A Novel Association Algorithm for Congestion Relief in IEEE 802.11 WLANs

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ABSTRACT

Many wireless local area network (WLAN) performance estimations are done with the assumption of uniformly distributed stations (STAs). In practice, on the contrary STAs are distributed unevenly among access points (APs), causing hot-spots and under utilized APs in a wireless network. Considering a WLAN is made up of multiple APs, having some APs carrying excessive loads (i.e. hot-spots) degrades both the considered APs as well as the overall network performance. The system performance can be improved by associating incoming STAs effectively throughout the network, in a sense to balance the network load evenly between APs and relieve the hot-spot congestion. Currently employed user association method in IEEE 802.11 WLANs considers only the received signal strength of APs at STAs, and associates STAs to the closest (in signal strength sense) AP, ignoring its load and interference value.

Novel user association algorithms are required for congestion relief and network performance improvement. In this work, a new distributed association algorithm taking into consideration not only the received signal strength of the APs at STAs but also AP loadings and interference is proposed. A new AP load calculation method acknowledging the interference between STAs and APs is presented. Our simulations demonstrate that the proposed algorithm can improve the overall system throughput performance more than 50% and offers a better load distribution across the network compared to conventional association algorithm.

Categories and Subject Descriptors: C.2.5 [Computer Systems Organization][Computer Communications Network]: Local and Wide-Area Networks

General Terms: Performance, standardization

Keywords: IEEE 802.11, load balance, hot-spot

1. INTRODUCTION

In IEEE 802.11 wireless local area networks (WLANs), an access point (AP) has a serving area defined by its transmission power and propagation channel condition. An AP can associate stations (STAs) in its own serving area. In a typical enterprise deployment, a WLAN is made up of multiple APs and usually APs have overlapping coverage areas. Therefore, a STA in an overlapped area can associate with any AP that has sufficient signal strength. Association control is the key to determine the individual AP loadings and network wide load balancing. The quality of each AP-STA link and connection speed depend on the channel condition and interference. With the helping of adaptive transmission schemes (e.g. Auto-Rate Fall back [2]), STAs can pick a modulation and coding technique that suits the best to the propagation condition. Current association technique lets STAs choose the AP that has the strongest signal strength, which might cause un-balanced load distribution in networks with hot-spots and eventually degrades the overall performance.

1.1 Problem Statement

In current IEEE 802.11 media access control (MAC) layer, each STA scans the wireless channel for a probe signal from APs (i.e. searches for physical preamble [5]); detects APs that are close by and associates itself with the AP that has the strongest received signal strength indicator (RSSI), ignoring its load and interference in the communication environment. Since STAs are not informed about AP loadings or interference, in a network configuration there might be some APs having an excessive load, whereas some having just a few STAs associated with it. From STA point of view, the current method lets STAs, that are in the transmission range of multiple APs, associate themselves with an AP that *promises* the maximum transmission rate. However, being able to communicate with the highest transmission rate (i.e. strongest signal) does not necessarily mean that this association would provide the best throughput and actual data rate. Association of a STA to a less loaded AP with weaker signal strength might supply a higher data rate and better overall network performance, especially in network hot-spots.

1.2 Related Work

Network performance improvement with user association control has been considered by both academic community and the industry. Association algorithms to balance the network load are already implemented by various WLAN equipment vendors [1], such as least loaded association algorithm which takes into account only the AP loadings and associates the new users to the AP that has the least load. An association algorithm which estimates the possible signal

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power to interference and noise power ratio (SINR) for each connection is proposed by [10]. The algorithm estimates the available SINR before association and chooses the best offer in a bi-directional link. However, in the algorithm of [10] adaptive data rate ability of wireless equipments is ignored and AP load or congestion relief are not taken into account. Another predictive association algorithm is described in [9]. In this study, each STA calculates its own RSSI value and compares it to average RSSI value of the STAs associated to the considered AP and runs the association algorithm relative to the condition of if STA's own RSSI is less or more than the AP average RSSI. In this association technique, limited number of available frequencies and the interference characteristic are not taken into account. An AP based association algorithm is described in [11]. In this scheme, association master decides on two thresholds: *i*) Overload threshold *ii*) Underloaded threshold. APs which pass the overload limit force their excessive STAs to associate to the neighboring APs. In another association control algorithm, Bejerano et al. in [12] illustrate network-wide fair bandwidth (BW) allocation among users independent of their locations, while maximizing the fair share of each user. Their fairness concept is called max-min fairness, which is a BW allocation if there is no way to give more BW to any user without decreasing the allocation of a user with less or equal BW. In their paper, AP load definition is explicitly defined, however the interference between terminals (i.e. AP or STA) is ignored which affects individual loads that are different on uplink and downlink connections. In [6], authors define a cost function which takes the average uplink throughput vector (e.g. AP throughputs are individual elements of the vector) as a variable and outputs a scalar value and they try to maximize this scalar value by choosing different user associations. The last two algorithms mentioned are required to run a central association algorithm to minimize the cost function and allocate BW fairly which is computationally complex and not suitable for large networks.

In this paper, we introduce an association algorithm which balances the network load and improves the average network throughput. A new AP load calculation method which depends on the number of users associated, their signal strength, interference and uplink-downlink communication ratio is presented. The proposed association algorithm improves the system performance and the performance increase reaches its peak in WLANs hot-spots. The rest of the paper is structured as follows. In the next section definition of AP load is given. Average interference calculation method is presented in section III. In section IV, the proposed association algorithm which balances the load across the network is explained. Assumptions and simulation results are discussed in section V. Finally conclusions are given in section VI.

2. LOAD DEFINITION

One of the biggest concerns in wireless network configuration is to balance the network load among APs to maximize frequency efficiency and to supply a fair service for each STA. A proper definition of load in WLANs is required for problem formulation. Intuitively, the load of an AP should reflect its inability to serve properly to its associated users. Considering that each STA has the same traffic characteristic, a STA that has the highest connection rate among the associated STAs would be the least burden on the AP. Hence a load imposed on an AP by a STA should be inversely proportional to connection rate STA experiences. The consistent load definition indicated in [12] will be used and augmented to include interference in this study. The load induced by user u on AP a is defined in [12] as the time that takes for an AP to provide user u one unit of traffic; and the total load y_a on AP a is the aggregate load of all its associated users. In order to generalize the AP load calculation formula to all the STAs in the communication environment, it is required to define a variable to indicate the association of the user to AP. It is assumed in this study, if a user $u \in U$ is associated with AP $a \in A$ then $x_{a,u} = 1$ and the user imposes a certain load on AP a that is inversely proportional to its connection rate, $r_{a,u}$. If it is not associated with AP a then $x_{a,u} = 0$ and it does not contribute to AP load. Therefore, the load of user u on AP a and the total load of AP a can be defined as follows:

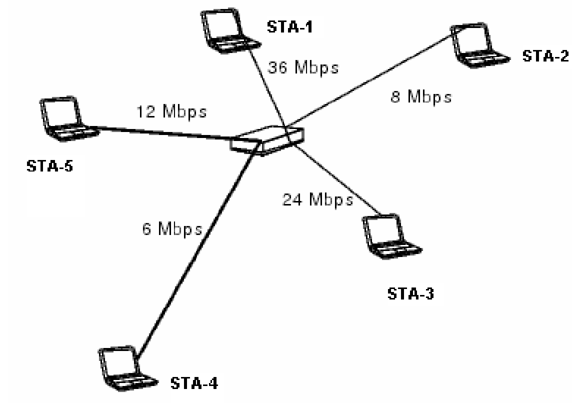

Figure 1: Example load calculation illustration

$$\forall u \in U, \forall a \in A : y_{a,u} = \frac{x_{a,u}}{r_{a,u}} \quad \text{and} \quad y_a = \sum_{u \in U} \frac{x_{a,u}}{r_{a,u}} \qquad (1)$$

A distinction should be made between the terms of connection rate and attainable data rate of a STA. *The connection rate* is the communication speed that a STA experiences when it is communicating with an AP. However, *the attainable data rate* is the actual data rate of STA that caused by the time sharing nature of common AP frequency with other associated users. Example 1 points out the difference between two definitions and demonstrates a load calculation of an AP.

2.1 Example 1

Consider that an AP is serving 5 STAs in a IEEE 802.11a WLAN having different data rates due to communication environment as illustrated in Fig. 1. Assume that, AP runs a scheduling algorithm that allocates transmission opportunity (TO) fairly to its associated users. This could be realized by either Point Coordination Function (PCF) access mechanism of IEEE 802.11 or any other fair scheduling algorithms described in [8]. Consider that for each transmission opportunity, a STA is sending a single MAC Service Data Unit (MSDU) frame. According to the IEEE 802.11 standard, the length of a MSDU frame must be less than or equal to 2304 octets [4]. Hence, the transmission duration of a MSDU frame for STA-1, which has *the connection rate* of 36 Mbps, would be $t_1 = 2304\,\mathbf{x}8\,(bits)/36e6\,(bps) =$

$512\,\mu sec$. If the same calculations are done for each STA, individual transmission durations of a single MSDU frame would be as follows $t_2 = 2304\,\mu sec, t_3 = 768\,\mu sec, t_4 = 3072\,\mu sec, t_5 = 1536\,\mu sec$. Since fair TO assumption is made, it can be claimed that the considered AP can serve a single MSDU of all of its associated STAs in a duration of $t_{tot} = t_1 + t_2 + t_3 + t_4 + t_5 = 8192\,\mu sec$. If we take into account the size of the MSDU frame, this would translate to 2.25 Mbps (i.e. $2304\mathbf{x}8, (bits)/8192\,\mu sec$) *attainable data rate* for each STA. As it can be seen, t_{tot} value represents the busyness of the AP to serve its users. The bigger this number gets, the worse the individual attainable STA data rate would be. The illustrated example assumes that each STA transmits a MSDU frame per connection. For the load definition, without loss of generality we can assume each STA sending a single bit instead of a whole MSDU frame. This would just have the scaling effect and the load of the AP in the example would be $0.444\,\mu sec$ instead of $8192\,\mu sec$. In this load definition, it is implicitly assumed that all STAs have a frame waiting for transmission (i.e. *"greedy user"*) when they have the opportunity for connection.

3. INTERFERENCE CALCULATION

For IEEE 802.11a, there are 12 non-interfering frequencies in U-NII (Unlicensed National Information Infrastructure) band that can be assigned to any AP. However, 4 of the frequencies are located in the lower U-NII band (5.150 - 5.250 GHz) with maximum transmission power of 40 mW, which is suitable for short-range indoor home and small office environments [7]. Other 4 Upper U-NII frequency bands (5.470 - 5.725 GHz) are suitable for bridging applications and outdoor operations with 1000 mW maximum output transmit power. The middle U-NII frequency bands (5.250 - 5.350 GHz) are suitable for Wi-Fi hot-spots and enterprise environments with transmission power of 200 mW, which parallels our study. Therefore in this paper it is assumed that there are 4 non-interfering operational frequencies available for IEEE 802.11a WLANs. To provide pervasive connectivity and mobility to areas like airports, conference halls and big enterprises more than four APs are required in the network, making the interference and overlap between AP cells inevitable. In this section assumed indoor propagation channel model, the calculation of thermal noise expected at the input to an 802.11 receiver, the details of average interference calculation in the communication environment as well as the modified AP load calculation method taking into account the interference are presented.

3.1 Propagation Environment

IEEE 802.11a PHY (Physical Layer) can serve its clients with high data rates up to 54 Mbps. However, maintaining reliable communication at higher data rates requires more signal power. An adaptive multi-rate transmission algorithm is responsible for selecting the data rate that gives the optimum throughput for the specific channel condition. An accurate wireless channel model is vital in order to estimate the received power level properly and to find out the communication rate of a STA in WLAN. For indoor propagation channel characterization, the pathloss model (in dB) that International Telecommunications Union (ITU) has recommended in 5 GHz band is given by Eq. 2 [3].

Table 1: Minimum SINR values for different IEEE 802.11a data rates

Data rate (Mbits/s)	SINR (dB)	Modulation
54	24.56	64-QAM
48	24.05	64-QAM
36	18.80	16-QAM
24	17.04	16-QAM
18	10.79	QPSK
12	9.03	QPSK
9	7.78	BPSK
6	6.02	BPSK

$$L_p = 41dB + 31log_{10}(r) + \sum_p WAF(p) + \sum_q FAF(q) \quad (2)$$

where the first term is the loss at 1 m; the second term indicates a path-loss exponent of 3.1; r is the distance between transmitter and receiver in meters; p is the number of walls and q is the number of floors between transmitter and receiver; finally WAF and FAF are wall attenuation and floor attenuation factors which depends on the construction material. In this study, we will assume that both transmitter and receiver are on the same floor and there is no wall between them. From basic theory the noise at 802.11 receiver can be calculated as:

$$N_0 = kTB = -101.4\ dBm \quad (3)$$

where k is Boltzman constant, T is ambient temperature and B is the bandwidth of receiver. It is assumed that the front-end of a nominally compliant 802.11 device has a noise figure of 10 dB [5]. A bit error rate of better than 10^{-5} is considered acceptable in WLAN applications. By using standard graphs of BER vs E_b/N_0 for different modulation schemes, it is possible to calculate the minimum required SINR values as illustrated in Table 1, [3]. The average SINR value of an individual STA can be found by calculating the received power, average interference caused by all STAs and APs that are using the same frequency and thermal noise. In the interference calculation, the time sharing of the operating frequency between AP and STAs as well as uplink-downlink connection ratio should be taken into account. Example 2 demonstrates an interference calculation scenario.

3.2 Example 2

Consider the communication environment illustrated in Fig. 3. According to the convention of wireless communication, *uplink connection* is defined as the data flow from STA to AP and *downlink connection* as the flow from AP to STA. In wireless networks, generally downlink connection dominates the overall connection. Uplink-to-total link ratio is indicated as ul. Consider that with each connection a STA sends a frame (MSDU) of 2304 octets. Assume that the uplink-to-total link ratio as 0.3, $ul = 0.3$, which means 3 out of 10 connections a STA makes with its associated AP are uplink connections. In the illustrated example, STA a-1 with 6 Mbps uplink data rate keeps AP-A busy for the duration of $t^u_{a1} = 2304\,\mathbf{x}\,8(bits)/6e6(bps) = 3072\,\mu sec$ for each uplink connection and $t^d_{a1} = 2048\,\mu sec$ for each downlink transmission. Uplink and downlink connection rates are different due to different interference levels on AP and STA. For 10 TO, with the assumed uplink ratio STA a-1 would keep AP-A busy $t^t_{a1} = 7\,\mathbf{x}\,t^d_{a1} + 3\,\mathbf{x}\,t^u_{a1} = 23552\,\mu sec$. Considering the fair TO, STA a-2 and STA a-3 total loads for 10 TOs on AP-A can be calculated as $t^t_{a2} = 1792\,\mu sec$ and $t^t_{a3} = 4608\,\mu sec$. The total normalized (i.e. transmission of single bit instead of one MSDU frame) load per connection (1 TO) of AP-A can be found as $t_A = 0.3153\,\mu sec$ by adding up the individual normalized STA loads. Assume that AP-A and AP-B are operating in the same operational frequency. Interference effect of AP-A and its associated users on the downlink connection of STA b-1 will be illustrated in this example. A STA can cause interference to another terminal (AP or STA) if they are using the same operational frequency and they are associated to different APs. A STA interferes whenever an uplink connection is established and AP interferes on the downlink. Our concern is to calculate the interference on the long term basis. For average interference calculation, we need to find out the relative time that each individual STA or AP occupies the channel. The relative channel occupation times can be found by estimating the individual to total AP load ratio. Let's denote the interference power of STA $a1$ affecting the downlink connection of STA $b1$ as $I_{a1,b1}$, interference power of AP-A as $I_{A,b1}$ and the total load of AP-A as t_A. The total average interference power affecting the downlink connection of STA $b1$, $\overline{I}^d_{b1}$, can be found as follows:

$$
\begin{aligned}
\overline{I}^d_{b1} &= \left(\frac{t^u_{a1}}{t_A} \times I_{a1,b1} + \frac{t^d_{a1}}{t_A} \times I_{A,b1}\right)\ldots \\
&+ \left(\frac{t^u_{a2}}{t_A} \times I_{a2,b1} + \frac{t^d_{a2}}{t_A} \times I_{A,b1}\right)\ldots \\
&+ \left(\frac{t^u_{a3}}{t_A} \times I_{a3,b1} + \frac{t^d_{a3}}{t_A} \times I_{A,b1}\right)\ldots \\
&= \overline{I}^u_{a1,b1} + \overline{I}^u_{a2,b1} + \overline{I}^u_{a3,b1} + \underbrace{\overline{I}^d_{a1,b1} + \overline{I}^d_{a2,b1} + \overline{I}^d_{a3,b1}} \\
&= \overline{I}^u_{a1,b1} + \overline{I}^u_{a2,b1} + \overline{I}^u_{a3,b1} + \qquad \overline{I}^d_{A,b1}
\end{aligned}
\tag{4}
$$

where $\overline{I}^u_{a1,b1}$ denotes the average interference caused by STA $a1$ uplink connection on STA $b1$ downlink connection. On each and every downlink connection, AP-A is the interferer, which is illustrated on the fifth line of Eq. 4.

4. PROPOSED ASSOCIATION ALGORITHM

In this section, the proposed low complexity distributed association algorithm for IEEE 802.11 WLANs is described. A distributed association algorithm is a must for large WLANs because of the complexity issues. An efficient association algorithm can be designed for WLANs if we take into account received signal strength of APs at STA, AP loadings, multi-rate transmission capability of devices, background noise, uplink-downlink ratio and interference. In the proposed algorithm, each STA associates with the AP that supplies the highest attainable data rate. In case of hot-spots, the algorithm chooses a less loaded AP which supplies a better attainable rate and relieves the possible congestion.

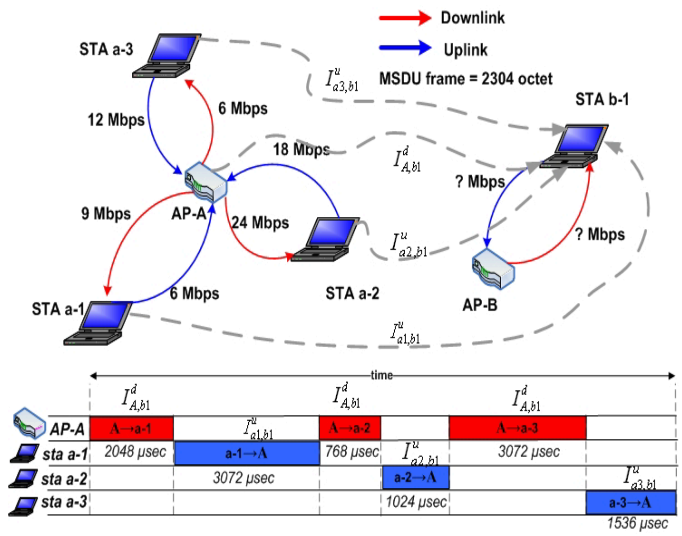

Figure 3: AP load calculation example with interference. AP-A and AP-B use the same operational frequency. STA b-1 is a new user to be associated with AP-B. AP-A, STA a-1, STA a-2 and STA a-3 will interfere with the STA b-1 connection and affect downlink data rate. For each TO, the terminals are assumed to be sending a MSDU frame.

In the algorithm, each STA not only checks the best AP (providing the best data rate) just at the association stage, but also periodically evaluates the available APs and their attainable data rate offer. In case of finding a better AP for the given configuration, it re-associates itself to the new AP. It is a very well known fact that the available data rate of the STA associated with an AP depends on the RSSI of the considered STA, number of the users connected to that AP, their connection speeds and interference which all determine the AP load. Therefore each STA estimates the possible data rate with each associable AP regularly.

5. SIMULATION RESULTS

The performance and load balancing ability of the proposed algorithm is compared to different association algorithms. Namely strongest signal first (SSF) and least loaded AP first (LLF) association performances are illustrated. In the simulations the proposed association algorithm is named as predictive association algorithm (PAA), since it predicts the possible attainable data rate before associating itself to an AP. Simulation results are presented for IEEE 802.11a networks because of the faster modulation techniques, higher number of non-interfering frequencies and spectrum and transmit power management extensions. An exhibition hall propagation environment is used for analysis. The size of the exhibition hall is 240m x 240m. The sixteen APs are regularly distributed on a grid of distance 60m. The number of STAs are varied in order to represent different loadings. Users are assumed to be greedy. Therefore the bottleneck of the communication is the wireless link. AP and STA transmit power level is assumed to be constant, 200 mW (23 dB). Uplink to total link connection rate is assumed to be 0.3. Initially, 50 users are considered to simulate moderately loaded WLAN and it is increased to 100 users to illustrate

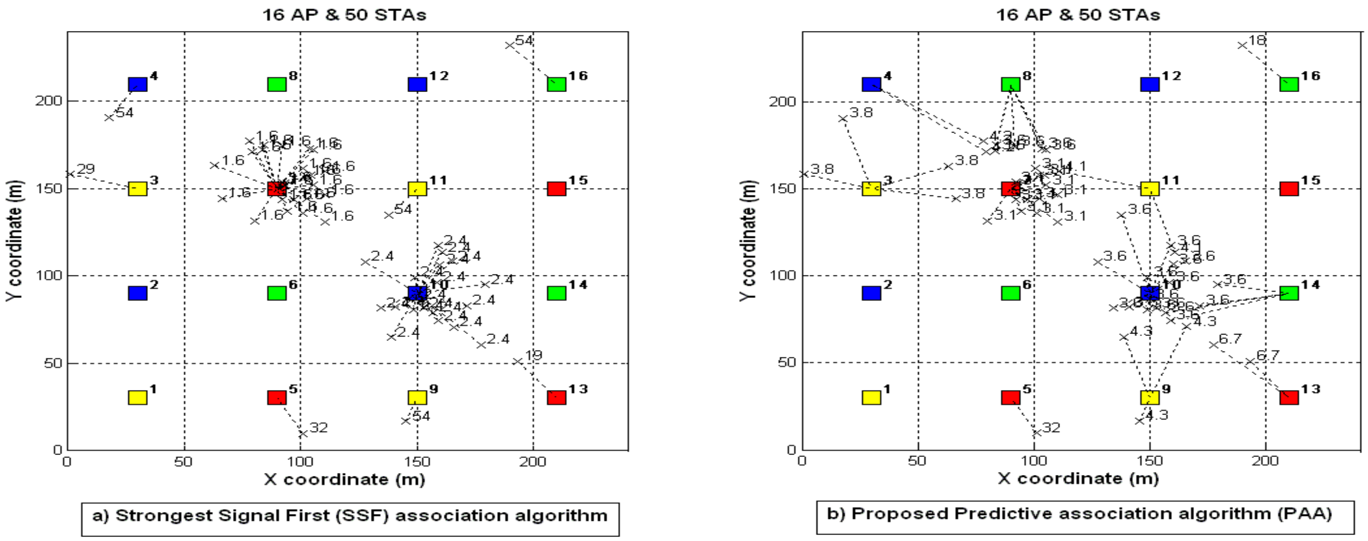

Figure 2: Illustration of simulation set-up with 16 APs and 50 STAs. STAs have the same locations but different association algorithms in figures. AP-7 and AP-10 represent the hot-spots in the network. Figure-a illustrates the association with the current IEEE 802.11 association algorithm. Figure-b shows the proposed association algorithm for hot-spot congestion relief.

the performance in heavily loaded WLANs. Hot-spot cells will be simulated by creating users uniformly in two circular areas with radius 30 m. A snap-shot of the simulation environment with generated AP and STA locations and the assumed frequency planning of available four non-interfering frequencies are illustrated in Fig. 2. As it can be seen from Fig. 2, AP-7 and AP-10 represents hot-spot areas in the network. STAs are illustrated along with their associated APs and attainable data rates in the figure. STAs have the same locations in figures Fig.2-a and Fig.2-b, the only difference is the employed association algorithm. Fig.2-a illustrates the SSF association algorithm, where most of the users selected AP-7 and AP-10 for communication. However, this scheme overwhelms the APs. Because of the congestion, AP-7 and AP-10 can only offer data rates of 1.6 Mbps and 2.4 Mbps to its associated users. Fig. 2-b shows the performance improvement with the proposed association algorithm. As it can be seen, the congestion of APs 7 and 10 is partially relieved. By association of some STAs to AP-4 and AP-8, users associated to AP-7 has a performance increase close to 100% compared to SSF association algorithm.

The performance improvement of the proposed algorithm can be illustrated by drawing the attainable data rate increase of the newly created user who utilizes PAA association algorithm instead of SSF Fig. 4 illustrates the data rate gain (i.e. $(Data\,Rate)^{PAA} - (Data\,Rate)^{SSF}$) of a new user in a communication environment illustrated in 2. As it can be seen from the figure, the performance improvement is mainly taking place in hot-spot areas, which proves the congestion relief ability of the proposed algorithm.

Figures 5 and 6 compares the load balance and attainable data rate abilities of SSF, LLF and PAA association algorithms with 50 and 100 users. First let's illustrate the effect of association algorithms on the AP loads in an IEEE 802.11a network configuration. Fig. 5 illustrates individual AP loads with different association algorithms. As it can be seen, SSF association algorithm only utilizes two APs caus-

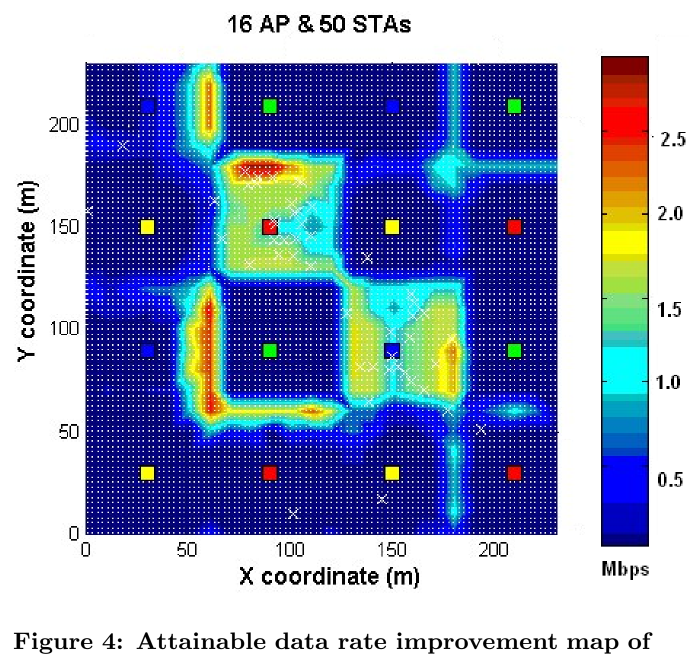

Figure 4: Attainable data rate improvement map of PAA association algorithm. The figure illustrates the possible data rate improvement of an additional STA that chooses PAA association algorithm instead of SSF.

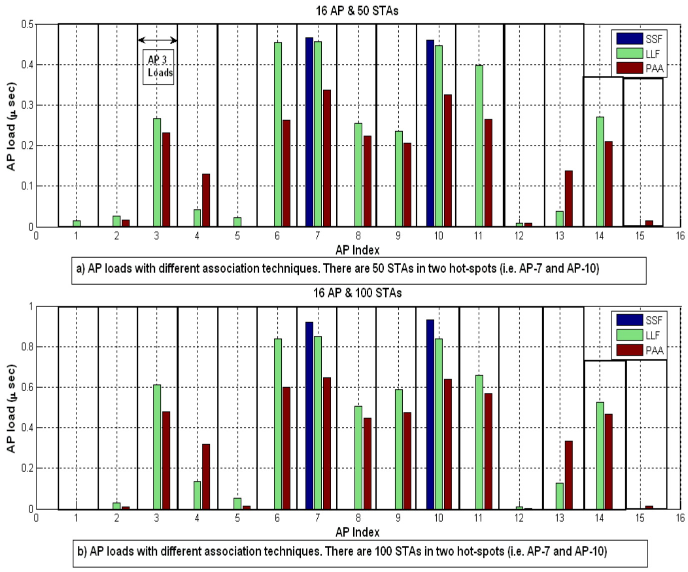

Figure 5: AP load values (μ sec) in 802.11a network configuration with SSF association algorithm with different number of STAs

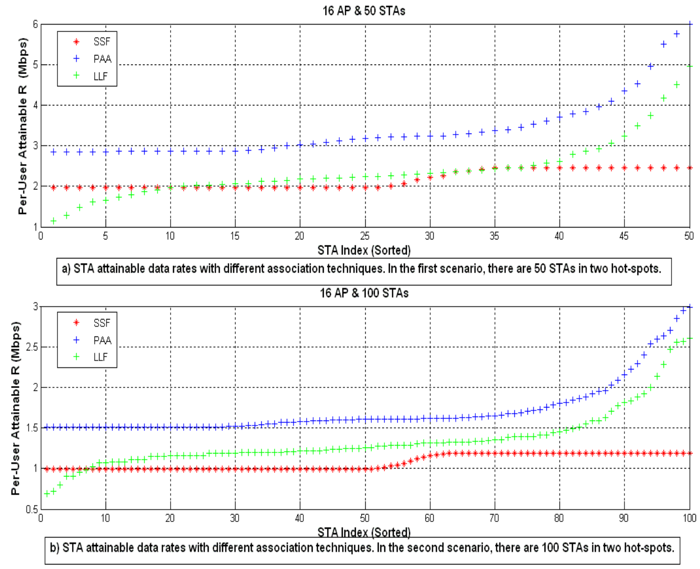

Figure 6: Individual sorted available STA data rates (Mbps)

ing congestion and leaving other APs under-utilized. Considering the two circular user distribution in the center of the communication environment, those two APs are the closest APs to the most of the STAs and the ones that have the highest RSSI level. If we look at the LLF algorithm performance, we notice that algorithm tries to balance the AP loadings by shifting users to the neighbor APs on the side. However, this forced shifting results in high loads, which means STAs are connected with very low connection rates to APs which will affect per user data rate. The PAA assigns the users to APs that offer high attainable data rates. Therefore it balances the network load without excessive AP loadings. Fig. 6 shows the network performance from STA perspective. The Y axis represents the per-user attainable data rate and the X axis represents the sorted STA index. User attainable data rates are sorted in increasing order. STA locations are varied at each simulation run and mean data rates are obtained by averaging the results over 500 runs. If we look at the median point, it can be seen that on average the PAA outperforms other algorithms by 50%.

6. CONCLUSION

WLANs promise increased productivity and convenience in public areas by providing ubiquitous connectivity and mobility. Scarce number of available WLAN frequencies and interference from other technologies make the resource management a must in large area deployments. The fact that STAs are distributed unevenly among APs just makes the already assigned task more difficult. A better performance in terms of attainable data rate and load balance can be obtained by associating the STAs efficiently in the network. In this paper, the consistent load definition of [12] is extended to cover the interference concept. An interference calculation method acknowledging the time share nature of IEEE MAC layer and uplink-downlink connection ratio is introduced. A novel distributed user association technique for hot-spot congestion relief is described. It has been shown that the proposed algorithm improves the average system attainable data rate by 50%. This improvement reaches to 100% in hot-spot regions demontrating the congestion relief ability of the algorithm. The network load balance superiority of the proposed algorithm over the current association algorithm has also been illustrated.

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