves is implemented by Mobile IP operation. When an MN moves across the boundary to another subnet during communication, the Mobile IP network-level handoff process is performed [9, 10]. It initiates a handshake between the HA and the new FA (or the MN with collocated address for Mobile IP or the MN for Mobile IPv6) at the medium access control (MAC) level. After completion of handoff, the data packets destined to the MN are tunneled by the HA to the new subnet, and then to the MN.

IP Mobility Support with Wireless WANs

Recently, the basic technical concept of wireless LANs has been extended to wireless WANs. Among current wireless broadband WAN technologies, WiMax (which stands for Worldwide Interoperability for Microwave Access) is a most promising one. It is based on the maturing IEEE 802.16 standard [11], which specifies the radio frequency technology for wireless MANs and point-to-multipoint wireless networking. This is also partly because of successful marketing by the WiMax Forum, strong support from commercial chip vendors such as Intel, and the participation of most of the major radio access network vendors. IEEE 802.16 divides its MAC layer into sublayers that support different transport technologies, including IPv4 and IPv6, Ethernet, and asynchronous transfer mode, which lets vendors use WiMax no matter which transport technology they support.

WiMax extends the area coverage of Wi-Fi. WiMax provides fixed as well as mobile wireless broadband connectivity without the need for direct line of sight with a base station. In a typical cell radius deployment of 3–10 km, WiMax systems are expected to deliver a capacity of up to 40 Mb/s/channel for fixed and portable access applications. This provides enough bandwidth to simultaneously support hundreds of business clients with speedy connectivity and thousands of residences with digital subscriber line (DSL) speed connectivity. Mobile network deployments are expected to provide up to 15 Mb/s of capacity within a typical cell radius deployment of up to 3 km.

Compared to Wi-Fi, WiMax cells are relatively large and can support more MNs. Although the early versions of IEEE 802.16a and 802.16d do not support interdomain mobility, IEEE

802.16e supports mobility at pedestrian speeds. Furthermore, WiMax has recently begun adding Mobile IP mobility support in the IP/network layer.

IP Mobility Support for Cellular and Heterogeneous Mobile Networks

Cellular networks have traditionally been developed for voice telephony service using circuit-switched technology. They are usually complex and large in terms of their network scale and operational features: high-speed mobility, low data rate, and wide-area coverage. Today's cellular networks are in the process of evolution from 2G (e.g., Globe System for Mobile Communications [GSM], IS-54, IS-95, Digital Cellular System [DCS]) to 3G, which is under the 3G Partnership Projects (3GPP and 3GPP2) involving participants worldwide. The aim of the process is to have an all-IP network architecture to provide high-bit-rate multimedia services including voice, video, and data [4, 5, 10]. Multimedia services typically require multiple sessions over one physical channel, which could be provided by packet-switched networks. The common protocol set for packet-switched networks is IP.

An all-IP network can be viewed as a cellular network with an IP-based radio access network (RAN) architecture, IP core network architecture, MNs (terminals) that are IP host devices, and an air interface optimized for packet data delivery. The IP-based RAN architecture with which we are concerned here is for providing radio bearer services and radio resource management. The IP core network architecture includes the packet core network for wide area mobility and bearer services, and the new IP multimedia core network system for IP-based multimedia service including Mobile IPv4 and Mobile IPv6 functionalities, Session Initiation Protocol (SIP), and AAA.

The 3G cellular technologies include Universal Mobile Telecommunications System (UMTS) and code-division multiple access 2000 (CDMA2000). The UMTS evolved from the GSM network in Europe, and CDMA2000 evolved from the CDMAOne network originated in the United States. Both CDMA2000 and UMTS were defined by the International Telecommunication Union (ITU) in the IMT-2000 framework. Based on the combination of circuit and packet switching, both CDMA2000 and UMTS combine mobile and IP technologies to provide personal communications and personalized content. A data session is established to carry IP packets between the network access server and the MN in both CDMA2000 and UMTS networks. Both networks use tunnels to support user mobility [5]. However, the 3G networks including CDMA2000 and UMTS currently solve their mobility problems at the link layer (layer 2) only, not in the IP layer (layer 3). There may exist several overlaid wireless networks including 2G networks, 3G networks, wireless LANs, and wireless WANs over the same geographical area. It becomes clear that this situation will continue in the future. Mobile IPv6 and its hierarchical mobility management extensions may provide a solution for internetwork mobility as well as intranetwork mobility. In the future, Mobile IPv6 capabilities may be implemented in silicon on the firmware level, rather than the TCP/IP software stack, which will help improve system performance. With Hierarchical Mobile IPv6, the Mobile IPv6 protocols may manage global mobility while the MAP may handle local mobility. Security and QoS considerations arise with mobility support. Figure 5 shows IP mobility support with the provision of AAA and QoS control services.

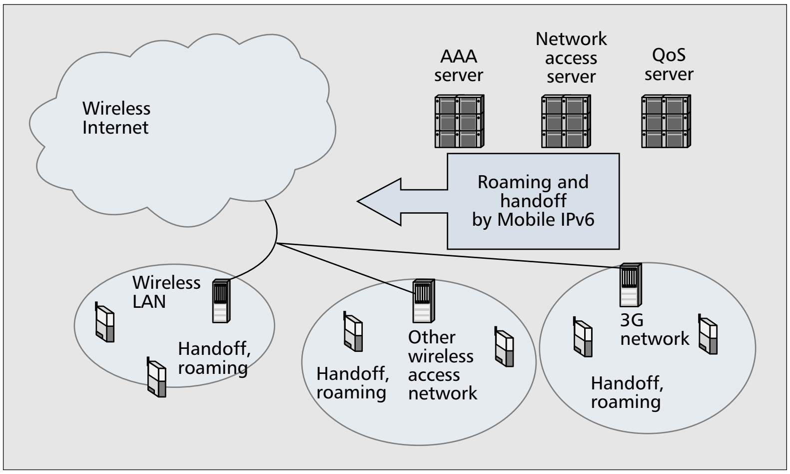

Figure 5. *IP mobility support for next generation heterogeneous mobile networks.*

Conclusion

In this article we have discussed various major technical issues in IP mobility support for IP-based wireless networks. Mobile IP and Mobile IPv6 are basic technologies for the wireless Internet. To improve the performance of Mobile IPv6, Hierarchical Mobile IPv6 is proposed. Due to the architecture of IP-based networks, cryptographic authentication is required for registration and routing. Mobile IP and Mobile IPv6 provide solutions for IP mobility support in both wireless LANs and WANs. IP-based wireless networks will become the core for future cellular networks. There may exist several overlaid wireless networks in the same geographical area. Mobile IPv6 and its hierarchical mobility management extensions offer internetwork as well as intranetwork mobility. However, how to implement mobility support efficiently and securely with the provision of AAA and QoS control services remains an open issue.

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