Link Quality based Association Mechanism in IEEE 802.11h compliant Wireless LANs

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***Abstract*— When deploying IEEE 802.11 LANs, it is important from the performance perspective to associate the users to the available access points in an efficient way. The efficiency of an association relates to the average rates that the users can achieve with the particular association. Current implementations of 802.11 LANs do not take into account physical channel information in making association decisions. This usually results in much lower user rates than what can be ideally achieved. In this paper, we propose a new user association control framework for infrastructure-based wireless LANs compliant with the IEEE 802.11h specification in light of these issues. By using the new information that is implicitly provided by 802.11h specifications, our framework, takes into account the channel conditions when associating stations with the access points. Simulation results show that the proposed schemes improve the throughput of the network, compared with the static allocation without channel quality information. This improvement is significant, especially in an environment where external interference is present.**

I. INTRODUCTION

In recent years, IEEE 802.11 [4] wireless LANs (WLANs) have been rapidly deployed in enterprises, public areas and homes. In current WLANs, each user scans the wireless channel to detect its nearby access points (APs) and associate itself with the AP that has the strongest received signal strength indicator (RSSI). Thus, it is expected that a user associates itself with the closest/strongest AP. Recent studies have shown that this simple association approach leads to inefficient association of stations among the available APs [1], [2], [6]. The most important disadvantage is that RSSI does not give any information about uplink and downlink channel conditions. In fact, in current 802.11 implementations transmission power level of AP is unknown to the stations. Thus, a far away AP with high transmission power can have higher RSSI than an AP which is closer but with lower transmission power.

With the advent of PCF mode of operations, quality of service (QoS) became more important in WLANs. The perceived QoS depends not only on the signal quality but more on the delivered combined uplink and downlink rate to the user. Meanwhile, uplink and downlink rates depend on the interference levels observed at AP and user locations as well as their corresponding transmission power levels. Finally, interference in PCF mode occurs due to the ongoing transmission in adjacent cells as well as external radio devices (such as radar, HyperLan, appliances, etc). An association decision that takes into account all these factors can clearly provide better user satisfaction.

The recently announced 802.11h [5] protocol provides new features that can be used to effectively control user association and handoff in wireless LANs. 802.11h is designed to meet European Radiocommunications Committee regulatory requirements in the 5 GHz band. The two important new mechanisms introduced are Transmission Power Control (TPC) and Dynamic Frequency Selection (DFS). TPC is used by the APs to limit the maximum transmission level of the stations, whereas DFS is used to detect and prevent interference to/from other stations operating in the same frequency band. These mechanisms also provide new procedures for the stations and APs to become more aware of the current channel conditions. New information available to the stations and APs include the link degradation, estimated link margin, maximum allowable transmission level for the stations, and received signal strength indication measurements.

In this paper, we propose a simple-to-implement association/handover method for the stations, which utilizes the new mechanisms included in 802.11h. The association/handover method utilizes a greedy approach and selects the AP that can provide the maximum (estimated) bi-directional link rate. Under the proposed scheme, stations first estimate channel conditions both in the uplink and downlink, and use this information in making their associations. Consequently, the stations select APs more efficiently, and thus maximizing the throughput of the network.

The paper is organized as follows: In Section II, we provide a brief background on IEEE 802.11h framework. In Section III, we explain our proposed user association and handover method based on the estimation of the channel quality. We present our simulation results in Section IV, and we summarize our conclusions in Section V.

II. IEEE 802.11H FRAMEWORK

802.11h is proposed as an enhancement of 802.11 MAC in order to meet European Radiocommunications Committee regulatory requirements in the 5 GHz band and improve the configuration and the efficient function of wireless LANs [5]. 802.11h defines two fundamental procedures the **Transmis-**

sion Power Control (TPC) and the **Dynamic Frequency Selection (DFS)** to meet these objectives.

1) Transmission Power Control (TPC): TPC deals with the control of stations' transmission power levels. Prior to 802.11h, there was no specific framework for this purpose. TPC in 802.11h defines a framework within which stations can adjust their transmission power levels. First, TPC framework defines regulatory rules for the power levels: The maximum transmission power of the channels in the 5 Ghz band are limited to 200mW indoor in 5150-5350 MHz and 1W indoor/outdoor in 570-5725 MHz frequency bands.

In the new framework, an AP, taking under consideration the transmission power capabilities of its stations and the level of interference in the area, determines **Local Maximum Transmit Power Level** of its cell. A STA can dynamically adjust the transmission power of every frame as long as its transmission power is less than the Local Maximum Transmit Power Level. The local maximum transmit power level may be updated dynamically as the environment conditions change. The level is announced by AP to the STAs by using Beacons, Probe Response and Association Response frames which now has a new field carrying this information. AP is responsible for maintaining the network stability by determining how often or how much it should change the local maximum transmit power level. The objective of TPC procedure is to conserve the interference to adjacent cells to a low level and to ensure reliable transmission of frames of the stations.

From the perspective of this work, a new important feature of TPC framework is that it allows stations gather channel information among themselves: In this framework, a STA can ask for information about the condition of the channel in a neighborhood of another STA, sending to it a new control frame that is called TPC request frame. The receiver of a TPC request frame answers with a TPC report frame, which contains the power level that is used to send the frame and the estimated link margin. The second value is defined as the ratio of the received signal power of the TPC Request and the signal power required for effective communication for the current rate of transmission. Thus, the station that initializes the procedure is informed about the condition of the channel in both directions. Similarly, the Beacon, Probe Response and Association Response frames sent by the AP contain the information on transmission power of the specific frame. Thus, using this information, a station can now estimate the path loss in the downlink channel.

2) Dynamic Frequency Selection (DFS): The second basic procedure that is defined by IEEE 802.11h is the Dynamic Frequency Selection. One of the aims of this procedure is to reduce the interference to other wireless systems in the surrounding area that operate in the 5 Ghz frequency band, e.g., radars. Another aim is to spread wireless systems uniformly across a minimum number of channels. In order to reach these objectives, 802.l1h introduces new procedures and new frames by which a STA measures channels and reports the results to the AP. This information is used by the AP to decide on switching of the cell to a new channel.

In DFS framework, every station scans the channel periodically for the presence of primary users. The scanning procedure takes place during Quite Periods (which is a period that is defined by the AP during which all the STAs of the cell remain silent) or during normal operation. If a station determines the existence of a primary user, it informs the AP and then remains silent.

TABLE I
RSSRI CLASSES

RSSRI class	Power Observed at the Antenna (dBm)	Tolerance (dBm)
0	Power < -87	+5
1	$-87 <$ Power ≤ -82	±5
2	$-82 <$ Power ≤ -77	±5
3	$-77 <$ Power ≤ -72	±5
4	$-72 <$ Power ≤ -67	±5
5	$-67 <$ Power ≤ -62	±5
6	$-62 <$ Power ≤ -57	±5
7	$-57 <$ Power	-5

In addition to scanning, a station may perform other channel measurements. There are tree kinds of measurements that a station can do in a specific channel:

Basic measurement: During the Basic measurement, the station monitors the medium, seeking for frame transmissions that indicate the existence of other wireless devices in the same frequency. Thus, the report for this measurement is an indication about the existence of another wireless LAN system as Hiperlan or of a primary user (radar).

Clear Channel Assessment (CCA) measurement: In this measurement, the station monitors the medium, measuring the time period over which the channel was busy during the measurement period.

Received Signal Strength Report Indication (RSSRI) measurement: During this measurement, the station monitors the medium, measuring the time periods over which it receives signals with certain strengths during the measurement period. The signal strength is quantized into eight intervals as shown in table I. The report for this measurement contains the histogram of RSSRI for the eight classes. The histogram of RSSRI for a class is defined as the fractional period in which the station was receiving signals with power level between the corresponding thresholds.

III. USER ASSOCIATION AND HAND-OFF

The 802.11 standard has a framework for association of stations with the access points [1]. The framework consists of three phases: **(1) Scanning phase:** Initially, when a STA turns on, it listens to every channel for a specific period of time and in the process, collects Beacons or Probe Response frames from the available APs at the beginning of the PCF. The process is called Scanning. **(2) Decision phase:** After collecting these frames, the STA identifies (decides on) the AP with which it will start an Association procedure. **(3) Association phase:** The STA exchanges control packets with the selected AP in order to become a member of its cell. If the user is authenticated, it is allowed to be a member of the cell.

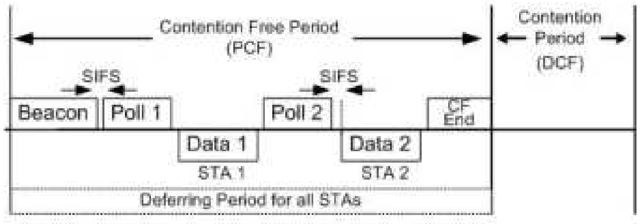

Fig. 1. PCF mode of IEEE 802.11 Standard

The association occurs in the DCF (Distributed Coordination Function) part of the 802.11 frame.

The link conditions may vary in time due to interference or mobility of the stations. Consequently, the stations may periodically examine the medium (by Passive Scanning) in order to determine if there exists a “better” AP for association. If such an AP exists, then the station triggers a **Reassociation/Handoff** phase to switch from the current AP to the new chosen one. In both Association and Reassociation, the 802.11 framework does not identify the criteria for association decisions. The questions that remain to be answered include: (a) What information can the APs provide to STAs within the 802.11h standard to allow STAs to make efficient association decisions, and (b) How does a STA determine the *best* AP by observing this information that it receives from the available APs?

In current implementations of 802.11, during the scanning phase, no information is available to the STA with regard to the channel quality, the interference statistics, or the transmission power of the AP. The association decisions are made solely based on the received signal strength of the Beacons or Probe Requests sent by APs. By selecting the AP with the highest RSSRI, the STA expects that it will be associated with the AP that has the clearest channel. Thus, it expects to achieve high rates of communication in the network. This implicit inference is not always correct. That is because, RSSRI not only depends on the distance of the APs but also the transmission powers of the APs. As 802.11 gives no information about the transmission power of these frames, relying solely on RSSRI often leads to inefficient associations.

Recently, Sang et. al [3] has proposed an Association procedure for CDMA-based wireless LANs with downlink traffic. The proposed scheme is based on the number of the users in every cell. According to this method, each AP broadcasts the number of users in its cell. Based on this information, as well as on signal strength in the downlink channel, a STA selects the cell that will have the highest expected throughput after the new association. However, the authors considered **only downlink traffic** in their method. As depicted in figure 1, for 802.11 WLANs operating in PCF mode, the traffic is usually symmetric on the uplink and the downlink. Every downlink packet is usually followed by an uplink packet. Thus, in order to maximize the overall throughput in such a scheme we must consider the throughput in both uplink and downlink channels. We define as STA to AP throughput the **bi-directional** channel rate that can be supported by the MAC.

Based on the previous fact, we propose a new association procedure that maximizes the bi-directional throughput between the STA and the AP. Our scheme determines the AP that maximizes the transmission rates in **both** channels by considering the link quality in the uplink and the downlink. In our scheme, every STA estimates the signal to interference ratio (SINR) for the uplink and the downlink for every candidate APs. The estimation procedure is given as follows:

For the downlink:

A STA knows the received signal strength of the broadcast packets it received. Operating under the framework of 802.11h, the STA performs a ”Received Signal Strength Report Indication (RSSRI) measurement” resulting in a table with the RSSRI densities as it it described in table I. Using this table it calculates the mean interference in its neighborhood. It concludes on the SINR estimation by using the following formula:

$$SINR^{d}_{n,k} = \frac{S^{r}_{n,k}}{I^{k}_{est}}, \tag{1}$$

where

- $SINR^{d}_{n,k}$ is the estimated SINR for the downlink between AP n and STA k,
- $S^{r}_{n,k}$ is the signal strength on the receiver (STA k) for the downlink (beacon packet from AP n),
- I^{k}_{est} is the mean estimated interference in the neighborhood of the STA k.

For the uplink:

For the uplink, a STA does similar estimations. Due to the fact that now the STA does not have all the information it needs, there are some slight but important modifications in the procedure. Similar to the previous situation, the STA needs the strength of the received signal in the AP as well as the table with the RSSRI densities in the AP, in order to estimate the SINR in the uplink. STA determines these values in the following way:

The received signal strength of an uplink packet in the AP is estimated as the transmission strength of the packet multiplied by the link degradation factor which depends on the physical medium. The link degradation can be calculated as follows: As we have mentioned, under the 802.11h framework every AP broadcasts via its Beacons the **Local Maximum Transmit Power Level**. This is the maximum limit for the transmission power of every STA belongs to the specific cell. Thus, STA uses this power for the estimation of the SINR in the uplink (assuming that it will transmit using the maximum allowable power in the specific cell). On the other hand, the AP now includes in its Beacon the power level used in the transmission of Beacon. The STA with the knowledge of the transmission power and the reception strength of the specific packet can calculate the link degradation factor due to the propagation loss.

Finally, the STA needs the interference RSSRI density table measured by the AP in order to estimate the mean interference in the uplink. This information is available in the AP and it can be broadcasted easily to the interested STAs. One alternative for the relay of this information is by adding a new Information

Element in the Beacon containing the information. Note that the length of the specific table is only a few bytes, so it does not increase the overhead significantly. Another alternative is by requesting a RSSRI measurement (as it is defined by the 802.11h) from the APs, during the Scanning procedure.

Therefore, the STA can proceed in the estimation of the SINR in the uplink as follows:

$$SINR^{u}_{n,k} = \frac{\left(C * S^{t}_{k,n}\right)}{I^{n}_{est}} \tag{2}$$

where

- $SINR^{u}_{n,k}$ is the estimated SINR for the uplink between AP n and STA k.
- C is the propagation loss of the transmission power.
- $S^{t}_{k,n}$ is the estimated transmission power from STA k to AP n.
- I^{n}_{est} is the mean estimated interference in the neighborhood of the AP n.

Given uplink and downlink SINR, the STA can calculate the Packet Error Probability (PER) by using the methods described in [8]. We denote with p_u and p_d the PER for the uplink and the downlink respectively. We characterize the channels as lossy channels. Therefore, every transmitted packet is successfully received with probability p_u and p_d respectively. We estimate the mean number of PCF frames required for a successful packet transmission as follows.

$$\begin{aligned} E(\#frames) &= \sum_{k=1}^{\infty} k(1-p_u p_d)^{k-1} p_u p_d \\ &= \frac{p_u p_d}{1-p_u p_d} = \frac{1}{\frac{1}{p_u p_d} - 1} \end{aligned} \tag{3}$$

In order to minimize the number of frames required for a successful transmission we should maximize the product $p_u p_d$. Thus, the STA selects the AP that provides the maximum $p_u p_d$.

IV. NUMERICAL ANALYSIS

A. Simulation model

For the simulations, we have used OPNET [7]. Wireless Module of OPNET has been designed to simulate in a detailed way the transmission and reception of a packet. With a pipeline execution sequence of 13 functions, it follows in a very realistic way the physical layer behavior. Thus, during transmissions, it takes under consideration the packet transmission power, the path loss, the BER, the interference and the noise that every STA experiences. Such factors are very important in the implementation of our protocol in order to have realistic results. We use a multi-cell system as depicted in 2.

In our simulations, Contention Free Period (for PCF) is 85% of the super-frame while Contention Period (for DCF) is the remaining 15%. The transmission power of every AP is same and equal to 200mW. The locations of the APs are such that there is 25% overlapping between two neighboring cells. The transmission power of every STA is constant and equal to the transmission power of the APs. For the transmissions of packets by any STA (or AP), we use physical model of IEEE 802.11a OFDM physical layer, i.e., BPSK modulation which allows physical rate of 6 Mbps is used. We assume that a successful bi-directional service occurs when a successful transmission from AP to STA is followed by a successful transmission in the opposite direction. Thus, the transmissions are assumed to succeed in pairs (bi-directional throughput). We measure the throughput of the network based on amount of data that is transmitted by these successful bi-directional packet exchanges. We compare our algorithm with the Association procedure scheme that is based on the signal strength of the Beacons. In the figures, we named this scheme ”802.11” since this is scheme the current 802.11 systems employ.

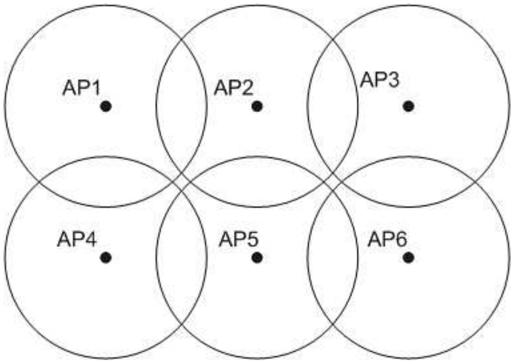

Fig. 2. The multi-cell environment of the simulation

We assume that the STAs are uniformly distributed in the area of the network. In order to have a dynamically varying physical medium, i.e., the interference levels around STAs changing in time, we define two states for every STA: “on” state and “off” state. When a STA is in “on” state, it transmits packets with 1024 kbps. On the other hand, when the STA is on “off” state it remains inactive, i.e., do not transmit anything. Every STA alternates between “on” and “off” states. There is no synchronization between the STAs in regard to when they alternate between two states. Thus, the interference in each cell changes dynamically as time evolves. The “on” and “off” periods of a STA are equal and relatively large. When a STA is in “off” state, it behaves like it is turned off. When it starts an “on” period, it behaves as it has just turned on. Thus, it executes the association procedure as it is defined in the previous section. After STA has been associated with an AP, it executes the re-association procedure periodically. The reassociation interval is quite small compared with the “on” state interval, so that a STA executes reassociation four times during its active state. We concluded on the length of these intervals by testing several values on the simulations and observing that these values lead the system in a stable behavior.

B. Simulation results

In the first experiment, we study the behavior of our protocol as the number of the STAs in the area increases. We executed 12 simulation runs, and in each run, we increased the number of STAs from 5 to 60. The network throughput with the proposed association scheme and 802.11 is given in figure 3. The percentage increase in the throughput that our protocol achieves in comparison to the 802.11 is shown in figure 4.

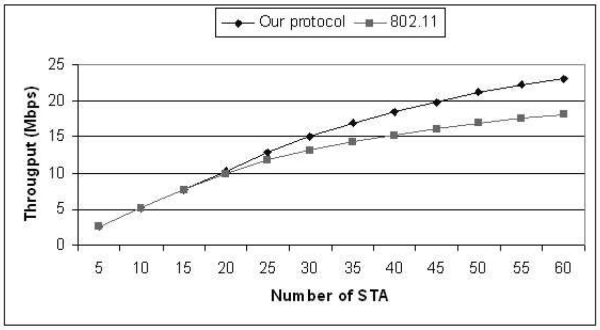

Fig. 3. The change in network throughput as the number of STAs increases.

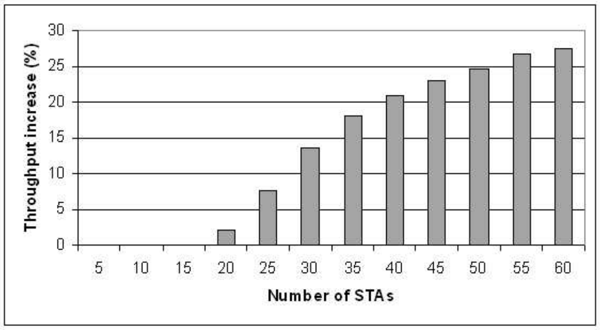

Fig. 4. The change in network throughput as the number of STAs increases.

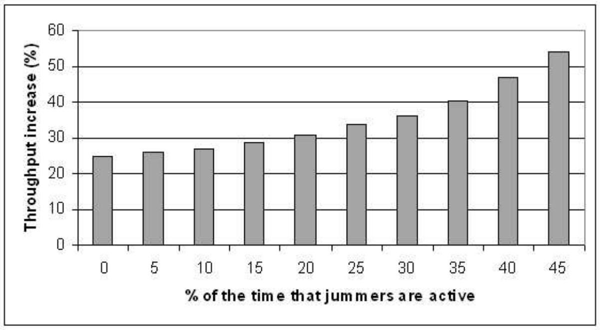

Fig. 5. Increase of the throughput with jammers in the system.

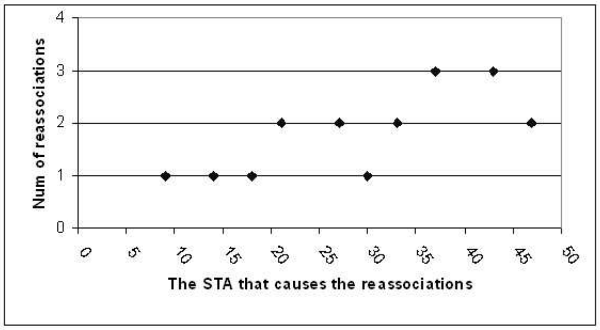

Fig. 6. The number of re-associations that the association of every STA causes

From figures 3 and 4, it can be seen that our protocol behaves more efficiently; increasing the overall throughput of the network at a much faster rate as the number of the STAs increases. Under heavy network load condition our protocol achieves approximately 27% increase, as it is depicted in figure 4. This is due to the fact that our protocol, taking under consideration the SINR in the uplink and the downlink, reacts in a sophisticated manner to the change of the interference between the cells by changing dynamically the associations of the cells. On the other hand, by not considering interference in the association decisions, 802.11 scheme performs static associations.

In order to study the behavior of our protocol under external interference conditions, we performed additional experiments where interference generating *jammers* are added in the network. The jammers are components when they are active, continuously transmit jamming packets that cause interference. The jamming packets cannot be received correctly by any STA, and cause collision with any other transmitting packet in their region. In the next experiment, we add three jammers into the network. The jammers are located close to APs 1,2 and 3. When a jammer is active, it destroys the reception of the neighboring AP. Every jammer alternate its state between active and inactive. We run simulations by varying the percentage of the active period for each jammer. The results of these simulations in regard the increase of the throughput of the proposed protocol, compared with the current approach is depicted in figure 5.

As depicted in figure 5, our protocol is more robust in the presence of external interference. Under the new association procedure, the STAs realize the presence of the jammers, and thus if they have an alternative, i.e., if their location is such that they can associate with a cell that does not have jammer, they proceed with this reassociation. On the other hand, the current 802.11 association approach, cannot detect the presence of the jammers and react effectively. Thus, the STAs remain associated with the jammed APs, trying to communicate with an AP that is ineffective due to the high external interference around it. The longer the jamming duration is, the higher the increase in the throughput with our approach. In high external interference environment, our protocol can achieve an increase of approximately 54% compared with the current approach.

In our last experiment, we study the stability of the proposed association procedure. We consider the same multi-cell environment, but we add stations in random locations every constant period of time. The number of STAs starts by 1 and is increased until when there are 50 STAs in the network. Every STA, when it turns on, associates with an AP, and then it transmits continuously with a rate of 512 kbps. Every constant period, STAs generate a re-association procedure in order to examine the network for a more efficient association. The interference of the network dynamically changes, every time a new STA turns on. In this experiment we measure the number of re-associations that the presence of a new STA may cause.

From figure 6, we can see that when a new STA arrives in the network, some re-associations will occur, since the operation of the new STA changes the interference environment of its neighborhood. Some of the re-associations affect the decision of STAs around, creating a domino effect and forcing the STAs to re-associate with a more capable AP. As the number of STAs increases, we can see that two or three re-associations usually occur after a specific association that changes the dynamic of the system. The important thing to notice is that once the system is adapted in the new conditions, it remains stable until a new entrant causes significant change in the interference environment.

V. CONCLUSIONS

In this paper we propose a framework for association control for 802.11 wireless LANs. We have designed our method to be in compliance with the new 802.11h Standard in order for our methods to be practically implementable immediately. However, the ideas in this paper can easily be extended to other future standards. The proposed scheme allows stations to associate with the best AP by taking into consideration the quality of the channel on both the uplink and the downlink. Simulation results of the proposed approach demonstrate that our scheme achieve an increase in throughput by more than 55% as compared with previously employed association methods in IEEE 802.11 based LANs, in environments with high interference.

We expect further improvements in system efficiency when we jointly perform power and association control. It is our future objective to investigate this problem.

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