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A Handoff Solution in Wireless Mesh Networks by Implementing Split Channels

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***Abstract*— Seamless handoff support is an essential issue to ensure continuous communications in wireless mesh networks (WMNs). Due to the existence of multi-hop wireless links, traditional handoff schemes designed for single-hop wireless access networks can hardly guarantee the low handoff latency requirement in WMNs. Existing solutions on reducing the handoff delay in WMNs ignore one important factor for the long handoff delay: the channel access delay of handoff signaling packets over the multi-hop wireless mesh backbone network. In this paper, we address the seamless handoff issue in WMNs from a different perspective and propose a channel splitting strategy to reduce the channel access delay of handoff signaling packets over multi-hop wireless links. Based on the proposed channel splitting strategy, the handoff procedures and two transmission strategies for scheduling the delivery of handoff signaling packets are designed. Simulation results show that using the proposed channel splitting strategy, the handoff delay requirement in WMNs can be guaranteed regardless of the background data traffic, and the channel throughput can also be improved.**

***Index Terms*— Wireless mesh networks, handoff, Mobile IP, channel splitting.**

I. INTRODUCTION

Wireless mesh networks (WMNs) have emerged to be a promising cost-effective solution for providing large-scale wireless Internet access [1]. A WMN is composed of a combination of static mesh routers (MRs) and mobile mesh nodes (MNs). MRs form a wireless multi-hop backbone network. Some MRs, called gateway MRs, are connected to the Internet via wired links and serve as the Internet entry points to other mesh routers via single-hop or multi-hop wireless links. MNs access the network via a mesh router which serves as the wireless access point (AP).

This paper focuses on the handoff design in WMNs. When the movement of an MN causes its attachment point change in the Internet, i.e., the MN accesses the Internet via a different gateway, the complete handoff process may include two steps: the link-layer handoff and the network-layer handoff. For mobile users, seamless handoff support is an essential issue to ensure continuous communications. If the total handoff delay is short enough, the movement of MNs is transparent to applications. However, the low handoff latency in WMNs can be hardly guaranteed using traditional handoff schemes designed for single-hop wireless access networks. The existence of multi-hop wireless links in the mesh backbone network can degrade the throughput significantly due to the delay of channel access over multi-hop links [2, 3], which was not a problem in the conventional handoff management design. Hence, this multi-hop wireless transmission in WMNs increases the transmission delay of signaling messages during a handoff process. As a result, it increases the total handoff delay in WMNs.

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Existing solutions on reducing the handoff delay in WMNs mostly focus on shortening the link-layer channel scanning delay [4], optimizing the Mobile IP [5] protocol for better network-layer handoff support [6], and improving the multi-hop routing in the mesh backbone [7]. However, they ignore one important reason for the long handoff delay in WMNs: the channel access delay caused by the contentions between handoff signaling packets and data packets at each mesh router connecting an MN to the Internet. Considering this point, we address the seamless handoff issue from a different perspective and propose a channel splitting strategy to split each channel in the wireless mesh backbone into two channels: a data channel and a control channel. The data channel is used to transmit data packets, while the control channel is specialized for delivering handoff signaling packets and other control packets. Although such channel splitting method has been proposed previously [8, 9], it has not been well designed to reduce both the link-layer and network-layer handoff latency in WMNs. In our proposed handoff design, data packets and signaling packets are delivered in separate channels. They do not interfere with each other, thereby the handoff latency can be maintained within a certain level regardless of the background data traffic. In addition, the design of the control channel bandwidth is based on the average size of signaling packets without causing channel congestion or under utilization.

The rest of this paper is organized as follows. In Section II, related work is introduced. In Section III and Section IV, our proposed channel splitting strategy for handoffs is described. In Section V, OPNET [10] simulation results are given, followed by the conclusions in Section VI.

II. RELATED WORK

Various solutions on WMN handoff management have been proposed to optimize the handoff process in order to shorten the handoff latency [11]. [12] points out that the channel scanning delay accounts for more than 90% of the overall link-layer handoff delay. Hence, different link-layer handoff schemes are proposed on improving the channel scanning process to reduce the link-layer handoff delay [13, 14]. [15]

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designs a flat routing protocol which is triggered by an MN's reassociation to decrease the overall handoff latency. [16] allows MNs to probe the neighboring APs by accessing the common control channel to shorten both the probe delay and the authentication delay. [17] introduces the concept of temporary IP addresses to shorten the delay of applying a new Care-of Address. [6] presents a new WMN mobility management scheme to reduce the signaling cost as well as to shorten the handoff latency. [7] provides a solution to reduce the route discovery delay in the WMN network-layer handoff. [18] uses more than one AP to handle the moving clients to realize fast handoffs in WMNs.

To sum up, existing WMN handoff schemes do not consider to resolve the wireless channel access contentions between handoff signaling packets and data packets during a handoff process. Hence, the handoff delay can be very long during the network-layer handoff, which generates handoff signaling traffic that needs to be delivered over the multi-hop wireless mesh backbone.

In this paper, we propose a channel splitting strategy to address the above unconsidered issue. The contribution of our work mainly lies in the following points:

- Designing a channel splitting strategy to shorten both the link-layer and network-layer handoff latency;
- Proposing two designs for the splitting channel medium access control (MAC) in the wireless mesh backbone network to improve the performance of both handoff and data throughput;
- Evaluating the performance of the improved designs using OPNET simulations.

III. Proposed Handoff Procedures Based on Channel Splitting

In WMNs, network-layer handoff signaling packets, including the signaling messages for obtaining a new IP address for the MN (e.g., *Agent Solicitation, Agent Advertisement*), finding a new route to the new gateway, and updating the new IP address, are transmitted over the mesh backbone with data packets in the same backhaul channel in the traditional design. In this scenario, signaling packets compete with data packets for the same wireless resources. Therefore, the more data packets in the mesh backbone, the more possible collisions between the two types of packets, which results in longer handoff delay. In addition, the contention of the two types of packets in the same channel results in collisions, thereby increasing the transmission delay of both packets.

In order to solve the above problem, we propose that data packets and handoff signaling packets are transmitted separately in their own channels. Since there is no collision between data packets and signaling packets by using different channels, it is possible to achieve lower handoff latency and higher channel throughput. In the traditional design, every AP located in WMNs has two wireless channels: one serves as the access channel supplying the wireless interface to MNs; the other is the backhaul channel providing connections to the mesh backbone. In our design, the access channel remains the same but only for the transmission of data packets between an MN and an AP. The backhaul channel is split into two channels: a data channel and a control channel, which are configured with two transceivers. The data channel only serves for the mesh backbone but is specialized for the transmission of data packets. The control channel serves for both the wireless access and the wireless mesh backbone and is only responsible for the transmission of signaling packets. Hence, when an MN performs a handoff, it can use this backbone control channel as an access control channel to communicate with its new AP and new gateway. Based on this channel splitting design, we propose (1) selective control channel scanning to reduce the link-layer handoff delay and (2) separate channel transmissions to shorten the network-layer handoff delay.

When an MN moves between different APs, it needs to know the control channel information of the possible APs it may be handed off to. To address this issue, we propose that APs are configured with a control channel list containing the control channel information of neighboring APs, which can be provided to an MN in a handoff signaling message. Since MNs are often configured with only one transceiver, the data transmission and handoff process at an MN cannot be executed at the same time. However, MRs deployed in the WMN has two split backhaul channels. We propose two improvements for the overall handoff process, as compared to the traditional method: (1) By using the selective control channel scanning, the total channel scanning delay can be reduced in the link-layer handoff; (2) both the link-layer and network-layer handoff signaling traffic is delivered in a separate control channel in the wireless mesh backbone without competing with the data traffic.

Fig. 1 shows our proposed handoff procedures in IEEE 802.11-based WMNs, based on extending the Mobile IP scheme to multi-hop wireless networks, using the channel splitting strategy. When an MN detects that the RSS (Received Signal Strength) is less than a threshold RSS_thr, it sends a *Handoff Request* message to its current AP informing that it needs a handoff. Having received the *Handoff Request* message, the AP sends a *Handoff Reply* message to the MN containing the control channel information of the surrounding APs. The number of the channels in the list is less than the total number of available channels. Then, the MN first switches its transceiver to one of the channels in the control channel list. After sensing the control channel idle, the MN broadcasts a *Probe Request* message and starts the *ProbeTimer* simultaneously. When the *ProbeTimer* expires, it continues to scan the next control channel in the list. After finishing scanning all channels in the list, the MN processes all the received *Probe Request* messages to choose the AP with the best RSS value as its new AP. Then, the MN switches its transceiver to the control channel of the new AP and continues to proceed the authentication and reassociation process as in the traditional design. To get a new Care-of Address, the MN sends an *Agent Solicitation* message to the new AP, which replies an *Agent Advertisement* message containing the new IP address. After getting the new IP address, the MN first finds an available route to the new gateway using the multi-hop routing protocol adopted in the mesh backbone and then sends a *Registration Request* message which is delivered through the split control channel by mesh routers in the wireless mesh backbone to the home agent (HA). When getting this *Registration Request* message, the HA updates the binding information of the MN and sends a *Registration Reply* message to the MN. When receiving the *Registration Reply* message, the MN switches its transceiver to the access channel of the new AP. Finally, the HA forwards all the data packets through the split data channel to the MN's new Care-of Address.

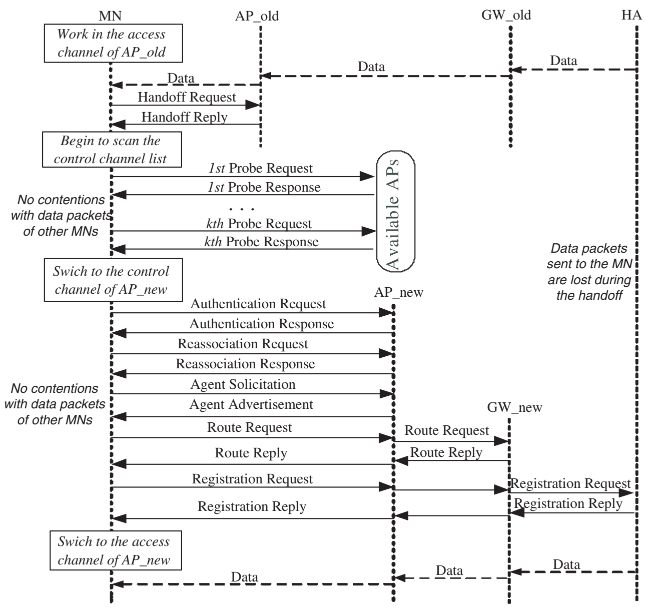


Fig. 1. Proposed handoff procedures when an MN has one transceiver.

To sum up, as shown in Fig. 1, the MN only probes the channels in the list to determine the new AP, so its probe delay can be reduced. Since there is only one backhaul channel in the same WMN, the MN only needs to probe one channel when it moves inside the WMN. In addition, since the handoff signaling packets are delivered in a separate control channel, the channel access contentions between the handoff signaling packets and data packets of other MNs are eliminated during both the link-layer handoff and the network-layer handoff.

IV. Proposed MAC Design in the Wireless Mesh Backbone Based on Channel Splitting

In the previous section, we proposed a channel splitting strategy such that the handoff signaling packets are delivered through a split control channel in the wireless mesh backbone. Since the IEEE 802.11 CSMA/CA based MAC protocol does not provide an effective solution to multi-channel models, it is necessary to find an efficient mechanism to schedule the delivery of data and signaling packets. In addition, the split channel designs proposed in [8, 9] are inefficient for MRs with two transceivers, because when the traffic load in the control channel is very high, the RTS/CTS of data packets cannot be transmitted in time in the control channel, which results in long idle periods in the data channel. In this section, we propose two MAC designs for the scheduling of the transmissions of data and signaling packets. We assume that data packets are transmitted based on the IEEE 802.11 CSMA/CA access mechanism with the RTS/CTS option.

A. Non-related Channel Transmission

In this design, both the reservation and the transmission process of data packets are carried out in the data channel. The control channel is only used to carry handoff signaling packets, such as *Agent Solicitation*, *Agent Advertisement*, *Registration Request*, and *Registration Reply*. As shown in Fig. 2, the contention to the control channel is only among the signaling packets and all the data packets only compete in the data channel. Therefore, the two types of packets no longer affect each other. This method is applicable to the situation that the total number of handoffs in the WMN is high and a separate channel is required to deliver the high volume of signaling packets to guarantee the handoff delay. On the other hand, if both channels are always saturated, a high network throughput can be achieved.

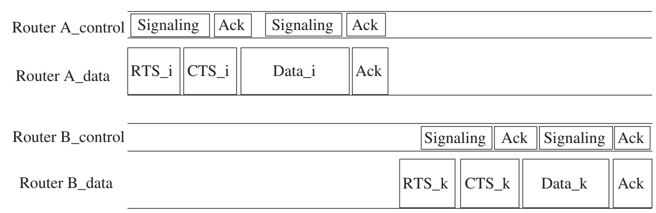


Fig. 2. Non-related channel transmission.

B. Combined Channel Transmission

In this design, mesh routers can determine whether to deliver the RTS/CTS of data packets in the control channel or in the data channel, thereby improving the overall channel utilization. To realize this design, three Network Allocation Vectors (NAVs) are proposed for all MRs in the scheduling of data packet transmission: *NAV_data*, *NAV_control*, and *NAV_backup*. *NAV_data* is maintained for the data channel containing the expiration time of the data channel busy state, which is dynamically updated when receiving RTS/CTS in both channels. *NAV_control* is obtained from the RTS/CTS transmitted in the control channel, which provides the time required for the next data packet transmission. *NAV_backup* is used to save the value of *NAV_data* before it is updated. In addition, in the data channel reservation process, receiving the CTS of a data packet in the control channel can be considered as the end of the channel reservation, so a *reserved_flag* is used to determine whether the next data channel transmission has already been reserved or not. Furthermore, in order to avoid idle periods in the data channel, the reservation should be finished before the completion of the current data transmission. Fig. 3 shows that Router A and Router B with the same data channel and control channel can determine whether to deliver the RTS/CTS of data packets in the control channel or in the data channel dynamically according to the current

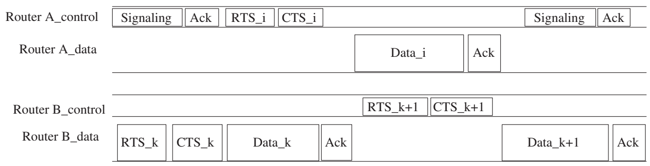


Fig. 3. Combined channel transmission.

channel status. The protocol details of the combined channel transmission are shown in Algorithm 1, 2, and 3.

In conclusion, this design can utilize the data channel with high efficiency, because the time required to reserve the data channel is consumed in the idle period of the control channel. Therefore, the RTS/CTS overhead in the data channel is reduced and the overall channel throughput is improved. However, it may be unfair to signaling packets, because it brings more contentions in the control channel, as compared to the non-related channel transmission design. Therefore, this design can be applied to the WMN where the handoff traffic volume is low, leaving sufficient idle periods on the control channel for the data channel reservation.

Algorithm 1 MRs which want to transmit a data packet

If (*data_channel_idle*)
  Send RTS containing *NAV_data* in the data channel
Else If (*data_channel_busy* **and** *control_channel_idle*)
  and (*reserved_flag* == FALSE)
  and (*NAV_data* - *current_time* > *reservation_time*)
  Send RTS containing *NAV_control* in the control channel
Else
  Wait until *NAV_data* expires
  Send RTS containing *NAV_data* in the data channel
Endif

Algorithm 2 MRs already sent RTS in the control channel

If (*reserved_flag* == TRUE)
  Wait until *NAV_data* expires
  reserved_flag = FALSE
  Transmit the data packet in the data channel
Else
  Wait until CTS containing *NAV_control* is received
  reserved_flag = TRUE
  Wait until *NAV_data* expires
  reserved_flag = FALSE
  Transmit the data packet in the data channel
Endif

Algorithm 3 Other MRs with the same backbone channel

If RTS containing *NAV_control* is received
  NAV_backup = *NAV_data*
  NAV_data = *NAV_data* + *NAV_control*
Endif
If CTS containing *NAV_control* is received
  NAV_backup = *NAV_data*
  NAV_data = *NAV_data* + *NAV_control*
  reserved_flag = TRUE
Endif
If *NAV_backup* expires
  reserved_flag = FALSE
Endif

V. PERFORMANCE EVALUATION

In this section, we assess the performance of the MAC designs proposed in Section IV using the OPNET [10] simulator. Since OPNET 14.5 does not provide multi-transceiver wireless router models, we implement new wireless router models to support our proposed MAC designs. In the simulation, APs and MRs are configured with three and two wireless transceivers, respectively, and each transceiver has one IP address.

We first compare the network performance with different bandwidth ratios of the split data channel to control channel. In the simulation, two wireless hops with 33% background data traffic from the AP of the MN to the gateway are implemented in the WMN. As shown in Fig. 4, when the bandwidth ratio of the data channel to control channel is greater than 7 : 3 and less than 9.5 : 0.5, the tradeoff between the total handoff delay and data packet end-to-end (ETE) delay can be well balanced. However, in order to maximize the data traffic capacity in the mesh backbone, it is reasonable to allocate more bandwidth to the data channel, if the total handoff delay is not compromised. Based on this analysis, the channel bandwidth ratio of 9 : 1 is implemented in our channel splitting strategy in the simulation.

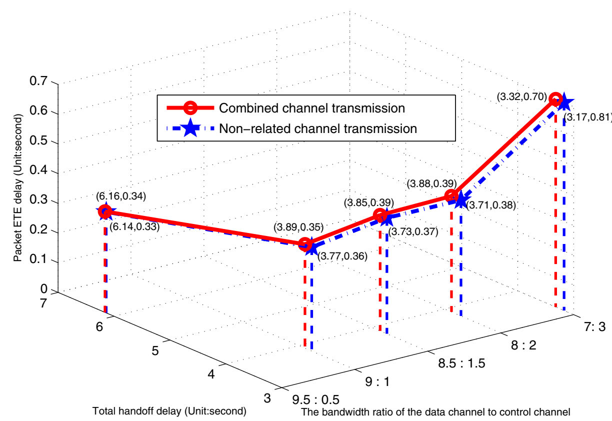
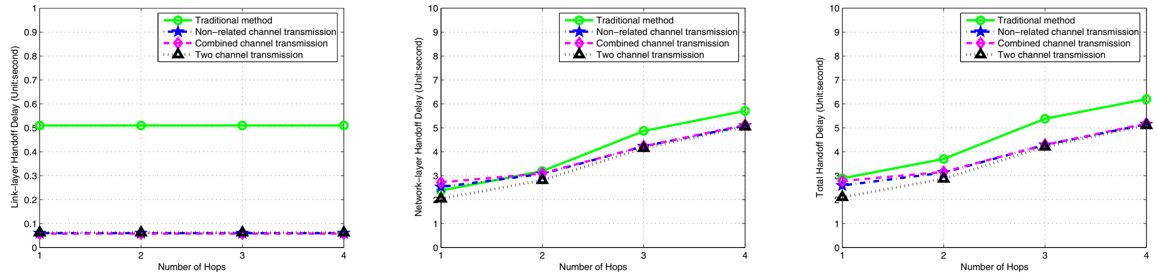


Fig. 4. Performance with different split channel bandwidth ratios.

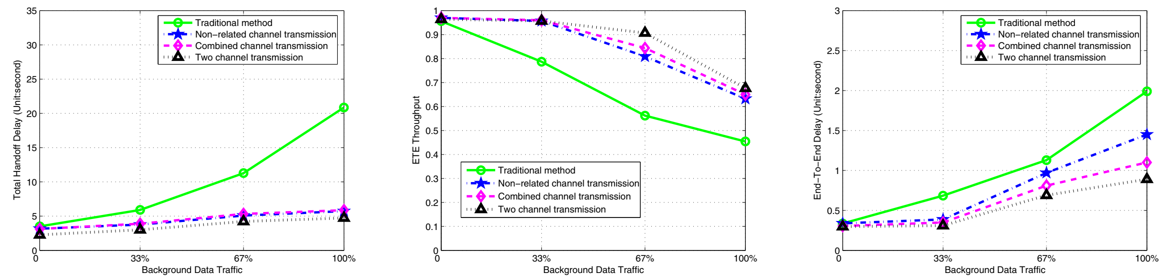
Fig. 5 shows the link-layer, network-layer, and total handoff delay under different number of hops between the AP of the MN and the gateway with no background data traffic. In Fig. 5(a), since an MN only scans one access control channel during the link-layer handoff using the channel splitting strategy, the link-layer handoff delay is significantly reduced, as compared to the traditional single-channel method. Fig. 5(b) shows that the network-layer handoff delay can also be decreased using the improved designs in the no background traffic environment. Fig. 5(c) shows that since the network-layer handoff delay accounts for a large percentage in the overall handoff delay, our proposed channel splitting strategy can reduce the overall handoff delay.

Fig. 6 demonstrates the handoff performance in two-hop WMNs with different percentage of background data traffic. As shown in Fig. 6(a), the handoff delay sharply increases along with the background data traffic under the traditional single-channel handoff design. However, it can be maintained within a stable range under our channel splitting design. In other words, the handoff delay is relatively independent of the background data traffic volume under our proposed channel splitting design. In addition, the handoff delay under the two-



(a) Link-layer handoff delay (b) Network-layer handoff delay (c) Total handoff delay

Fig. 5. Handoff delay in WMN with no background traffic.



(a) Total handoff delay (b) ETE throughput (c) ETE delay

Fig. 6. Handoff performance with background data traffic in two-hop mesh backbones.

channel design has no big difference from our channel splitting design. This is because when the background traffic volume is high, the main reason for the long handoff delay is the channel access delay, not the channel bandwidth. Fig. 6(b) and Fig. 6(c) show that the data packet ETE throughput and ETE delay can also be improved by using the channel splitting design.

VI. Conclusion

In this paper, a channel splitting strategy is proposed to improve both the link-layer and network-layer handoffs in WMNs. We proposed handoff procedures using the channel splitting strategy. In our design, the time for the link-layer channel scanning process can be reduced and the contentions between handoff signaling packets and data packets in the multi-hop wireless mesh backbone is eliminated. In addition, we proposed two transmission strategies in the wireless mesh backbone: non-related and combined channel transmission. OPNET simulation results show that the handoff delay, ETE data throughput, and ETE delay can be improved by using the proposed channel splitting strategy.

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