Energy Efficient Wi-Fi Tethering through Fast Convergent Transmission Power Adaptation

Yu Zhang * †, Guoqiang Zhang †, Wenjuan Zhao * ‡, Md Shazarul Alam †, Ruiheng Xie §
* Ningbo Institute of Northwestern Polytechnical University, Ningbo, China
† School of Computer Science, Northwestern Polytechnical University, Xi'an, China
‡ School of Life Science, Northwestern Polytechnical University, Xi'an, China
§ Department of Computer and Information Sciences, University of Delaware, Newark, USA
zhangyu@nwpu.edu.cn, {guoqiangzhang,zhaowenjuan}@mail.nwpu.edu.cn, rahatalamnpu@yahoo.com, xierh@udel.edu

Abstract—Energy-efficient Wi-Fi tethering has received sustained attention. However, most existing Wi-Fi tethering schemes use maximum power to transmit data regardless of the distance between a mobile access point (MAP) on a smartphone and other associated devices. This problem is becoming increasingly important with the popularity of MIMO deployment because they offer more offload traffic and a higher data rate. In this paper, we design a Distance-aware Adaptive Transmission Power Control (called DATPC) scheme. Hence, DATPC can set the appropriate transmission power at the right moment. We have prototyped DATPC on commercial 802.11n WiFi devices and evaluate its performance in various indoor and outdoor scenarios. Experimental results show that within 3m distance, DATPC reduces the energy consumption of a MAP smartphone by up to 60% while ensuring the same transmission quality as the default maximum transmission power when sending data packets.

Index Terms—IEEE 802.11, mobile access point (MAP), Wi-Fi Tethering, energy saving, transmission power adaptation.

I. Introduction

With the development of the wireless communication technology, there are more and more intelligent devices owned by individuals [1], such as smartphones, smartwatches, tablet computers, laptops, etc. Many of these devices may not have a data plan, for example during oversea travel, to access the Internet directly, instead they may share the cellular network connection of a smartphone over Wi-Fi. This is known as Wi-Fi tethering which is widely supported on commercial smartphones since this functionality provides the ubiquitous Internet connectivity for users. Wi-Fi tethering essentially turns a smartphone into a wireless router, and shares its connection with all of the other devices connected to it. However, this may place additional energy burden on the tethering smartphone which may will use up nearly an order of magnitude more energy consumption than the phone turning off this service [2] [3].

Studies [4] [5] show that in typical Internet application traffics there exist many frequent idle periods where the Wi-Fi interface of a tethering phone is set to the high power state. Hence, most existing studies focus on how to efficiently put its Wi-Fi interface into sleep when the Wi-Fi network is idle. Based on the traffic pattern analysis, the authors in [2] uses a lightweight and reliable sleep request response protocol for a tethering phone to coordinate its sleep schedule with its clients and designs an adaptive sleep algorithm to allow a tethering phone to automatically adapt to the various on-going traffic load for the energy saving. In order to support more work modes clients such as power save mode (PSM), adaptive PSM, and constant awake mode (CAM), the E-MAP protocol is proposed to make sleep mechanism more compatible and applicable [3]. Recently, Lim and Shin [6] proposed POEM to reduce energy consumption of the MAP protocol by allowing its Wi-Fi interface to sleep even during data transfer. Through testbed experiments, they discovered that the previous sleep algorithms improve the power efficiency of MAP only if the packet inter-arrival interval (PAI) is long. As for some popular applications with very short PAI such as video streaming and file sharing, POEM lets MAP enter the sleep mode based not only on the idle time but also on the WiFi channel utilization.

However, existing energy efficient Wi-Fi tethering schemes do not deeply take into account the impact of the transmission power of a MAP on energy consumption of both the MAP and its client. The built-in Wi-Fi tethering on existing smartphone always uses a maximum power to transmit data packets no matter a MAP is close to its clients or not. Moreover, with the rapidly increasing popularity of 5G and MIMO deployment [7] [8], new Internet traffics such as AR and VR applications need to have a long offload interval to transmit and receive [9] [10] [11]. Hence, selecting the appropriate transmission power for data packets transmission is becoming increasingly important to energy saving in Wi-Fi tethering.

In this paper, we propose a novel Distance-aware Adaptive Transmission Power Control (DATPC) scheme to reduce the energy consumption of MAP while ensuring not to impact the data rate, network throughput. The objective of DATPC is to automatically adjust the transmission power of the MAP based on the current network condition, thus delivering data with minimum energy consumption. Conceptually, the client continuously monitors the distance changes by collecting the Received

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Signal Strength (RSS) from packets transmitted by the MAP to obtain the current path loss, If the distance is found to be changed, this client then informs the MAP to dynamically reset the current transmission power and transmit at (current path loss + TP_{min}), where TP_{min} is the minimum power at which the client can decode packets while the MAP has the minimum energy consumption.

To the best of our knowledge, we are the first to study the impact of transmission power of a MAP on energy efficiency in Wi-Fi tethering. This paper makes the following contributions:

1) We study the impact of transmission power of a MAP on Wi-Fi tethering. We show that selecting the appropriate transmission power is becoming increasingly important for energy saving of Wi-Fi tethering.
2) We design a simple yet practical approximate algorithm to help the MAP quickly converge the appropriate transmission power under the current link quality. We develop a lightweight collaborative algorithm to set the appropriate transmission power at the right time.
3) We implement DATPC on off-the-shelf smartphones and evaluate its performance in various indoor and outdoor scenarios. The evaluation results show that DATPC is able to significantly save the power in Wi-Fi tethering while not impacting the data rate, network throughput.

The remainder of the paper is organized as follows. Section II introduces the research motivation. It follows by the design framework for the entire DATPC scheme in Section III. The implementation and the evaluation of DATPC are in Section IV and Section V respectively. Related works is in Section VI. Section VII concludes the paper.

II. Preliminary and motivation

Since there exist many frequent idle periods in typical Internet application traffics, most existing studies focus on how to efficiently put its Wi-Fi interface of the MAP into sleep to save energy when the Wi-Fi network is idle. Existing studies [2] [3] [6] have not considered the power consumption when the Wi-Fi interface of a MAP is in the transmission state and how to save energy in the new traffic scenario. With the rapidly increasing popularity of 5G or MIMO deployment [7] [8], new Internet traffics such as AR and VR applications need to have more persistent time to transmit packets with higher data rate [9] [10] [11]. Moreover, existing energy efficient Wi-Fi tethering schemes do not deeply take into account the impact of the transmission power of a MAP on energy consumption of both the MAP and its client.

Lin [12] found that there is a linear positive correlation between transmission power and RSSI in wireless sensor networks. Therefore, lin fits a linear equation between RSSI and transmission power, and adjusts the transmission power according to the change of RSSI. However, the point is based on the assumption that the distance between nodes is constant. In the case of Wi-Fi tethering, the distance between MAP and Client will change. This situation will cause a decrease in the accuracy of the linear model prediction and an increase in the number of transmission power adjustments.

Now, let us theoretically analyze the relationship between RSS and the difference in signal propagation distance. In the Wi-Fi positioning system, the information we can easily get from the receiver is RSS, the name and location address of the AP. Therefore, RSS is necessary information to estimate the propagation distance of the signal. Many signal attenuation models have been summarized in previous work [13] . For convenience, this article uses a logarithmic distance model. As shown in [14] , it can be described in the following ways:

$$P_r(d) = RSS = P_r(d_0) - 10nlog_{10}(d/d_0) \tag{1}$$

where d represents the signal propagation distance from the MAP to the client. $d_0$is the reference signal propagation distance and usually set to 1m. $P_r(d)$ represents the RSS value, and n is the path loss exponent. According to Equation 1, the RSS difference can be described by:

$$\begin{aligned}\triangle RSS_{i,j} =& RSS_i - RSS_j \\ =&(P_r(d_i) - 10nlog_{10}(d_i/d_0)) \\ &-(P_r(d_j) - 10nlog_{10}(d_j/d_0)) \\ =&10nlog_{10}(d_j/d_0) - 10nlog_{10}(d_i/d_0) \\ =&10n(log_{10}(d_j/d_i))\end{aligned} \tag{2}$$

where $\triangle RSS_{i,j}$ is the difference between RSS_i and RSS_j. We can see that the RSS difference has a logarithm relationship whith the propagation distance. We can judge whether the distance has changed based on the change of RSS.

III. Design of DATPC

Guided by the results in Section II, we propose Distance-aware Adaptive Transmission Power Control (DATPC) strategy for energy efficient Wi-Fi tethering. The design goals of the DATPC are as follows: 1) Without decreasing the transmission rate and network throughput, the transmission power of the MAP when sending the data packets should be as low as possible, so as to achieve energy saving; 2) The transmission power of the MAP can adapt to the change of the link quality.

The overall design of the DATPC strategy is as shown in Fig.1, which includes: 1) The client processes the RSS and monitors the changes of RSS to determine whether the distance between the MAP and the client has changed; 2) If the client judges that the current distance has changes, it will call estimation model to calculate an optimal transmission power reference value at the current link;

3) Collaborative algorithm ensures that the transmission power is set at the right time. 4) The MAP sends the data packets to the client by using this appropriate transmission power found in the previous step before the next change of the distance.

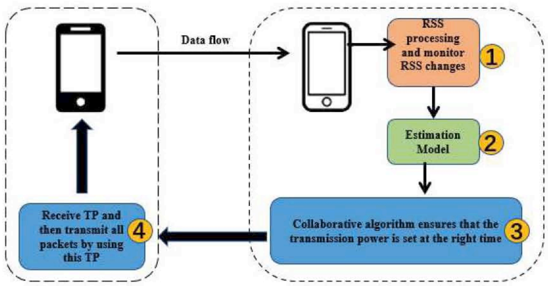


Fig. 1: Overview of the DATPC Design

A. Estimation model of DATPC

The basic idea of the estimation model of DATPC is that the transmission power should be as low as possible as long as the MAP can maintain the maximum radio frequency of the device. One of the key indicators for maintaining the maximum transmission data rate of the MAP is the magnitude of the received signal strength of the connected client. Therefore, we derive the optimal transmission power value of the link of the MAP by the received signal strength value of the client.

Firstly, $PL(t)$ is used to represent the path loss value of the current link moving from the MAP to the client, which includes the effects of the multi-path fading, shadow fading, path loss and so on. The value is determined by the difference between the current power transmission value of the MAP and the received signal strength of the client:

$$PL(t) = TP_{cur} - RSS(t) \tag{3}$$

we mentioned in Equation 3. Secondly, the value TP_{MAP} of the transmission power of the MAP under the current link is obtained, and it is the sum of the minimum received signal strength RSS_{min}that the client should maintain, the path loss value $PL(t)$ under the current link and the extra buffer M. Thus, the estimation model of the optimal transmission power of DATPC under the current link can be obtained:

$$TP_{MAP} = PL(t) + RSS_{min} + M \tag{4}$$

since if the buffer is not added, the received signal strength of the client can only be maintained at RSS_{min}. Therefore, due to the short-term noise caused by the multi-path, etc., the received signal strength of the client is likely to be less than RSS_{min} in a period of time, and there is no way to maintain the target data rate, so the extra buffer M is added, to prevent the effects brought by the short-term noise.

B. RSS signal processing

Using RSS to determine whether the distance has changed and calculating the transmission power are closely related to the accuracy of RSS. But when signal is conducted in actual point, because the radio-frequency signal is not stable, wireless signal propagation in the indoor environment is very complex, with a lot of interference factors, the received RSS signal has time-varying characteristics and bigger fluctuation, making the measured RSS value not accurate enough. So if we want to realize the RSS calculation distance and calculate the transmission power , first we need to consider the preprocessing of the collected RSS value.

Kalman filtering is the optimization algorithm based on linear minimum mean square error prediction and linear recurrence updating, and the predictive value of the current moment is updated according to the predictive value of the previous moment and measured value of the current time, which can effectively solve the filtering problem of the interference noise obeying the normal distribution, suitable for the filtering processing of RSS measured value. The "measurement - prediction - updating" is conducted on RSS values, to eliminate the system random noise, and smooth RSS signal.

$$X(k) = A * X(k-1) + B * u(k) + w(k) \tag{5}$$

$$Y(k) = C * X(k-1) + v(k) \tag{6}$$

$X(k)$ is the estimation of RSS at k^{th} instant using the previous $RSS\ X(k-1)$.Transmission power at time k is given as $u(k)$. $w(k)$ represents the atmospheric interference noise. A is the transition matrix which relates the previous estimated RSS at $(k-1)^{st}$ time instant to the estimated RSS at k^{th} time instant. B is the transition matrix which relates the Transmission Power and the estimated RSS. $Y(k)$ is the measurement equation for RSS at k_{th} time instant. C is the output transition matrix for RSS. Noise occurring during measurement is given as $v(k)$. $w(k)$ and $v(k)$ are independent, white and with normal probability $p(w) \quad N(0,Q)$ and $p(v) \quad N(0,R)$.

Using the time updation step, the RSS can be predicted using the expected value of the RSS, $Xh(k)$ and the associated covariance matrix, i.e., $P_{xh}(k)$ is shown in the equation 7 and 8 . Q is the state error covariance matrix.

$$X_h(k) = A * X_h(k-1) + B * u(k) \tag{7}$$

$$P_{th}(k) = A * P_h(k)A' + Q \tag{8}$$

Kalman gain is a parameter used for fine tuning, the computation of the Kalman gain $K(k)$ is given in equation 9.

$$K(k) = P_{th}(k)C[CP_x(k)C' + R]^{-1} \tag{9}$$

Where $P_{xh}(k)$ is the estimated error covariance matrix and R is the measurement error covariance matrix. The expected measurement $Y_h(k)$ is given in equation 10.

$$Y_h(k) = CX_h(k) + R \tag{10}$$

Innovation parameter $Inov(k)$ is the error obtained between the actual RSS and estimated RSS as shown in 11. The value of estimated RSS is updated using $Inov(k)$. This improves the accuracy of estimation. If $Inov(k)$ is zero, the actual and estimated value are equal which is the required target to be achieved.

$$Inov(k) = Y(k) - Y_h(k) \tag{11}$$

The Kalman gain and the Innovation parameter are used to update the expected value of RSS, $X_h(k)$ as shown in equation 12.

$$X_h(k) = X_h(k) + K(k) * Inov(k) \tag{12}$$

The associated error covariance $P(k)$ is now updated as given in equation 13.

$$P(k) = [1 - K(k)]CP_{xh}(k) \tag{13}$$

C. Transmission Power Collaborative Set

Another problem is how to ensure that the transmission power of the MAP is set at the right time. In the section III-A, when the RSS difference between the two data packets collected by the client in the DATPC strategy is more than one level, it will be determined that the link quality between the two ends has changed significantly so that the transmission power value of the MAP will be recalculated and set. But when the MAP re-sets its own transmission power, the received signal strength of the client needs to take a period of time to reach a stable interval.

We measure the period of time by conducting some experiments. The distance between the MAP and the client is fixed in the whole process of the experiment. The MAP will first maintain its fixed transmission power for a period of time, and then adjust it from high to low, and then after keeping it for a period of time, adjust it from low to high, and the RSS changes in the client during the whole process are shown in Fig.2. When the transmission power of the MAP changes, the RSS of the client will not reach a stable interval instantly but will take a while to achieve. Δt1 and Δt2 in Fig.2 show the time taken by the client's RSS to reach a stable interval during the process of the transmission power value changing from high to low and low to high. During this time, RSS has been in drastic change. If this period of time is not processed, it will bring a serious problem, that is, conventional ATPC strategies cannot distinguish whether the dramatic change of RSS is caused by the change of the relative distance between the MAP and the client, or by the change of the transmission power of the MAP.

To solve this problem, we need to develop a lightweight collaborative algorithm. In Algorithm 1, when the client calculates a new transmission power value and returns it to the MAP, the send flag will be set as false from true. Before the send flag bit is changed back to true, it will not be returned to the MAP even if the new transmission power value is recalculated. The send flag bit will be changed back to true after receiving the SIGNAL signal from the MAP. The MAP will first set it to its own transmission power value after receiving the new transmission power value from the client every time. Then, after a time delay as Delay, the SIGNAL signal will be returned to the client, so that the client can return the new transmission power value to the MAP.

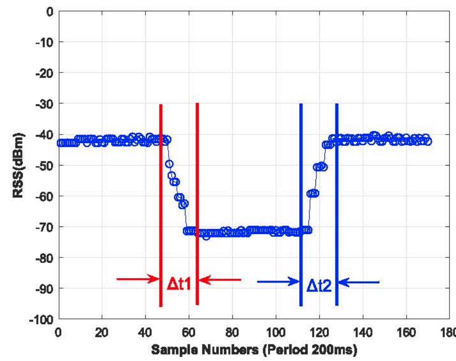


Fig. 2: The phenomenon of RSS delay stabilization

Algorithm 1 Transmission Power Collaborative Set

```
procedure Client
    calculates a new transmission power;
    if sendingflag is True then
        send new transmission power to MAP;
        sendflag ← False
    end if
    if client recieve SIGNAL from MAP then
    end if
    sendflag ← True
end procedure
procedure MAP
    receives and sets a new transmission power from client
    Sleep(delay);
    send SIGNAL to client;
end procedure
```

IV. Implementation

We have implemented a prototype of DATPC on Nexus5 specifically. The overall architecture consists of three parts: RSS real-time monitoring, feedback based system workflow and transmission power level adjustment and selection.

For enabling the client side to obtain RSS of a data packet from MAP in real time, we use libpcap of network data packet to write data packet sniffer of the client side, so as to enable the client side to be on the application layer. In this way, it can obtain copies of all data packets of underlying specified data flow through calling callback function, so that it can extract *RSS* and transmission speed in each data packet.

The current smartphones do not have transmission power self-adaptive function and always use the maximum transmission power to transmit data acquiescently. We use the tool of cross-compiling, Native Development Kit (NDK), to compile the commands, iwconfig, that can adjust transmission power and can run in Android, and use Android Debug Bridge (ADB) to transmit them to Linux system of Android device. These commands can be controlled through the mode of ADB remote connection, and also be controlled through Android application compiled by the application layer. The specific control mode is iwconfig interface txpower xdBm with interface referring to wireless network card interface number and expected RF gain.

We set up the transmission power adjustment level of MAP to be 3dB. We observed in [15] that if the transmission power adjustment level is lower than 3dB, the effect after adjustment is not likely to be as well as expected. Furthermore, we select 3dB to be the transmission power adjustment level for having fine-grained control on the transmission power of MAP as far as possible. As our experimental device network card is BCM4339, the effective range of transmission power change is 0 to 20dBm. Thus, the adjustable sequence of MAP transmission power is 20, 17, 14, 11, 8, 5, 2. If the predicted value calculated by estimation model of DATPC is not in this sequence, it will take the nearest value upwards. Besides, as the scenario we are targeting is the MAP under 802.11n and the experimental device is Nexus 5 smartphone, the value shall be -64dBm for maintaining the maximum RF rate MCS7 of the device according to MCS Index Table [16].

V. Experimental evaluations

We evaluate the performance of DATPC in indoor and outdoor environments by answering the following questions. 1) How about the transmission powers, transmission speeds and network throughputs under situations of using DATPC compared to not using DATPC in mobile scenario? 2) How the transmit power of MAP would be controlled when two or more clients are connected through the MAP? 3) How much power of MAP and connected clients are going to save using DATPC?

A. Experiment Setup

Fig.3 shows our experimental environment. The left device is laser range finder and the model is Bosch DLE4000, being used for the accurate measurement on the distance between the devices of two ends in a stationary scenario. The middle device, Google Nexus5, is used to be the MAP in the experiment with the version number being KOT49H, the kernel version being Linux 3.4.0-gadb2201 and the network card model being BCM4339. The right device is an ACER laptop with preloaded Ubuntu14.04 system, network card model being Qualcomm Atheros AR9287 and the kernel version being Linux 3.4.110.

We choose laptop and smartphone to be the client-side device in the experiment because most of current mobile network card devices support Monitor Mode, and it can capture RadioTap information by compiling Libpcap library and Tcpdump command in Android smartphone, hence it can get the information like RSS and transmission speed, etc. carried by each data packet. To measure energy consumption accurately, we unload the battery of Nexus5 smartphone, use Agilent DC power supply analyzer (Agilent Technologies N6705A) to supply power in constant voltage and record the current change of the device during the experimental process.

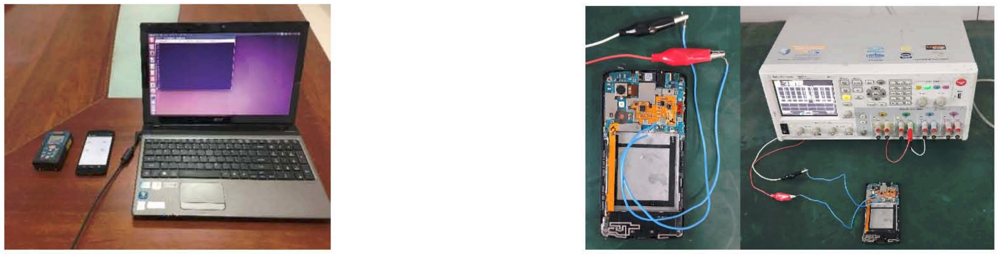
B. Verification in Mobile Scenario

We experimented in an office room. One smartphone is used as a MAP, one laptop and one smartphone is used as a client in turn. In such an indoor environment, we make the distance between MAP and client side to be 0.5m, 1m, 2m, and 3m, respectively. The MAP first uses the default maximum transmission power to send data packet and then open DATPC energy-saving strategy to send data packets. We measure the changes of MAP transmission power value, network throughput, and client-side RSS during this process.

Fig.4 (a) shows that when the distances are 0.5m, 1m, 2m, and 3m, respectively, the transmission powers are 5dBm, 8dBm, 8dBm, and 8dBm, respectively under the situation of using DATPC strategy, which saves 60% to 75% comparing with the default maximum transmission power of the device. For DATPC strategy without convergence phase, although the transmission power after being stable is smaller than the default maximum transmission power of the device, it is 27% to 70% higher than the transmission power gotten by DATPC strategy. Fig.4 (b) shows that the throughput of using DATPC to transmit data is very close to that of using the default maximum power of the device to transmit data no matter what distance it is. As shown in Fig.4 (c), when the distance is relatively small, the client-side RSS is relatively large, which shows that it has a lot of space to reduce the transmission power of the MAP.

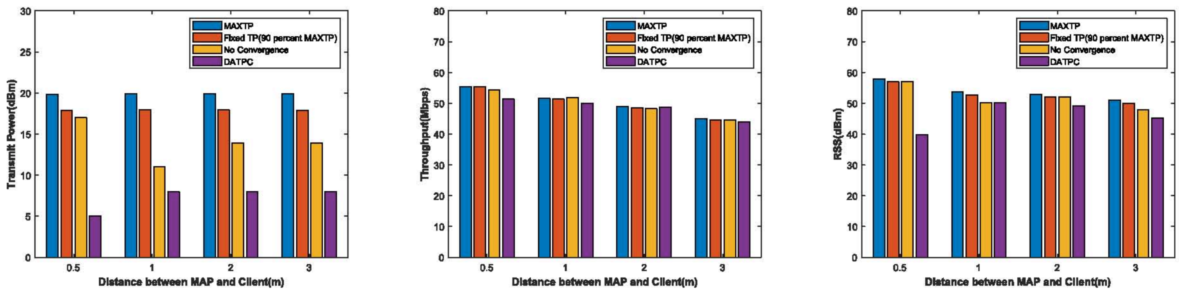
C. Verification in Multiple Clients Scenario

To investigate the multiple Clients and APs impact, we study the energy consumption of MAP and the throughput of network: an office room, and an outdoor park, as shown in Fig.5. In the indoor environment, we connect 1-5 clients to the MAP and two fixed APs are used as interference. In the outdoor environment, 1-5 clients are connected to one MAP, and two other mobile APs (MAP2, MAP3) are used as interference. In the experiments, we let MAP connected by clients first use the default maximum transmission power to send data packets and then change transmission power to 90% maximum transmission power



(a) (b)

Fig. 3: Equipment for distance-aware transmission power (a) The left a device is a laser range finder, The middle device, Google Nexus5, is used to be the MAP in the experiment, The right device is an ACER laptop; (b) equipment for total power consumption of smartphone

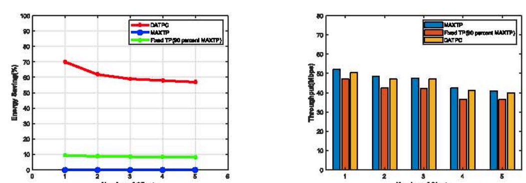


(a) (b) (c)

Fig. 4: The (a), (b) and (c) three figures, the comparisons among MAP transmission power value, network throughput and client-side RSS respectively when it is the device default maximum transmission power, DATPC strategy without convergence phase and DATPC strategy with convergence phase

and finally open DATPC energy-saving strategy to send data packets. Fig.6 (a) shows the energy saving of MAP in indoor environment. According to the results, DATPC can reduce the average power by about 58% regardless of the number of clients, compared to both the default maximum transmission power of legacy system and other fixed 90% maximum transmission power of existing system. The energy saving of MAP using DATPC in multiple APs coexisting scenario is lower than the energy saving of MAP using DATPC in a single APs scenario. This is because there are other APs that interfere with the MAP.

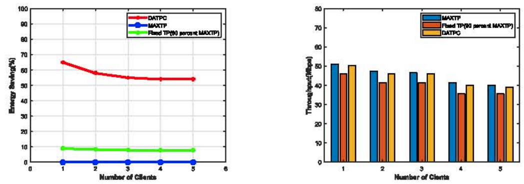
Fig. 5: Indoor and outdoor environment



(a) (b)

Fig. 6: Energy saving of MAP and throughput in indoor environment:(a)Energy saving;(b)Throughput

As shown in Fig.7(a) in comparison to Fig.6 (a), it can be concluded that the energy savings of DATPC in outdoor environment is slightly lower than that of DATPC in indoor environment. This is because the outdoor environment is more complicated and have more factors affecting RSS value. The optimal transmission power estimated by DATPC in outdoor environment is not as accurate as in indoor environment.



(a) (b)

Fig. 7: Energy saving of MAP and throughput in outdoor environment:(a)Energy saving;(b)Throughput

As shown in Fig.6(a), we compared the experimental results with that of the indoor environment (see Fig.7(b)), we notice that the number of clients and its corresponding throughput bar demonstrate similar trends and variations in these two different environments. And we also note that the throughput of network is slightly lower than the throughput in the indoor environment. Because in the outdoor environment, there are many other factors that would affect the link quality. Such as interference from other more APs nearby can influence the throughput.

VI. Related Work

Energy-saving strategy for Wi-Fi tethering. The current MAP energy-saving schemes [2] [3] [6] aim to reduce the power consumption of the Wi-Fi tethering by putting the Wi-Fi interface of a MAP into sleep mode whenever possible. However, in the scenario of large traffic, the sleep time that the current MAP energy-saving strategy can get is very little and the energy-saving effect will not be good. Furthermore, the current strategy does not consider the energy consumption under the transmission state. It always uses the a default single maximum transmission power to send data regardless of distance, and it could cause unnecessary energy waste.

ATPC method for WLAN. [17] does not consider that the theoretical optimal value is not the optimal in the actual scenario, and it also does not consider the problem of RSS stable delay. [18] applies rate self-adaptive and power self-adaptive scheme based on packet loss probability. But the accurate obtaining on Expected Transmission Time (ETT) will be difficult in the current MAP scenario, as the client side is likely to have PSM or APSM in the MAP scenario. And the data packet of MAP is likely to be cached for a while for the client side which is in sleep state before sending actually [19].

ATPC method for Wireless Sensor Network. Most of the work is used for solving the problem of topology control. [20] [21] [22] only make the simulation experiment and assume that the device transmission range is unchanging, but this assumption does not exist in an actual scenario. [23] studies the impact of transmission power control on the link quality. It brings in a blacklisting mechanism and saves more energy. As most of sensor nodes are work under the stationary state, each node of [24] establishes models of all adjacent neighbor nodes, which are used for describing the relations between transmission power and link quality. Under this model, nodes can reflect and adjust the transmission powers of neighbor nodes according to the monitored link quality. But this method has poor adaptability on mobility. [25] applies Adaptive and Distributed Transmission Power Control(ADTPC) scheme, once a node energy drops below certain threshold, the node requests its neighbors to increase their transmission power. The nodes that receive this request check their energy level, and based on the amount of available energy that they have, they decide to increase their transmission power or continue at the current mode. [26] is to increase the number of hops between source and destination pairs if intermediate nodes exit between them. This will reduce the transmitted power required. In this way can attain throughput neutrality while reducing the energy used to transport the data. But the approach only attempts to discover two independent paths to the destination and on each path, it attempts to limit the breakup of single hops down to a maximum of 4 hops where possible.

ATPC method for Bluetooth. [27] evaluates the mean and standard deviation of the RSSI for each one of the BLE4.0 beacons, by controlling the distance to increase the beacon accuracy, to achieve the best transmission power to find the best transmission power setting. [28] shows that further transmit-power reduction is possible by reducing the Golden Receive Power Range (GRPR) from the specified value. But using a smaller GRPR has a disadvantage that the frequency of making power-adjustment requests is increased and increasing the overhead cost. [29] proposes the power control algorithms in Bluetooth transceiver. These power control algorithms are implemented at the LMP level, and the control is focused on the uplink. Based on its RSSI, determine if the transmitter on the other side of the link should increase or decrease its output power level. But the host controller interface (HCI) RSSI commands are used for information only, and the host is not involved in altering the transmit power of Bluetooth device. The difference with our method is that [30] does not save energy by adjusting the transmitted power. It designs an online adaptive algorithm, which adjusts the important parameter T_c (the connection interval) according to the throughput required by the application traffic pattern and the size of buffer, so that the master can save energy and meet the requirements of application delay.

VII. Conclusion

In this paper, we propose DATPC, aiming to save energy of the MAP through automatically adjusting transmission power based on current network conditions with negligible impact on transmission data rate and network throughput. DATPC has mainly two advantages: 1) The transmission power of MAP can quickly reach to the appropriate value under the actual link condition from the theoretical estimation reference value through the convergence stage; 2) The appropriate transmission power of MAP can be set at the right time under the new link condition by a lightweight collaborative algorithm. In our future work, we will extend our DATPC to support more mobile platforms with legacy MAPs and clients in 802.11ac or 802.11ax WLANs.

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