A New Data Buffering Moment for Seamless Hand-off in Wireless Mesh Networks

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Abstract

Layer-3 mobility is a superset of Layer-2 mobility. An 802.11-enable client must perform Layer-2 hand-off before it can begin that of Layer 3. Most of existing works use Re-association event in discovery phase of Layer-2 hand-off to not only trigger Layer-3 hand-off but also buffer the data to reduce the packet loss during the roam. However, the problem is that mobile users can not receive from its current master while it is on scanning status for both active and passive mode. If the scanning time is long, the on-going applications will experience the throughput degradation. In the worst case, they will be dropped. We propose that data should be buffered when the MC sends De-association event to break the Layer-2 association to its current master and start for looking for a new one. This can make sure to cut the packet loss to zero at the cost of higher memory usage. With the support of fast Layer-2 hand-off using selective scanning algorithms, the memory usage can be improved significantly to an acceptable value. The performance analysis shows that our proposal has a very smooth throughput in hand-off time compared to existing works with different data buffer moments.

1. Introduction

Wireless Mesh Network (WMN) is a promising technology for several commercially interesting applications such as broadband home networking, community networks, intelligent transportation systems and etc. WMNs have several significant advantages, including increased reliability, low installation costs, large coverage area, and automatic network connectivity [1] [2]. There are two kinds of physical devices in a typical WMN: *Mesh Routers* (MRs) and *Mesh Clients* (MCs). MR is also called Routing Access Point (RAP) which is rarely mobile and may not have power and memory constraints. MRs are ad-hoc like connected to form a *network back-bone*. They also work as the APs (in WLANs) that serve Mesh Clients. A small subset of them is required to attach to a wired network and operate as Gateways to Internet (IGW-Internet Gateway or GRAP-Gateway RAP). MCs, either stationary or mobile, can get network access through it serving MR. An MC should be able to move out of its current MR's coverage and associate to a new one with minimum hand-off time to reduce as much as possible the packet loss that can degrade significantly the performances of its current applications. A typical WMN with MRs and MCs is shown as Figure 1.

In general, the hand-off process in WMNs is similar to that of WLANs. It includes two phases: Layer-2 hand-off

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WLANs) [3] [4]. Many of existing works have been conducted to reduce the hand-off latency in both Layer-2 and Layer-3 in WLANs. Most of them can not be applied directly to WMNs due to differences in characteristics of two kinds of networks. APs are considered Layer-2 devices and work independently while MRs work like real routers, maintaining routing tables and running routing protocols. The capability of peer communication among MRs permits WMNs to fulfill a seamless hand-off more effectively than WLAN. Each MR will construct a table context that is helpful for a hand-off process and transfer the table to its neighboring MRs. Whenever a MC joins a MR, it will receive a context table from that MR and just analyze the information in it in case it needs to initiate a roam.

Layer-3 hand-off is taken place right after Layer-2 hand-off. Thus, using Layer-2 event to trigger Layer-3 hand-off process should be promoted. There are a couple of moments we should take into consideration as the trigger such as De-association event and Re-association event. The former is used to trigger the layer-2 hand-off and start doing probe to look for a new available AP and the latter is trigger layer-3 hand-off. *Re-association event* which MC initiates to leave its HA is rational to take into account. In our paper, we raise a new issue to support seamless Layer-3 hand-off for WMNs. When is the correct moment to buffer data? All the current works choose the moment when old MR receives the re-association event from MC through the new MR. However, the problem is that MC can not receive data from the currently associated MR while it is on channel scanning status for both active and passive mode. If the scanning time is long, the current applications will experience throughput degradation. In the worst case, they will be dropped. We propose that data should be buffered when the MC sends *De-association event* to break the Layer-2 association to its current MR. This can make sure to cut the hand-off latency to zero at the cost of higher memory usage. With the support of low Layer-2 hand-off latency, the memory usage can be reduced significantly to an acceptable value for MRs.

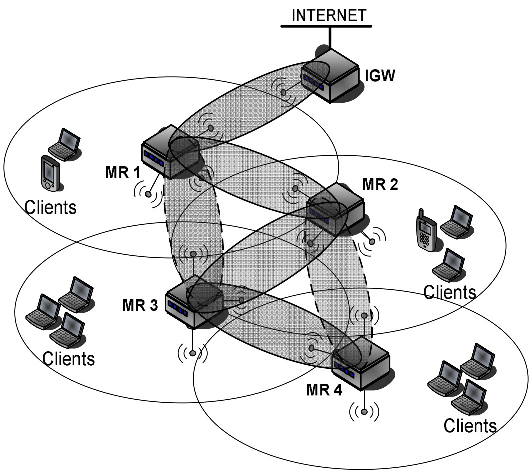

Figure 1. A Probing process in the IEEE Standard 802.11

The rest of this paper is organized as follows: Section 2 presents the basic characteristics of the IEEE 802.11 hand-off process. Section 3 lists related works that inspire our ideas. Section 4 introduces network models and assume-ptions necessary for our analysis. Section 5 depicts our proposed scheme for Seamless Hand-off in WMNs. Section 6 studies the performance of our proposed scheme through experiments. Section 7 concludes the paper.

2. Typical IEEE 802.11 roaming

There are two forms of roaming in wireless network: seamless roaming and nomadic roaming. Seamless roaming is the best analogized to a cellular phone call. Yet as you roam, you do not hear any degradation to the voice call. On the contrary, nomadic roaming is different from seamless roaming. It is best described as the use of 802.11-enable laptop in an office environment. The client will break its connectivity to current AP right before the move and resume it after associating with the new AP. However, nowadays seamless hand-off is really a need in 802.11 due to the emerging of IP-based real time application such as VoIP, video on demand, ect. For an example, a hand-off completed in less than 50ms provides a VoIP user not only a continuous conservation but also an unnoticeable transition of the call [5] [6].

A hand-off process in 802.11 Hand-off involves in both Layer 2 and Layer 3 and is carried out by a sequence of messages exchanged between an AP and a roaming user.

1. Layer 2-Hand-off Process

The complete Layer-2 handoff process is typically comprised of a sequence of decisions [4]:

a) Decision on when to roam- How to determine a good moment to initiate a hand-off is not defined in IEEE 802.11 standard. The vendors implement roaming algorithms for their own products. Some factors such as Signal to Noise Ratio (SNR), frame acknowledgement and missed beacons, are usually taken into consideration for the algorithm. The roaming algorithms must balance between fast roam time and client stability. For example, an extremely sensitive roaming algorithm might not tolerate a missed beacon or missed acknowledgement frame. The algorithm might view these occurrences as degradation in signal and initiate a roam. But it is normal for such occurrences in a BSS, and as a result, a stationary station might roam, even though it is stationary.

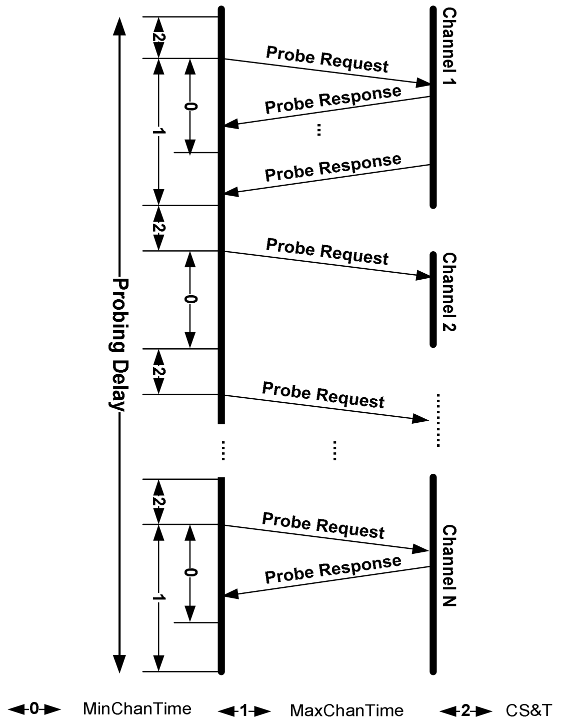

Figure 2. A Probing process in the IEEE Standard 802.11

b) Decision on where to roam- The MS must figure out a suitable AP, breaking its connection with the current AP before associating with the new one. We call it "*break before make*" [4]. Active scanning is the most thorough mechanism used to find an AP. As the name suggests, the MS sends *probe request* on each channel and receives responses from available APs. The detailed active scanning procedure is as follows [7] [8] [9]:

- The MC broadcasts a probe request frame, sets a probe timer and waits for probe responses.
- If no response has been received within *MinChannelTime*, the next channel is scanned.
- If one or more responses are received within $Min-ChannelTime$, the timer is extended to $Max-ChannelTime$ for getting all possible probe responses.
- The above steps are repeated for the next channel. $CS\ \&\ T$ (Channel Switching and Transmission Over-head) is considered as channel switching time.

The probe delay T therefore can be approximated as follow:

$$N \times MinChannelTime \le T \le N \times MaxChannelTime$$

where N is the number of channels available (Figure 2).

The most intuitive method for reducing the probe delay is to reduce the number of channels to be probed. Namely, the probe delay can be reduced by probing only selected channels rather than all channels. Another method is to refine the *MinChannelTime* and *MaxChannelTime* values for the purpose of reducing the channel waiting time.

c) Decision on initiating a roam- The station uses 802.11 *re-association frames* for associating with a new AP. The procedure includes *re-authentication* and *re-association*. Authentication is a process in which the AP either accepts or rejects the identity of the MS. Once a successful authentication has been accomplished, the MS can send a re-association request frame to the new AP, which then replies with a re-association response frame containing an acceptance or rejection notice. Re-authentication is illustrated in Figure 3.

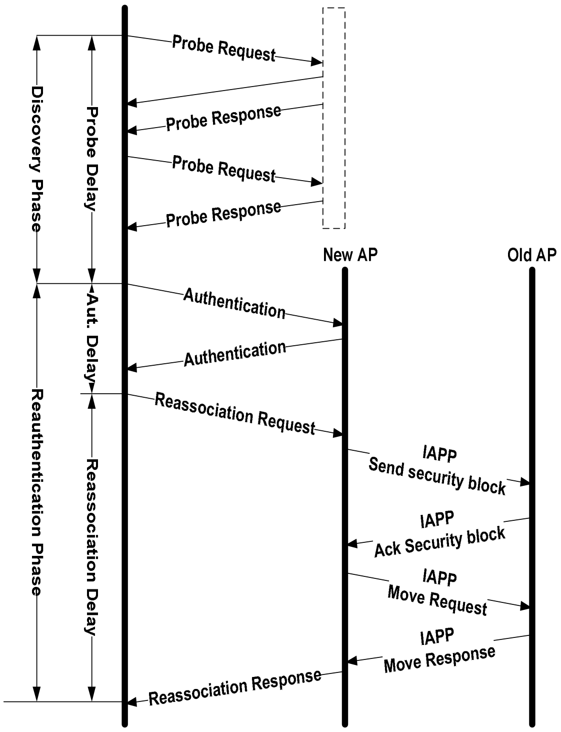

Figure 3. Re-authentication phase in IEEE 802.11 Layer-2 Hand-off.

2. Layer 3-Hand-off Process

Mobile IP is a big support for IEEE 802.11 hand-off process. Accordingly, an 802.11-enabled client has to perform Layer-2 roam before it can begin a Layer 3 roam. Layer-3 roaming process as shown in Figure 4 involves the following steps:

- An MS is communicating with its CN (Correspondent Node) while it is roaming from AP1 to AP2 which are located in different domains (or different subnets).
- Whenever the MS detects the presence of the FA (Foreign Agent), it registers with FA to get the CoA (Care of Address) from it.
- The FA then negotiates with the HA (Home Agent) to establish a Tunnel between them.
- Packets destined to MS are forwarded to the HA, getting through the Tunnel to FA and reaching their destination (dash line numbered 1).
- The route from MS to CN will be decided by FA. It can use the old route by employing "reverse tunnel" mode or set up a new route directly to CN (dash line numbered 2).

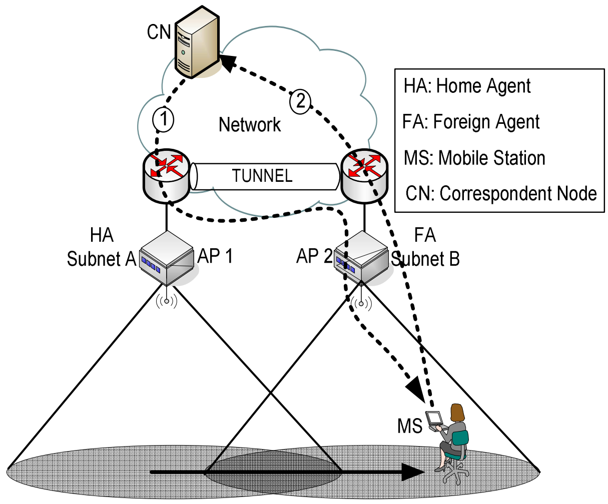

Figure 4. A typical terms for Layer-3 roaming process

Tunneling in Mobile IP is synonymous with encap-sulation. Tunneling allows two disparate networks to connect directly to one another when they normally would not or when they are physically disjointed. This capability is key for Mobile IP because tunneling is what allows the HA to bypass normal routing rules and forward packets to the MN.

3. Related work

Mobile IP [10] and Mobile IPv6 [11] describe IP mobility management schemes that are widely used in wired network supporting IP. Each Mobile Host adheres to a HA which works as an indirection point to destine the packets for the MH in FA. Mobile IP has two major problems. First, it adopts periodic signaling messages to trigger the Layer-3 hand-off. Second, when the MH is far away from the HA, even though it moves from one FA to the next that is nearby, the hand-over latency can be very large since the HA is involved.

The second disadvantage of Mobile IP can be solved with enhanced schemes such as HAWAII [13] and Cellular IP [14]. Instead of using a macro-mobility management protocol such as Mobile IP for each local movement, the new schemes localize mobility signaling messages to handle local movement in WMN domain. By introducing a Gateway Foreign Agent (GFA) for each domain, they hide the mobility related signaling messages within one domain.

However, the first drawback is left unsolved.

Different from wired network where the hand-off process almost happens at Layer 3, a hand-off process in WMNs includes both that of Layer-2 and Layer-3. Layer-3 hand-off is taken place right after Layer-2 hand-off. Thus, using Layer-2 event to trigger Layer-3 hand-off process should be promoted. *Re-association event* which MC initiates to leave its HA is rational to take into account in some existing work [12] It is really intuitive because re-association event is considered as Layer-3 trigger sign. However, that moment faces a big disadvantage when Layer 2 hand-off latency takes so long.

4. Network models and assumptions

Multi-channel approach using multiple radios is applied at each MR to lessen potential co-channel interference. Accordingly, non-overlap channel is assigned to two MRs which are within the interference range of each other. Because the number of interfaces per node is limited, each node typically used one interface to communicate with multiple of its neighbors. In our paper, we assume that each MR is equipped with two radios: one for communicating in the back-bone network, i.e., with other peer MRs using ad-hoc mode while the second radio is used to serve MCs. We also call the second one serving channel.

Probing is a dominating factor in hand-off latency, accounting for 90% of the overall hand-off time. Probing time is subject to the total number of distinct channels N being selected to probe. A mechanism to construct a dynamic Neighbor Graph (NG) is applied at each node. Based on NG, a node can be aware of network context by exchanging the update information with its neighbors. That helps to limit the number of scanned channel the MC has to do in scanning phase. Accordingly, the Layer-2 hand-off latency can be reduced significantly. To do that, each MR maintains a Neighbor Context Table NCT) which is updated by periodic local broadcast hello messages or event-driven triggers. Events include the changes in neighbors' serving channel, neighbor adding or deleting action and neighbors' configuration adjustments. Whenever a new MC joins the MR, it will receive the NCT from its serving MR and just use it for roaming decision.

5. Seamless IEEE 802.11 Hand-off

Compared to conventional approaches such as Mobile IP, HAWAII or Cellular IP which use periodic signalling messages to trigger Layer-3 hand-off process, MAC layer associate event can do that more efficiently. Layer-2 trigger is more accurate but consumes no extra bandwidth. However, the general terms of Mobile IP is kept in most of the work.

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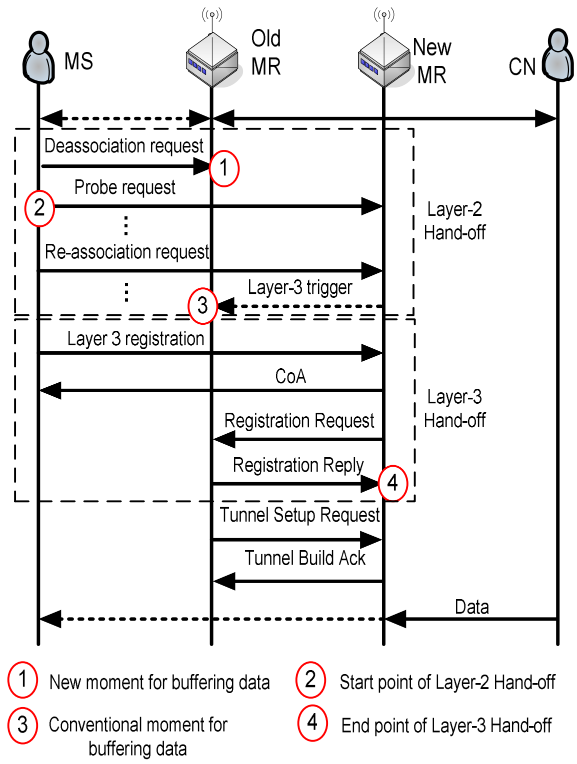

Figure 5. Layer-3 Hand-off process with different buffering data moments.

6. Performance Analysis

In this section, we have conducted a couple of experiments to evaluate the operation and performance of our proposal.

Eeach MR (a typical desktop PC) is equipped with two 802.11b wireless network interface cards. One card operates in ad hoc mode to form a mesh network back-bone. The other is on master mode to serve its mobile users or MCs. We considered a topology like Figure 6 with four MRs, namely MR1, MR2, MR3 and MR4, running ad-hoc mode on the same channel (channel 11). Every MR has two neighbors. Two neighboring MRs use non-overlap channels (channel 1 and channel 6) on for their master modes. MR4 is physically connected to a server that is considered as CN node. The CN is running a voice application with a MC (a laptop) moving in the roaming domain formed by the four MRs.

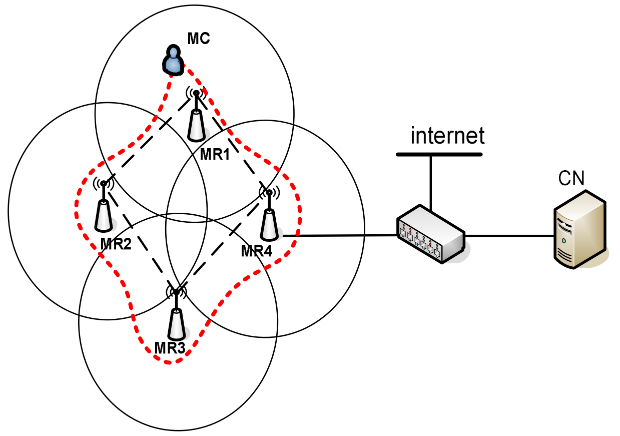

Figure 6. The mesh network testbed topology

An ftp application runs between the MH and the CN in three scenarios. The first two scenarios are employed Layer-2 hand-off with context-aware using NGs. The difference between them is the moment to trigger the buffering data: De-association event trigger (introduced in our proposal) and re-association event trigger (proposed in existing works). The third scenario is simply employed typical Mobile IP using signalling message trigger.

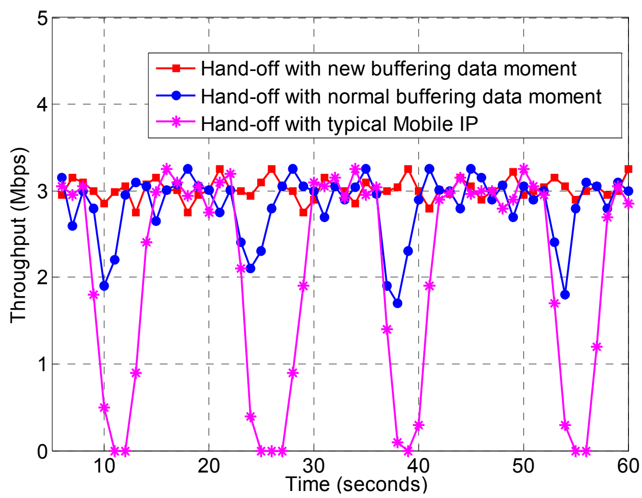

Figure 7. TCP throughput observed at CN node.

As can be seen in the Figure 7, our proposal (Hand-off with new buffering data moment) can offer real seamless hand-over. It can cut the packet loss to zero during each hand-off event. If we buffer data on receiving re-association event (Hand-off with normal buffering data moment), the packet loss occurs considerably in hand-off time, specifically in scanning phase as we described in section V. In the third scheme (Hand-off with typical Mobile IP), the throughput reaches zero in hand-off time due to large latency (up to a few seconds) due to Layer-3 hand-off signalling trigger that introduces much delay. However, our seamless hand-off scheme has to pay a cost of memory usage.

7. Conclusion

In this paper, we described and evaluated an enhancement for seamless IEEE 802.11 standard hand-off in WMNs. It is the new data buffering moment to cut the packet loss in hand-off process to zero at the cost of memory usage. However, our proposal just works much effectively when we apply selective scanning algorithm to reduce Layer-2 hand-off latency. From the experimental, we conclude that our scheme works well towards our proposed goals.

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