Performance Comparison of Handover Mechanisms in Wireless LAN Networks

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***Abstract*— The discussion about integrating the Wireless LAN standard into future mobile networks of the 4th Generation (4G) does not only strengthen the importance of the IEEE 802.11 standard family, but necessitates the support of Quality-of-Service (QoS) even when the user moves between different Access Points. In this paper, we study different Wireless LAN handover mechanisms and their ability to support QoS traffic. Therefore, we implemented the handover mechanisms and additional proposals in a simulation environment and analyzed their ability to support a specific QoS level.**

***Index Terms*— WLAN, Handover, QoS, IAPP, VoIP, DCF**

I. Introduction

Wireless Local Area Networks (WLANs) based on the IEEE 802.11 standard [1] have seen an immense growth in recent years. When considering large networks with many Access Points (APs) where the client can cross the coverage areas of several APs, the system should ensure that the connection is maintained. A *handover* is the process, where the client leaves the coverage area of one AP and enters another. Data loss and delays should be kept minimal to ensure seamless handover. The WLAN handover is initiated by the mobile, i.e. the client decides according to the signal strength, when it has to perform a handover.

If the WLAN standard is integrated into future mobile networks, the handover times will have to be minimized to ensure a specific QoS level. In this paper, we want to show that it is possible to support QoS traffic in a WLAN even if the stations have to perform a handover. Therefore, we implemented five different handover mechanisms in the OPNET modeler. All handover mechanisms are analyzed with regard to their delay and we will see that at least two mechanisms are fast enough to provide QoS traffic.

The paper is organized as follows. In Section II, the basic medium access mechanism is introduced and Section III describes the handover mechanisms for WLAN networks. After the description of the simulation scenario in Section IV, the performance of the different handover mechanisms is evaluated in Section V. Finally, Section VI concludes this paper.

II. WLAN Specifications

The IEEE 802.11 standard specifies the Medium Access Control (MAC) layer and the Physical (PHY) layer to provide a WLAN that enables station mobility transparent to higher protocol layers. The standard supports three different topologies: Independent Basic Service Set (IBSS), Infrastructure Basic Service Set (BSS), and Extended Service Set (ESS).

The IBSS networks are often referred to as ad-hoc networks, where all stations are communicating directly with each other and must be in direct communication range. In contrast, a BSS network is divided by the use of an AP. The AP is used for the entire communication, including the communication between mobile stations in the same area. An Extended Service Set network combines different BSS networks.

For our simulations, we choose one ESS network with a variable number of BSSs. To offer a continuous coverage area in one ESS, the different BSSs have to overlap and the interference between the APs has to be minimized. To reduce the interference, the APs have to be configured to use different channels on the 2.4 GHz frequency band. Due to the fact that these channels overlap, the APs have to be separated by a minimum of five channels. The APs in our simulations are configured to use channel one, six, and eleven.

To move from one BSS to another, the stations have to accomplish a layer 2 handover. When moving from one ESS to another, a layer 3 handover is needed which can be accomplished using Mobile IP. The goal of this paper is to analyze the layer 2 handover mechanisms in one ESS between the different Basic Service Sets.

A. Medium Access Control (MAC) Layer

The Distributed Coordination Function (DCF) is the primary access mode using the CSMA-CA protocol for sharing the wireless medium as shown in Fig. 1. Stations which want to transmit a packet have to compete with each other for access and all stations have equal rights. However, WLAN stations are not able to detect a collision on the medium.

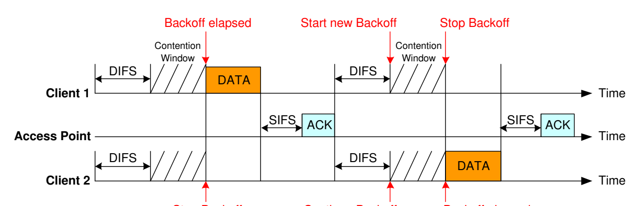

Fig. 1. Carrier Sense Multiple Access with Collision Avoidance

Therefore, an acknowledgment scheme has to be performed. If no Acknowledgment is received by the sending station it will simply retransmit the packet. In order to reduce the collision probability on the wireless medium, the stations sense the medium for a period of time (DIFS) and perform a backoff before transmitting a packet.

III. Handover Mechanisms

The basic parameter for a roaming station is the *Signal-to-Noise Ratio* (SNR). When the SNR drops below a threshold, called *Cell Search Threshold*, the station starts searching for new APs and if the difference between the SNR of the old AP and one possible new AP has passed a threshold known as *Delta SNR*, the station initiates the actual handover. These two parameters depend on the AP density shown in Table I.

TABLE I

IEEE thresholds

Threshold	AP Density		
	Low	Medium	High
Cell Search [dB]	10	23	30
Delta SNR [dB]	6	7	8

The WLAN handover itself consists of three individual steps: *scanning*, *authentication*, and *association*. During the scanning process, the station searches for new APs to associate to. The authentication procedure is needed to exchange information about the station and data encryption. Finally, the station has to associate with the AP.

A. Scanning

The IEEE 802.11 standard defines two scanning mechanisms, *active* and *passive scanning*. A station using *passive scanning* switches to the first channel and waits for *Beacon* frames. If the station receives a Beacon frame, it measures the SNR and stores additional AP information. After a specific time, the station switches to the next channel until every channel is scanned. Scanning every channel results in a lot of overhead and therefore, most stations scan only the non-overlapping channels, for example channel one, six, and eleven which is referred to as *fast passive scanning*.

The second main type of scanning is called *active scanning*. Here, the station transmits a broadcast *Probe Request* frame using the DCF, starts a timer called *Min Channel Time* and processes all incoming *Probe Response* frames. If the medium is not busy during Min Channel Time, the station scans the next channel. If the channel gets busy, the Min Channel Time is canceled and the station waits for Probe Response frames until the maximum time, Max Channel Time, has expired as seen in Fig. 2. Each AP receiving the Probe Request frame has to respond with a Probe Response frame. Like in passive scanning, the station may be configured to scan all channels, *normal active scanning*, or scan only the non-overlapping channels, *fast active scanning*.

Finally, there is one additional active scanning mechanism, *scanning with neighborhood detection*, which is not included in the IEEE 802.11 standard. Different proposals [2], [3], and [4] try to reduce the channel scanning time. Therefore, the moving station has to know the MAC address and current channel of the AP to be scanned in advance. The information is placed in all Beacon and Probe Response frames, see [3]. The maximum number of AP information within a single Beacon and Probe Response frame is set to twelve to reduce the overhead.

If a station uses neighborhood scanning, it picks up an AP from the list and transmits the Probe Request frame directly to this AP. The AP responds after a Short Interframe Space (SIFS) directly to the request, when the address of the Probe Request frame matches. If the AP does not reply after Min Channel Time, the station picks the next AP from the list and transmits another Probe Request frame. This reduces the scanning time compared to other active scanning mechanisms, because the station does not have to scan three or all channels and wait for the Max Channel Time to expire.

B. Authentication

A station has to authenticate before joining a network, but the standard does not limit the station to authenticate only to one AP. The station might authenticate during the first association procedure with all APs in the network, see [4]. This form of pre-authentication is used for the simulation, as we can ignore the whole authentication process during a layer 2 handover.

C. Association

To gain full access to the network, the station has to associate with an AP or reassociate with a new AP. Because we are simulating a handover, where the station has already associated with an AP in a specific ESS, only the reassociation procedure is taken into account.

If a station moves from the coverage area of one AP to a new one, the reassociation procedure is used to inform the entire network of its new location. Therefore, the station transmits a *Reassociation Request* frame to the AP which it wants to connect to, see Fig. 3. The new AP has to verify that the station was connected to the previous AP by using the *Inter Access Point Protocol* (IAPP) over the wired backbone network. IAPP defines messages and data to be exchanged between APs to support roaming. Afterwards, the AP replies with a *Reassociation Response* frame. After having received an acknowledgment, the station has completed the handover and the traffic is forwarded through the new AP to the station.

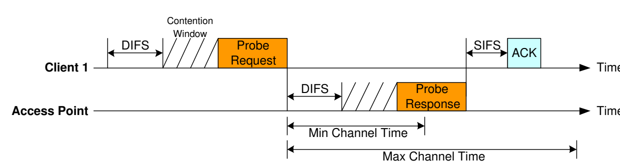

Fig. 2. Active scanning procedure

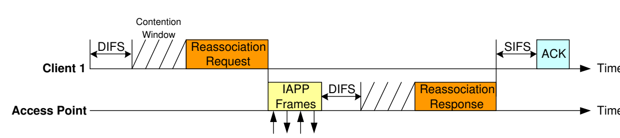

Fig. 3. Reassociation procedure

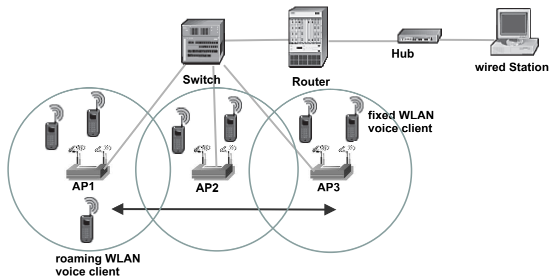

Fig. 4. Simulation scenario with background traffic

IV. Simulation Overview

We implemented a simulation of the WLAN IEEE 802.11b standard using the OPNET simulator. The IEEE 802.11b is a part of the IEEE 802.11 family allowing data rates of up to 11 Mbps. Our implementation accounts for the MAC, PHY layer, all handover mechanisms, and the IAPP layer.

Fig. 4 shows the scenario for our simulations. AP1 uses channel 1, AP2 channel 6, and AP3 channel 11. The circles around the Access Points mark their coverage areas. One client, using a voice application, moves between the different Wireless LAN cells. Some fixed clients are placed in the WLAN cells to produce background traffic with voice and FTP applications.

A. Traffic Model

Our simulations are configured to use voice traffic. The most important voice codecs are G.711 (64 kbps), G.729 (8 kbps), and G.723.1 (5.3 or 6.3 kbps). Earlier studies regarding the suitability of voice codecs in WLAN environments have shown that the G.723.1 [5] voice codec with 5.3 kbps and a frame size of 30 ms provides the best performance. It is possible to support up to 18 voice clients in one cell with the necessary QoS level from the ITU-T [6].

V. Results

The results section is divided into two different parts. In the first part, we analyze the WLAN handover and show which part of the handover process is responsible for the most delay. The second part focuses on the handover performance using a voice application.

A. Handover with no background traffic

First, we analyze the handover with the five different scanning mechanisms described in Section III. Fig. 4 shows the simulation scenario with the APs transmitting a Beacon frame every 100 ms. The mobile client moves between the APs and uses the normal DCF while communicating with a workstation in the backbone network. The station starts the scanning process when the SNR drops below 10 dB. Fig. 5 shows the ratio between the scanning and the reassociation process for the five different scanning mechanisms. For all mechanisms, the reassociation process takes the same amount of time, but the scanning time varies. If the normal passive scanning is used, the station scans each of the thirteen channels for 100 ms, resulting in a total scanning delay of 1.3 s or 99.8 % of the total handover time. The scanning time can be

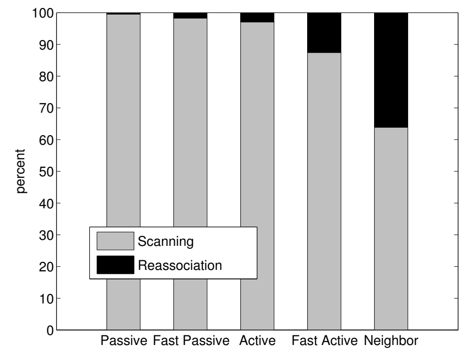

Fig. 5. Scanning versus reassociation time

reduced if neighborhood scanning is used, but still takes about 63 % of the total handover time. Since the reassociation time always takes the same amount of time, the different scanning mechanisms have to be analyzed and optimized to reduce the whole handover time. First of all, we analyze the scanning delay for the two passive scanning mechanisms. The passive scanning delay depends on the inter-arrival time of the Beacon frames. Most AP vendors set this value to 100 ms, but the IEEE 802.11 standard does not specify this value. Therefore, we set up the Beacon inter-arrival time between 4 ms and 100 ms and simulate the maximum throughput on the wireless link. In our case, the station acted as a saturated UDP source, such that it utilizes the whole remaining bandwidth. This maximum achievable throughput is shown as the solid line in Fig. 6. The dashed line shows the total handover delay using the fast passive scanning mechanism.

For a Beacon inter-arrival time between 4 ms and 50 ms, the maximum throughput increases from 4.4 Mbps to more than 5.5 Mbps. If we choose a Beacon interval greater than 50 ms, the maximum throughput does not further increase, thus the Beacon inter-arrival time should be set to 50 ms to get a maximum throughput of about 5.5 Mbps on the wireless link. This reduces the complete handover time to 652.65 ms for the normal passive scanning and to 152.65 ms for fast passive scanning.

The scanning time with active scanning depends on the Min Channel Time and the Max Channel Time. Therefore, we

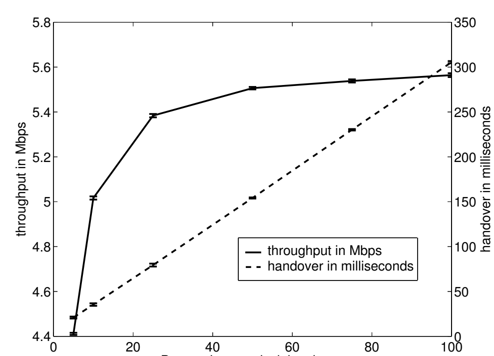

Fig. 6. Fast passive scanning with different Beacon inter-arrivals

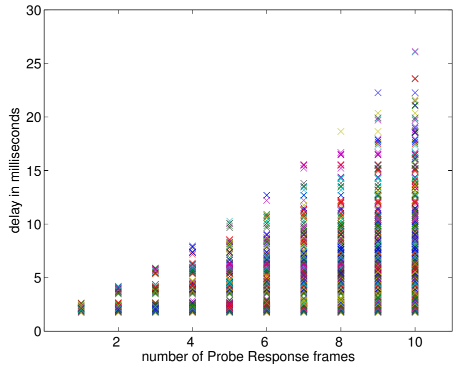

Fig. 7. Probe Response frame delay

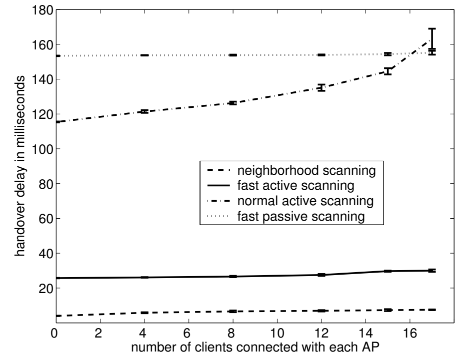

Fig. 8. Handover time / number of clients

simulate the time an APs needs to reply to a Probe Request frame. The number of APs is varied from one to ten APs within the reach of the station. Each cross in Fig. 7 shows the point of time a Probe Response frame arrives at the scanning station.

The probe-wait time tends to be between one millisecond and seven milliseconds for three or less Probe Response messages. For four to eight response messages the responses take up to 17 ms. Otherwise, it tends to be within an interval from four milliseconds to 27 ms. This shows that the Max Channel Time should be set according to the number of APs within the reach of the station. The first Probe Response frame is always received within 0.8 ms and so the Min Channel Time is set to this value for the following simulations. The IEEE standard created a value for the number of APs, called AP density which is normally used for handover decisions. Table II shows our settings of the Max Channel Time according to the AP density. The simulations with no background

TABLE II
MAXCHANNELTIME BASED ON THE AP DENSITY

Number of Responses	AP Density	Max Channel Time
1-3	low	7 ms
4-7	medium	17 ms
8-10	high	27 ms

traffic have shown that the scanning mechanisms are mainly responsible for the handover delay. Therefore, we analyzed the different scanning mechanisms and adjusted the parameters. In the next part, we analyze the handover performance with a voice application to show if it is possible to support QoS even if a handover has to be performed.

B. Handover with voice traffic

For the voice scenarios, we use the G.723.1 voice standard. The Beacon inter-arrival time is set to 50 ms according to the results in the previous part. When we are using normal passive scanning, the handover takes at least 652.65 ms, which does not suffice the ITU-T guidelines for QoS during a voice conference [6]. Therefore, normal passive scanning is not taken into account for the following simulation runs.

The remaining four scanning mechanisms are simulated with a different number of fixed voice clients in each wireless cell. The number of fixed voice clients is increased from 0 to 17. Fig. 8 illustrates the results for this simulation scenario. The x-axis shows the number of voice clients in each Basic Service Set and the y-axis illustrates the complete handover time. Only the normal active scanning is influenced by the number of background traffic and is even worse than fast passive scanning for a large number of voice clients. The handover delay itself with active and fast passive scanning mechanisms is still conform to the ITU-T guidelines, but if we take the coding delay and the delay on the wired network into account, an adequate echo control has to be assumed.

VI. CONCLUSION

In this paper, we investigated the handover mechanisms described in the IEEE 802.11 standard and subsequently published proposals. Only two of the three parts of the handover were analyzed, since we assumed a form of pre-authentication for the simulations. We showed that the scanning process dominated the handover time and thus concentrated on analyzing the different scanning mechanisms.

We have shown that a 50 ms Beacon inter-arrival time does not decrease the maximum throughput, but highly improves the handover performance for the passive scanning mechanisms. However, the normal passive scanning still does not suffice the QoS requirements for interactive voice traffic. For the active scanning mechanisms, we have shown a way to adapt the Max Channel Time according to the Access Point density. Our studies proof that QoS support in WLAN environments is possible even if the station has to perform a handover. Further studies have to take a closer look at prioritizing multimedia traffic and analyzing the system performance in case of overlapping and co-located cells.

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