Micro-Mobility Mechanism for Smooth Handoffs in an Integrated Ad-Hoc and Cellular IPv6 Network Under High-Speed Movement

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***Abstract*—The success of the Internet has attracted more people to take part in network navigation. Numerous wireless-communication devices have rapidly evolved in the past decade. The demand for mobile communications is increasing and packet data services through Internet protocol (IP) networks have become a trend. To supply more IP addresses to network devices and improve network performance, a new IP version 6 (IPv6) was developed by the Internet Engineering Task Force in 1994. IPv6 supports certain features that make mobility management more efficient in mobile IP. A cellular architecture is needed to improve the communications quality and to reduce power consumption, both at the base and mobile stations. In a cellular environment, handoffs occur frequently. Reducing the defects caused by handoffs is extremely important in the mobile network environment. This is especially important for high-speed moving devices. In this paper, a handoff strategy called neighbor-assisted agent architecture, which takes advantage of the *ad-hoc* network to improve handoff performance, is proposed. Timing analytical and simulation results show that the proposed mechanism can provide a better solution than mobile IP for handoff breaks during high-speed movement.**

***Index Terms*—Ad-hoc, cellular, handoff, Internet protocol version 6 (IPv6).**

I. Introduction

THE Internet has become ubiquitous in recent years and there has been tremendous growth in wireless communications. Many wireless-communication techniques are commercially available, such as the wireless local area network (LAN), Bluetooth, global system for mobile communications (GSM), general packet radio service (GPRS). Because all Internet protocol (IP) networks will become the trend, access to the Internet via wireless communications has become important. Mobility support in the IP, therefore, provides a standard solution for mobility at the IP layer.

Cellular networks were formed to reduce power consumption and to reuse the limited radio-spectrum resources. Cell size is one of the factors in the channel-reuse rate, which is higher for a smaller cell size than for a larger cell size. Micro-mobility is, therefore, the inevitable direction for future mobile systems. Frequent and fast movements usually characterize micro-mobility. A cellular architecture would then present a challenge to the frequent handover procedures for a smaller cell size and usually induces a higher handoff frequency.

The *ad-hoc* network is another network architecture for wireless networks, which is a noninfrastructure architecture in which the nodes can access services from one another regardless of where they are. An excellent routing protocol is crucial for *ad-hoc* networking to function at a high performance. The main difference between a cellular environment and an *ad-hoc* network is that the *ad-hoc* method has no fixed infrastructure, allowing the nodes to communicate with one another at any time from anywhere.

A number of micro- or pico-mobility solutions using an *ad-hoc* mechanism have been discussed in the literature, including the following.

A. IPv6 Flow Handoff in Ad-Hoc Wireless Networks Using Mobility Prediction [1]

This research was performed in an *ad hoc* environment, in which mobile nodes act as moving routers and the network topology is constantly changing due to the node mobility. This research proposed a new protocol, the flow-oriented routing protocol (FORP), for routing real-time flows in highly mobile *ad hoc* wireless networks.

They introduced a new concept, the multihop handoff, to anticipate topological changes and to perform rerouting. In this way, the flow disruption due to the changing topology is reduced.

To rebuild a flow route prior to a routing change, they proposed a scheme that uses the mobility information obtained from the mobiles to predict the topological changes. This method can give us some idea of how to search for the movement direction.

B. Mobile-Assisted Data Forwarding: A Novel Approach to Add an Ad-Hoc Overlay Onto a Fixed Cellular Infrastructure [2]

The author proposed an architecture called mobile-assisted data forwarding (MADF). In this system, as illustrated in Fig. 1, they added an *ad-hoc* overlay onto a fixed cellular infrastructure and used special channels (forwarding channels) to connect users in hot (shaded) areas and the surrounding cold cells without going through the hot cell's base station. Data may hop through more than one forwarding agent before a base station receives it. Under a certain delay requirement, the throughput in one cell can be improved.

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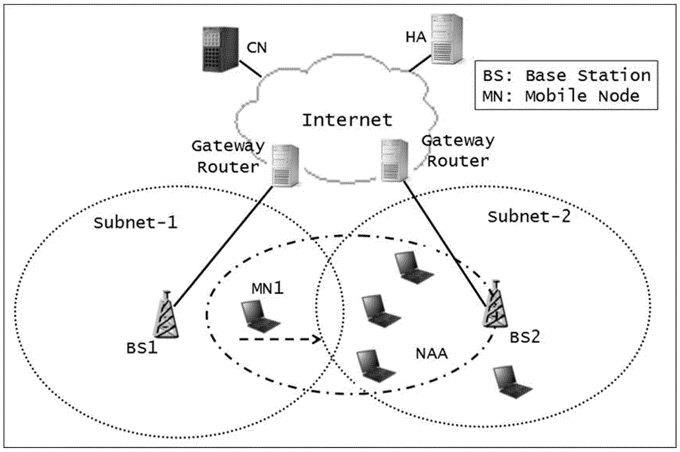

Fig. 1. Wireless data network with data forwarding [2].

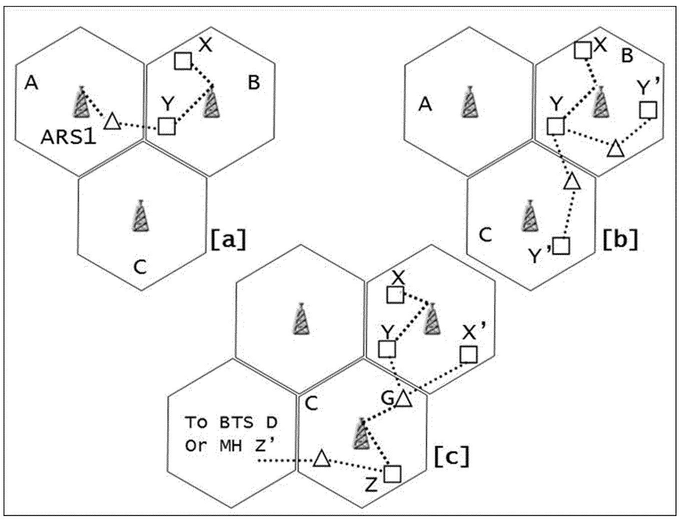

Fig. 2. An integrated cellular and *ad-hoc* relay system [3].

This mobile-assisted data-forwarding idea is similar to the NAA in our research. The main differences are that the MADF is used for forwarding data packets, while the NAA is used for transmitting control packets. Data packets occupy more wireless bandwidth in the neighboring node than do control packets. Another difference is that the MADF may forward packets through more than one hop, while the NAA operates under a one-hop protocol without the complex path-routing issue.

C. Integrated Cellular and Ad-Hoc Relaying Systems: Integrated Cellular and Ad-Hoc Relaying Systems (iCAR) [3]

Cellular infrastructure and modern *ad-hoc* relay-technology integration is proposed in Fig. 2, which shows the secondary relaying to free up a channel for mobile host (MH) X: 1) MH Y to base transceiver station (BTS) A, 2) MH Y to MH Y, or 3) cascaded relaying (i.e., MH Y to BTS C and MH Z to either MH Z or BTS D). The key device in this architecture is the *ad-hoc* relay stations (ARSs). A number of ARSs are placed at strategic locations.

In this architecture, ARS are placed in the system before system initiation. This system does not need to implement an ARS discovery algorithm. The ARS is just like an active router.

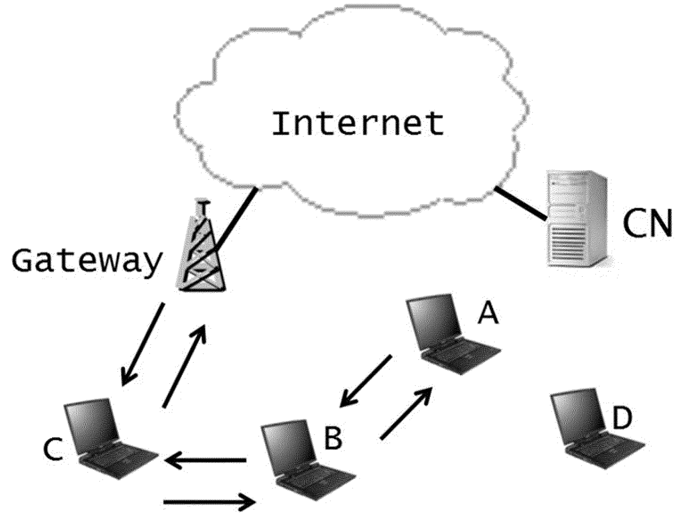

Fig. 3. Mobile *ad-hoc* network where A is communicating with the gateway to the Internet through B and C; CN is correspondent node [4].

Depending on the ARS system, the traffic load balance between cells is maintained by relaying traffic from one cell to another.

The author estimated that the maximum number of seed ARSs needed is, at most, $3n - \lfloor 4\sqrt{n} - 4 \rfloor$ to ensure that a relay route can be established between any BTS and MH located anywhere in any cell where n is the number of cells in the system.

D. Evaluation of Mobile Ad-Hoc Network Techniques in a Cellular Network [4]

This study evaluated the performance of certain routing protocols developed for mobile *ad-hoc* networks (MANETs), i.e., *ad-hoc* on-demand distance vector (AODV), dynamic source routing (DSR), destination-sequenced distance-vector routing (DSDV), and the temporal-ordered routing algorithm.

A MANET is an autonomous system (shown in Fig. 3) that has gateways to a fixed network. When node A would like to transmit a packet, a route needs to be established first, after the packet is being received by B, from B to C and from C to the gateway (GW) to the Internet. The author proposed a combination of cellular and *ad-hoc* networks to enhance the network capacity.

The authors discussed applications for the above MANET protocols and announced that DSR is the best *ad-hoc* routing protocol when integrating cellular and *ad-hoc* networks.

E. Dynamic Adaptive Routing for Heterogeneous Wireless Network [5]

The HWN integrates a cellular network with an *ad-hoc* network to enlarge the communications scope for the *ad-hoc* network and to improve the throughput for the cellular network. They also proposed a dynamic adaptive routing protocol (DARP) to fit a heterogeneous wireless network.

Under this network architecture (shown in Fig. 4), the number of base stations can be reduced and connections can be made without the help of the base stations. The base station in this architecture can be seen as a part of the mobile *ad-hoc* nodes. This is accomplished in the *ad-hoc* routing algorithm.

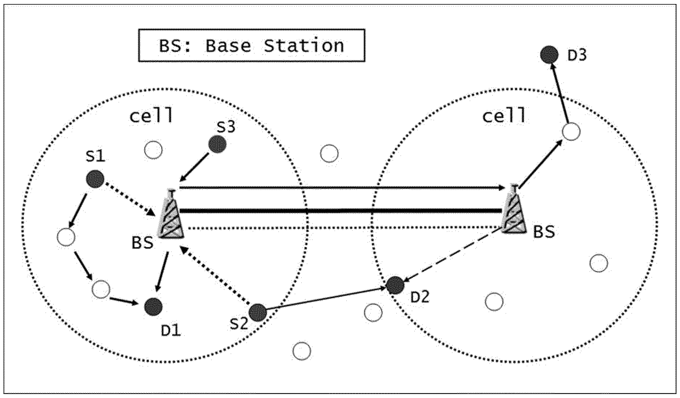

Fig. 4. Heterogeneous wireless network [5].

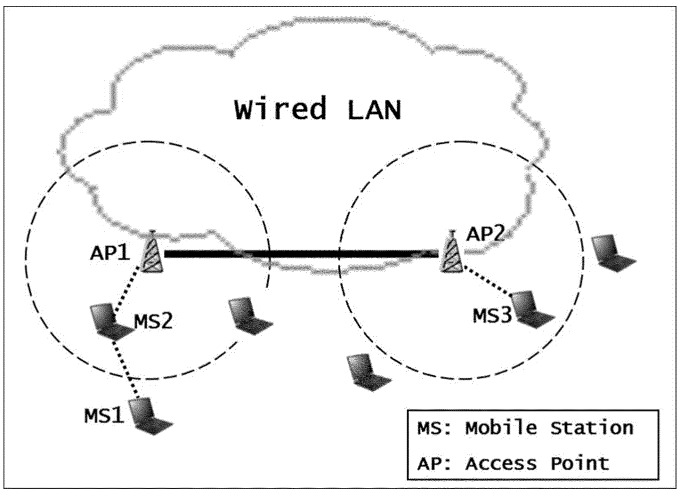

Fig. 5. Multihop wireless LAN [6].

F. Multihop Wireless IEEE 802.11 LANs: A Prototype Implementation [6]

The multihop wireless network is composed of a traditional single-hop cellular network and an *ad-hoc* network. This method reduces the number of required base stations and improves the throughput performance.

The major component in this architecture is the bridging protocol, base-driven multilhop bridging protocol (BMBP). The access points and mobile stations use the BMBP to enable multihop routing and roaming.

The operation procedures are illustrated in Fig. 5. The mobile station 1 (MS1) cannot communicate with MS3. MS2 can help MS1 to forward packets to access point 1 (AP1). The AP1 knows where MS3 is located through the help of AP2. The MS1 can communicate with MS3 indirectly.

G. Fast Handovers for Mobile IPv6 [7]

Internet engineering task force (IETF) fast handovers that allow the use of L2 triggers to anticipate the handover are presented. The IETF fast handover allows the mobile node to create a new care of address (CoA) before it moves to a new access router domain. Therefore, it can minimize the handover latency.

There are three phases in the IETF fast handover: handover initiation, tunnel establishment, and packet forwarding. The handover initiation can be either a mobile node-control handover or a network-control handover. The mechanism is explained in detail as follows.

State 1: The previous access router (PAR) requests a new CoA to the new-access router (NAR) by sending a handover initiation (HI).

State 2: The NAR replies with a handover acknowledge (HACK), which contains a new CoA to the PAR. The CoA is valid after duplicate-address eetection (DAD).

State 3: The PAR sends a proxy router advertisement (PrRtAdv), which contains a new CoA that the mobile node will use at the NAR.

State 4: The mobile node sends a fast binding update (FBU) to the PAR before moving to indicate its departure.

State 5: The PAR sets up a tunnel toward the NAR after it receives the FBU. From now on, the packets are forwarding between the PAR and the NAR.

State 6: The PAR sends a fast binding acknowledgment (FBACK) to the mobile node.

State 7: The mobile node sends a fast neighbor advertisement (FNA) to the NAR after it establishes a connection with the NAR to inform the NAR of its arrival.

State 8: The NAR checks its cache for this mobile node. If the entry for the mobile node exists, then the NAR will forward packets to the new CoA of the mobile node.

From the above discussion, we realize that nearly all of the proposals for *ad-hoc* network integration with the wired network are similar. The main differences are the routing algorithms used to determine the routing paths. In this paper, a mechanism called the NAA is proposed to facilitate seamless handoff during high-speed movement. No complicated *ad-hoc* routing protocol is needed in the proposed architecture. The system needs only one intermediate node, NAA, to access to the wired network. To maintain the NAA, an algorithm called NAA discovery is proposed. The NAA discovery algorithm is designed according to the IETF standards to be compatible with the IETF standards. The NAA discovery algorithm will not cause *ad-hoc* broadcast storms. The proposed mechanism can also be used to solve the broadcast storm problem, route-maintenance problem, and implemention of an *ad-hoc* protocol in a heterogeneous wireless network. Other algorithms were also adopted in this research to make the NAA mechanism more suitable for the handoff procedure. For example, the neighbor-binding table (NBT) is used to binding duplication with the correspondent node (CN), the binding-arrival (barrival) packet enhances security when binding with the CN, and one additional bit (called the "N bit") in the control packet is used to distinguish the proposed mechanism from the IETF MIPv6 handoff mechanism. This research takes advantage of certain movement-detection methods proposed by previous researchers to make the proposed mechanism more precise in movement detection.

As for the comparison between fast handoff and NAA, these two mechanisms use the L2 signals to trigger the handover and then obtain the new CoA. Some procedures are similar in the proposed mechanism. For example, the NAA discovery in the proposed mechanism is similar to the combined procedure of the HI, HACK, and the PrRtAdv in the IETF fast handover when it is going to obtain a new CoA. The *sub-binding update* in the proposed mechanism is similar to the fast binding update (FBU)