Temporary Access Selection Technology in WIFI Networks

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Abstract

Currently, increasing numbers of access points (AP) are being deployed in enterprise offices, campuses and municipal downtowns for flexible Internet connectivity, but most of these access points are idle or redundant most of the time, which causes significant energy waste. Therefore, with respect to power conservation, applying energy efficient strategies in WIFI networks is strongly advocated. One feasible method is dynamically managing network resources, particularly APs, by powering devices on or off. However, when an AP is powered on, the device is initialized through a long boot time, during which period clients cannot be associated with it; therefore, the network performance would be greatly impacted. In this paper, based on a global view of an entire WLAN, we propose an AP selection technology, known as Temporary Access Selection (TAS). The criterion of TAS is a fusion metric consisting of two evaluation indexes which are based on throughput and battery life, respectively. TAS is both service and clients' preference specific through balancing the data rate, battery life and packet size. TAS also works well independently in traditional WLANs in which no energy efficient strategy is deployed. Moreover, this paper demonstrates the feasibility and performance of TAS through experiments and simulations with Network Simulator version 3 (NS3).

Keywords: energy efficiency, access selection, throughput, battery life, packet size

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1. Introduction

Increasing numbers of enterprise offices [1], university campuses [2] and municipal downtowns [3] deploy WLANs for flexible Internet connectivity. In many offices and campuses, WLANs are deployed consisting of hundreds and even thousands of APs (access point), which make the WLAN high-density to meet the increasing demand of network accesses. Many of those WLANs, so-called traditional WLANs, are designed to improve the usage of users during times of peak demand, but peak demand rarely occurs [4]. All APs in traditional WLANs are always-on to ensure the coverage of the network, and many of the APs are considered idle or redundant when no users are associated with them. The utilization rate is even lower during weekends or school holidays, representing an avoidable type of energy wastage.

To achieve power conservation in high-density WLANs, we are working on an energy efficient strategy for efficient wireless resource management, which is driven by clients' demand. APs, switches and controllers would be powered off when no clients are present or when the traffic load is low, and powered on based on the number of users and volume of traffic. However, powering on and off network devices, particularly the former, costs time, called the boot time, for devices to initialize. During the boot time, network devices, particularly APs, cannot be associated with clients. In SEAR (Survey, Evaluate, Adapt and Repeat), which is an energy-efficient strategy in high-density WLANs proposed by Jardosh et al. to manage network resources [5], this problem has not been discussed. Clients would choose an AP to associate with randomly or based on RSSI (Received Signal Strength Indication), and the network performance would be severely affected.

To improve the network performance during the boot time, an access selection technology known as Temporary Access Selection (TAS), is proposed in this paper. TAS is a method of fusion decision and consists of two evaluation indexes, which are based on throughput and battery life, respectively. To clarify the scenarios where TAS could be functional, we introduce two scenarios, one of which is in a WIFI network with an energy efficient strategy where an AP is powered-on and then TAS selects an AP for a client during the boot time. The other is in a traditional WLAN, where TAS would supply an AP to a client to balance the data rate and battery life.

The remainder of this paper is arranged as follows. Section II presents the background of our research and related works regarding access selection algorithms. The energy efficient strategy for WIFI networks is introduced firstly followed by expression of models and assumption for TAS, and we subsequently detail the problem descriptions of TAS based on throughput and conduct simulations with NS3 (Network Simulator version 3) in Section III. In Section IV, we analyze the extra power consumption due to TAS based on throughput, and introduce a second index based on battery life for TAS and with a preference parameter and the indexes based on throughput and battery life, we propose TAS technology. Section V provides simulation results and performance analysis. Section VI presents the conclusions and discussion of the paper.

2. Background and Related Work

In many offices and campuses, WLANs are deployed consisting of hundreds or thousands of APs, which make the WIFI network high-density in terms of AP. We propose an energy efficient strategy in high-density WLANs to reduce the power consumption policy-based, and Temporary Access Selection (TAS) is an important part of our strategy.

Our energy efficient strategy has not been published to date; therefore, SEAR (Survey, Evaluate, Adapt and Repeat) [5] is introduced to show the definition and working mechanism of an energy-efficient strategy. SEAR was proposed by Jardosh as a demand-driven strategy to efficiently manage APs in high-density WLANs. SEAR is a policy-based method, which means it can be tailored to achieve the performance desired by WLAN administrators. Based on some certain policies used, SEAR can conserve energy while maintaining the same performance that clients receive in its always-on counterpart. A good introductory survey for SEAR can be found in [5].

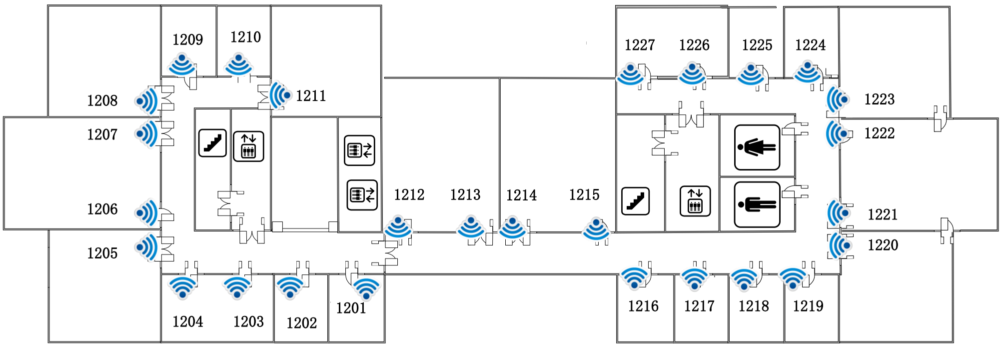

Fig. 1. The floor layout and AP deployment of our office, and the numbers denote doors.

In our energy efficient strategy, as in SEAR, we propose a clustering algorithm to form AP clusters and select cluster-head AP first, which is named Green Clustering Algorithm [6]. It is a type of algorithm that can maintain the basic network coverage with a small part of APs when few users are online or the traffic is low. In our previous works, we implemented our own green clustering algorithm based on an Evolutionary Algorithm. The floor structure where our office resides and the AP deployment are shown in **Fig. 1**. Twenty-seven APs are deployed on this floor, and the results of our Green Clustering Algorithm are shown in **Fig. 2**, where a solid blue triangle denotes an AP, and the colored nodes represent reference points we set, on which RSS values denoted by different colors from each AP are measured and recorded. As the results of our method, 9 APs are powered-on to provide the basic network coverage whereas the other APs are off, and approximately 2/3 of the energy is saved.

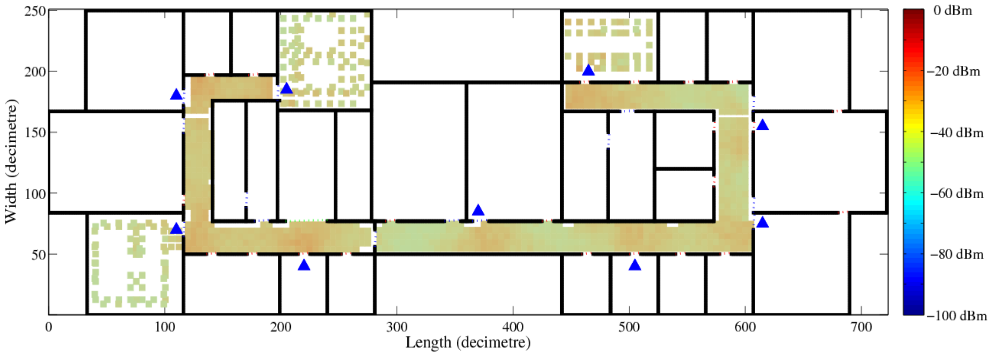

Fig. 2. RSS measured on our floor; only the maximal RSS at each RP is recorded.

In high-density WLANs, it is possible to save energy during the intervals of low load by powering off the secondary APs. When the traffic or the number of end users increases (which causes heavy load), one or more secondary APs are required to be powered-on policy-based with minimal impact on client performance. As shown in **Table 1**, the boot time of APs is normally 13 to 35 seconds [5], during which the AP is not accessible, available or even detectable. Hence, we propose an AP selection algorithm to supply an AP with the best gain on the data rate and energy efficiency for clients to access the network temporarily until the initialization of the powered-on AP is finished.

Table 1. Boot time and power consumption of Aps.

Device	Boot time (s)	Power Consumption (W)
Lucent WP-IIE	35	11
Soekris 5501	24	8.2
Linksys WRT54G	13	7
DLink DI524	12	5

AP selection and association are important to improve the user experience in WIFI networks [7-18]. Although the signal-noise ratio (SNR) is popularly used for AP selection, it has been demonstrated as a bad idea by Judd and Steenkiste [19]. In their paper, the AP load and some other information were taken into consideration as criteria for AP selection. In [20], Papanikos et al. introduced a combined metric that consists of the number of stations associated, the mean RSSI for station set of AP and the regular RSSI. A similar AP-assisted approach is proposed in [21] to supply client associated load information through beacon frames. In centralized WLANs, Bejerano et al. [22] and Murty et al. [23] took the entire WLAN into consideration and achieved better AP selection decisions. F. Xu et al. proposed an online AP association method based on throughput, computation and transmission overhead in [24]. However, none of these works consider the terminals' power consumption.

At present terminal devices driven by batteries are widely spread in WIFI networks, in which case battery life is usually considered as the most limiting factor in mobile devices. Therefore, energy efficiency plays an important role in network performance. In this paper, based on a global view of an entire WLAN, we propose an AP selection technology, known as Temporary Access Selection (TAS), which is service and client preference specific. TAS is proposed as the subsequence of the Green Clustering Algorithm [6]. The criterion of TAS is a fusion metric consisting of two evaluation indexes that are based on throughput and battery life. Moreover, it is both service and client preference specific, because we bridge the packet size with decisions and introduce a preference parameter to balance clients' demands between better data rate and longer battery life.

3. Temporary Access Selection Based on Throughput

3.1 Model and Assumption

We introduce two scenarios to illustrate where and when TAS can apply to. To specify network parameters, we assume the WIFI network as an IEEE 802.11n WLAN.

Firstly, parameters of 802.11n are introduced.

Table 2. Data rates (Mbps) of 802.11n.

MCS	SS	Modulation Method	Code Rate	BW(20MHz)		BW(40MHz)	
				GI=800ns	GI=400ns	GI=800ns	GI=400ns
0	1	BPSK	1/2	6.5	7.2	13.5	15
1	1	QPSK	1/2	13	14.4	27	30
2	1	QPSK	3/4	19.5	21.7	40.5	45
3	1	16-QAM	1/2	26	28.9	54	60
4	1	16-QAM	3/4	39	43.3	81	90
5	1	64-QAM	2/3	52	57.8	108	120
6	1	64-QAM	3/4	58.5	65	121.5	135
7	1	64-QAM	5/6	65	72.2	135	150
8	2	BPSK	1/2	13	14.4	27	30
9	2	QPSK	1/2	26	28.9	54	60
10	2	QPSK	3/4	39	43.3	81	90
11	2	16-QAM	1/2	52	57.8	108	120
12	2	16-QAM	3/4	78	86.7	162	180
13	2	64-QAM	2/3	104	115.6	216	240
14	2	64-QAM	3/4	117	130	243	270
15	2	64-QAM	5/6	130	144.4	270	300
23	3	64-QAM	5/6	195	216.7	405	450
31	4	64-QAM	5/6	260	288.9	540	600

Table 2 includes part of data rates supported by 802.11n (mainly in the case of 1×1 MIMO), in which MCS stands for Modulation and Coding Scheme, SS denotes Spatial Stream and GI represents Guard Interval. Considering that the scenarios where TAS resides are basically indoor, and to avoid the ISI effect, GI is set to 800 ns. Moreover, SS and BW are set to 1 and 40 MHz, respectively. Thus, the data rates in this paper can be determined as highlighted in **Table 2**. **Table 3** includes sensitivity that is another important parameter in 802.11n.

Table 3. Data rates (Mbps) of 802.11n.

Modulation Method	Code rate	Sensitivity (dBm)	
		BW=20MHz	BW=40MHz
BPSK	1/2	-82	-79
QPSK	1/2	-79	-76
	3/4	-77	-74
16-QAM	1/2	-74	-71
	3/4	-70	-67
64-QAM	2/3	-66	-63
	3/4	-65	-62
	5/6	-64	-61

Scenario I: In a Green WLAN, where an energy efficient strategy (like SEAR or ours) resides, as shown in **Fig. 3**, AP1 and AP2 are cluster-head APs of green clusters. In Cluster 1, except for the new client, there are in total n clients, and the number of users is 1 for Cluster 2. The concentric circles around AP2 represent the boundary of an area where the data rates AP can be supported by an AP based on IEEE 802.11n, and from inside to outside, the data rates are 135 Mbps, 81 Mbps, 40.5 Mbps and 13.5 Mbps. For AP1, we only indicate the boundary of

135 Mbps. AP3 is a secondary AP in Cluster 1, and it is powered-off to save energy until a new client asks for access. The energy efficient strategy that resides in the central controller implements a decision of powering-on AP3 through the PoE (Power over Ethernet) port. As shown in **Fig. 3**, AP3 is not available to be associated during the boot time. At this moment, in SEAR, the new client would be associated with an AP randomly chosen from a set of available APs. However, in our strategy, the central controller is able to supply the AP with a high data rate or energy efficiency for the new client. In this scenario, the accessible candidate APs (during the boot time of AP3, the new client can connect) are AP1 and AP2.

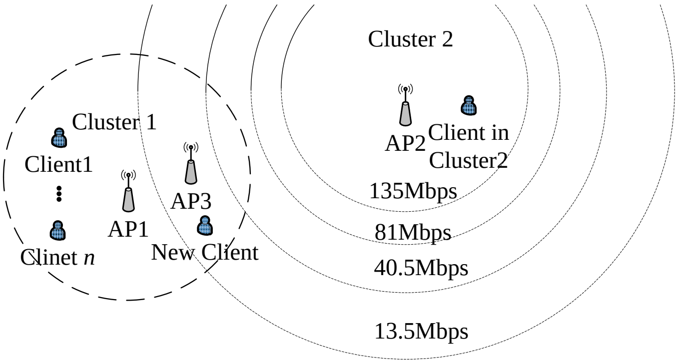

Fig. 3. Illustration of Scenario I in an energy efficient WLAN.

Scenario II: Unlike Scenario I in a Green WLAN, Scenario II is set in a traditional WLAN. In this scenario, TAS resides in a terminal device. As shown in **Fig. 4**, AP1 and AP2 are deployed in Room1 and Room2, respectively, and there are n and only one traditional devices, which means no TAS inside Room1 and Room2. APs broadcast beacon frames periodically in the basic service sets (BSS), and the hosts that receive the frames from these APs select one to access, according to the RSSI selection mechanism. In this scenario, hosts in Room1 associate with AP1, and the counterpart in Room2 associates with AP2. At this moment, a new host, in which TAS resides, asks for access, and TAS selects an AP between AP1 and AP2 for the new client policy-based.

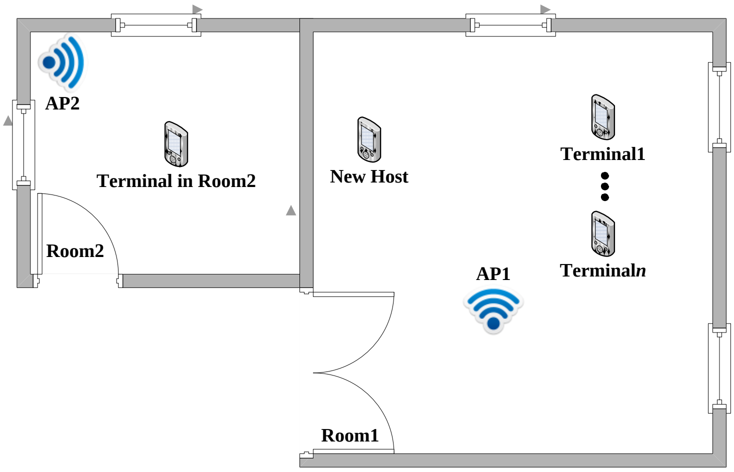

Fig. 4. Illustration of Scenario II in a traditional WLAN.

In both Scenario I and Scenario II, it is assumed that the Tx power of AP is fixed to 19 dBm (79 mW), which is one of the results achieved by the Green Clustering Algorithm [6], and the hosts are all in the polling lists of the APs. During the experimental period, all of the hosts always are holding data or transmitting packets, which mean that the system is constantly saturated. Because of the assumption that all of the hosts are in polling lists, there is no need for clients to compete for channel reservation during the CP (Contention Period); therefore, DCF (Distributed Coordination Function) is not considered. Thus, the system is assumed to be a pure PCF (Point Coordination Function) system.

3.2 System Description

In this paper, an AP selection technique is proposed, which enables clients to connect an AP with the highest value of algorithm gain that we define (detailed in Subsection 4.3). To achieve the access selection, the proposed approach implements a fusion decision that estimates the algorithm gain for any available APs.

The algorithm gain consists of both throughput and battery life. To calculate some information, such as the expected payload of the data frame, the proportions in the entire transmission, data rates, the clients' concern about battery life and etc., are gathered. With a specific set of gathered information, the proposed method can achieve a decision to supply the client with a best candidate AP, of which the algorithm gain is the greatest.

Once the client is associated with the AP, the information of this client is still gathered to check whether it is necessary to switch to a different AP. If the gain of a new AP is greater than the value of the currently selected one meanwhile the difference is greater than a threshold, the switch occurs (the threshold is set to avoid frequent reassociations).

3.3 Temporary Access Selection Based on Throughput

For association, there are mainly two methods for wireless hosts to obtain the information of the wireless networks from the surroundings: one is passive scanning, which means that wireless hosts only listen for the beacon information from APs, and the other is active scanning, which means that in addition to listening, the hosts also send Probe Request Frames and achieve network information through receiving Probe Response Frames. With the information, the RSSI selection mechanism suggests connecting to the AP with the largest RSS (Radio Signal Strength) value of received beacons. This is a simple and direct method, but it is not efficient or valid. The selection mechanism based on RSSI could not achieve and implement load balancing, and may make some APs work under heavy load.

In contrast to the RSSI selection mechanism, the proposed Temporary Access Selection (TAS) does not only consider the RSS from APs but also the number of devices associated with the APs, the payload and extra energy consumption due to TAS. Therefore, TAS is a fusion decision. In this subsection, TAS based on throughput is discussed, and the evaluation index is the ratio of the payload of a data frame to the transfer delay for the data frame.

As the models introduced in Subsection 3.1, TAS can apply to Scenario I, Scenario II and other similar scenarios. Based on the assumptions of Subsection 3.1, in the PCF system, channel allocation is managed by APs; therefore, there is no CP. The duration of the media being idle detected by an AP approaches SIFS (Short IFS, Short Inter-Frame Space), then AP sends Polling Frames to terminals in BSS, and the terminals being polled send data to the AP until the duration of the channel being idle is SIFS. In an SIFS, after receiving information, the

AP sends an ACK (Acknowledgement) frame to the source node for confirmation or adds an acknowledgement message to the Polling frame for the next terminal and sends them together. **Fig. 5** shows the transmitting of frames in PCF.

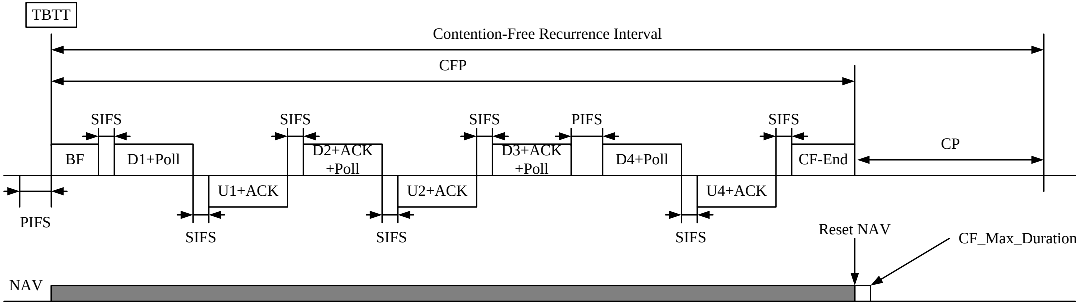

Fig. 5. Illustration of the PCF frame.

In **Fig. 5**, TBTT is the Target Beacon Transmission Time, BF is the Beacon Frame, NAV is the Network Allocation Vector, PIFS is the PCF Inter-Frame Space, CFP is the Contention-Free Period, *Di* denotes the frame sent by the PC (Point Coordinator), and *Ui* represents the frame sent by the polled station.

Usually, there are three primary categories of PCF working mechanisms, which are,

Working Mechanism1: The data flow is unidirectional, and only the transmitting from STA (Station) to AP is considered. The process is that AP polls STA, STA sends data to AP, and AP overlays ACK to the Polling frame for the next STA.

Working Mechanism2: The data flow is unidirectional, and only the transmitting from AP to STA is considered. The process is that AP sends data to STA, and STA sends ACK after receiving.

Working Mechanism3: The data flow is bidirectional, and the process is that AP sends cached data to STA when polling, STA sends a response to AP, and ACK is in the data frame.

As mentioned above, the evaluation index of TAS based on throughput is the ratio of the payload of a data frame to the transfer delay for the data frame. S under different working mechanisms of PCF is discussed below.

A. Unidirectional data flow, STA->AP

S can be defined by

$$S = \frac{E\left[payload\ of\ \ a\ data\ frame\right]}{E\left[delay\ for\ the\ data\ frame\ to\ transfer\right]} \tag{1}$$

under Working Mechanism1, and according to **Fig. 5** S can be expressed by

$$S_1 = \frac{E\left[P\right]}{E\left[Poll\right] + \delta + SIFS + H + E\left[P\right] + \delta + SIFS} \tag{2}$$

where $E\left[P\right]$ denotes the mean value of the payload, $E\left[Poll\right]$ denotes the time delay for transferring CF-ACK and CF-Poll frames, which is the time cost to transfer a 192 bit preamble sequence and 28 bit MAC (Medium Access Control) layer data. H denotes the transfer time for the header of a data frame, which is also the time cost to transfer a 192 bit preamble sequence and 28 bit MAC layer data. δ denotes the propagation delay, and in a cell of which the radius is 300 m, propagation delay $\delta = 300 / (3 \times 10^8) = 10^{-6}$ s = 1 μs. The value of $SIFS$ is taken as 10 μs in general. In the 802.11n protocol, the transmission rate for PHY headers and the maximal rate for MAC frames are 13.5 Mbps and 135 Mbps, respectively.

B. Unidirectional data flow, AP->STA

Corresponding to Working Mechanism2, S can be expressed by

$$S_2 = \frac{E[P]}{H + E[P] + \delta + SIFS + ACK + \delta + SIFS} \tag{3}$$

where ACK is the acknowledgement frame sent from STA to AP, and the transfer delay is the time to transmit a 192 bit preamble sequence and 14 bit MAC layer data.

C. Bidirectional data flow

With respect to Working Mechanism3, it is assumed that the data frame sent from STA to AP and the frame from AP to STA are of same size, so S can be expressed by

$$\begin{aligned} S_3 &= \frac{E[payload\ of\ a\ data\ frame]}{E[transfer\ delay\ for\ the\ data\ frame]} \\ &= \frac{2E[P]}{H + E[P] + \delta + SIFS + H + E[P] + \delta + SIFS} = \frac{E[P]}{H + E[P] + \delta + SIFS} \end{aligned} \tag{4}$$

From (2), (3) and (4), the values of S_1, S_2 and S_3 relate to $E[P]$, so the TAS proposed also relates to $E[P]$. The evaluation index of TAS is the ratio of the payload of a data frame to the transfer delay for the data frame. We combine the three working mechanisms, and the evaluation index of TAS based on throughput can be expressed by

$$R = \alpha S_1 + \beta S_2 + \gamma S_3 \tag{5}$$

where R denotes the evaluation index of TAS based on throughput. α, β and γ are the proportions in the entire transmission between STA and AP, which can be obtained through statistical analysis by APs in the network, respectively.

In the scenarios modeled in Subsection 3.1, we apply TAS to the new clients. The RSS received by the new client from AP1 is bigger than that from AP2, and according to the RSSI selection mechanism, the new client would connect to AP1. However, TAS based on throughput selects an AP not only based on RSS but mainly on R, and the values of R with different APs are considered, compared and estimated. In the scenarios modeled in Subsection 3.1, we calculate R_1 if the new client is associated with AP1 first, then R_2 with AP2 is calculated. We compare and estimate R_1 and R_2 by

$$\Delta R = P_2 \bullet R_2 - P_1 \bullet R_1 \tag{6}$$

where ΔR is the decision of TAS, which is also related with $E[P]$, and P_i denotes the probability of communication represented by R_i. The values of P_i are determined by PCF polling systems, and it is assumed that, in the scenarios introduced, the PCF polling system is the Cyclic Polling System. This polling system consists of N infinite size queues [25,26] and a single server, which servers them one at a time.

If the value of ΔR is positive, the better candidate AP is AP2. To achieve a higher data rate, the new client should be associated with AP2. On the contrary, AP1 would be better in terms of data rate according to the decision of TAS. Examples are presented here to show the results of TAS.

We assume AP2 could supply access services with 13.5 Mbps data rate for the new client and 135 Mbps in terms of AP1. N_1, which denotes the number of terminals already associated with AP1 is set to 2, 3, 4, 5, 8, 9, 10, 11, 15 and 20; and the value of N_2, which denotes the number of terminals already associated with AP2, is set to 1 with respect to AP2. The values of $E[P]$ are set from 1 to 4400 bytes. The results of TAS are shown in **Fig. 6**.

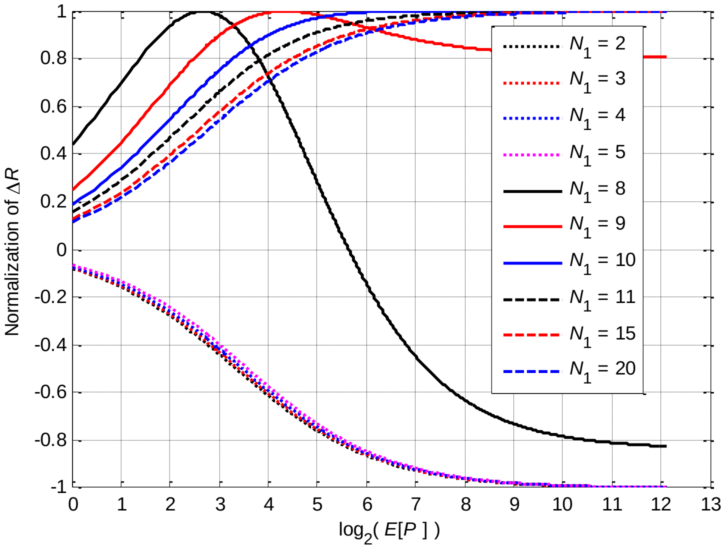

Fig. 6. Results and decisions of TAS under different loads.

In **Fig. 6**, for clarity, $E[P]$ is in logs and ΔR is normalized to $[-1,1]$, and when N_1 is 2, 3, 4, or 5, no matter how the packet size changes, the better candidate AP is AP1 in terms of a higher data rate. When N_1 is greater than or equal to 9, the new client should be associated with AP2 for the benefits of a higher rate. When N_1 is equal to 8, variations appear, and the decisions change over the values of packet size with the same tendency. When the packet size is smaller, TAS makes the decision to associate with AP2, and when the packet size is bigger, the decision changes to AP1. This is because the preamble sequences in $E[Poll]$, H and ACK cost a relatively fixed time delay for transmission. When the packet size is smaller, the new terminal does not benefit much from a 135 Mbps link, but the polling mechanism of AP has a greater effect and lowers the performance of the new client due to the bigger N_1. When the packet size is bigger, the entire transfer delay increases, which makes the fixed transfer time for preamble sequences a small part of the entire transfer time, and the rate profits associated with AP1 gradually grow. When the packet size is sufficiently large, the rate profits with AP1 finally exceed that with AP2, as shown in **Fig. 6**.

3.4 Simulation Results and Analysis of TAS Based on Throughput

In the above subsection, the evaluation index of TAS based on throughput R associated with different APs in the scenarios introduced is considered, compared and estimated, and in this subsection, simulations running on NS3 (Network Simulator version 3) are conducted to verify the validity and efficiency of TAS based on throughput.

P_iR_i under different conditions can be achieved, as can ΔR, and the results are shown in **Fig. 7**. From **Fig. 7**, the results of our experiment have similar trends with the theoretical results shown in **Fig. 6**, and in both, the curve $N_1 = 8$ switches associated APs as the packet size increases. According to (5), the evaluation index based on the throughput calculated from the simulations is an average value. As we record each frame we considered through the tracing system in NS3, we find that the values of R calculated with each frame are different, and this phenomenon becomes more obvious when the packet size is large because during the simulations, control frames are also recorded, and the lengths of the control frames are shorter, e.g., the length of an ACK frame is 14 bytes and 20 bytes for PS-Poll CF-End and CF-END+CF-ACK frames, which make the transmit efficiency lower.

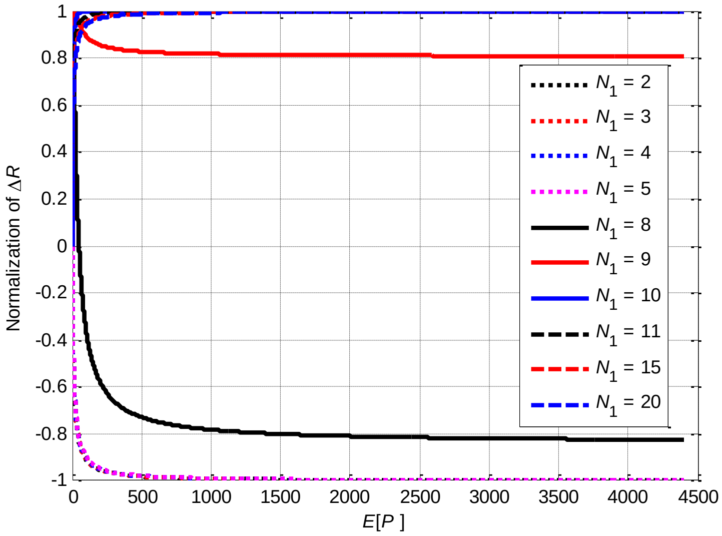

Fig. 7. Simulation results of TAS under different loads.

4. Temporary Access Selection Based on Battery Life

In Section 3, Temporary Access Selection (TAS) based on throughput is discussed. In this section, the extra energy consumption due to TAS is discussed, and the battery life variation of a terminal with TAS inside is introduced as the energy efficient complement to TAS. Finally, the implementation of TAS is presented.

4.1 Analysis of Extra Energy Consumption due to TAS based on Throughput

TAS is one important part of our energy efficient technology for WIFI networks and the subsequence of Green Clustering Algorithm [6]. The devices of greater concern in the Green Clustering Algorithm mentioned above are APs, and energy conservation could be achieved by powering-off APs. However, the energy consumption of terminals has been rarely considered. Because energy conservation of APs has already been achieved by the Green Clustering Algorithm, in TAS, the terminals and APs are taken into consideration as a whole in terms of energy efficiency, and specifically the power consumption of terminals is discussed.

In the scenarios modeled in Subsection 3.1, if the decision of TAS is to connect with AP2, which is followed by the harsh channel condition, the mechanism of TAS may cost the new client more energy to send a packet for the performance of the BER (Bit Error Rate).

The property of the error bit is one of the most important indexes for the PHY layer in WIFI networks and is usually described by BER, FER (Frame Error Rate) or PER (Packet Error Rate).

An IEEE 802.11n system often adopts the modulation method of BPSK, QPSK, 16-QAM or 64-QAM, and for the common Long PLCP PPDU format, the length of the PSDU (PLCP Service Data Unit) or MAC frame is usually 34 to 2346 bytes. For the analysis of extra energy consumption due to TAS, the property of the error bit is discussed.

In general, the BER in a fading channel can be expressed as

$$P_e = \int_0^{\infty} P_b(x) \bullet f(x)\,\mathrm{d}x \tag{7}$$

where x is a specific SNR, $P_b(x)$ is the BER with a random modulation mode in a fading channel under the specific SNR x, and $f(x)$ is the probability density function of x in a fading channel. The property of the error bit can be described by BER, but FER or PER is usually of greater concern. It is assumed that P_e is independent for each bit, so the probability of receiving one bit correctly is $1-P_e$. The probability of receiving n bits correctly is $P^n = (1-P_e)^n$, which means the probability of receiving n bits incorrectly is $1-P^n$, so PER can be expressed by

$$PER = 1-(1-P_e)^N \tag{8}$$

where N denotes the number of bits in a packet.

In the scenarios introduced, the channel condition between the new client and AP2 is considerable worse than that between the client and AP1, and as the assumption that the power of APs has already been fixed to maintain the basic network coverage, when data are sent from clients to APs, the worse channel condition may make the Tx power of the terminals increase for the acceptable value of PER. If TAS based on throughput supplies a worse channel to a terminal for a higher data rate, the battery life of the terminal would vary, and the variation of battery life is introduced as the second evaluation index of TAS. This index for power is greater for terminals that are more sensitive than APs on this issue because the power supply modes of APs, such as PoE power supply and alternating current, are much more stable and consecutive.

According to (8), when PER is fixed the relations between the values of packet size N and BER are given by

$$BER = 1 - (1 - PER)^{\frac{1}{N}} \tag{9}$$

The packet size relates to the service and channel conditions, and if we change the P_e in (7) with (9), the relations between the packet size and RSS at a certain PER can be obtained. The results when $PER = 8\%$ are shown in **Fig. 8**. In **Fig. 8**, the curves denote the upper bounds of the packet size with a specific value of RSS, adopting different modulation methods (BPSK, QPSK, 16-QAM and 64-QAM in 802.11n), and the bounds are also the optimal values of packet length with specific values of RSS.

During an interval that is sufficiently short, the location of a terminal is fixed, so RSS can be considered as a constant, and the evaluation index of TAS based on battery life can be formulated according to a parameter named the minimal Tx power $\min Tx$ with a regular value for PER, which can also be considered as a constant.

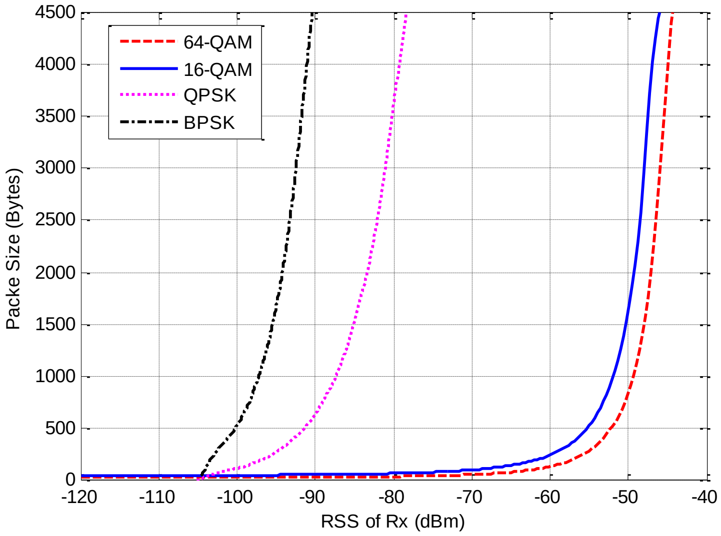

Fig. 8. Illustration of relations between Rx RSS and packet size under different modulation methods.

The scenarios modeled in Subsection 3.1 are indoors, so the radio propagation within the scenarios can be defined as small-scale fading, among which multipath fading is typical, and the received envelope is in accord with the Rayleigh distribution. The path loss can be estimated with some statistical models for indoor propagation, but there is convenience in the scenarios that the Tx power of the AP is a fixed value. If it is assumed that during a short interval the channel properties of an AP's uplink and downlink remain the same, the path loss from STA to AP can be substituted by the path loss from AP to STA for convenience, and the path loss L from AP to STA can be expressed by

$$L(\mathrm{dBm}) = P_{Tx\_AP}(\mathrm{dBm}) - P_{Rx\_STA}(\mathrm{dBm}) \tag{10}$$

where P_{Tx_AP} denotes the Tx power of AP, and P_{Rx_STA} represents the Rx power of STA. Therefore, the minimum Tx power of STA $\min Tx$ can be given by

$$\min Tx = L + Sens_{\text{mod}} = P_{T\_AP} - P_{R\_STA} + Sens_{\text{mod}} \tag{11}$$

where $Sens_{\text{mod}}$ denotes the minimum value of RSS that maintains the data rate and PER in a specific modulation method. The extra power consumption can be achieved by comparing the values of $\min Tx$ when STA is associated with AP1 and AP2.

4.2 Temporary Access Selection Based on Battery Life

In Section 3, TAS based on throughput which improves the data transfer rate is implemented, and because of the sensitivity to battery life of the terminals, in this subsection, TAS based on battery life is proposed.

The variable $\min Tx$ is a function consisting of the AP's Tx power, RSS received by STA from AP, PER, and packet size. In Scenario I, it is assumed that the values of RSS received by the new client from AP1 and AP2 are -45 dBm and -78 dBm, respectively. According to (11), the relations between the $\min Tx$ and packet size when $PER = 8\%$ are shown in **Fig. 9**. Link1 denotes the conditions of STA associated with AP1, Link2 denotes the conditions of STA associated with AP2, and the Variations of Tx is the Tx power variations between Link1 and Link2 at the same PER. In **Fig. 9**, the Tx power at Link2 exceeds that at Link1 and the variations are always positive, traversing the values of packet size under the given conditions.

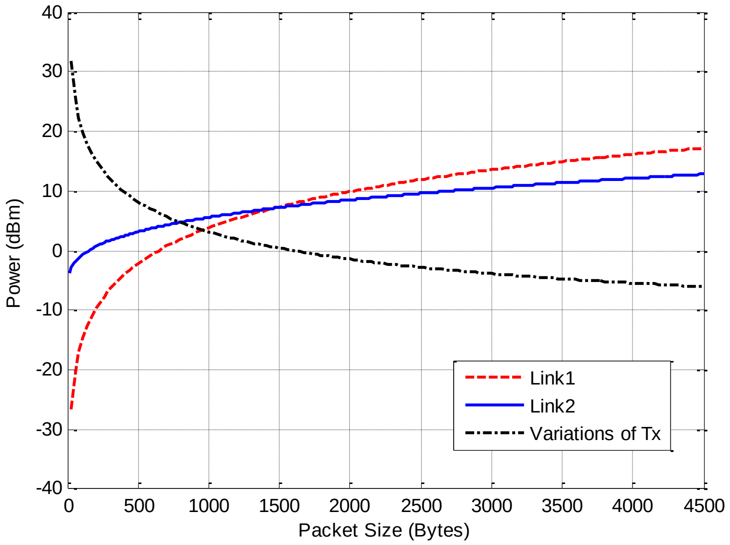

Fig. 9. Tx powers of two different access methods, .and the difference between them.

With respect to a terminal's battery life, the power consumption consists of the consumption related and unrelated to RF, which is given by

$$PER = 8\% \tag{12}$$

If P_{RF} changes to $P_{RF}{}'$, P_{TOTAL} can be expressed as

$$P'_{TOTAL} = P'_{RF} + (1+\kappa) P_{OTHERS} \tag{13}$$

where κ denotes a scaling factor describing the levels of P_{OTHERS} influenced by the variations of P_{RF}, and κ is considered to be zero, so

$$P'_{TOTAL} = P'_{RF} + P_{OTHERS} \tag{14}$$

and the variation degree ΔT of battery life is given by

$$\Delta T = \frac{BL - E[BL]}{E[BL]} \tag{15}$$

where $E[BL]$ denotes the expectation value of battery life, and BL denotes the practical life at a certain P_{RF}. If the total battery energy is E, ΔT can be expressed by

$$\Delta T = \frac{\dfrac{E}{P_{RF} + P_{OTHERS}} - E[BL]}{E[BL]} \tag{16}$$

With $\min Tx$, the second evaluation index of TAS ΔBL can be given by

$$\begin{aligned} \Delta BL = \Delta T_2 - \Delta T_1 &= \frac{\dfrac{E}{P_{RF2} + P_{OTHERS}} - E[BL]}{E[BL]} - \frac{\dfrac{E}{P_{RF1} + P_{OTHERS}} - E[BL]}{E[BL]} \\ &= \frac{E}{E[BL]} \frac{\min Tx_1 - \min Tx_2}{(\min Tx_1 + P_{OTHERS})(\min Tx_2 + P_{OTHERS})} \end{aligned} \tag{17}$$

where $\min Tx_i$ denotes $\min Tx$ at Link i.

Hence, according to (17), the value of ΔBL can be achieved, and if ΔBL is positive, then AP2 is the better candidate. Otherwise, in terms of the energy efficiency, AP1 is better.

4.3 Implementation of the Proposed Temporary Access Selection

The criterion of TAS consists of ΔR and ΔBL as different types of clients with diverse needs. We introduce a scaling factor θ to describe clients' preferences for the data rate and battery life, so the criterion of TAS can be expressed as

$$Decision = (1-\theta)\Delta R + \theta\, \Delta BL \tag{18}$$

where if $Decision > 0$, the decision of TAS denotes that AP2 is the better candidate AP, and in the opposite conditions AP1 would be the better one.

Combining data rate and battery life, a fusion decision, named TAS, is implemented. This fusion decision does not only apply to Scenario I, which is in a Green WLAN, but it is also appropriate for Scenario II, which is in a traditional WLAN.

Although ΔR in (6) and ΔBL in (17) are both differences, ΔR is dimensional and ΔBL is dimensionless. According to (6) and (17), (18) can be modified as

$$Decision = (1-\theta)\frac{P_2 R_2}{P_1 R_1} + \theta\,\Delta BL \tag{19}$$

As the changes of TAS evaluation indexes when accessing to different APs are of greater concern, for clarifying variation tendencies, $Decision$ can be transformed into

$$Decision(\mathrm{dB}) = (1-\theta)10\log\left(\frac{P_2 R_2}{P_1 R_1}\right) + \theta \bullet 10\log(\,\Delta BL) \tag{20}$$

where $Decision(\mathrm{dB})$ is defined as TAS Gain, which is positive for a link with AP2 and negative for a link with AP1. Therefore, the decision of TAS is client specific, expressed by θ, and service specific, expressed by the values of the packet size.

A decision between two choices has been implemented; nevertheless, in practice, access selection among several APs is necessary. In WIFI networks, the number of non-overlapping channels is relatively small (typically 3 for 802.11 b/g, 15 for 802.11n, and 24 for 802.11a), so to avoid collision and co-channel interference, the number of APs deployed in a close region is small, which makes the number of trial APs to compare relatively small. Therefore, the alternative fusion decision iterates among all APs, and finally, the best candidate can be achieved.

5. Simulation Results and Analysis of Temporary Access Selection

In this section, we perform simulation experiments to verify TAS. In addition to the assumptions and models introduced in Subsection 3.1, more parameters for devices are needed for the simulations. The type of device used in our simulation is an iPhone 5S ® [28], and the battery is 1560 mAh. $E[BL]$ in (17) is 10 hours when working with WIFI.

5.1 Experiment 1

Assume that $\theta = 0.5$, $RSS_1 = -45\,\mathrm{dBm}$, $RSS_2 = -78\,\mathrm{dBm}$, $N_1 = [2,3,4,5,8,9,10,11,15,20]$ and $N_2 = 1$. The values of the packet size are set from 200 to 2400 bytes, the acceptable PER is set to 8%, the battery is set to 1560 mAh and the expectation value of battery life is set to 10 hours when working with WIFI. The network parameters refer to IEEE 802.11n. **Fig. 10** shows the results of TAS under the given conditions, and except for $N_1 = 8$, the polarities of the TAS Gains remain constant during the simulation process. The decisions of TAS do not make changes. For $N_1 = 8$, TAS Gain is positive when the values of packet size are smaller, and with increasing packet size, the data efficiency increases. To maintain the property of the error bit, the Tx power of the new client increases, which makes the criterion of the fusion decision TAS Gain decline and turn negative at approximately $PacketSize = 400\,\mathrm{bytes}$.

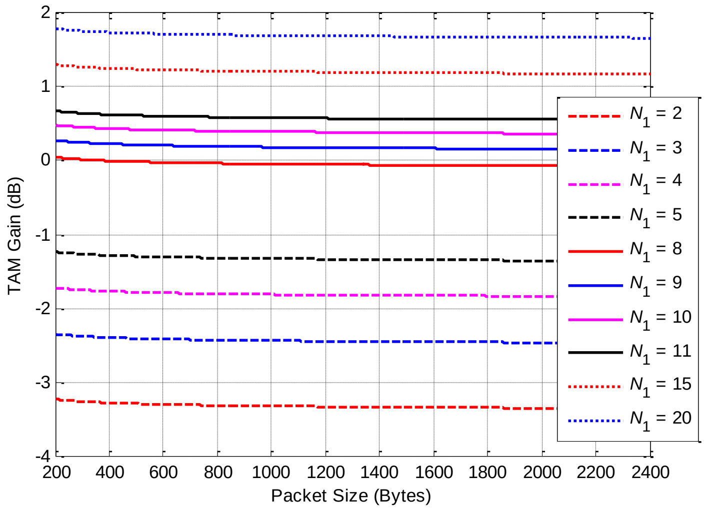

Fig. 10. Decisions achieved by TAS with different clients in Area1 under 802.11n.

According to the result of the decision function (20), a better candidate AP is recommended. If the result of (20) is positive, the better candidate is AP2; if the result is negative, AP1 is considered better. Therefore, the curve that denotes the values of TAS Gain change from positive to negative, or from negative to positive, that means the recommended AP to access changes. And, the horizontal line $\text{TASGain} = 0$ can be considered as the change of the strategy. To be clearer, The partial enlarged view of the curve when $N_1 = 8$ in **Fig. 10** is shown as **Fig. 11**.

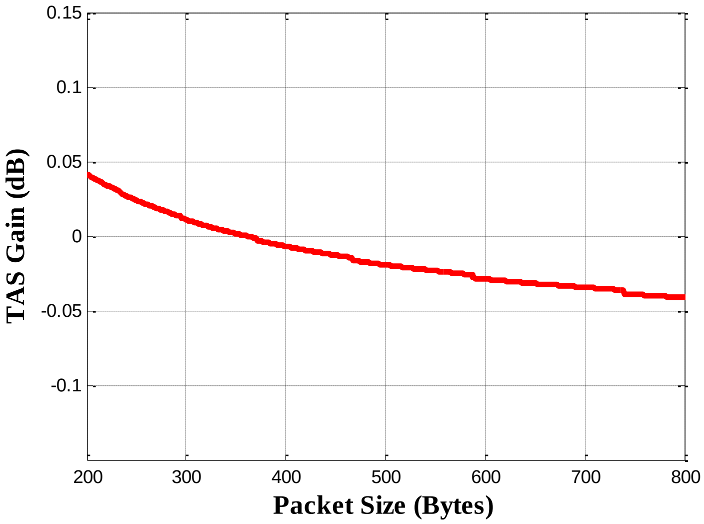

Fig. 11. The partial enlarged view of **Fig. 10**.

From **Fig. 11**, it is much clearer that the recommended AP changes from AP2 to AP1 when $N_1 = 8$ at approximately $PacketSize = 400$ bytes.

5.2 Experiment 2

The assumptions here are the same conditions as in Simulation I except θ and N_1. In Simulation II, for analyzing the relations between θ and the decisions of TAS, N_1 is set to 8 because the curve at $N_1 = 8$ is different from others, and the values of θ are set from 0.1 to 0.9. The results of Simulation II are shown in **Fig. 12**. The decisions of TAS are influenced to some degree by θ, and although the downward tendencies of the curves expressing TAS Gain are similar, the zeroes are different. With increasing θ, the zeroes of the TAS Gain decrease. If a client is more sensitive about the battery, TAS would supply a smaller Tx power, which makes BER bigger in the same modulation method; therefore, the packet size would decline to maintain the required property of the error bit.

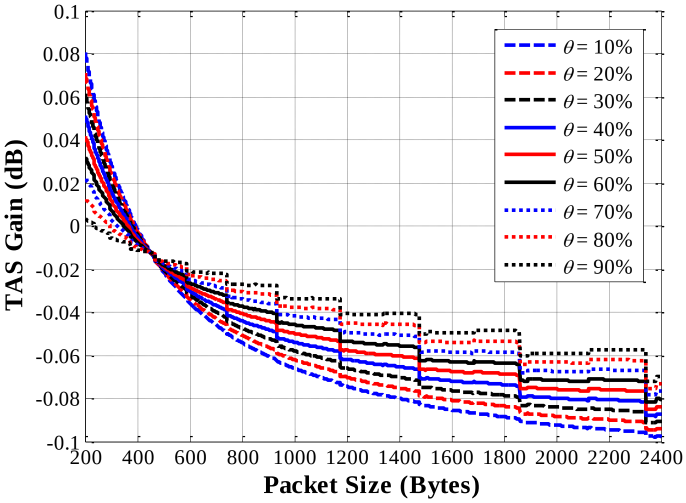

Fig. 12. Decisions achieved by TAS with different clients' preferences.

5.3 Experiment 3

An experiment that can demonstrate that different decisions depend on different services (described by different packet sizes) is conducted. Statistically, the averages and standard deviations of five typical types of applications are shown in **Table 4** [29].

Table 4. Averages and standard deviations of 5 applications (bytes)

Application	Average	Standard deviation
FTP	1000.4	305.8
Foxmail	498.7	347.2
WWW	928.7	145.6
BT	619.4	189.4
eMule	432.5	226.3

Several typical values of packet size are assigned to different applications, and the other simulation parameters are the same as the conditions in Simulation II. The scenarios of which different people with different demands (described by the preference parameter θ) use different applications (described by packet size) are simulated, and the results are shown in **Fig. 13**. θ is the parameter that demonstrates a client's preference between the data rate and battery life, so the horizontal axis denotes 9 types of users who are of mildly, moderately and severely concern about the lifespan of devices. Moreover, according to results, the smaller typical packet size of the application of eMule changes the AP for association with increasing θ, and the other services remain associated with a fixed AP. The TAS gains decrease as θ increases, which is not sufficient for TAS to change the decision. Therefore, when services (applications) are specific, TAS is able to make a decision based on the typical packet size of this type of applications.

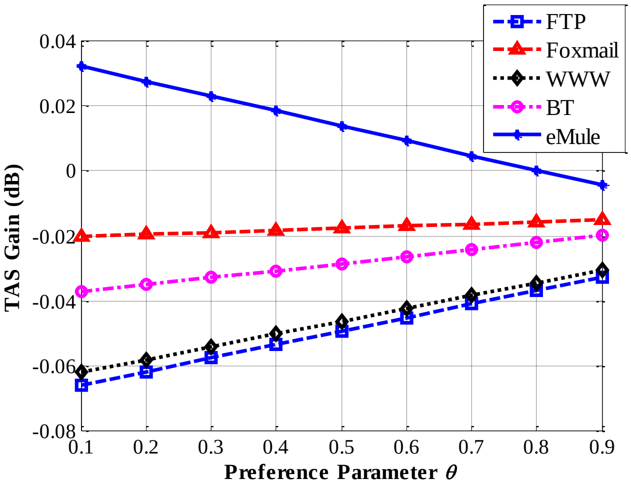

Fig. 13. Decisions achieved by TAS with different applications.

Through Experiments 1, 2 and 3, the proposed TAS is proved to be service and client preference specific by comparing the TAS Gain based on the throughput and battery life, and with given parameters of service and the preference of clients, TAS is able to calculate the value of TAS Gain, and makes an access decision for users to ensure that clients can be associated with the best candidate AP.

5.4 Comparisons and Analysis

In the above subsections, simulations are conducted, and the designed goal of TAS has been achieved provably. In this subsection, comparative experiments are presented.

The proposed TAS is a fusion decision, and the criterion consists of throughput and battery life. Scenario I is the most typical environment for TAS, and TAS is proposed as the subsequence of the Green Clustering Algorithm. The implementation of green clustering can power-off some APs while maintaining the basic network coverage as the always-on counterpart when traffic load is low or when few users are online. APs will be powered-on policy-based along with the increasing of traffic or users. TAS is proposed to improve the performance of the Green WLAN during the boot time of APs by providing terminals with an already-on AP to be associated with temporarily. Once the powering-on AP completes the initialization, the client will end the temporary link. Few works study the performance improvement during the boot time and access selection based on battery life; therefore, for comparison, the criterion of TAS is divided into the throughput and battery life. Firstly, comparative experiments about throughput are presented.

1) Throughput.

Four methods are introduced for comparison here, which are based on RSSI, proposed in [5], [24] and [30]. The original methods in [24] and [30] are not designed for temporary access, so we implement them with the concept of temporary access. Experiments are performed under different numbers of background stations of AP1 in Scenario I, and the results during the boot time are shown in **Fig. 14**.

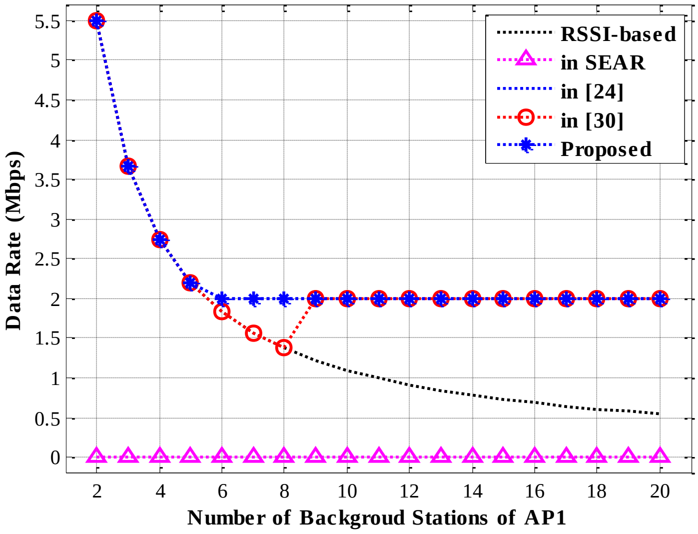

Fig. 14. Comparison of throughput.

During the boot time of AP3, the new terminal associates with no APs according to the access method in [5], until AP3 finishes the preparation, so the data rate remains 0 during the experiment. The new client connects to AP1 consistently based on the RSS values. The access selection decisions are almost the same between the method in [24] and the proposed method. However, the method in [30] is not accurate for temporary access selection. Therefore, the method in [24] and the proposed one outperform all of the other counterparts.

The access selection method in [24] is implemented based on the framework of neural network, and the approach in [30] is an optimization procedure, so both are time-consuming. On the account of the short-time characteristic of boot time, the scheme of temporary access selection should be efficient. In the experiment of time consumption, it is assumed that the new client appears and AP3 is powered at t_1, and additionally, all access selection technologies begin to work from t_1. At t_2, AP3 finishes preparation, and the time between t_1 and t_2 denotes the boot time of AP3. Another assumption is that the value of RSS from AP1 is greater than that from AP2 and AP3 received by the new client. This experiment is conducted in which the number of background terminals associated with AP1 is set to 10, and the results are shown in **Fig. 15**.

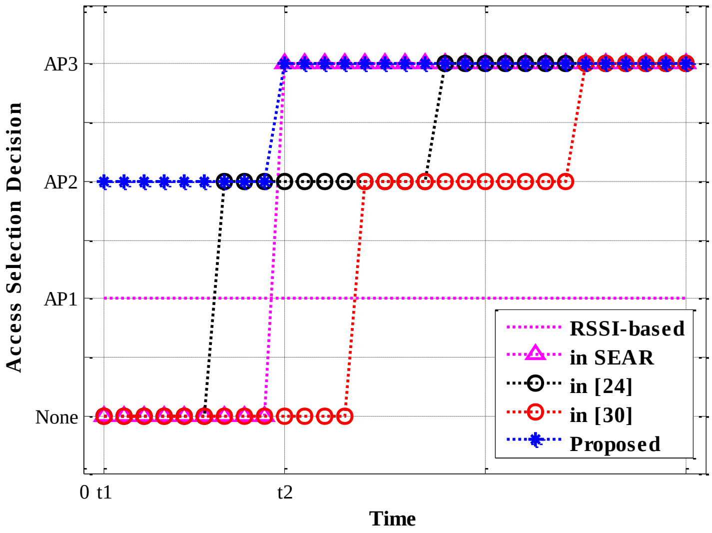

Fig. 15. Comparison of time efficiency.

Under the conditions of the experiment, the best candidate AP is AP2 during the boot time, and it changes to AP3 once AP3 completes the initialization at t_2. From **Fig. 15**, the method based on RSSI determines that the new client connects to AP1 consistently. According to the method in SEAR [5] the terminal associates with no APs until AP3 is available. Both methods in [24] and [30] provide the client with the corresponding best AP, but the time delay is not acceptable, especially in the method of [30]. Therefore, in terms of efficiency, the proposed TAS outperforms the other approaches.

2) Battery life.

Most access selection approaches focus on the improvement of throughput and mobility, but few works study the consequences of the end users' battery life when an access selection operation is introduced.

The proposed TAS is the subsequence of the Green Clustering Algorithm. When the traffic is low or when few end users are online, green clustering powers-off several APs, and if the traffic or the number of end users increases, the powered-off APs will be turned on. However, an AP takes a period of time to prepare, and during this boot time, the AP is not available. TAS is proposed for the improvement of throughput during boot time. Additionally, the energy efficiency for end users is taken into consideration. The Green Clustering Algorithm implements energy conservation among APs whereas TAS is designed for terminals. Therefore, TAS consists of the throughput improvement and the complement of clients' energy efficiency. The energy efficient component of TAS is application and client –specific, and is not studied by any other comparative work. In terms of energy efficiency, during the boot time, the proposed TAS outperforms the other methods.

6. Conclusions

In this paper, we propose an access selection technology, known as Temporary Access Selection (TAS), to improve the experience of clients in WIFI networks. Although TAS is introduced mainly for energy efficient strategy in WLANs, it is also functional in traditional WLAN, which is modeled in Scenario I and II, respectively. Moreover, TAS is service and clients' preference specific, which are expressed by packet size and a parameter measuring the level of concern about the data rate and battery life.

Therefore, the criterion of our algorithm consists of two evaluation indexes, which are based on throughput and battery life. In this paper, the TAS evaluation index based on data is discussed first. This index is the ratio of the payload of a data frame to transfer delay for the data frame. In the IEEE 802.11 PCF system, there are three primary categories of working mechanisms for PCF, and each mechanism makes the direction of data flow different from others, which means the index based on throughput could be diverse. However, with the statistical information of a WIFI network an index based on throughput for TAS can be achieved, and simulations of the index are conducted with NS3. The results of the simulations prove the effectiveness and validity.

Another index is then discussed from the perspective of energy efficiency for terminals. The extra power consumption due to TAS based on throughput is first considered. A connection is established between packet size and Tx power in different modulation methods. After that, the second evaluation index is proposed based on the definition of the minimum Tx power of STA. Simulations with different RSS values are conducted, and the results show that in the scenarios modeled TAS bridges the change between the power consumption of terminals and the RSS values of APs' beacon frames under a similar error bit condition.

Next, we introduce a preference parameter about a client's balance between the data rate and battery life, and with this preference parameter and the indexes based on throughput and battery life, we propose the criterion of TAS.

Lastly, simulations of TAS based both on throughput and battery life are conducted. For practical purposes, we modify the criterion of TAS and adapt it from dimensional to dimensionless. Our method is able to supply an access mode for clients, and clients can be associated with the best candidate AP. In order for comparison, comparative experiments are performed, and in terms of time or energy efficiency and the improvement of throughput, the proposed TAS outperforms the counterparts.

In sum, the proposed TAS achieves the design requirement to support a higher data rate with less power consumption. Therefore, according to the mechanism of TAS, when the traffic load increases from low to heavy, the proposed approach can improve the network performance and the user experience through decreasing the influence caused by the boot time of APs. After TAS, the mechanism of estimating users' demand based on the Markov Chain Model and queuing theory will also be studied and proposed for energy efficiency in high-density WLANs in the near future.

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