A Novel Handover Scheme for Improving the Performance of WLANs

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Abstract

Recently, wireless LANs have become popular and more widely used. New technologies to improve WLAN provide high data rates and support for real-time services such as Voice over WLANs (VoWLAN), e-conference, and e-learning. However, performance is another important issue to be addressed in order to avoid bottleneck problems and support for real-time services. In this paper, we present a plan to improve network efficiency by reducing latency time in the handover process and balancing the traffic load in a wireless network. We eliminate the need for both the detection phase and the search phase in the conventional handover scheme by proposing a proactive scan phase, which works during normal connectivity. In the proactive scan phase, the mobile station (STA) will scan for information from the neighbor access points (AP) using the active scan mode, which is used to decide whether or not to perform a handover. The handover process begins when the STA finds a neighbor AP that can provide higher quality than the current AP and/or when the signal quality of the current AP falls below a certain threshold. The results from our simulation show that the proposed handover scheme is more effective than the conventional one in terms of providing a handover process with low latency and shared traffic load with a neighbor AP.

Keywords: *handover; handoff; wireless LANs; 802.11*

1. INTRODUCTION

Wireless Local Area Networks (WLANs) based on the IEEE 802.11 standard are now becoming popular and widely used for mobile internet services. Since 2002, NTT Communications Corporation has launched hotspot WLAN service in many places, including train stations, airports, hotels, and coffee shops, that provides mobile access to the internet via laptop computers and personal digital assistants (PDA). These hotspots enable users to enjoy broadband internet access in wireless environments. In the near future, voice-based applications will be developed as a catalyst for continuous mobility in wireless networks such as Voice over WLAN (VoWLAN), e-conference, and e-learning.

Supporting real-time applications with continuous mobility implies that the total latency (layer 2 and layer 3) of the handover process must be fast. Specifically, the overall latency should not exceed 50ms to prevent excessive delay and jitter. Unfortunately, the vast majority of IEEE 802.11 based networks do not currently meet this goal. Recent research [14] by Koodli shows that layer 2 latencies contribute to approximately 90% of the overall latency, which exceeds 100ms, while handover-related latencies in layer 3 have an average of 15.37ms [5].

To accomplish this handover latency time issue, we propose a novel handover scheme to improve wireless network efficiency by reducing the latency time in layer 2 and balancing the traffic load. In this scheme, we reduce delay time in the detection phase and in the search phase by means of a proactive scan phase that works during normal connectivity. This phase will scan for information from neighbor APs, which will be compared with the current AP to decide whether or

Based on "A Novel Handover Scheme for Reducing Latency in WLANs", by T.MANODHAM et al., which appeared in the Proceedings of the IEEE Vehicular Technology Conference, VTC 2005 Fall, Texas, USA, September 2005. © 2005 IEEE.

not to start the handover process. The STA will start the handover process when it finds a neighbor AP that can provide higher performance than the current AP and/or when the signal strength from the current AP is lower than the threshold. We will analyze the increased traffic load in the STA and the AP from the proactive scan phase that might affect the performance of the wireless network. Our approach does not require any special network devices such as a special network system or base station. Instead, the STA needs only to update the firmware to support this novel handover scheme.

The rest of the paper is organized as follows. The next section describes the conventional handover procedure, handover issues, and related work. Section 3 presents the advantage and disadvantage of the proposal. Section 4 analyzes the simulation of the proposed handover scheme and its results. The paper concludes in Section 5.

2. HANDOVER PROCEDURE

The handover process is a function or process that refers to the mechanism or sequence of messages exchanged by the AP and the STA that result in a transfer of physical layer connectivity and state information from one AP to another with respect to the STA in consideration. In IEEE 802.11, the conventional handover process is a type of hard handover [1], and as described in [3] the process has been divided into three phases: detection, search, and execution (see Fig.1a). These phases are explained in more detail below.

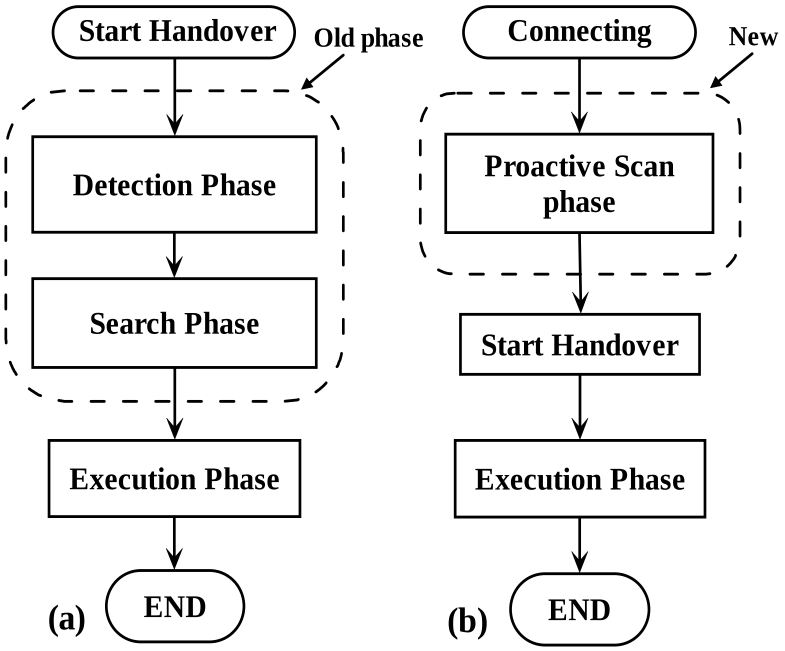


Figure 1. The Handover Scheme.

In the detection phase, the need for a handover is discovered. The STA detects a reason for current frame loss from the following options: packet collision, interference, fading radio signal, or the STA is out of the AP's transmission range. If the reason for frame loss is the last reason, then the STA decides to start a handover.

In the search phase, a set of actions are performed by the STA to find the information needed to perform a handover. The IEEE 802.11 standard specifies two scanning modes (active and passive [1]) that are used by the STA to scan and find the information from neighbor APs in range.

The execution phase is a two-step process. The STA sends a reassociation request frame to the new AP, which later confirms the reassociation by sending back a response frame with a status value of successful. This phase could take less time if the new AP did not have to authenticate the STA before successful reassociation could occur.

Generally, the main problem in the detection phase is how to determine the reason for frame loss. In the conventional handover scheme (Fig.2), the STA assumes that the current AP is always in range. When the STA moves far away from the associated AP, the signal strength received from current AP becomes weak, and frame loss occurs. The STA will try to retransmit data for a period time by reducing its data rate. If the STA cannot receive any response after some period of time, then the reason for frame loss is determined to be that the STA is out of transmission range. The time elapsed until the reason for frame loss has been clarified is the delay time in this phase. After the reason for frame loss is established, the STA will begin the search phase by broadcasting a probe request frame in each channel and then waiting for probe responses. The APs in range will reply to a probe request frame by sending back information, including the details of the AP. Finally, the STA receives all of the responses, analyzes it, and then decides to handover by starting the execution phase. The delay time in the search phase corresponds to the amount of time necessary to send the probe requests and to wait for and receive probe responses from all of the APs in range. In the execution phase, the STA begins the authentication process by sending an authentication request frame that informs the new AP of its identity. Then, the new AP responds with an authentication response frame indicating its acceptance or rejection. Once a successful authentication has been accomplished, the STA can send a reassociation request frame to the new AP, which then replies with a reassociation response frame that contains information (supported bit rates, network ID, etc.) that is necessary to resume communication with the STA. The delay time in this phase corresponds to the amount of time necessary for authentication and reassociation to the new intended AP.

According to the test-bed in different wireless LAN cards in Table 1 [3], the performance of delay time in the conventional handover scheme does not meet the requirements of real-time applications such as VoWLAN (less than 50ms). The detection phase, which takes the longest, and

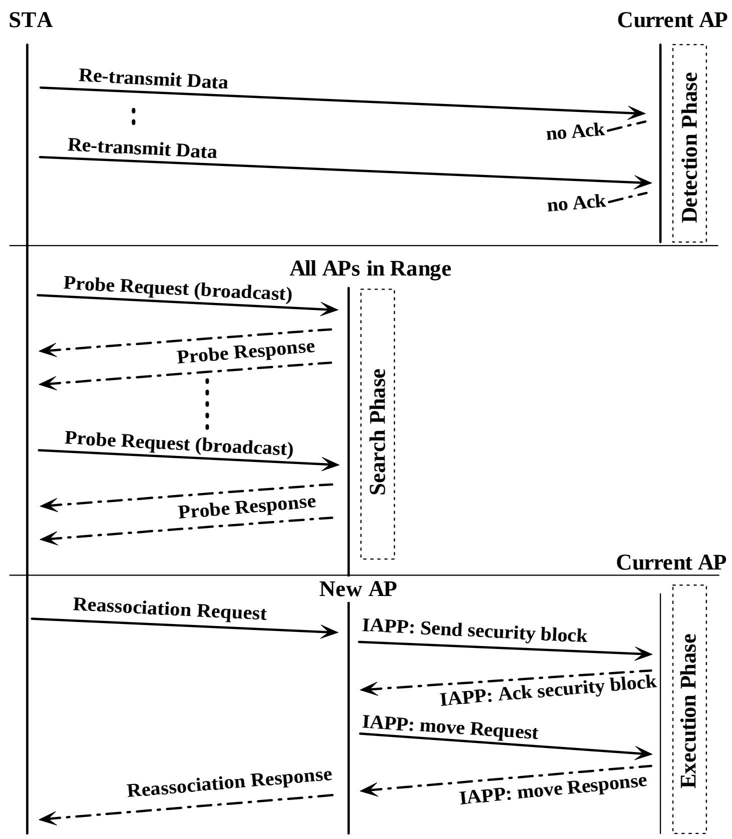


Figure 2. Three handover phase procedure.

the search phase, which takes longer than the execution phase, take too much time to support such application; the execution phase is short enough to be ignored. Thus, the idea of a novel handover scheme that provides a seamless handover and supports traffic load sharing becomes very attractive.

Table 1: Handover time for different IEEE 802.11 cards

	D-Link	***Spectrum***	***Zoom Air***	***Orinoco***
Detection	1630 ms	1292 ms	902 ms	1016 ms
Search	288 ms	98 ms	263 ms	87 ms
Execution	2 ms	3 ms	2 ms	1 ms
Total	1920 ms	1393 ms	1167 ms	1104 ms

To date, many solutions have been proposed to reduce the handover latency time in WLANs. Such researches try to reduce delay time in the search and execution phases, but there is no research that reduces delay time in the detection phase, which is the longest phase in the handover process. "Context Caching using Neighbor Graphs for Fast Handoffs in a Wireless Network" by Mishra [5] is an example of trying to reduce delay time in the search phase. This technique reduces the number of APs scanned by the STA during the search phase using a neighbor graph technique. The current AP will provide information about neighbor APs to the STA, and when the STA starts the handover process, the STA will scan only APs in the list provided by the current AP. This technique was included in IEEE 802.11k, which is currently under standardization. "Fast Inter-AP Handoff using Predictive-Authentication Scheme in Public Wireless LAN" by Pack [10] focuses on minimizing handover latency in the execution phase by reducing the authentication procedure at the new AP. In this technique, the STA entering the area covered by the AP will perform authentication procedures for multiple APs, rather than just for the current AP. These multiple APs are selected using a frequent handoff region (FHR) selection algorithm that takes into account users' mobility patterns, service classes, etc. Since the STA is registered and authenticated for the FHR in advance, the handover latency resulting from re-authentication can be minimized.

As previously mentioned, no study has focused on reducing handover delay time in the detection phase and sharing the traffic load with a neighbor AP. Therefore, a new technique to reduce delay time in both the detection phase and the search phase that also provides AP traffic load sharing becomes very attractive.

3. THE PROPOSED HANDOVER

In this novel handover scheme, we reduce the latency time by proposing a proactive scan phase that eliminates the need for the detection phase and the search phase (see Fig.1b). The proactive scan phase will work during normal connectivity (active every 2 seconds when the signal strength of the current AP falls below -80dBm where the STA and the AP can communicate in 1 Mbps data rate) to scan and find information from neighboring APs. The STA will compare this information with the current AP to decide whether or not to start a handover. This information is also useful when there is a frame loss: the STA can analyze the reason for frame loss and begin the handover process if the STA is out of the current AP's transmission range.

In the proactive scan phase (shown in Fig.3), the STA will continue to check the signal strength and traffic load of its associated AP. At the same time, the STA will scan neighbor APs in range every 2 seconds. If a packet is sent between the STA and its associated AP during this time, it will wait until the transaction is completed. The STA first sends a buffer request message to its associated AP to buffer data that might be sent to the STA during this phase; this prevents packet loss. The STA later scans neighbor APs in range by using the active scan mode to broadcast a probe-request frame in each channel. The information from all neighbor APs in range, including signal strength, AP properties, and traffic load conditions, is replied to the STA. Then, the STA analyzes and compares this information to the associated AP. An example of the operation data is shown in Table 2. The handover algorithm and its associated terminology are shown in Algorithm 1, which is used by the STA to analyze and compare data from neighboring APs with its associated AP.

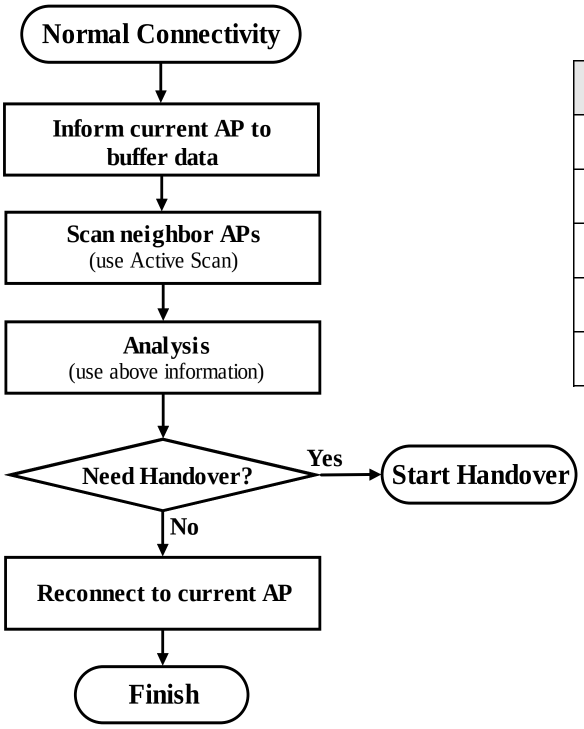


Figure 3. Proactive Scan Phase.

Table 2: the example of data in the STA

From	*Signal Strength*	*Traffic Load*
AP1	- 87 dBm	42 %
AP2	- 73 dBm	38 %
AP3	n/a	n/a
:	:	:
APn	- x dBm	y %

In Algorithm 1, we first calculate the average signal strength of the packets sent by the current AP (Xc) and the neighboring AP (Xn) using the weighted average shown in Eq.1. Wireless channel conditions are highly variable, especially in urban areas and/or high-mobility scenarios. Thus, the weighted average is intended to smooth the variable conditions of the signal strength along time. At the same time, we calculate the average traffic load (the throughput in the MAC layer) of the current AP (Yc) and neighboring APs (Yn) using Eq.2.

$$Xc = \frac{\sum_{i=1}^{n} w_i Xc_i}{\sum_{i=1}^{n} w_i} \quad and \quad Xn = \frac{\sum_{i=1}^{n} w_i Xn_i}{\sum_{i=1}^{n} w_i} \tag{1}$$

$$Yc = \frac{\sum_{i=1}^{n} w_i Yc_i}{\sum_{i=1}^{n} w_i} \quad and \quad Yn = \frac{\sum_{i=1}^{n} w_i Yn_i}{\sum_{i=1}^{n} w_i} \tag{2}$$

Note: $w_i = \frac{1 + (n - i)}{n + i}$ and $n = 4$

$$HOF_C = \frac{X_C - X_{TH}}{X_{TH}} + \frac{Tr_{MAX} - Tr_C}{Tr_{MAX}} \tag{3}$$

Algorithm 1

1: *Xc*: Signal strength measured from current AP
Xn: Signal strength measured from neighbor AP
Xth: Signal strength threshold
Yc: Traffic load of current AP
Yn: Traffic load of neighbor AP
H: Hysteresis
HOFc: Handover Factor for current AP
HOFn: Handover Factor for new AP
HOFth: Handover Factor Hysteresis

2: **if** Xc < Xth and Xn > (Xth + H) **then**
3: **start handover**
4: **else if** Xn > (Xth + H) and HOFn > (HOFc + HOFth) **then**
5: **start handover**
6: **end if**

$$HOF_N = \frac{X_N - X_{TH}}{X_{TH}} + \frac{Tr_{MAX} - Tr_N}{Tr_{MAX}} \tag{4}$$

To compare capabilities of a current AP with a neighbor AP, a handoff factor (HOF) parameter has been defined. The HOF (shown in Eqs. 3 and 4) gives us a practical way to compare two APs, taking into account both the signal strength and traffic load conditions. If the signal strength of the packet sent from the current AP is lower than the threshold (meaning that the STA is out of range) and the signal strength of the packet sent from the new intended AP is higher than the simple sum of the threshold and the hysteresis (used to prevent the ping-pong effect) [16], then the STA will start a handover to the new AP. If the signal strength of the current AP is higher than the threshold, then the STA will start a handover process only if the new AP can provide better performance than the current AP, meaning that the signal strength from the new AP is higher than the simple sum of the threshold and the hysteresis and that HOFn is higher than a sum of the current AP (HOFc) and the HOF of the hysteresis (HOFth). Otherwise, the STA will continue to associate with the current AP by sending a reconnect signal to the current AP, and then the current AP will send all buffered data to the STA.

Using the proactive scan phase, the STA can estimate the reason for frame loss and make a decision to start the handover process or to re-transmit data. The STA can also start the handover to a neighbor AP that provides higher performance than the current AP when the performance of the current AP falls below a certain level. We compare the performance of the APs in terms of signal strength and traffic load conditions to guarantee that the STA will not handover to high traffic load APs in the event that the signal strength is better than that of the current AP. If the STA continues to communicate with the current AP and there is a frame loss, then the STA will try to re-transmit data using a RTS/CTS mechanism; in this case, the collision or radio signal fading is assumed as the reason for frame loss.

So far, we have shown that the proactive scan phase can detect the reason for frame loss and scan for information from neighboring APs, thus omitting the detection and search phases. The proactive scan phase also supports the idea of shared traffic loads among neighbor APs. The active scan mode (Fig.4) illustrates how the proactive scan phase can find information from neighbor APs in range. When the STA is idle, the STA will scan all available neighbor APs, meaning that the STA will broadcast a probe request frame in each channel and then wait for probe responses. After the STA receives all responses from the neighbor APs, the STA will arrange them in the AP list by quality of signal strength and traffic load conditions. When the STA is busy, the STA will scan only two or three APs in the list and then rearrange them. With active scan mode, we can reduce delay time in the proactive scan phase; this reduces delay time from 70-87ms to 16-36ms. Note that for IEEE 802.11b/g, there are only three channels that will not interfere with one another, and most wireless networks use only three channels. Therefore, scanning only three channels is sufficient to find most of the neighbor APs in range.

3.1 Advantage

As described, the proactive scan phase omits both the detection phase and the search phase of the conventional handover scheme. The STA will start the execution phase directly; thus, delay time in the novel handover scheme refers only to the execution phase. Recent work by Mishra et al. [5] demonstrates a proactive caching approach for reducing delay time in the execution phase to 1.69-15.37ms.

Moreover, by comparing information from neighbor APs to the current AP, the STA can make a decision to start handover to the new AP, without waiting for frame loss, if it finds that the new AP can provide higher performance than the current AP. The novel handover scheme can also balance traffic loads in a wireless network. The STA will handover from the current AP with high traffic load conditions to a new AP with lower traffic load conditions and similar or better channel conditions than the current AP. This prevents packets from being dropped due to traffic overload in one cell.

The proposed handover scheme is compatible with all commercial wireless LAN cards. Customers only need to update the firmware, which is generally downloadable from the vendor's website, without adding or changing any hardware component.

3.2 Disadvantage

In the proactive scan phase, the STA scans and finds neighbor APs in range during normal

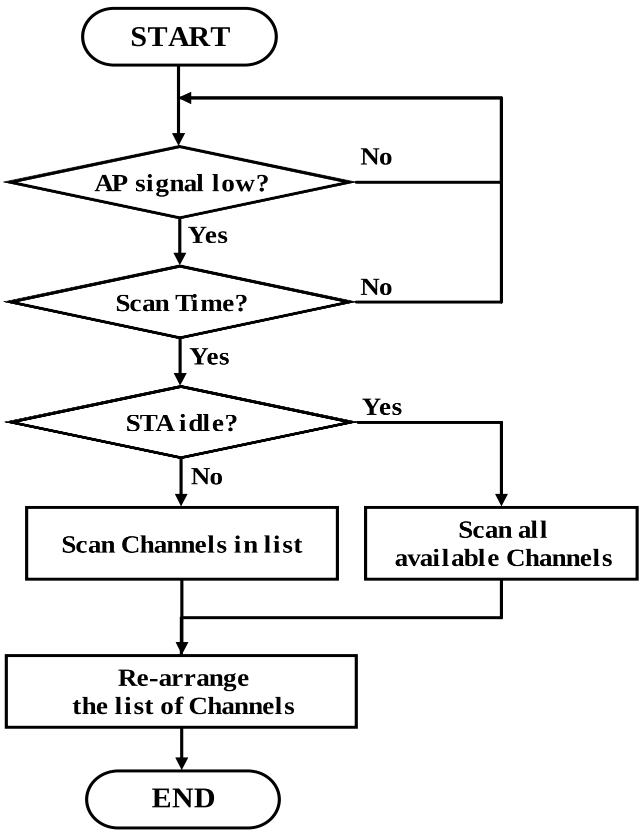


Figure 4. Active Scan mode

connectivity. This means that the STA must reserve time to broadcast a probe request frame to neighboring APs and then wait for the probe response, thus increasing traffic load. In contrast, when the APs in range receive the probe request frame, the AP will reserve time to reply a probe response frame to the STA, thus increasing the traffic load in the AP.

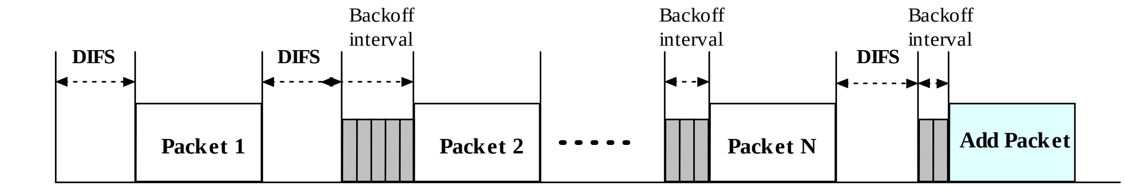
As shown in Fig.5, with the packet transmission mechanism using CSMA/CA, the additional packet will appear in both the STA and the AP. In the STA, an additional packet appears every 2 seconds in CSMA/CA. The number of APs in range is the main factor that increases traffic load in the STA. Therefore, we can reduce this traffic load by using the active scan mode to scan neighbor APs in range during the proactive scan phase. This technique can reduce the number of APs that the STA will scan. In the AP, the number of additional packets in CSMA/CA depends on the number of probe request frames from external STAs (the STAs in the neighbor APs). This means that when the STA broadcasts the probe request frame more often, traffic load will increase. Therefore, broadcasting a probe request frame every 2 seconds increases the traffic load in the AP to a level that is still acceptable.

4. PERFORMANCE EVALUATION

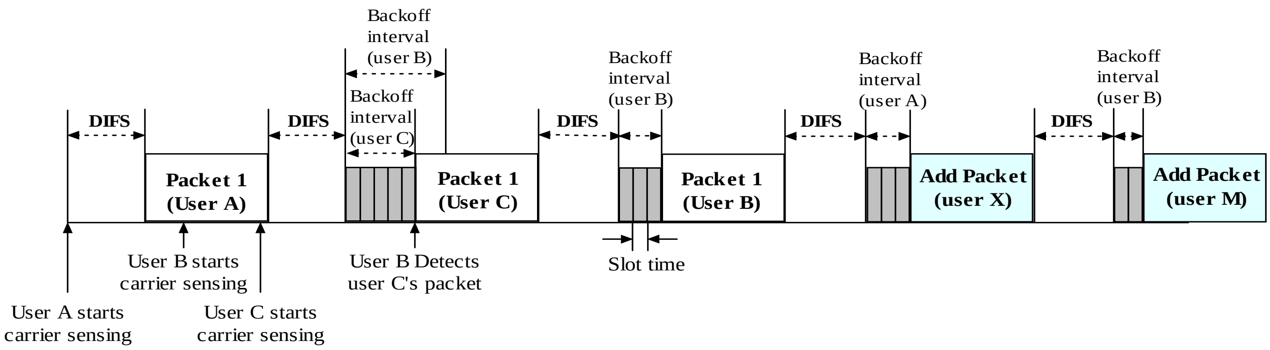
In this section, we evaluate the performance of our proposed handover scheme and compare it with the existing handover scheme. The base simulator used to implement our proposed scheme is OPNET Modeler version 10.5 with Wireless Module [19]. Fig.6 shows the simulation environment: two APs with cell radius of 300m and output power of 200mW connect to each other via a gateway. The distance between the centers of two neighbor APs is 500m. A STA moves from AP1 to AP2 at walking speed (5km/h).

We consider the Voice over IP (VoIP) traffic using the G.711 codec standard [17]. We assume that a VoIP packet is generated every 20 ms, with 160-byte data, 12-byte RTP header, 8-byte UDP header, and 20-byte IP header. The VoIP packet size at the 802.11 MAC layer becomes 200 bytes per packet, and the data rate is 80 kbps.

First, we simulate the move of STA from AP1 to AP2 using the conventional scheme. The STA moves away from AP1 and begins to receive some failed packets. When the STA moves out of range, the STA disconnects from AP1 and starts looking for a new AP by broadcasting a probe request frame in each channel and then waiting for the probe response. The STA finally finds a new



(a) Multiple packet transmission using CSMA/CA (in STA)



(b) Multiple packet transmission using CSMA/CA (in AP)

Figure 5. Packet transmission using CSMA/CA

AP (AP2) and starts the handover process to connect.

We also simulate the STA in the proposed scheme as moving from AP1 to AP2. The STA starts the proactive scan phase when the signal strength received from AP1 becomes lower than -80dBm. Using the proactive scan phase, the STA compares the information received from the neighbor AP2 with AP1 through the calculation of the respective HOFs. It starts the handover to AP2, which can provide better performance than AP1.

We monitor the throughput, delay time, and traffic load of the STA in our simulations and compare the results in the next section.

4.1 Throughput

The initial results from our simulation (Fig.7) show that the STA can begin handover more quickly in the proposed scheme than in the conventional scheme. The STA uses the proactive scan phase to find neighbor APs in range and begin handover at 266m; we consider signal strength and traffic load conditions as well as the hysteresis factor in order to avoid the ping-pong effect. The total handover delay time in the proposed scheme yields between 20 and 35ms (it is between 1700 and 1900ms for the conventional scheme). When the STA is moving near its associated AP, however, the proposed scheme demonstrates the same throughput as the conventional one. This is because the proactive scan phase will not run when the signal strength from current AP higher than -80dBm. However, when the proactive scan phase is running, the throughput is lower than that of the conventional scheme, because the proactive scan phase decreases the throughput of the STA.

4.2 Delay Time

The results in Fig.8 show that the proposed scheme does not affect end-to-end packet delay time when the STA is moving near its associated AP. This is because the proactive scan phase is not running when the signal strength from its associated AP is higher than -80dBm. When the STA moves far away from AP1, the end-to-end packet delay time exceeds that of the conventional scheme but is still lower than 40ms, even at the time of handover (266m). In the conventional scheme, the end-to-end packet delay increases to “no available value” when the STA starts handover at 298m; this means that the delay time is more than the “maximum receive lifetime” set in OPNET (500ms) and that packets are dropped during this period. Therefore, in this situation, the proposed scheme can provide a smoother handover process to support VoIP.

4.3 Traffic Load

Finally, we evaluate the performance of the proposed handover scheme in terms of traffic load. Using the same simulation environment (Fig.6), the STA begins the proactive scan phase to

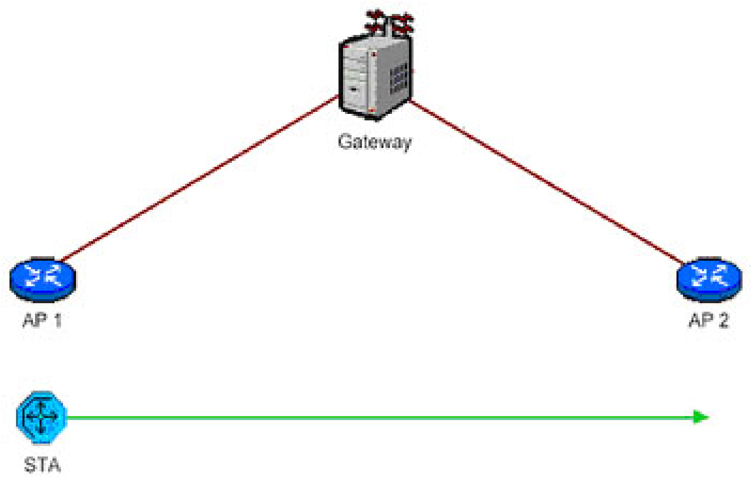


Figure 6. Simulation Model

broadcast a probe request frame to neighbor APs in range every 2 seconds when the signal strength from AP1 became lower than -80dBm. The result in Fig.9 shows the proposed scheme slightly increases traffic load in the STA to a level that is still acceptable (3% average).

To analyze the traffic load in the AP, we divide the traffic load into 2 cases: in case 1, the proposed scheme increases traffic load to the AP, and in case 2, the proposed scheme allows shared traffic load among neighbor APs.

In case 1, the proposed scheme increases traffic load to the AP depending on the number of external STAs trying to connect to the AP. In this simulation, we assume three neighbor APs, each with three STAs (Fig.10). Each STA connects to its associated AP with a data rate of 80kbps. The packet transmission frame using the DSSS physical layer (with DIFS = 50μs, SlotTime = 20μs, and other parameters is set by the standard value [1]). The results in Fig.11 show that the increased traffic load depends on the number of external STAs trying to connect to the AP but still remains at an acceptable level (less than 6.4%) when there are six external STAs trying to connect to the AP.

In case 2, we analyze the effective traffic load of the proposed scheme compared to the conventional one in terms of sharing traffic loads. By using the same assumption previously stated (shown in Fig.6), we simulate a group of 10 STAs moving in the overlap area of 2 neighbor APs using the proposed scheme. The initial results in Fig.13 show that the proposed handover scheme can balance the traffic load among neighbor APs. Comparing the traffic load conditions of a neighbor AP with that of the current AP, the STA will start handover to a neighbor AP with lower traffic load conditions and similar or better channel conditions compared to the current AP. Such traffic load sharing is not supported by the conventional scheme (Fig.12).

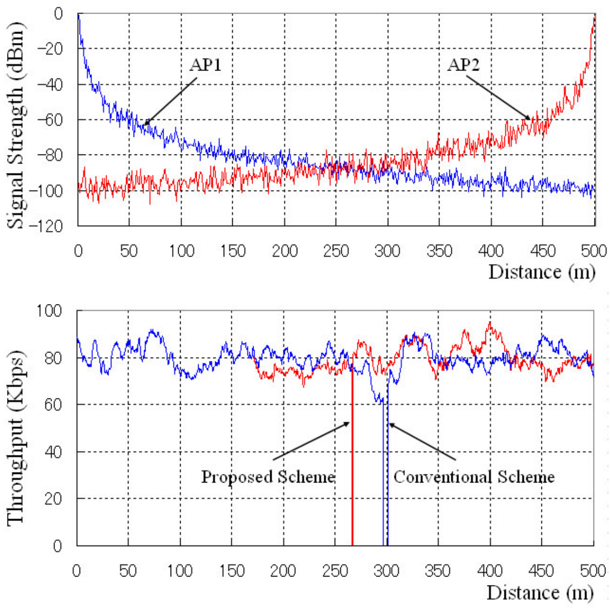


Figure 7. Start Handover Time from AP1 to AP2

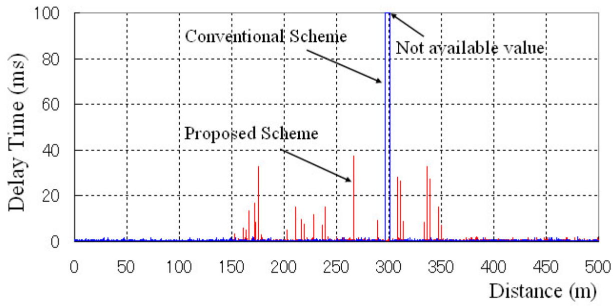


Figure 8. Comparison of Delay Time

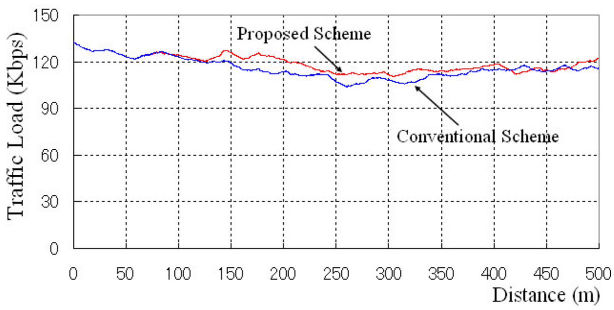


Figure 9. Increased Traffic Load in STA

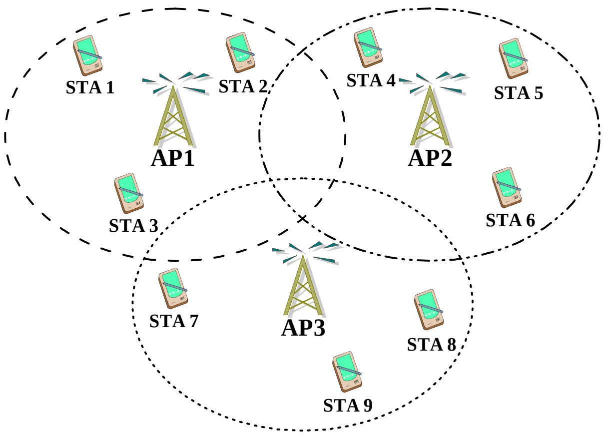


Figure 10. Network Architecture

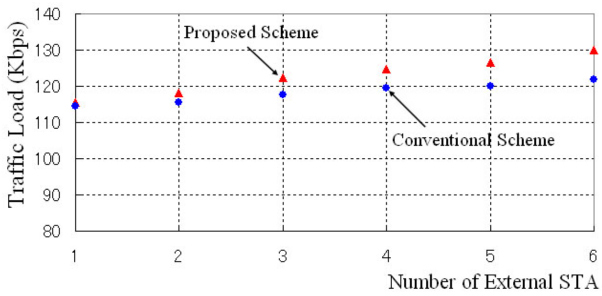


Figure 11. Increased Traffic Load in AP

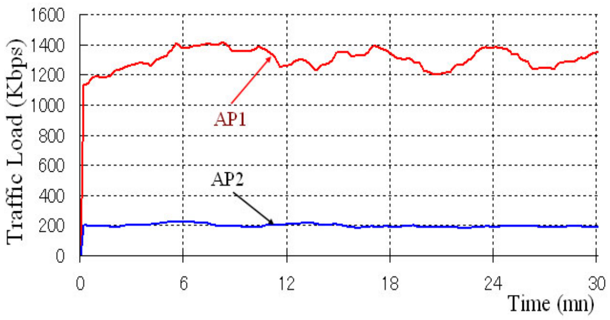


Figure 12. Traffic Load in AP (Conventional scheme)

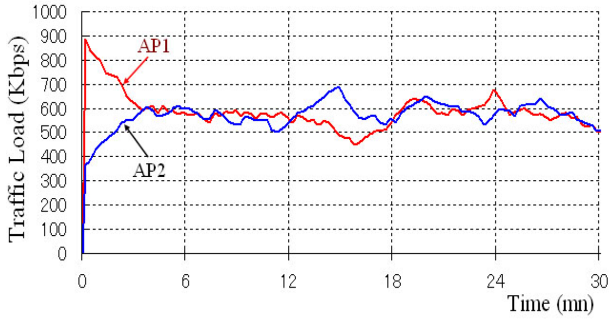


Figure 13. Traffic Load in AP (Proposed scheme)

5. CONCLUSION

In this paper, we have proposed a novel handover scheme to improve the performance of Wireless LANs. By using the proactive scan phase in the novel handover scheme, the STA can perform a more effective handover process. The results from our simulation show that the STA can start handover to a better AP and support traffic load sharing among neighbor APs. In addition, the total handover delay time has been reduced to support real-time applications including VoWLAN, e-conference, and e-learning. Moreover, the novel handover scheme increases traffic load in both the STA and the AP to a level that is still acceptable. Therefore, the novel handover scheme might be more suitable for future Wireless LANs than the conventional scheme, especially to support real-time services.

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Article received: 2007-04-13