Using Fuzzy Logic to Mitigate IEEE 802.11 Handoff Latency

Chi-Yuan Chang, Hong-Jie Wang and Han-Chieh Chao
andrew@mail.ndhu.edu.tw, m9123022@em91.ndhu.edu.tw, hcc@mail.ndhu.edu.tw
Department of Electrical Engineering, National Dong Hwa University, Hualien, Taiwan

Abstract- Multimedia transmissions are delay sensitive Internet applications. Because mobile stations move all of the time, handoff processes are necessary and unavoidable in wireless network environments. Since handoff processes tend to break the communication link, some researches have been done to reduce the break time and arrival delay during Internet multimedia applications. In this paper, we propose an approach based on Fuzzy Logic to evaluate the average and variation in signal strength received by a mobile station. According to our investigation, a mobile station needs to execute an active scan process only once to obtain the complete handoff parameters. Therefore, smaller handoff latency is expected.

Keyword-handoff, handoff latency, Fuzzy Logic, active scan

I. INTRODUCTION

The wireless network has the advantage of mobility. Therefore, we care about whether a handoff affects the degree of fluency for multimedia applications in a wireless network. For example, the maximal end-to-end delay for Voice over IP (VoIP) is about 50ms [1]. It is regrettable that the majority of wireless LAN cannot complete L2 handoff procedures within 100ms [2, 3]. It is observed that the L2 handoff latency would be 60ms to 400ms depending on the wireless card and access point vendor. The probe delay would dominate the L2 handoff latency, accounting for approximately 85% of the overall cost.

In this paper, we propose two simple and efficient L2 handoff schemes to improve the handoff latency. They are the Fuzzy Logic handoff and the unicast Probe Request. The Fuzzy Logic evaluates two input signal strength data, which are the signal strength average and variation. The most important part of Fuzzy Logic is the membership function and control rule design. We derive a FitAP factor for the Fuzzy Logic. This factor represents the degree that indicates the handoff possibility and access point (AP) that fits a given mobile station (MS). According to the FitAP factor, a mobile station needs to execute an active scan process only once to obtain the complete handoff parameters. Therefore, smaller handoff latency is expected. Besides, if a certain channel has more than two access points within the coverage area, the scanning mobile station transmits a Probe Request after gaining access to the medium. It is very possible that more than two access points would respond with a Probe Response that contains the network parameters. Note that the second Probe Response would follow the Distributed Coordination Function (DCF) rules and must wait for the congestion windows to elapse before it could be transmitted. To avoid collisions, the unicast Probe Request scheme is proposed. The simulation shows that the handoff latency is further improved.

Section II introduces the motivation and related works. Section III describes the proposed approach and simulation model. Section IV shows the simulation results. The conclusion and future work are given in Section V.

II. MOTIVATION

According to the IEEE 802.11 standard, there are two kinds of networks (the Infrastructure Network and Ad-Hoc Network). Most wireless network applications focus on the Network Infrastructure. We survey and study the handoff latency source when mobile stations move under the Network Infrastructure. The handoff latency is still large enough to affect the quality of most wireless network multimedia applications. It would be very useful if the handoff latency could be improved.

A. Survey of Related Works

In the IEEE 802.11 standard, passive scan and active scan are defined to let mobile stations create their connections with the access points. In the passive scan mode, when the mobile station needs to switch to some other channel, it would periodically listen to get the Beacon frames generated by the access points. When a mobile station needs to switch to some other channel under the active scan mode, it sends out a Probe Request frame and waits to receive the Probe Response frame from the access point. Generally speaking, the active scan mode has shorter handoff latency than the passive scan mode. In this paper, we focus on the active scan mode.

The handoff latency is composed of three parts, the probe delay, authentication delay and re-association delay. In the study by Arunesh, Minho and William [2], the probe delay dominated the handoff latency for approximately 85%. It was also found that when the handoff took place, the active scan process needed to be applied to every possible channel (11 channels in US [4]). The solution would be a method to improve the probe delay and decrease the number of channels that required an active scan process to improve the handoff latency.

Minho and William [3] proposed a method to improve the latency of 802.11 handoff. Based on the Inter-Access Point Protocol (IAPP), the authors used the Neighbor Graph (NG) algorithm and NG-pruning algorithm to construct a data
structure that represents the handoff relationship of different access points. Using this constructed relationship, the mobile station could perform an active scan for fewer channels. The result shows that the average number of channels that needed an active scan was decreased to 2.5 and the handoff latency was improved to about 70ms.

B. The Handoff Latency Source Analysis

The following descriptions focus on the probe delay analysis and active scan procedure.

The active scan procedure is performed when the signal-to-noise ratio level received by the mobile station drops down to the cell search threshold. To obtain the handoff parameter for each channel and access point, the mobile station must execute an active scan on each channel. In the IEEE 802.11 standard, the Probe Request broadcast message frame is sent to request one channel. The access points then reply with the Probe Response frame if its BSS ID matches the data within the request frame. The mobile station chooses the access point with the maximal signal-to-noise ratio level after each channel has been visited. The authentication phase is then entered for the selected access point after the handoff procedure.

As illustrated in Fig. 1, a mobile station transmits a Probe Request frame. There are two access points within the coverage area that would reply with a Probe Response almost simultaneously. The handoff procedure is described in detail as follows.

At point \( \text{\textbullet} \) in Fig. 1, the mobile station executes an active scan to transmit the Probe Request frame after gaining access to the medium. Both access points reply with Probe Response frames that contain their network parameters. At point \( \text{\textcircled{a}} \) in Fig. 1, the mobile station waits for the minimal channel time, MinChannelTime, to elapse. If the medium is not busy, there is no usable network channel. The mobile station then switches to the next channel and repeats the access point action \( \text{\textbullet} \). If the medium is busy during the MinChannelTime interval, it must wait for the maximal channel time, MaxChannelTime, to elapse to collect more Probe Response frames from other access points. Point \( \text{\textcircled{b}} \) is shown in Fig. 1. Note that the second Probe Response must follow the DCF rules and wait for the congestion windows to elapse before it can be transmitted.

Through the above active scan process, we find four cases that could affect the handoff latency. They are described as follows.

Case 1: The mobile station sends out a Probe Request frame to some channel where no access point exists. The mobile station will not acquire a response from this access point but it will still need to wait for the MinChannelTime.

Case 2: The mobile station sends out a Probe Request frame to some channel and only one access point exists in this channel. Normally, the mobile station will acquire a Probe Response frame from this access point before the MinChannelTime expires. The mobile station will then automatically wait for the MaxChannelTime to collect the Probe Response frames from other access points. In this case the mobile station will not acquire any response from other access points. The wasted extended waiting time is therefore obvious.

Case 3: The mobile station needs to perform the active scan procedure for each of the channels to get all possible access point parameters. In this situation the wasted time would gradually accumulate. This time accumulation forms the main part of handoff latency.

Case 4: Under the IEEE 802.11 wireless network, the Probe Request and Probe Response frame must follow the DCF rules when some channel contains many access points. Probe Response frame collisions would occur frequently and sometimes the mobile station would not be able to receive all of the possible access point responses within the MaxChannelTime period.

III. PROPOSED APPROACH AND SIMULATION MODEL

A. Proposed Approach

It is evident that if the mobile station does not receive any beacon frames at some channel, we can infer that there is no wireless network at that channel. Therefore, this channel can be omitted from the active scan process and the handoff latency increment for case 1 could be resolved.

To reduce the handoff latency in case 3, we propose a method that uses Fuzzy Logic to evaluate the mobile station’s average received signal strength and signal strength variation to conclude a FitAP factor. This factor represents the degree that indicates the access point handoff probability that fits this particular mobile station. According to the FitAP factor, the mobile station needs to execute the active scan process only once to obtain the complete handoff parameters.

We propose an approach that modifies the Probe Request frame from broadcast to unicast to further improve the handoff latency increment. Under IEEE 802.11, unicast transmission would obtain positive acknowledgements. All transmitted
frames must be acknowledged. If any part of the transmission fails, the frame is considered lost. Therefore, we use a Fuzzy Logic handoff scheme to determine one suitable access point and then send a unicast Probe Request frame to this access point. In this method, Probe Response collision could be avoided and the handoff latency increment could be reduced when the mobile station sends out the unicast Probe Request frame and only one access point replies with the Probe Response frame. Another advantage of our proposed method is that the mobile station would not need to wait for the MaxChannelT ime to elapse. The mobile station could immediately execute the next handoff phase when it receives the Probe Response from the unicast Probe Request which is an acknowledgement of the unicast Probe Request. Hence, the case 2 handoff latency increment could be resolved and the case 4 handoff latency increment could also be improved.

B. Simulation Model

We define SSa(t) and SSv(t) as the input variables for Fuzzy Logic. SSa(t) means the average of signal strength and SSv(t) indicates the variation in signal strength. Both are measured as dBm. The average signal strength SSa(t) at time t for the mobile station is listed as (1) where n is the number of beacon frames received within time t. SSbeacon(i) represents the signal strength based on the beacon frame received by the mobile station. For a given time period k, SSv(t) is listed as (2) and it represents the variation in signal strength during this time period. The sign and value for SSv(t) could indicate the movement relationship between the mobile station and the access point.

\[
SSa(t) = \frac{\sum_{i=1}^{n} SS_{\text{beacon}}(i)}{n}
\]  

(1)

\[
SSv(t) = \frac{SSa(t) - SSa(t-k)}{t - (t-k)}
\]  

(2)

As shown in Figs. 2 and 3, the general triangular membership functions are defined to perform the fuzzification for the input variables. The n-fuzzy variables membership function intersection is used in the decision logic. Fig. 4 shows the fuzzy inference rules defined in this paper. We use a method, called the center of gravity, to conclude the FitAP factor. The FitAP is listed as (3) where Wi means the suitable degree generated from the ith control rule and Bi is the center point of the membership function used by the ith control rule.

\[
\text{FitAP} = \frac{\sum_{i=1}^{n} WiBi}{\sum_{i=1}^{n} Wi}
\]  

(3)
IV. SIMULATION RESULTS

Fig. 6 illustrates the simulation environment for the handoff process when the mobile station moves along a trajectory from position A to position B. The coordinate values of the access points AP1, AP2 and AP3 are (100.0, 92.0), (81.0, 92.0), and (110.0, 58.0) respectively. The radio coverage area radius is approximately 36 meters, and the signal strength must follow the Indoor Propagation Model \[5\]. We want to simulate the mobile station handoff process and observe the signal strength diversity resulting from the current and proposed Fuzzy logic handoff schemes.

In the simulation model, the mobile station moves from location A to location B within 120 seconds. The mobile station signal strengths within the simulation model are shown in Figs. 7 and 8. The signal strengths are based on the current and Fuzzy Logic handoff schemes, respectively. As shown in Fig. 7, two handoffs occurred when the mobile station moved from A to B. When the first handoff occurred, the mobile station switched the connection from AP2 to AP1. After a short period of time, the second handoff occurred and the mobile station switched the connection from AP1 to AP3. The signal strengths decrease gradually during the period that the mobile station is connected to AP1. It is evident that the current handoff strategy is not very appropriate.

The proposed Fuzzy Logic handoff scheme considers the variation in signal strength. Under the proposed scheme, the mobile station chooses the most suitable handoff access point according to the FitAP factor. From Fig. 8, the handoff process occurs only once when the mobile station moves from A to B. The signal strengths still increase gradually for a while after the handoff takes place. It is obvious that the proposed Fuzzy Logic handoff scheme is better than the current scheme.
Figs. 9 and 10 show the handoff latency performance for the Fuzzy Logic handoff scheme and the current scheme. Clearly, the two schemes have similar latency variation curves. From Fig. 9, we see that the proposed Fuzzy Logic handoff scheme has better handoff latency performance than the current scheme. The improvement is approximately 70% resulting from the mobile station needing to execute the active scan process only one time. From Fig. 10, we see that the proposed Fuzzy Logic handoff scheme has better handoff latency performance when the number of access points varies. Moreover, when the Probe Request is sent using the unicast frame, the handoff latency performance can be improved further and the latency is independent of the number of access points within the radio coverage range. This kind of independence results from the fact that many Probe Response collisions could be avoided when the Probe Request is sent by a unicast frame. Table I shows a summary of the proposed scheme and related researches.

V. CONCLUSION AND FUTURE WORK

We propose a Fuzzy Logic handoff scheme to enhance the current scheme to improve the handoff latency under the IEEE 802.11 wireless network. The basic idea is to reduce the number of active scan processes for every channel. The Fuzzy Logic chooses a suitable channel according to the FitAP factor and only one active scan process is performed.

The simulation results for the proposed Fuzzy Logic handoff scheme and the current scheme are shown in Section IV. The performance of the proposed mechanism is better than the current handoff scheme and the improvement is approximate 70%. Moreover, after using the Fuzzy Logic handoff scheme, we changed the Probe Request frame from broadcast to unicast to avoid Probe Response collisions at the same channel. Through the proposed scheme, the handoff latency is independent of the number of access points at the same channel.

Our future work involves implementing the proposed scheme under a real wireless network to verify the performance. Finding other methods to reduce the handoff latency would be another interesting research aspect.

REFERENCES

<table>
<thead>
<tr>
<th>Handoff Scheme</th>
<th>Sweep Type</th>
<th>Tactic</th>
<th>Frame Type</th>
<th>Handoff Latency (a)</th>
<th>Handoff Latency (b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Handoff Scheme [2]</td>
<td>Full Sweep</td>
<td>SNR(Max.)</td>
<td>Broadcast</td>
<td>Approx. 60 ~ 400ms</td>
<td>&gt;400ms</td>
</tr>
<tr>
<td>NG [3]</td>
<td>Short Sweep</td>
<td>IAPP</td>
<td>Broadcast</td>
<td>~26ms</td>
<td>Increase to 82ms</td>
</tr>
<tr>
<td>NG-pruning [3]</td>
<td>Short Sweep</td>
<td>IAPP</td>
<td>Broadcast</td>
<td>~20ms</td>
<td>Increase to 38ms</td>
</tr>
<tr>
<td>Fuzzy Logic handoff*</td>
<td>Short Sweep</td>
<td>Listen Beacon</td>
<td>Broadcast</td>
<td>~22ms</td>
<td>Increase to 85ms</td>
</tr>
<tr>
<td>Fuzzy Logic handoff using unicast Probe Request frame*</td>
<td>Short Sweep</td>
<td>Listen Beacon</td>
<td>Unicast</td>
<td>~20ms</td>
<td>Independent</td>
</tr>
</tbody>
</table>

* Proposed scheme

(a) Probe Request frame type

(b) Handoff latency versus handoff numbers

(c) Handoff latency versus number of access points