Potential Throughput Based Access Point Selection

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***Abstract*—Mobile nodes in wireless LANs connect themselves to the Internet via their associated access points (AP). Although more and more APs are being deployed, nodes tend to gather around some common hotspots, contending for few APs and leaving other APs idle. The traffic unbalance affects both per-node throughput and network throughput. In this paper, we aim to solve this problem by AP selection. We jointly consider the two key factors--channel availability and link quality--that determine the achievable throughput of a node, and suggest the potential throughput (PT) metric for AP selection. The PT metric is defined as the maximal throughput that can be achieved by a node if it exclusively occupies the remaining idle channel. In this way, a node can achieve higher throughput by associating with a farther but less used AP and the congestion of the network can be alleviated. The simulation results show that the PT metric can greatly improve the total throughput when nodes are unevenly distributed around APs. The testbed experiments with the off-the-shelf WLAN cards also confirm that the per-node throughput can be effectively improved with the proposed method.**

Keywords- AP selection, air-time ratio, potential throughput, load balancing

I. INTRODUCTION

Wireless LANs (WLAN), supporting mobile access to the Internet, are growing quickly these days. Nodes in WLANs connect themselves to the Internet via their associated access points (AP).

Due to convenience and popularity of WLANs, APs are widely deployed in the offices and at home, besides the conventional hotspots. The probability, with which a node finds multiple APs nearby, increases with the AP density. Then, a natural question is: how should a node select a suitable AP when multiple are found? Of course not all nearby APs are available. Some of the APs might have miscellaneous restrictions (e.g., secure association requirement, regulatory maximal transmit power, etc.), as are advertised by the information elements in the periodical beacon frames. These restrictions usually are associated with an extended service set (ESS), which identifies a logical network. It is clear that a node should only choose an AP from the ones whose constraints are satisfied.

To enable better coverage with a limited number of APs and provide more choices to nodes, it is necessary to increase the number of available APs. All APs, managed by a single entity, can be made open to all valid users. As for the home application, usually each AP is only reserved for its own user. Recently there is a trend for users to mutually share their private APs: A user opens his private AP to others. As a return, he can use the APs of others as well. In this way, FON [1], the largest WiFi community, comes into being.

The number of orthogonal channels available to wireless LANs is limited (3 in 2.4GHz ISM band). Therefore, the number of wireless links sharing the same channel increases with the number of total nodes. Due to the attraction of some common interest, many nodes may gather around some APs, contending for the limited channel resource while leaving APs far away less used. The traffic unbalance degrades both the per-node throughput and network throughput. Since the channel is shared in a distributed way via carrier sense multiple access (CSMA), too many nodes in the same contention domain also lead to frequent collision. In addition, the policy of selecting the AP with the strongest RSSI (Receive Signal Strength Indicator), overstressing the effect of link quality, sometime even makes things worse.

In this paper, we aim to both maximize per-node throughput and improve the total throughput in WLANs via AP selection. We focus on the non-saturation scenarios, where the throughput that can be achieved by a node depends on two key factors: the link quality (the transmit rate on the link) and the channel availability (the share of the channel). The potential throughput (PT, the maximal throughput available to a node if this node exclusively occupies the idle part of the channel), which takes the optimal tradeoff between the two key factors, is suggested for AP selection. Using PT as the metric, each node selects an AP that maximizes its own throughput. In this way, when too many nodes gather around an AP, some of them are smoothly pushed away since a congested AP offers little PT. Therefore, the load unbalance is removed. The simulation results show that the proposed PT metric can greatly improve the total throughput of the whole networks, especially when nodes are unevenly distributed. In addition, the testbed experiments confirm that the per-node throughput can be effectively improved as well.

The rest of the paper is organized as follows: We discuss the related work in Sec. II and present the protocol details in Sec. III. The results of simulation evaluation and testbed experiments are described and analyzed in Sec. IV and Sec. V, respectively. Finally Sec. VI concludes the paper.

II. Related Work

APs in WLANs usually are connected to the backbone networks via broadband cables. It is assumed that these cables have sufficient bandwidth compared with the wireless link. In other words, only wireless links between nodes and APs are bottlenecks, which choke the end-to-end path. Then, the main concern is how to choose an AP (the last hop wireless link).

The first issue on AP selection is how to find candidate APs. APs, running on different channels, notify their presence to the nodes via periodical beacon frames. When a node is turned on, it scans all channels to find APs nearby, by passively collecting beacon frames, or actively sending probe request frames and receiving probe response frames. When a node is equipped with a single WLAN card, scanning a different channel interrupts the on-going traffic. Fortunately, the device driver [2] usually supports background scanning, i.e., scanning channels in the idle time so that the information of candidate APs is available when needed. There also have been some efforts made on fast channel scanning to enable quick handover [3].

With the information of candidate APs being available, the next issue is what metric to use in selecting APs. This is the main focus of this paper. RSSI is a widely used metric for AP selection and it has already been implemented in the MadWiFi device driver [2]. Although the policy of strongest RSSI can remove some weak links, it is also possible that many nodes nearby associate with a common AP, leading to traffic unbalance and degrading the network throughput.

Some efforts have been made to remove the load unbalance via AP selection, taking into account factors such as the channel load and available bandwidth [4][5][6]. The number of associated nodes and the packet error rate (PER) of the candidate link are combined together as a metric for AP selection in [4]. The rationale is that each node fairly shares the channel by distributed contention. But the channel load in terms of the number of nodes is inaccurate and rate adaptation is not considered either. In [5] probing packets are sent to measure the actual throughput. This, however, both takes much overhead and is time-consuming. In addition, it requires a special server for the purpose of probing. In [6], the throughput is calculated from the estimated collision probability, and the accuracy is only high when the network is near the saturation state.

Since nodes discover APs with beacon frames, an alternative and implicit way to realize load balancing is via the cell breathing technique [7]. A transmit power, less than the full power, is used by an AP to transmit beacons in times of congestion. In this way, nodes far from the congested AP are effectively pushed away. However, it is possible that coverage holes may come into being when a node is outside the beacon transmission range of all APs.

Compared with previous works, in this paper, we focus on AP selection over channels which are not saturated. We take into account both the channel congestion degree and link quality. It is already feasible to directly measure the actual channel congestion degree by the off-the-shelf WLAN cards [8], and such information is successfully used in congestion-aware rate adaptation in [9] to statistically diagnose the reason of packet errors. In our work, the PT metric is calculated from the channel congestion degree and transmit rate, and used to find a suitable AP. In addition, we verify the effectiveness of the PT metric via both simulation and testbed experiments.

III. Design Of AP Selection Protocol

In this section the proposed AP selection protocol is discussed in detail. First, the PT metric is defined. Then, the AP selection procedure, using the PT metric, is presented. Later, the key parameter is tuned via simulations.

A. *Definition of potential throughput*

Figure 1 shows the concept of PT. *Air-time ratio* (ATR), the percentage of time during which a channel is busy, is defined as the congestion degree of the channel; the transmit rate is used to indicate the link quality. In Figure 1, the traffic between four nodes (*A*, *B*, *C* and *D*) and one AP (AP1) occupies *ATR*=60% of the channel. As a new node *E* associates with AP1, the maximal channel share for it is 1-*ATR*=40%, and the PT achievable at different rates is shown in the right side of Figure 1. In the following, we discuss PT in details, taking into account actual transmission procedure and protocol overhead.

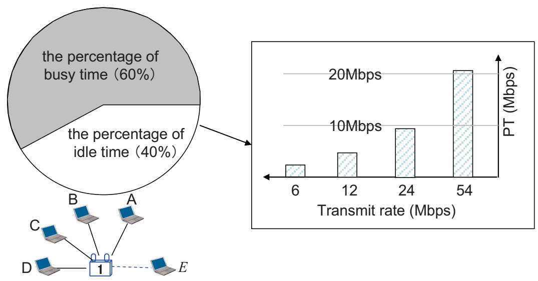

Figure 1 Concept of potential throughput.

Figure 2 shows the transmit procedure of a single packet in IEEE 802.11. The MAC payload (PSDU) is transmitted inside the Data frame, followed by an ACK frame. The transmission includes overhead such as the preamble, header etc. Although rate adaptation is widely used, usually it is only applied to part of the frame, mainly the MAC payload. With a fixed payload length *L*, the overhead ratio gets higher with the rate.

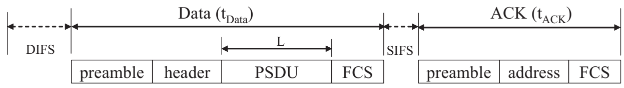

Figure 2 Composition of frames.

$$t_{AP,STA}^{bit} = \frac{t_{Data} + t_{ACK}}{8 \cdot L} \cdot \frac{1}{1 - PER_{AP,STA}}$$

$$= \frac{t^{OH1} + t^{OH2}(r_{AP,STA}) + 8 \cdot L / r_{AP,STA}}{8 \cdot L} \cdot \frac{1}{1 - PER_{AP,STA}} \quad (1)$$

t^{OH1}: rate-irrelevant overhead such as preamble
t^{OH2}: rate-dependent overhead such as frame header
$r_{AP,STA}$: transmit rate between AP and STA
L: payload length in bytes
$PER_{AP,STA}$: packet error rate at the given transmit rate

The transmission of a MAC PSDU with payload length L takes t_{Data} for the Data frame and t_{ACK} for the ACK frame. To be consistent with the ATR measurement in the WLAN cards, where DIFS/SIFS is not involved, the inter-frame spaces (DIFS, SIFS) are purposely left out of the overhead time. Then, $t^{\mathrm{bit}}_{\mathrm{AP,STA}}$, the average time taken to transmit a single payload bit between AP and STA at the rate $r_{\mathrm{AP,STA}}$, is shown in Eq.(1). It reflects the actual link quality.

It is well known that the carrier sense in wireless networks is locality sensitive. In other words, two nodes that compose a wireless link may have different sensing of the channel due to different propagation conditions (path loss and fading). As a result, their measured ATR values are also different. Since a successful transmission requires a clear channel both at the transmitter (carrier sensing) and at the receiver (avoiding interference), the channel should be jointly sensed by the two end nodes of a link. Then, the actual ATR for the link between AP and STA is the function of ATR_{AP} and ATR_{STA}:

$$ATR_{AP,STA} = f(ATR_{AP}, ATR_{STA}) \quad (2)$$

Currently, $f = \max(.,.)$ is used. We will further study the correlation between ATR_{AP} and ATR_{STA} in the future.

ATR only reflects how much the channel is physically busy. It does not contain inter-frame spaces (DIFS/SIFS) and the backoff slots. Therefore, ATR cannot reach 1.0. Let the maximal value of ATR be ATR_m. The percent of channel available for transmitting packets is $ATR_m - f(ATR_{AP}, ATR_{STA})$. With each payload bit taking the time in Eq.(1), the PT for the link AP-STA is calculated in Eq.(3).

$$PT_{AP,STA} = \frac{ATR_m - f(ATR_{AP}, ATR_{STA})}{t^{bit}_{AP,STA}} \quad (3)$$

The PT metric differs from previous efforts in that it is designed to work in the non-saturation scenario. A node, wishing to join the network, estimates the PT and effectively exploits the idle part of the channel. But it should not generate more traffic to overload the channel. Once the channel is saturated, the channel share of each node depends on the distributed contention and the transmit rate becomes the main factor of PT. In such cases, PT degenerates to the RSSI metric. Although it still distinguishes the quality of different associations, it cannot reflect the actual throughput.

B. AP selection procedure

The basic procedure, for a node to select an AP when the node is turned on, is shown in Figure 3 and works as follows:

1. Each AP keeps monitoring the channel it works on and calculates the ATR value.
2. A new information element, ChInfo, is added to the beacon frame. ChInfo carries the ATR value (ATR_{AP}) measured at the sending AP.
3. A node (STA), wishing to join the network, scans nearby APs on all channels. The node measures the ATR (ATR_{STA}) of the channel around itself when dwelling on that channel.
4. On receiving beacon frames from APs, a node detects the RSSI, infers the transmit rate according to an empirical RSSI-rate table, and finds ATR value from the ChInfo element inside the beacon frame.
5. For each of the available APs, its offered PT is calculated according to Eq.(3) using the inferred rate, the ATR value measured at the node and the ATR value obtained from the ChInfo element.
6. The node, according to Eq.(4), chooses the AP which maximizes its PT.
7. The node associates with the selected AP.

$$AP = \arg\max_{AP} PT_{AP,STA} \quad (4)$$

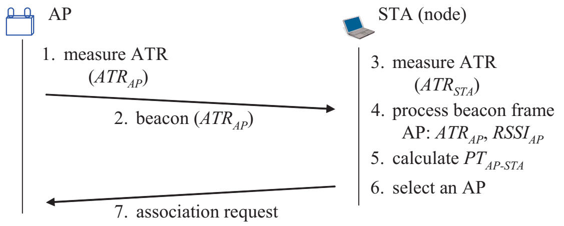

Figure 3 AP selection procedure.

With the above AP selection procedure, it is expected that a node may associate with a farther (with a low rate) but less congested AP (with a low ATR), and achieve higher throughput.

When a node moves away from its associated AP, the RSSI gradually decreases. The procedure to handle the handover works as follows: When the RSSI gets below a pre-determined RSSI threshold $RSSI_{handover}$, a new AP is selected among the APs whose RSSI is above $RSSI_{handover}$. To accelerate the handover and enable smooth handover, this procedure can be further optimized: A node keeps monitoring the PT of each candidate AP and switches to a new AP with a PT greater than the current throughput. The effect of this optimization, however, depends on the freshness of the scanning results (ATR, RSSI etc.).

C. Tuning the ATR_m parameter

The parameter ATR_m plays an important role in the calculation of PT. It determines how much the channel can be used. To find the optimal ATR_m, it is necessary to further investigate how the channel busy time is measured.

In the off-the-shelf WLAN cards with Atheros chipsets, the channel is divided into slots and two counters, 'slot counter' and 'busy slot counter', are used to respectively count the number of slots and the number of busy slots within a certain period. Via the openHAL for MadWiFi device driver [8], these counters can be obtained and then ATR is calculated as the ratio of 'busy slot counter' to 'slot counter'.

How the 'busy slot counter' is increased in the chipsets is not very clear. We did experiments to measure the actual ATR by transferring the ICMP echo packets (using the program 'ping') between a node and its associated AP, using a given packet size, different packet generation intervals and a fixed transmit rate. On the other hand, with the intervals and packet size, the ATR value can be theoretically calculated. We tried different calculating methods and matched the calculated results against the experiment results. The calculation method that best matches the experiment results is shown in Figure 2, where only t_{Data} and t_{ACK} are included. It means that the 'busy slot counter' is increased when the channel is physically busy, which is quite reasonable.

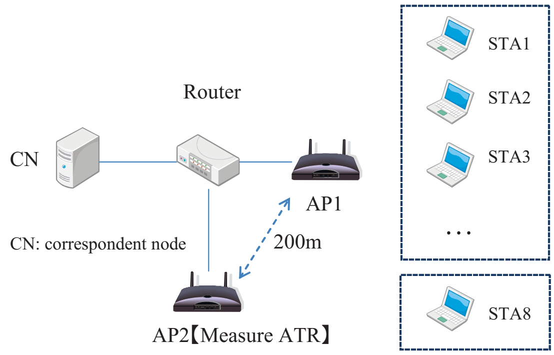

Figure 4 Topology for choosing *ATRm*.

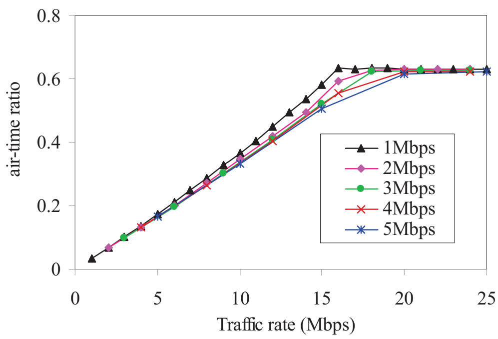

Figure 5 Evaluation of airtime ratio.

We implemented the channel sensing mechanism of Atheros chipset in the network simulator, Scenargie [10]. With the topology in Figure 4, we choose the ATR_m via simulation. STAs are gradually turned on. Each STA associates with AP1 and initiates a CBR (constant bit rate) flow with the CN (correspondent node). All STAs use the same CBR rate, 1, 2, 3, 4, or 5Mbps. The ATR values are shown in Figure 5, where the horizontal axis is the total offered traffic rate (which changes with the number of active STAs). As more STAs are turned on and start their CBR flows with the CN, the ATR value increases with the offered traffic rate. At some point, ATR starts to approach a constant value, which indicates that the channel gets saturated. At the given payload length L (L=512 bytes for Figure 5), the maximal values of ATR at different per-node traffic rates are nearly constant. On this basis, ATR_m is chosen.

IV. Simulation Evaluations

We evaluate the proposed scheme with the network simulator, Scenargie [10]. In the evaluation, we compare the throughput achieved by the RSSI metric and the PT metric respectively, using the IEEE 802.11a parameters [11].

Figure 6 shows the simulation scenario. Three APs are connected to the common router via broadband cables. They run on orthogonal channels. The numbers of nodes deployed around AP1, AP2 and AP3 are n_1, n_2, n_3, respectively. In the simulation, n_1+n_2+n_3 is fixed at 12. Nodes are gradually turned on. They scan all channels and associate with a proper AP according to the RSSI metric or the PT metric, and initiate a bi-directional CBR flow with CN. The CBR traffic generated by each node is the same, with the following setting: the channel is near the saturation state when it is shared by four nodes.

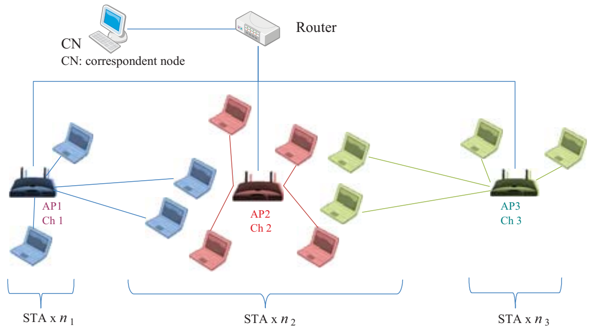

Figure 6 Topology for AP selection (different channels).

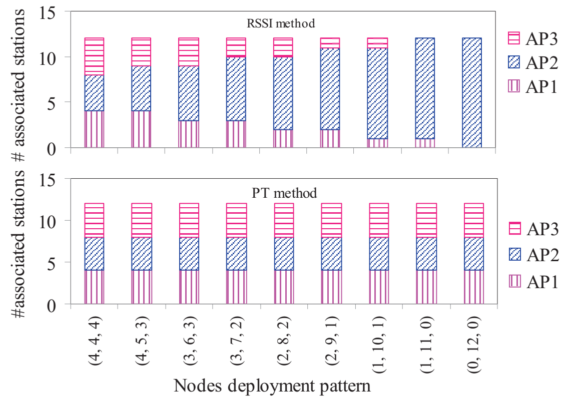

Figure 7 #associated nodes under different node deployment patterns.

Figure 7 shows the number of nodes, associated with APs after all nodes are turn on, and Figure 8 shows the resulting total throughput. In both figures, the horizontal axis is the nodes deployment pattern determined by the triple (n_1, n_2, n_3). On the leftmost side of the horizontal axis, (n_1, n_2, n_3) equals (4, 4, 4) and there is no unbalance in the node density. Therefore, the association relationship and the total throughput are the same in the RSSI method and the PT method. Moving right along the horizontal axis, the unbalance in the node density becomes serious. Therefore, with the RSSI method, more than 4 nodes associate with AP2. The offered traffic of these flows is beyond the channel capacity while the adjacent AP1 and/or AP3 are not fully used. Therefore, the total throughput of the RSSI method gradually decreases. On the rightmost side of the horizontal axis, all nodes in the RSSI method associate with AP2 and the total throughput reaches the minimum. As a comparison, the total throughput of the PT method almost remains unchanged since each AP always has the same number of associated nodes. For the extreme case where (n_1, n_2, n_3) equals (0, 12, 0), the gain of PT over RSSI reaches the maximum, 3.38 in this scenario, as can be explained below: Three channels are fully used in the PT method, while only one channel is used in the RSSI method. The gain is at least 3. The extra gain is due to the following factor: Many nodes gathering in the same contention domain in the RSSI method leads to higher collision probability and further degrades the total throughput. From Figure 8 it is clear that the throughput gain depends on the bias in node density.

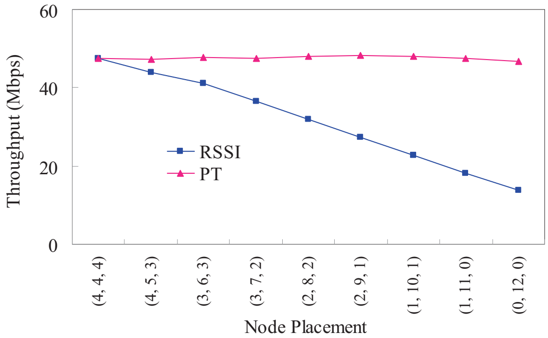

Figure 8 Throughput under different number of nodes.

In the scenario where all three APs share the same channel, the ATR values of three APs are almost the same. Then it is the rate that mainly determines the throughput and the PT metric works in a similar way as the RSSI metric.

V. TESTBED EVALUATIONS

We implemented the proposed scheme on the Linux testbed using the MadWiFi device driver [2]. Among the different versions of MadWiFi drivers, currently the information of the channel state counters can only be obtained in the non-stable MadWiFi trunk version. We ported the related codes to the old stable version, MadWiFi 0.9.4. Then, we added a new information element, ChInfo (carrying the ATR value), to the beacon frame. In addition, the driver is modified so that a node records the ATR value in its scanning table on processing the ChInfo element and uses the calculated PT in the AP selection.

Figure 9 shows the experiment topology where 802.11b is used. Two APs, AP1 and AP2, are connected to the wired network. AP1 and AP2 run on different channels and are near to each other. Due to the different number of associated nodes, the channel around AP1 is more congested. Therefore, AP1 has a higher ATR than AP2. A new node, STA, nearer to AP1 and farther from AP2, is turned on. It scans channels and finds the two APs. The two candidate links have different RSSI (rates and PER) and ATR (PT). STA selects AP1 when RSSI is used as the metric; STA associates with AP2 when PT is used. Iperf (UDP) is used to measure the average throughput between STA and CN in each 30s period.

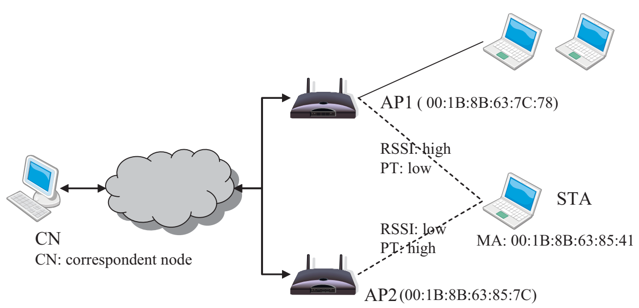

Figure 9 Experiment topology.

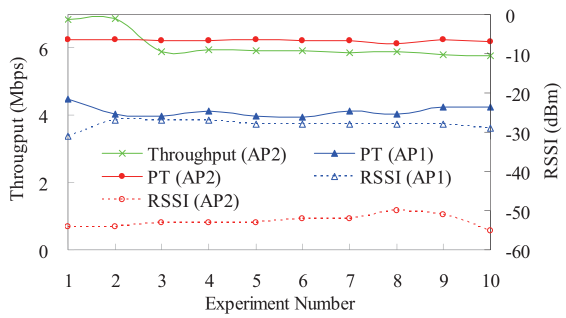

Figure 10 Throughput and RSSI under different experiments.

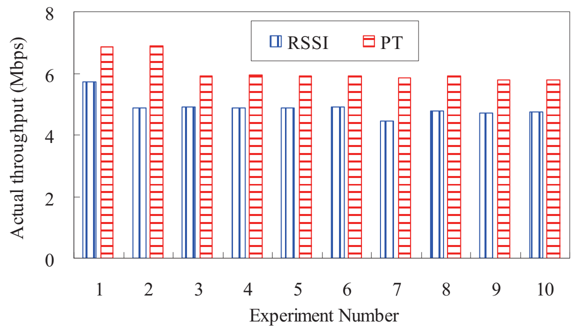

Figure 11 Throughput under different experiments.

Figure 10 shows the PT and RSSI at AP1 and AP2 obtained in 10 experiments. From this figure, it is clear that (i) AP2 provides higher PT [PT(AP2)] than AP1 [PT(AP1)] although the RSSI of AP2 [RSSI(AP2)] is less than that of AP1 [RSSI(AP1)]. This is because the channel congestion degree plays the major role in this scenario. (ii) At AP2, the calculated PT [PT(AP2)] well matches the actual throughput [Throughput(AP2)].

Figure 11 compares the throughput achieved by STA. Higher throughput is achieved with the PT method, compared with the one achieved with the RSSI method. The average throughput is 6.10Mbps in the PT method and 4.89Mbps in the RSSI method, respectively. This gain depends on the unbalance in the channel congestion degree and the transmit rate.

VI. CONCLUSION AND FUTURE WORK

Because the last hop wireless link usually is the bottleneck of the whole route, the AP selection has a great influence on the end-to-end throughput. In this paper we analyzed that the achievable throughput over the wireless link depends on two key factors: channel availability and transmit rate. On this basis, we suggested combining the two factors by the PT metric and that a new node should select an AP which maximizes its PT. The simulation results show that the PT metric does improve the total throughput of the entire network and that the throughput gain depends on the unbalance in node density. The testbed experiments also confirm the feasibility and effectiveness of the proposed scheme. In the future we will continue the evaluation of the AP selection, and jointly optimize AP selection and transmit power control.

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