Design of Multi-hop Handovers for Hybrid Ad hoc Networks in Multi-Channel Environments

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Abstract—To provide Internet connectivity to mobile ad hoc networks, several solutions have been proposed. Most of the proposals focus on the suitable and optimal gateway selection and handover schemes in accordance with the network status and node mobility. However, since an integration of the Internet and ad hoc networks is a function of the network layer, they do not consider characteristics of lower layers such as a multi-channel capability. If the operating channels of each gateway are different, mobile nodes connecting to one gateway cannot receive any messages from other gateways, and thus they cannot perform handovers to other gateways. In this paper, we propose a new handover scheme for hybrid ad hoc networks in multi-channel environments. We revise and extend the previously proposed handover schemes namely the forced handover and optimized handover. We also studied the performance of the proposed two schemes through ns-2 simulations.

I. INTRODUCTION

The Internet connectivity of mobile ad hoc networks is one of very active and interesting research issues, and several protocols have been proposed to integrate mobile ad hoc networks into the Internet [1-4]. In such integrated scenarios, also known as hybrid ad hoc networks, ad hoc nodes should be able to communicate with hosts or servers in the Internet. Therefore, ad hoc and Internet routing protocols should understand each other to deliver packets successfully in each direction. However, because conventional ad hoc routing protocols are based on a flat addressing model, they cannot be directly combined with the Internet routing protocols which use a hierarchical addressing model. To overcome this problem, a concept of gateway which can understand both ad hoc and Internet routing protocols is commonly accepted in literature. Fig. 1 shows a general architecture of hybrid ad hoc networks. A gateway is connected to the Internet via wired or wireless links and communicates with ad hoc nodes using conventional ad hoc routing protocols.

In hybrid ad hoc networks, ad hoc nodes should discover a gateway prior to communication with nodes in the Internet because a gateway acts as a default router for all incoming and outgoing packets of ad hoc networks. If an ad hoc node detects a gateway through a gateway discovery mechanism, it configures a global IP address and chooses the gateway as a default router for packets destined to the Internet. After selecting a gateway via initial discovery process, an ad hoc node performs a handover if it switches to a new gateway from the current one due to its mobility. The efficiency of a handover operation has a strong impact on the overall performance of hybrid ad hoc networks, especially when a mobility of ad hoc nodes is high.

There have been various proposals in the literature for handover in hybrid ad hoc networks. However, since the integration of the Internet and ad hoc networks is a function of the network layer, the proposed methods do not consider the characteristics of lower layers including a multi-channel capability. The IEEE 802.11 standard and many other protocols forming ad hoc networks allow using different channels among adjacent networks. In such a multi-channel scenario, ad hoc nodes should select and maintain one channel to communicate with its gateway. Although this multi-channel scenario can enhance the network capacity due to channel diversity, existing handover operations cannot work properly because ad hoc nodes can discover only the gateways operating in the same channel.

In this paper, we propose a new handover scheme for multi-channel hybrid ad hoc networks. Handovers in hybrid ad hoc networks occur when either the path to the old gateway is broken (forced handover) or more optimal gateway is found (optimized handover) [6]. We revise and extend the two types of handover to switch to a new gateway on a different channel efficiently. To the best of our knowledge, there is no existing
work on handover schemes for hybrid ad hoc networks in multi-channel environments.

The remainder of this paper is organized as follows. In the next section, we briefly describe related work on hybrid ad hoc networks. In Section III, we present the proposed handover schemes. Performance evaluation results are shown in Section IV and, finally, we conclude this paper in Section V.

II. BACKGROUND

A. Internet connectivity for ad hoc networks

IETF MANET working group and many research projects have studied to interconnect ad hoc networks to the Internet using a gateway concept. Existing proposals can be grouped according to the version of Internet protocols (IPv4, IPv6) and gateway discovery mechanisms (proactive, reactive).

In IPv4 based architecture, a gateway serves as a home agent and foreign agent of Mobile IPv4 [1, 2]. If a home agent receives packets destined for an ad hoc node which moves to another network, it encapsulates and forwards the packets to the ad hoc node’s current foreign agent. Once the foreign agent which acts as a gateway receives the encapsulated packets, it decapsulates and forwards them to the corresponding ad hoc node. The proposals receiving more attention within the IETF and the research community are based on the IPv6 [3, 4]. In [3, 4], an ad hoc node which obtains a network prefix from an advertisement message derives a global IPv6 address and uses it to communicate with nodes in the Internet. One of the advantages of these IPv6 based proposals is that they do not require foreign agents.

A gateway discovery mechanism strongly influences the overall performance of hybrid ad hoc networks [5]. A gateway can be discovered proactively or reactively. In proactive approaches, gateways announce themselves by sending an advertisement message periodically. In contrast, an ad hoc node sends a solicitation message to gateways in reactive approaches when it has packets to destination node in the Internet. There are also hybrid approaches in which advertisements are only flooded within a certain number of hops. Nodes located out of that scope will reactively find gateways.

Wakikawa et al. proposed an Internet draft entitled “Global Connectivity for IPv6 Mobile Ad Hoc Networks” [3]. (We will call the proposal as Wakikawa scheme from now on.) The Wakikawa scheme is one of the most feasible solutions for hybrid ad hoc networks. It defines both the proactive and reactive gateway discovery mechanisms based on IPv6. In the proactive mode, Internet gateway advertisement (IGWADV) messages are flooded periodically from gateways. In the reactive mode, a node broadcasts an Internet gateway solicitation (IGWSOL) message when needed and gateways send an IGWADV message as a response. IGWADV and IGWSOL messages can be implemented by simply modifying control messages in ad hoc routing protocols or the neighbor discovery protocol for IPv6. The IGWADV message contains the IPv6 address of a gateway, subnet prefix, prefix length, and lifetime. Therefore, when a node receives an IGWADV message, it can construct its own IPv6 address and selects the gateway as its default router.

B. Handover in hybrid ad hoc networks

The most commonly used handover metric in single-hop mobile networks is the quality of the wireless link. If the signal strength from the currently connected base station falls down under a certain threshold, a mobile node searches other base stations and connects to a new base station with highest signal strength. However, this metric cannot be used in hybrid ad hoc networks because ad hoc nodes are connected to a gateway via multiple intermediate nodes rather than a direct wireless link.

For a handover in hybrid ad hoc networks, referred to as a multi-hop handover, the number of hops from a gateway is usually used as a handover metric. The multi-hop handover can be categorized into forced handover and optimized handover [6]. A forced handover occurs whenever a path between an ad hoc node and a gateway is disrupted due to movement of a node itself or intermediate nodes. The ad hoc node should perform a gateway discovery to establish a new path to a previously connected gateway or a new one. An optimized handover occurs as a result of route optimization. If an ad hoc node detects a new gateway with a shorter path than the current one, a communication path can be optimized. In such case, the node performs an optimized handover by registering to the new gateway although there is a path to the current gateway.

To perform a forced handover, an ad hoc node simply broadcasts advertisement messages after disconnecting from the current gateway. In contrast, the operation of an optimized handover is differentiated according to a gateway discovery mechanism. In proactive gateway discovery schemes, advertisement messages from gateways are flooded periodically thus ad hoc nodes can detect other gateways easily. However, in reactive gateway discovery schemes, ad hoc nodes cannot know the existence of other gateways before the path to the current gateway is broken. To enable an optimized handover in reactive gateway discovery schemes, ad hoc nodes should send solicitation messages periodically.

III. MULTI-HOP HANDOVER FOR MULTI-CHANNEL ENVIRONMENTS

The 802.11 based WLAN and Bluetooth technologies which are used to form ad hoc networks can support multiple physical channels to network devices. It means that adjacent hybrid ad hoc networks can operate on different physical channels. As shown in Fig. 2, ad hoc nodes connected to Gateway1 use physical channel 1 and other nodes connected to Gateway2 use physical channel 2. In this network topology, although ad hoc node A-B and C-D are within a transmission range of each other, they cannot communicate with each other due to different physical channels. Therefore, control packets of ad hoc routing and gateway discovery protocols are flooded not to the entire networks but within the network using the same physical channel.
Although using multiple channels increases the network capacity by reducing the number of flooded messages, a handover scenario becomes more complicated. As explained in the previous section, existing multi-hop handover operations assume that advertisement and solicitation messages are flooded to the entire networks. Because ad hoc nodes cannot communicate with gateways in different physical channels, however, this assumption fails in multi-channel scenario. In this section, we propose a new handover operation for multi-channel environments. Basically, the proposed operations are based on the Wakikawa scheme, but can be adapted to other existing schemes.

A. Forced handover for multi-channel environments

The initiation of a forced handover for multi-channel environments is the same as the single-channel scenario. When a path between an ad hoc node and its gateway is broken, the ad hoc node starts to discover other gateways. First, the node sends an IGWSOL message without changing its physical channel. If it receives one or more IGWADV messages within \( T_{RTT} \) which is an expected round trip time between nodes and gateways. It selects a new gateway according to the number of hops from gateways. (We assume that nodes can obtain the hop counts from gateways through received IGWADV messages.)

If the node did not receive any IGWADV messages within \( T_{RTT} \), it concludes that there is no gateway using the current physical channel. Then it searches gateways in another physical channel by sending IGWADV message. After the node finishes a gateway discovery for all physical channels, a gateway which has a minimum hop count is selected as a new gateway. Fig. 3 summarizes the proposed forced handover scheme.

B. Optimized handover for multi-channel environments

One simple way to perform an optimized handover in multi-channel scenario is that an ad hoc node changes its operating physical channel periodically and sends an IGWSOL message on the new physical channel as a forced handover operation.

However, such a periodic channel changing causes a service disruption because the node cannot send or receive packets when it uses a different physical channel from the channel of the current gateway. The proposed optimized handover can minimize this service disruption period.

In the proposed optimized handover operation, three new control messages are used; proxy Internet gateway solicitation (PR_IGWSOL), proxy Internet gateway advertisement (PR_IGWADV), and proxy Internet gateway request (PR_IGWREQ) messages. PR_IGWSOL and PR_IGWADV messages are extended from IGWSOL and IGWADV messages respectively. All the three messages contain the sequence number and requester address. If an ad hoc node detects that the hop count of a path from the current gateway exceeds \( \text{Hop Limit} \), then it starts a two-phase gateway discovery process to select a shorter path than the current one. The \( \text{Hop Limit} \) is a system parameter to guarantee a reasonable path length to an ad hoc node.

Fig. 4 shows the operation of ad hoc nodes for optimized handover. In the first phase, the node sends a PR_IGWSOL message to all the physical channels and returns to its original channel to wait for \( T_{RTT} \). For the PR_IGWSOL message, the requester address is the address of the sending ad hoc node. Note that the ad hoc node does not wait for receiving IGWADV messages but immediately changes to a next physical channel after sending a PR_IGWSOL message.

If some nodes receive a PR_IGWSOL message, they become proxy candidate nodes. They change the source address of the PR_IGWSOL message with their own address and rebroadcast the message. When a gateway receives the PR_IGWSOL message, it determines whether the message is duplicated or not by checking the sequence number and requester address. If the received PR_IGWSOL message is the first one, then the gateway sends a PR_IGWADV message as a response. In the PR_IGWADV message, a requester address is copied from that of the PR_IGWSOL message. Since the gateway replies for the first received PR_IGWSOL message and ignores others, only one of the proxy candidate nodes receives the PR_IGWADV message and becomes a proxy node for that message. The proxy node saves the PR_IGWADV message for the second
The simulation network consists of 15 wired nodes, 3 gateways, and 100 mobile ad hoc nodes and spans a rectangular area of 1200m × 500m. Each gateway operates on non-overlapping channels. Ad hoc nodes move freely according to the random waypoint model with a uniformly selected speed in [0m/s, 20m/s] and pause times of 0, 50, 100, 200, 300, and 500 seconds. IEEE 802.11 is used as the MAC layer protocol and its transmission range is 250m. We use AODV [7] as an ad hoc routing protocol. 15 UDP source nodes in ad hoc networks send packets to wired nodes. These UDP sources generate 10 packets/second with 256 bytes packet length. The values of $T_{RTT}$, $T_{RTT}$, $Hop\_Limit$, and $Discovery\_Interval$ are set to 200ms, 20ms, 5, and 10s, respectively. Other system and protocol parameters of AODV and Wakikawa scheme are set with default values.

Fig. 5 shows the total number of handovers performed by ad hoc nodes. In both of the FHO and FHO+OHO cases, the number of handovers increases as the mobility rate increases (i.e., as the pause time decreases). We can see that ad hoc nodes change gateways more frequently when an ad hoc node is allowed to perform OHO. If nodes only perform FHO, it changes its gateway only when the path to the old gateway is broken. In contrast, if nodes perform OHO, handovers occur prior to a break of the path to the old gateway when the route to the new gateway is shorter than to the old one.

In Fig. 6, we compare the number of control packets of the two cases, which shows very similar pattern with Fig. 5. For the OHO operation, additional control packets such as PR\_IGWADV, PR\_IGWSOL, and PR\_IGWREQ messages are required. Moreover, since OHO causes additional handovers, control packets for a new path setup are also required. However, since OHO helps nodes maintain shorter path to gateways than the case that only FHO is used, we can expect that the performance of ad hoc nodes will be enhanced in terms of end-to-end delay and packet delivery ratio.

Fig. 7 shows the average end-to-end delay of delivered packets. Since the delay at the wired links is negligible and almost constant, these results reflect the delay by multi-hop propagation at the ad hoc networks. The major factors affect-
ing the average delay are the path length between gateways and nodes and the traffic load on the path. In Fig. 7, we can see that the average delay is reduced when nodes perform OHO. Although OHO causes much control packets, data packets are delivered faster due to the reduction of the number of hops to gateways. At a high mobility rate, the average delay increases significantly when the node performs FHO only. In contrast, if the nodes perform OHO, the delay does not exceed 60ms with the help of path optimization. (At the low mobility rate, path optimization rarely occurs, and thus the two cases show very similar results.)

Fig. 8 shows the packet delivery ratio defined as the percentage of successfully delivered data packets over all the data packets sent out by the sources. We can see that OHO can deliver more packets especially when the mobility is high. Although more handovers occur when nodes perform OHO as well as FHO, the packet delivery ratio does not decrease since our two-phase gateway discovery process of OHO was designed to minimize the handover delay. Moreover, the packets can be delivered more successfully since the average number of hops to gateways is reduced.

V. CONCLUSION

In this paper, we proposed a multi-hop handover scheme for hybrid ad hoc networks in multi-channel environments. The proposed handover scheme, consisting of forced handover and optimized handover, allows nodes to switch to a new gateway on the different channel efficiently. Since there is no prior work about handover schemes for multi-channel hybrid ad hoc networks, we evaluated the performance of the proposed two types of handover schemes. We analyzed and compared the performance of the case when only the forced handover is used with the case when both handovers are cooperatively used. The simulation results showed that the optimized handover helps ad hoc nodes to achieve better performance in terms of the average packet delay and packet delivery ratio, especially when the mobility of node is high.

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