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Adaptive Transmission Power Control for IEEE 802.11 Direct-Link Communication

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***Abstract*—The Direct-Link transmission mechanism of IEEE 802.11z enables point-to-point data transfer between the source and destination without the need for data to be relayed through an Access Point. In current IEEE 802.11 related products, the transmission of all data packets is mainly done at maximum power. While this strategy ensures fair channel allocation among all nodes, it may result in wasted energy and reduced reuse of channel space. Therefore, the power used when transmitting the packet is properly adjusted so that the node can select a suitable energy when sending the packet. In this way, the mutual interference between nodes can be reduced, unnecessary power consumption can be saved, and the spatial reuse rate of channels can be further improved.**

This paper proposes an adaptive transmission power control, named ATPC algorithm, which modifies IEEE 802.11 to select appropriate transmission power when sending packets, so as to reduce mutual interference between nodes. ATPC algorithm does improve space reuse rate and save limited energy of nodes.

***Index Terms*—Transmission Power Control, IEEE 802.11z, ATPC.**

I. INTRODUCTION

Data is transmitted from the source node to the destination node through Access Point in IEEE 802.11, and data is sent twice on the network, consuming twice as much power. However, the IEEE 802.11z Direct-Link Setup mechanism no longer relies on the Access Point to transmit data, but instead transmits data in a point-to-point manner. Since it is a one-hop way to reach the destination, the power consumption is less than that transmitted through the Access Point in half. In IEEE 802.11z, the source transmits the Direct-Link Setup establishment packet (TDLS Setup Request Frame) through the Access Point before data transmission. If the destination supports the IEEE 802.11z standard and allows the creation of this Direct-Link Setup, the destination responds with a corresponding Direct-Link Setup Response Frame to the source via Access Point. After the two nodes successfully pass the package created by Direct-Link Setup, they can transfer data through point-to-point, and no longer need to be transferred through Access Point. The Direct-Link Setup process is shown in Figure 1.

According to IEEE 802.11z Direct-Link Setup process has advantages in energy saving, and we propose to dynamically adjust the power during transmission, improve resource utilization and improve transmission efficiency. However, this operation of 802.11z Direct-Link Setup may cause the nodes in the same BSS (Basic Service Set) to increase the probability of mutual interference. In the IEEE 802.11 standard, nodes all use the maximum transmission power of the system (P_{max}) to transmit packets. If these six nodes as shown in Figure 2 use the same channel to transmit data at the same time, node 1 and node 5 are in each other's signal coverage, then the transmission of node 1 and node 2 will interfere with the transmission of node 5 and node 6. If a node no longer uses P_{max} but chooses an appropriate power for transmission, so that the two pairs of transmissions can transmit their data to their respective destinations at the same time and on the same channel without interference. In turn, the reuse rate of space is improved and the overall throughput can be improved. This is shown in Figure 3.

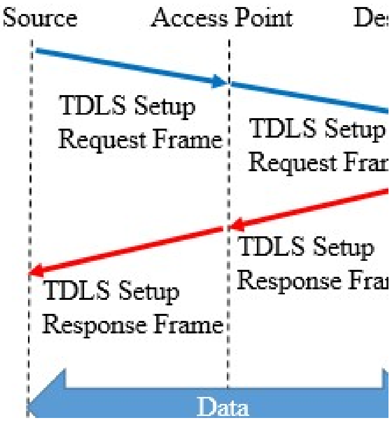

Figure 1: Direct-Link Setup process

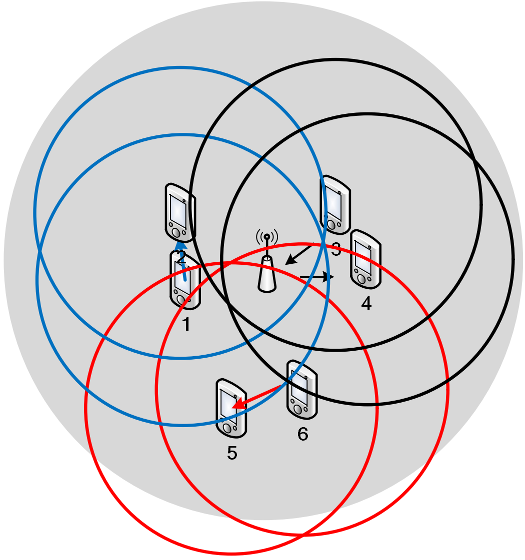

Figure 2: Nodes sending packets using P_{max} with mutual interference

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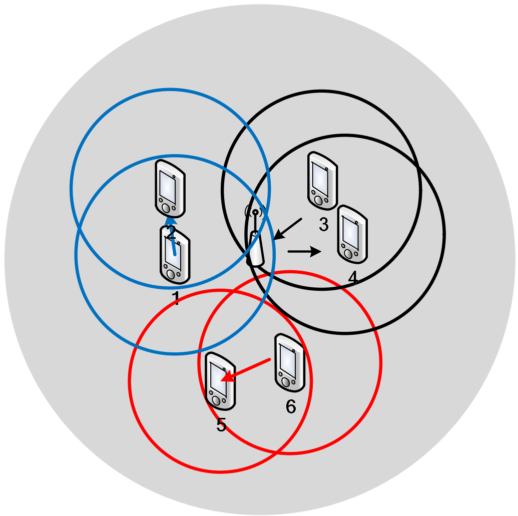

Figure 3: Nodes not using P_{max} to transmit packets have less interference

This paper intends to propose a novel of Adaptive Transmission Power Control applied in IEEE 802.11z. The node can adjust the power of the transmitted packet, instead of using fixed transmission power for saving energy consumption and reducing the interference between nodes.

The rest of the paper is organized as follows. The related works including channel gain and Power Control mechanism are introduced in Section 2. In Section 3, the proposed algorithm for Adaptive Transmission Power Control is described. The simulation scenarios of proposed algorithm are illustrated in Section 4. The experiment results are shown in Section 5. Finally, the conclusion is given in Section 6.

II. RELATED WORKS

A. Channel Gain

In the IEEE 802.11 standard [1], since the receiver cannot know how much power level the transmitter uses to transmit data, the data frame must have a field to record the power level used. The channel gain between two nodes can be calculated by the P_r when receiving the data frame and the P_t information carried in the data frame.

$$G_{ij} = \frac{P_t}{P_r} \qquad (1)$$

In equation (1), G_{ij} represents the channel gain between node i and node j, P_t represents the power level used by node i when sending data, and P_r represents the power level when node j receives data.

B. Power Control Mechanism

In the wireless network environment, the use of mobile devices is often limited by the power of the battery. IEEE 802.11 fixedly uses P_{max} to transmit packets resulting in unnecessary consumption of a lot of energy. Therefore, many papers discuss how to effectively implement the power control mechanism by selecting the appropriate P_t level in transmission frame [2]-[18].

Power Control of Control Frames (PCCF) [2] will maintain a table at each node that records the degree of interference with other nodes. According to this table, when a node wants to transmit data, it will select an appropriate P_t as the transmit power. The transmitter estimates the current SINR (Signal to Interference and Noise Ratio) to calculate the energy (P_{data}) required to transmit data, and then select an appropriate transmission power (P_{CTS}) from P_t and P_{data} to transmit CTS. When the receiver wants to respond to the CTS, it will put the P_{data} and P_{CTS} information into the CTS frame, and then send it back to the transmitter. The transmitter side will determine the energy used for the next data transmission according to the information in the CTS.

Reference [3] supposes a $Node_i$ uses P_{max} in initial transmission to send data to $Node_j$. If the transmission is successful and the corresponding ACK is received, the next transmission will use a smaller value P_t than P_{max}. Use this step to gradually reduce P_t. If three consecutive transmission failures occur, this power control mechanism will increase P_t until the transmission is successful. In the worst case, the transmitted energy will increase up to P_{max}.

Symphony's power control mechanism [4] will enter two phases before transmitting data: 1) REFERENCE (REF) PHASE, 2) OPERATIONAL (OPE) PHASE. In the REF phase, Symphony evaluates the best performance that can be achieved by each node, and then enters the OPE phase to calculate the minimum energy used under the condition that this performance can be achieved according to the performance evaluated by the REF phase, and then transmits the data.

Fragmentation-based Power Control MAC (F-PCM) [6] uses the maximum energy (P_{max}) in the current state for sending RTS/CTS in order to reduce the occurrence of hidden nodes. The energy required to transmit DATA/ACK is the minimum required energy (P_{min}) calculated by exchanging RTS/CTS. Each node will maintain a P_t table that records which node has been transmitted with and the transmission energy value P_t used [13] [15].

Correlative power control (CPC) mechanism [7] uses P_{max} when sending RTS at the beginning of transmission. When transmitting CTS/DATA/ACK, the minimum required energy (P_{min}) is calculated according to the channel gain and the lowest energy (receiving threshold) that can correctly decode the packet, as the energy used for transmission. Receiver Initiated power control Multi-Access (RIMA) [8] mechanism transmits RTS/CTS with the energy of P_{max}, while the transmission of DATA/ACK uses the transmission energy of P_{min}.

The power control mechanism of POWMAC [9] takes into account the degree of interference that each node can withstand, and evenly distributes the degree of interference that can be tolerated to all adjacent nodes. Each node maintains a P_t table. Through this table, node can know the information corresponding to itself and neighboring nodes, and select the appropriate P_t from this table. Therefore, even if the exchange of DATA/ACK is sent at the same time, it will not affect the nearby nodes.

Adaptive Power control MAC (APMAC) [10] is to evaluate the appropriate amount of transmission energy based on the SINR value and receiving threshold. APMAC defines codes for several possible states, and dynamically adjusts the energy used for transmission according to different code conditions.

Distributed Power Control (DPC) [11] adjusts P_t according to the minimum value of SINR measured by the receiver during receiving RTS/CTS/DATA/ACK. During the DPC receiving these frames, the measured minimum SINR value is put into the frame to be sent back to the other party. DPC refers to the minimum SINR value of the RTS just sent at the receiver and the minimum SINR value of the previous data sent to this node, averages the two SINR values, and then calculates the appropriate P_t as the energy for this transmission. When Slow Start Power Control (SSPC) [12] starts to send RTS, it uses a smaller P_t for transmission. If the transmission fails, increase the transmitted energy, resend the RTS, and repeat this step until the transmission is successful.

Through the adjustment of transmission rate and transmission energy, MRPC [16] wants to achieve multiple pairs of nodes to transmit at the same time to improve the spatial reuse rate of channels and increase throughput. Adaptive Transmission Power Control Protocol (ATPMAC) [17] calculates the minimum required energy P_{min} by reference to channel gain, SINR, and receiving threshold. Each node maintains a P_t table corresponding to other nodes, and the content of the table records the node name (Node ID), the minimum demand energy (P_{min}) transmitted to the node, and the maximum usable transmission energy (P_{max}). When a node wants to initiate a transmission, it queries its own table and selects the appropriate P_t for transmission.

From the above literature research, we found that the power control mechanism is implemented on the signal channel, and the appropriate Pt transmission frame is selected, instead of IEEE 802.11 using P_{max} to transmit all frames. This adjustment improves the data transmission between nodes. Here, we use POWMAC [9] as a representative and IEEE 802.11 for performance evaluation, as shown in Figure 4.

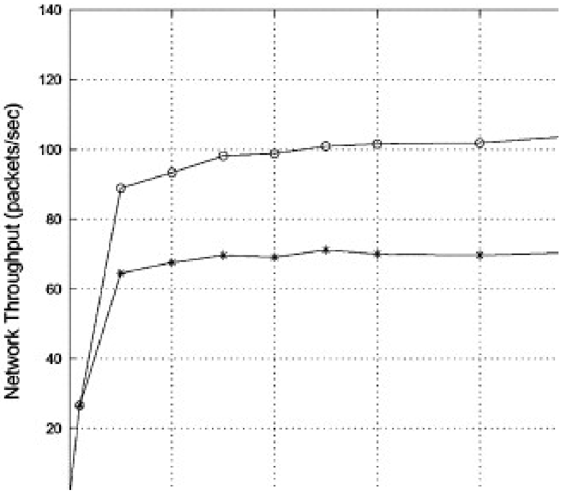

Figure 4: Performance comparison between POWMAC and IEEE 802.11.

III. ADAPTIVE TRANSMISSION POWER CONTROL

The ATPC algorithm proposed in this paper divides the energy of the transmitted packet into n power levels by observing the transmission and reception status of each packet, and dynamically adjusts to an appropriate transmission energy. The ATPC algorithm initially uses the minimum transmission power of the system (P_{min}) to send packets. The ATPC algorithm checks whether the sender receives the corresponding reply packet, and judges whether the transmission is successful.

- If the corresponding reply packet is successfully received, the algorithm maintains a successful transmission counter to record the number of successful transmissions.
- If no corresponding reply packet is received, the algorithm maintains a failed transmission counter to record the number of failed transmissions.

Then the ATPC algorithm adjusts an appropriate transmission energy according to the two counters of successful transmission and failed transmission.

- Reduction of Power Level: When the packet is successfully transmitted x times, the energy of the next packet to be sent will be lowered by one level.
- Increase of Power Level: When the packet fails to be sent y times, the power of the next packet sent will be increased by one level.

```
ATPC Algorithm
Input:   powerlevel[n], successcount, SSRC, successN, rtxN
Output:  totalPower
Begin
successcount←0; SSRC←0; n←0;
Step1:
 If (prevSSRC<SSRC) then
    successcount=0;
 If (prevSSRC==SSRC) then {
   successcount++;
   SSRC=0;                 }
Step2:
  If (successcount==successN) then {
    n--;
    txPower_dBm=Powerlevel[n];
    successcount=0;
    SSRC=0;                        }
  If (SSRC==rtxN) then {
    n++;
    txPower_dBm=Powerlevel[n];
    successcount=0;
    SSRC=0;                        }
Step3:
   txPower_J=txPower_mW*s;
   totalPower=totalPower+txPower_J;
End
```

Figure 5: ATPC Algorithm

Since IEEE 802.11z only needs to transmit the establishment packet through the Access Point when the Direct-Link is initially established, after the establishment is completed, the node uses the point-to-point method for transmission. The ATPC algorithm will adjust the power control of the point-to-point transmission of the node. The operation of the algorithm is shown in Figure 5. The notation meanings in ATPC algorithm are detailed in Table 1.

Table I. Notation Meaning

powerlevel[n]	the node sends a packet, there are n kinds of energy levels that can be used n={0,1,2,…,n}

prevSSRC	the number of failed transmissions for the last packet sent
SSRC	a failed transmission counter
successcount	a successful transmission counter
txPower_dBm	the Power Level used to send the packet
totalPower	total energy consumed (in joules)
successN	the number of successfully transmitted
rtxN	the number of failed transmissions
txPower_J	the energy consumed when sending a packet
s	the duration of sending the packet

IV. SIMULATION SCENARIOS

IEEE 802.11z Direct-Link can perform point-to-point direct transmission after the node forwards the packet through the Access Point. Therefore, the nodes using Direct-Link in the experimental simulation assume that the connection use point-to-point direct transmission. The experimental simulation is performed using QualNet v5.0 [19] which is a network environment simulation software developed by Scalable Network Technologies. The parameters of the experimental environment are shown in Table 2. Table 3 shows ten power levels preset in this experiment.

Table II. The parameters of the experimental environment

Simulation field	200 m × 200 m
Simulation time	300 seconds
Radio type	IEEE 802.11a
Data rate	6 Mbps
Retransmit limit	12
Traffic type	VBR
Packet size	512 bytes
Packet mean interval	0.005, 0.0033, 0.0025, 0.002, 0.01, 0.02, 0.04, 0.08 seconds
Node transmit power	20 dBm
Pathloss model	Two ray

Table III. Power level

Power[1]	1 dBm
Power[2]	3.01 dBm
Power[3]	5.37 dBm
Power[4]	6.81 dBm
Power[5]	8.6 dBm
Power[6]	10.25 dBm
Power[7]	11.76 dBm
Power[8]	15.63 dBm
Power[9]	18.79 dBm
Power[10]	24.49 dBm

This paper proposes two simulated network scenarios. After the simulation is finished, the power consumption of sending packets and the throughput are collected. The performance is compared with IEEE 802.11. The power consumption calculation is as in equation (2), J is the power consumption, the unit is joule, W is the energy used when sending the packet, the unit is watt, S is the time required to send the packet, the unit is second.

$$J = W * S \qquad (2)$$

Scenario 1*: Throughput evaluation in the Hidden Node environment*

The experimental scenario is shown in Figure 6. A network topology with hidden node problem is set up. Four nodes running the ATPC algorithm are placed in the same straight line. Each node is 100m apart, and the packet interval for transmission is 0.001 second. No matter which sender, the receiver of the other pair of transmissions cannot know the existence of the other party's node, so it will cause the problem of hidden node. The throughput of this simulated scenario is compared with the original IEEE 802.11 node.

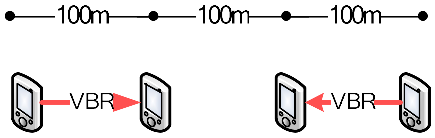

Figure 6: Scenario of hidden node

Scenario 2*: The ATPC node and the original IEEE802.11 node coexist in the same BSS, and the throughput and power consumption are evaluated.*

The purpose of this experiment is to observe the performance of ATPC nodes when there is interference from Access Point and other original IEEE 802.11 nodes. It is divided into two scenarios without background transmission interference and with background transmission interference for evaluation.

- Without background transmission traffic:

In the same BSS, we observe one pair of point-to-point transmission, as shown in Figure 7, and two pairs of point-to-point transmission, as shown in Figure 8. In the absence of interference from other node transmissions, the beacon continuously sent by the AP on this transmission. The packet interval of transmission is simulated respectively by sending 100, 200, 300, 400, 500 and 1000 packets per second. The control group was the original IEEE 802.11 node.

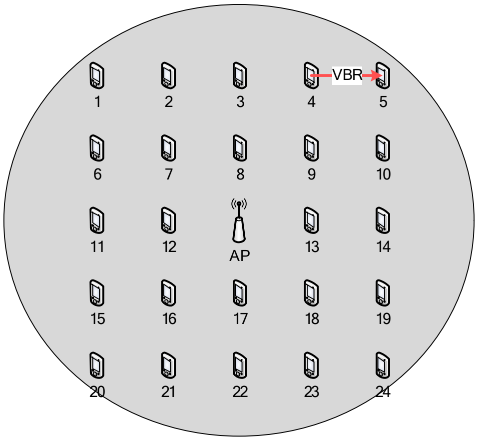

Figure 7: One pair of transmission scenarios in a BSS

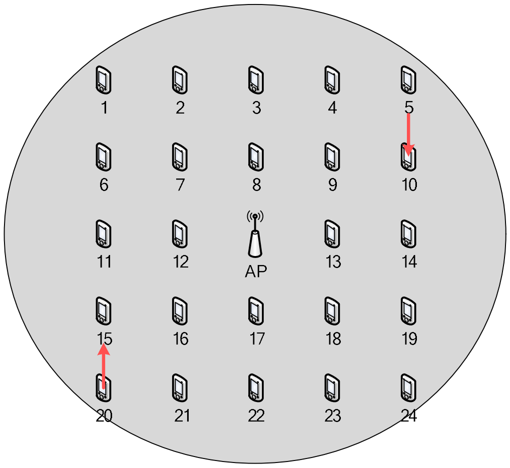

Figure 8: Two pairs of transmission scenarios in a BSS

Table IV. Simulation parameters

Case	1	2	3	4	5	6	7	8	9
one pair of point-to-point transmission	✓	✓	✓						
two pairs of point-to-point transmission				✓	✓	✓			
packet interval of other nodes is 0.02s	✓			✓			✓	✓	✓
packet interval of other nodes is 0.04s		✓			✓				
packet interval of other nodes is 0.08s			✓			✓			
packet interval of two pairs of point-to-point transmission is 0.01s							✓		
packet interval of two pairs of point-to-point transmission is 0.005s								✓	
packet interval of two pairs of point-to-point transmission is 0.0033s									✓

● With background transmission traffic:

We evaluate the performance of one pair of point-to-point transmission and two pairs of point-to-point transmission respectively. The rest of the nodes in the same BSS are all original IEEE 802.11 nodes and transmit data to the destination through the AP. For point-to-point transmission nodes, we use ATPC and original IEEE 802.11 nodes for simulation. Simulation parameters of case 1 to case 6 are shown in Table 4.

In order to highlight the ATPC mechanism proposed in this paper, it can effectively solve the hidden node problem, and then make the nodes transmit as much as possible at the same time. We design an experiment that fix the packet interval of background transmission, adjust the packet interval of the node for point-to-point transmission, and then observe whether the two pairs of ATPC transmission can use the remaining network traffic at the same time. Unlike the original IEEE 802.11 node, the two pairs of transmissions split the remaining network traffic equally. Simulation case 7, 8 and 9 parameters are shown in Table 4.

V. EXPERIMENT RESULTS

A. *Results of Scenario 1*

The energy consumed is shown in Table 5. Since ATPC can dynamically adjust the power of sending packets, the node with ATPC algorithm consumes far less energy than the IEEE 802.11 node during the simulation time. As shown in Figure 9, the node using the ATPC algorithm has higher throughput than the original IEEE 802.11 node.

Table V. Total power consumption

Type of Node	Total power consumption
ATPC	0.222936 joules
802.11	17.79057 joules

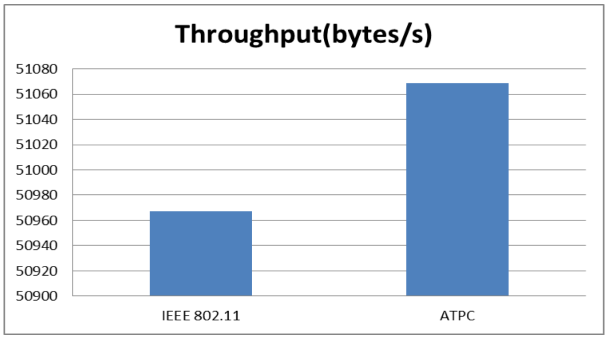

Figure 9: Throughput of ATPC and IEEE 802.11

B. *Results of Scenario 2*

● Without background transmission traffic

(1) One pair of transmission in a BSS: The average throughput and packet delivery ratio of point-to-point transmission are illustrated in Figure 10 and Figure 11. As the traffic load increases, the throughput and delivery ratio of the ATPC node and the original IEEE 802.11 node are almost the same when the AP sends 10 Beacon packets per second. The average throughput of the ATPC node even higher when the traffic is 1000 packets/s. The average power consumption is shown in Figure 12. Even when the traffic is 100 packets/s, the power consumption of the ATPC node is about 200 times less than that of the original IEEE 802.11node.

(2) Two pairs of transmission in a BSS: The average throughput and packet delivery ratio of point-to-point transmission are shown as Figure 13 and Figure 14. The performance of ATPC is almost the same as that of the original IEEE 802.11 when the traffic is 100 ~ 400 packets/s. When the traffic is 500 packet/s, the performance of ATPC is obviously superior, because the sum of the traffic of these two data streams has begun to approach the saturated load of the entire network. This phenomenon is more obvious in the

case of 1000 packets/s, because the sum of the traffic of the two data streams has obviously exceeded the saturated load of the system. Since IEEE 802.11 is a CSMA/CA network, if all nodes can sense each other's wireless signals, only one node can transmit data at the same time. As the traffic load increases, the node with ATPC algorithm can transmit two pairs of data simultaneously. The average power consumption is shown in Figure 15. Even in the case of similar receiving capacity, ATPC nodes consume about 200 times less power than IEEE 802.11 nodes. When the traffic is more than 500 packets/s, since the interaction of IEEE 802.11 nodes, most of the packets are discarded after waiting in the queue so the power consumption will not increase.

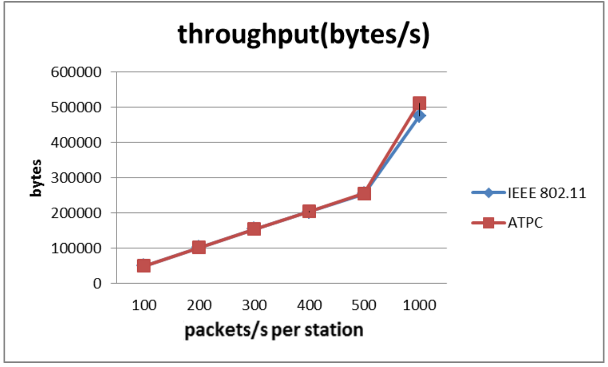

Figure 10: Average throughput of one pair of transmission without background traffic

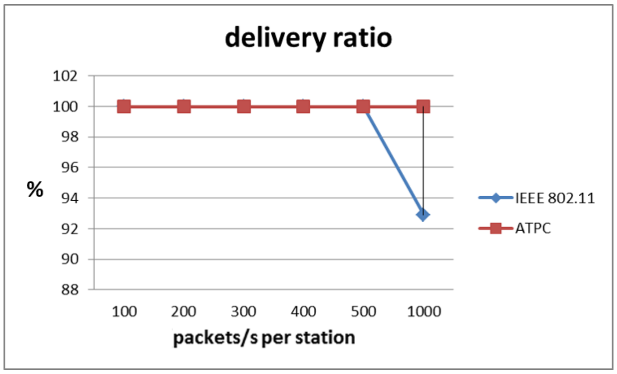

Figure 11: Deliver ratio of one pair of transmission without background traffic

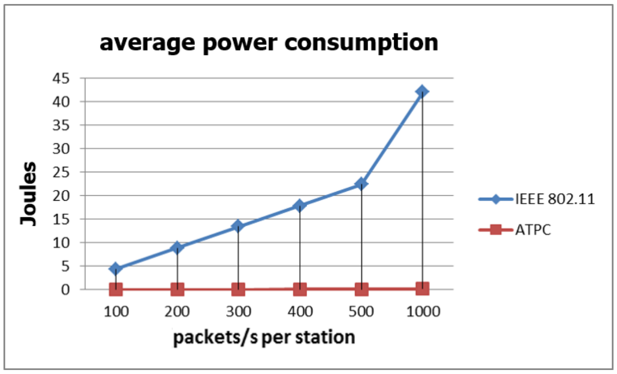

Figure 12: Average power consumption of one pair of transmission without background traffic

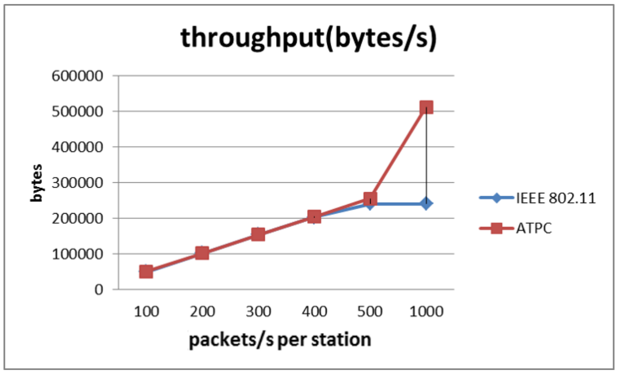

Figure 13: Average throughput of two pairs of transmission without background traffic

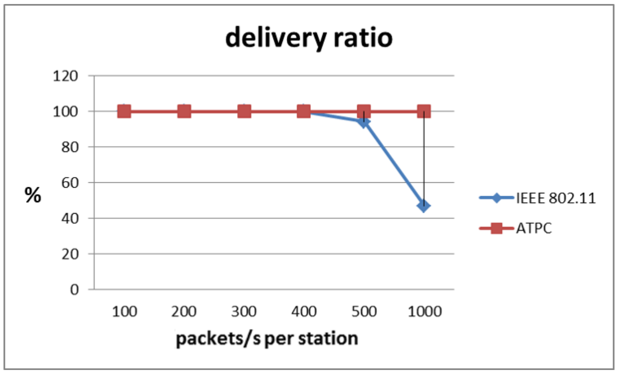

Figure 14: Deliver ratio of two pairs of transmission without background traffic

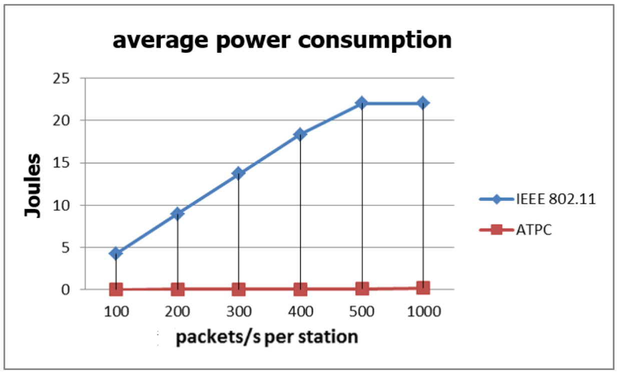

Figure 15: Average power consumption of two pairs of transmission without background traffic

- With background transmission traffic

(1) One pair of transmission in a BSS: According to the case 1, 2 and 3 in Table 4, the experiment is carried out respectively. The average throughput and packet delivery ratio of the point-to-point transmission as shown in Figure 16 and Figure 17. As the background traffic load decreases, the performance of ATPC nodes is still higher than that of original IEEE 802.11 nodes. The average power consumption is shown in Figure 18. When the background traffic sends 50 packets per second on each node, the background traffic interferes a lot with point-to-point transmission, so the power consumption is relatively high. When the background traffic is less, the interference of point-to-point transmission drops, and the power consumption is also reduced.

(2) Two pairs of transmission in a BSS: According to the case 4, 5 and 6 in Table 4, the experiment is carried out

respectively. The average throughput and packet delivery ratio as shown in Figure 19 and Figure 20. As the background traffic decreases, the impact of point-to-point transmission also decreases, and the performance of ATPC nodes is still higher than that of original IEEE 802.11 nodes. The average power consumption is shown in Figure 21. When the background traffic sends 50 packets/s on each node, the background traffic interferes a lot with point-to-point transmission, so the power consumption is relatively high. When the background traffic sends 12 packets/s, the interference of point-to-point transmission drops, and the power consumption is also reduced.

According to the case 7, 8 and 9 in Table 4, the experiment is carried out respectively. The average throughput and packet delivery ratio as shown in Figure 22 and Figure 23. When the background traffic is fixed and the amount of point-to-point transmission data increases, ATPC dynamically adjusts the power level of the transmission packet, so that two pairs of transmissions can be transmitted at the same time. Two pairs of ATPC transmissions can be used together in the remaining network traffic. However, IEEE 802.11 nodes use fixed power to send packets, so two pairs of IEEE 802.11 transmissions will affect each other. At the same time, only one pair will transmit data, and the remaining network traffic will be equally divided. This simulation proves that the ATPC algorithm can effectively enable multiple pairs to transmit data at the same time, and use limited network traffic more effectively.

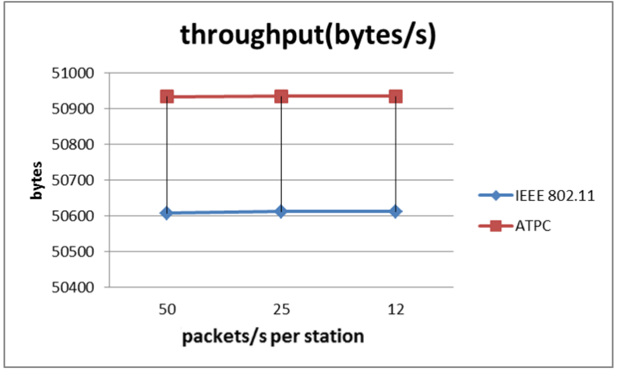

Figure 16: Average throughput of one pair of transmission with background traffic

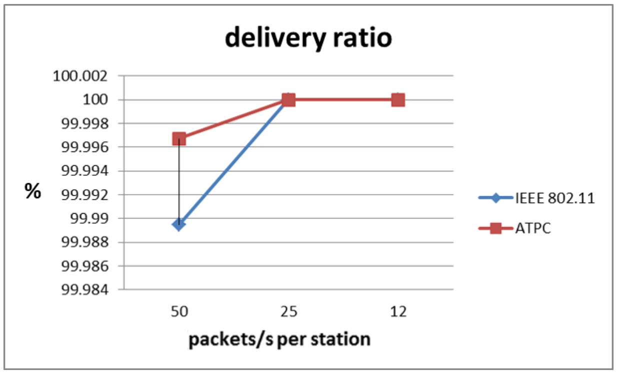

Figure 17: Deliver ratio of one pair of transmission with background traffic

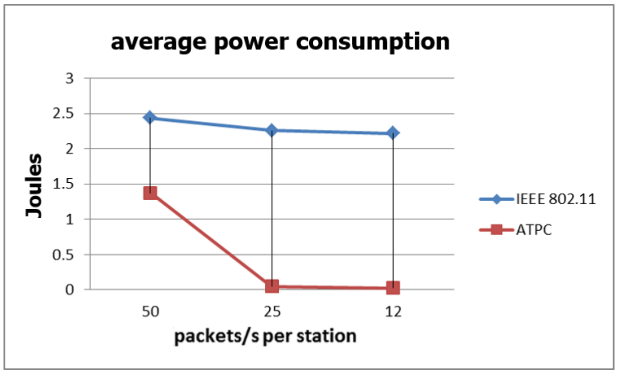

Figure 18: Average power consumption of one pair of transmission with background traffic

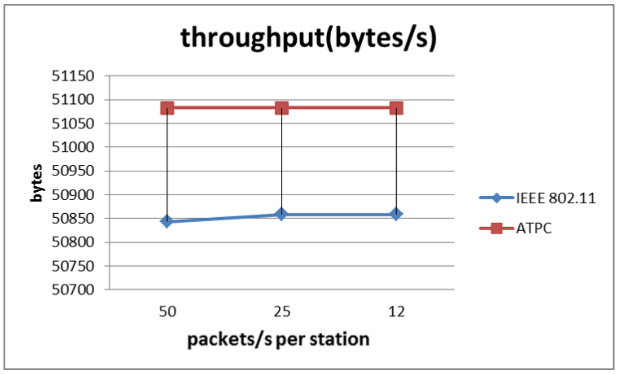

Figure 19: Average throughput of two pairs of transmission with background traffic

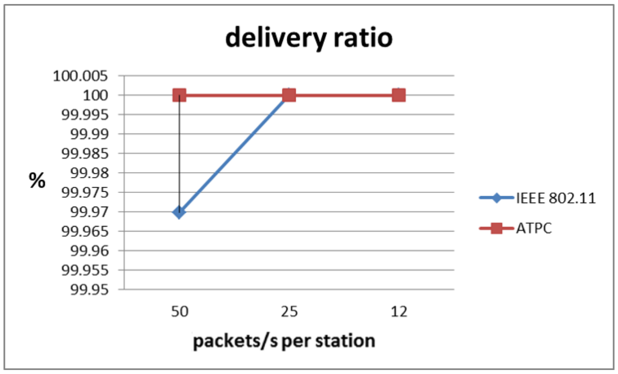

Figure 20: Deliver ratio of two pairs of transmission with background traffic

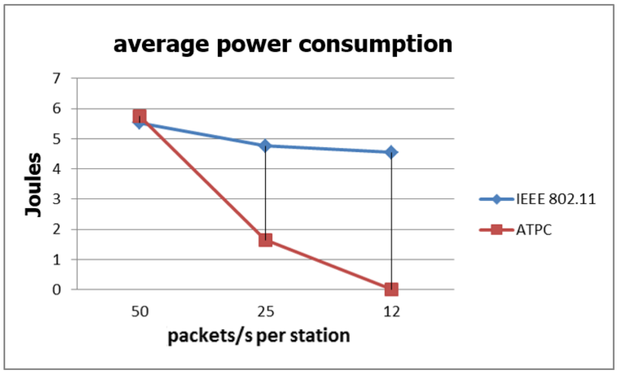

Figure 21: Average power consumption of two pairs of transmission with background traffic

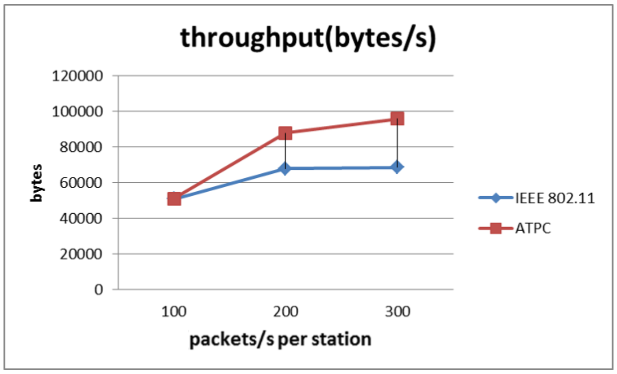

Figure 22: Average throughput of two pairs of transmission with background traffic is fixed

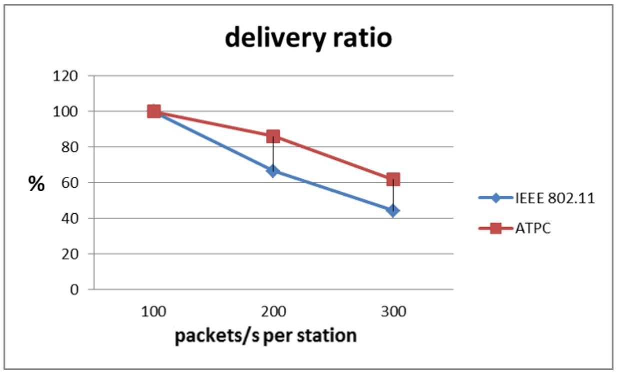

Figure 23: Deliver ratio of two pairs of transmission with background traffic is fixed

VI. CONCLUSION

This paper proposes an adaptive transmission power control for IEEE 802.11 direct connection mode, called ATPC algorithm, to dynamically adjust the power used when transmitting packets. Based on the number of successful or failed packet transmissions, it is judged whether the current transmission power needs to be changed. And the transmission power of the node to send packets is adjusted to be more effectively and save more power. More pairs of transmissions are delivered simultaneously.

According to the results of experimental simulation, if the node with ATPC algorithm is adjusted to a suitable power level and no longer uses the preset maximum power for transmission, more pairs of neighboring nodes can be transmitted simultaneously. Since nodes do not interact with each other, the overall throughput is improved. The energy used to send packets can be dynamically adjusted by the ATPC algorithm, which can save much of total power consumption when sending packets.

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