A Power Control MAC Protocol for Ad hoc Networks

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Abstract-The inadequacy of the classical media access protocols for considering the transmitter power as the critical resource and a tunable parameter for increasing the throughput, conserving the battery power, and providing the quality of service for the communication has given a new perception for the power controlled media access protocols in ad hoc networks. Former researchers have proposed some modifications of IEEE 802.11 with power control, but most of these protocols degrade network throughput. A novel power controlled MAC protocol based on SNR in mobile Ad hoc networks is presented in this paper. Simulation results demonstrate that compared to the IEEE 802.11 MAC protocol, the proposed protocol can decrease the power consumption greatly, and improve the energy utilization of mobile terminals while maintaining the throughput performance.

Keywords-Ad hocnetwork, MAC protocol, power control, computer simulation

Ⅰ. INTRODUCTION

Wireless hosts are usually powered by batteries which provide a limited amount of energy. Therefore, techniques to reduce energy consumption are of interest. One way to conserve energy is to use power saving mechanisms. Power saving mechanisms allow a node to enter a doze state by powering off its wireless network interface when deemed reasonable [1]. Another alternative is to use power control schemes which suitably vary transmit power to reduce energy consumption [2,3]. In addition to providing energy saving, power control can potentially be used to improve spatial reuse of the wireless channel. In this paper, we study power control for the purpose of energy saving.

A simple power control protocol has been proposed based on an RTS-CTS handshake in the context of IEEE 802.11[4]. Different power levels among different nodes introduce asymmetric links. Therefore, in the above scheme, RTS and CTS are transmitted using the highest power level and DATA and ACK are transmitted using the minimum power level necessary for the nodes to communicate. In this paper, we show that this scheme has a shortcoming, which increases collisions and degrades network throughput. We present a new power control protocol which does not degrade throughput.

This paper is organized as follows. Section 2 introduces the related work mainly focusing on the IEEE 801.11 MAC protocol and the basic power control MAC protocol. In Section 3, we propose a power control MAC protocol (802.11-PC) for MANETs. The performance evaluation is conducted by simulation in Section 4. Section 5 concludes the paper.

Ⅱ. RELATED WORK

IEEE 802.11 specifies two medium access control protocols, PCF (Point Coordination Function) and DCF (Distributed Coordination Function). PCF is a centralized protocol, we consider DCF in this paper.

A. IEEE 802.11 MAC protocol[6]

The DCF in IEEE 802.11 is based on CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance). Carrier sensing is performed using physical carrier sensing (by air interface) as well as virtual carrier sensing. Virtual carrier sensing uses the duration of the packet transmission, which is included in the header of RTS, CTS, and DATA frames. The duration included in each of these frames can be used to infer the time when the source node would receive an ACK frame from the destination node. For example, the duration field in RTS includes time for CTS, DATA, and ACK transmissions. Similarly, the duration field for CTS includes time for DATA and ACK transmissions, and the duration field for DATA only includes time for the ACK transmission.

Each node in IEEE 802.11 maintains a NAV (Network Allocation Vector) which indicates the remaining time of the on-going transmission sessions. Using the duration information in RTS, CTS, and DATA packets, nodes update their NAVs whenever they receive a packet. The channel is considered to be busy if either physical or virtual carrier sensing indicates that the channel is busy.

IFS is the time interval between frames. IEEE 802.11 defines four IFSs, that are SIFS (short interframe space), PIFS (PCF interframe space), DIFS (DCF interframe space), and EIFS (extended interframe space). The IFSs

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provide priority levels for accessing the channel. The SIFS is the shortest of the interframe spaces and is used after RTS, CTS, and DATA frames to give the highest priority to CTS, DATA and ACK, respectively. In DCF, when the channel is idle, a node waits for the DIFS duration before transmitting any packet. Figure 1 shows the handshake process of IEEE 802.11 protocol.

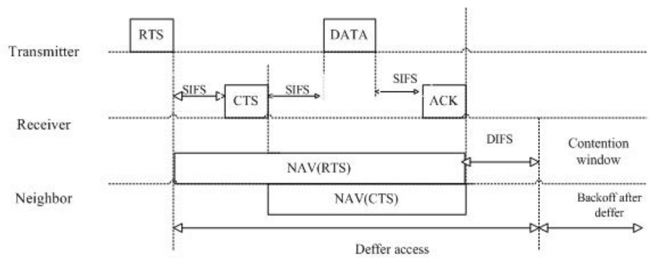

Fig 1: Handshake process of 802.11

B. Basic power control MAC protocol

Power control can reduce energy consumption, but it may introduce different transmit power levels at different hosts, creating an asymmetric situation where a node A can reach node B, but B cannot reach A. In the BASIC scheme, the RTS/CTS handshake is used to decide the transmission power for subsequent DATA and ACK packets. This can be done in two different ways as described below. P_{max} denotes the maximum possible transmit power level.

(1) Suppose that node A wants to send a packet to node B. Node A transmits the RTS at power level P_{max}. When B receives the RTS from A with signal level P_r, B can calculate the minimum necessary transmission power level $P_{desired}$, for the DATA packet based on received power level P_r, the transmitted power level P_{max}, and noise level at the receiver B. Node B then specifies $P_{desired}$ in its CTS to node A. After receiving CTS, node A sends DATA using power level $P_{desired}$.

(2)In the second alternative, when a destination node receives an RTS , it responds by sending a CTS as usual at power level P_{max}. When the source node receives the CTS, it calculates $P_{desired}$ based on received power level P_r and transmitted power level P_{max}, as

$$P_{desired} = \frac{p_{\max}}{p_r} \times Rx_{thresh} \times c \qquad (1)$$

where Rx_{thresh} is the minimum necessary received signal strength and c is a constant[8]. We set c equal to 1 in our simulations. Similarly, the transmit power for ACK transmission is determined when destination receives the RTS. The lowest acceptable received signal strength is estimated. Then, the receiver marks the minimum desired transmit power level in the control message field of CTS and sends CTS back to the transmitter.

C. Deficiency of BPCMP

BPCMP makes two assumptions. First, signal attenuation between source and destination nodes is assumed to be same in both directions. Second, noise level at the receiver is assumed to be below some predefined threshold. This approach may result in unreliable communication when the assumptions are wrong. However, it is likely to be reliable with a fairly high probability. Otherwise, using the fixed transmitting power level, P_{max}, for RTS/CTS is not energy efficient, since the distance between the transmitter and the receiver may change from time to time. The transmission at maximum possible power level causes to interfere other existing radio applications[5].

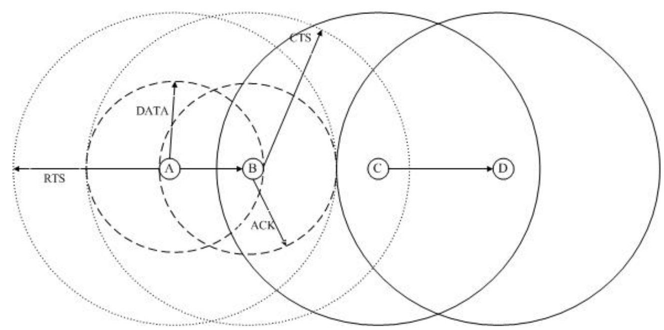

Fig 2:Different power levels in BPCMP

III. 802.11-PC MAC PROTOCOL BASED ON SIGNAL TO NOISE RATIO

In this section, we propose a novel power control MAC protocol 802.11-PC. It is similar to the BPCMP scheme in that it uses the minimum necessary transmit power for DATA/ACK transmissions. We now describe the procedure used in 802.11-PC.

◆Each node establishes its power list in which the sequence numbers are the mac addresses of other nodes'. The control frame transmission power level and data packet transmission power level are stored in the list.

Table1:Power list for each node

Mac_addr^0	Desir_power	Dist_power
Mac_addr^1	Desir_power	Dist_power
Mac_addr^2	Desir_power	Dist_power
…	…	…
…	…	…

If node i has a packet to transmit, it gets the destination node mac address, and then gets the control frame transmit power $Dist\_power^{(j)}$ of last time from its power list and calculates the transmission power of RTS

$$RTS_{tx} = Dist\_power^{(j)} \times \alpha \qquad (2)$$

Here α is a parameter reflecting the degree of topology changing, and then the resource node sends RTS with the power RTS_{tx}.

◆Upon recerving the RTS packet, the intended receiver uses the RTS_{rx} and RTS_{tx} to estimate the channel gain G_{ij}.

$$G_{ij} = \frac{RTS_{rx}}{RTS_{tx}} \qquad (3)$$

Where RTS_{rx} is the received power of RTS packet and RTS_{tx} is transmit power. We assume channel reciprocity and so,

$$G_{ji} = G_{ij} \qquad (4)$$

Accordingly, node j will be able to correctly decode the data packet if this packet was transmitted at power $P_{min}^{(ij)}$ given by:

$$P_{\min}^{(ij)} = \frac{SNR_{th}(P_{bgn} + P_{\text{int}}^{(i)})}{G_{ji}} = \frac{SNR_{th}\eta^{(i)}}{G_{ji}} \qquad (5)$$

Where SNR_{th} is the minimum SNR ratio that is needed to achieve the target bit error rate at that receiver, P_{bgn} is the background noise power, P_{int} is the interference noise power, and

$$\eta^{(i)} = P_{bgn} + P_{\text{int}}^{(i)} \qquad (6)$$

is the total noise power. The value of $P_{min}^{(ij)}$ in (5) is the minimum power that node i must use for data transmission in order for node j to correctly decode the data packet at the current level of interference. This power value does not allow for any interference tolerance at node j, thus all neighbors of node j will have to defer their transmissions during node j's ongoing reception. To allow for a number of future interfering transmissions to take place in its vicinity, receiver j requests that node i scales up the transmission power by the factor β, where $\beta \geq 0$, so

$$P_{\text{int\_}futrue}^{(i)} = P_{\text{int}}^{(i)} \times (1 + \beta) \qquad (7)$$

We get the future transmit power value P_0 with (5). Now we choose the bigger one as the transmit power of data packet.

$$P_{data} = \max\{P_o; Rx_{thresh}\} \qquad (8)$$

◆Since the network topology changes dynamically, the power level for sending RTS and CTS also needs to be adjusted according to the current node density. We estimate the transmitting power level using the distance between a trandmitter-receiver pair if the power is too low to reach any other node as a result of the topology changing greatly. We can also optimize the network topology through controlling the number of neighbors. It is common to model signal attenuation by $d^{1/2}$, where d is the distance between a transmitter and a receiver. Thus, the distance d can be estimated by

$$d = \sqrt{\frac{P_{RTS}}{P_{rec}}} \qquad (9)$$

Where P_{RTS} is the transmitting power level for the RTS/CTS packet, P_{rec} is the received signal power level. Supose the muber of neighbors should be controlled as m, so we can get the distances of neighbors, then calculate the everage distanc[5]

$$\bar{d} = \frac{1}{m}\sum_{i=1}^{m} d_i \qquad (10)$$

Where d_i is the estimated distance from the transmitter to the ith neighbor. The power level for transmitting control frame P_{dis} from the transmitter to the mth neighbor is determined by

$$P_{dis} = \bar{d}^2 \times Rx_{thresh} \qquad (11)$$

Where Rx_{thresh} is the minimum necessary received signal strength.

◆The destination node put P_{data} and P_{dist} into "P_tem" field and "P_dist" field of CTS packet, and sends it back to source node.

Frame control	Duration	Receive address	P_tem	P_dist	FCS

Fig3: Format of the CTS packet

The destination node estimate the transmit power of CTS packet and sends it back to source node with the estimated power value

$$CTS_{tx} = P_{dist} \times \alpha \qquad (12)$$

◆ The source node renews the *Desir_power* and *Dist_power* with the value in P_tem field and P_dist field after receiving the CTS packet and sends DATA packet using power level P_{data}.

◆The destination node sends back ACK packet with the same power.

Frame control	Duration	Receive address	RTS_{tx}	d	FCS

Fig4: Format of the RTS packet

Ⅳ.PERFORMANCE EVALUATION

A. Performance metrics

To evaluate the performance of a protocol for MANETs, we choose three common qualitative metrics

① Power efficiency: it is the power sonsumed per bit data delivered, which indicates the energy efficiency. The lower the rate means the more energy efficient.

②Throughput: it is the number of data bits delivered per second. It also implies the performance of network capacity. The higher the value is, the better the performance becomes.

③ Goodput ratio: it is ratio of the number of data packets correctly delivered out of the total number of data packets sent. This value should be as large as possible.

B. Simulation conditions

The performance of 802.11-PC is evaluated through computer simulation, we use OPNET [7] simulation software, which is a discrete event-drven simulator. The OPNET is widely used for MANETs research. Some existing MAC protocols used in MANETs, such as IEEE 802.11, have been also implemented in it. We set the simulation parameters as follows:

Table2: Simulation parameters

Simulation time	300（s）	Routing protocol	DSR
Network scope	600×300（m^2）	Max transmit power	0.2818（w）
Number of nodes	50	802.11data rate	2（M）
Packet interval	0.25（s）	Radio range of max power	250（m）
Data packet size	1024（bits）	SNR threshold	6（dB）
Node speed	5（m/s）	Reception threshold	7.33×10^{-10}（w）
Spause time	5（s）	β	0.2
α	1.4	*m*	5

C. Simulation results

The proposed 802.11-PC protocol has been compared with IEEE 802.11 and BPCMP based on the aforementioned three metrics for performance evaluation. The effects of the maximum moving speeds and the network load are studied. The results are plotted in the figures with respect to the above three performance metrics.

① *Effects of node moving speed*

We study the effects of the maximum node moving speed as it increases from 0 to 20m/s. The simulation results of power efficiency, throughput, and goodput ratio are shown in Fig 7, Fig 8,and Fig 9, respectively. It is known from Fig 5 that power consumption of 802.11-PC is lower than 802.11 and BPCMP, being about 34% of 802.11 and 45% of BPCMP. Fig6 shows that the throughput of 802.11-PC is almost the same with 802.11, but more than BPCMP by about 30%. From Fig7, we can see that the goodput ratio of 802.11-PC is better than both 802.11 and BPCMP, illustrates that the qulity of service can be improved by ensuring the SNR. With the increasing of node moving speed, the power efficiency and the throughput are reducing as well as the goodput ratio.

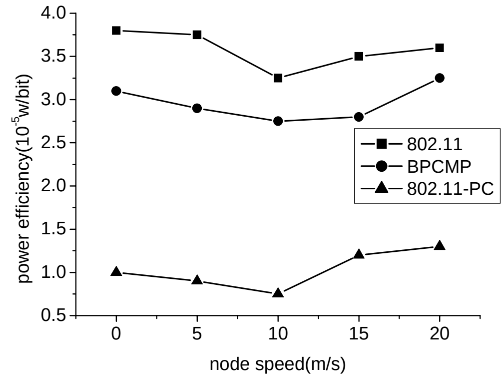

Fig5: The effect of node speed on power efficiency

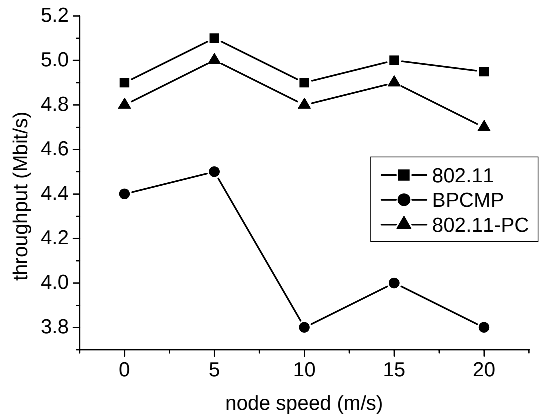

Fig6: The effect of node speed on throughput

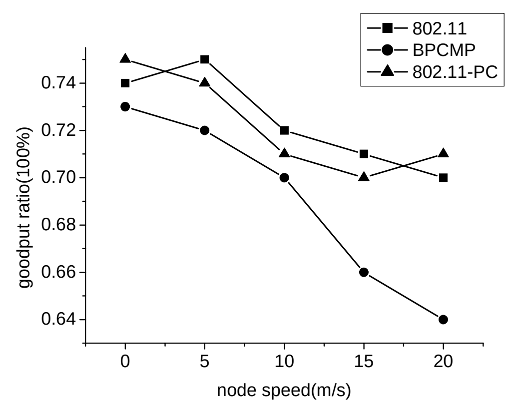

Fig7: The effect of node speed on goodput ratio

② *Effects of network load*

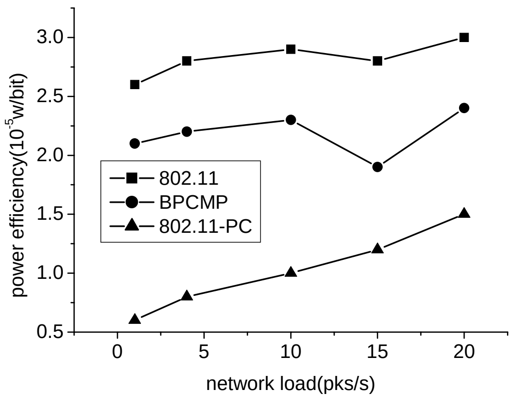

Fig 8: The effect of network load on power efficiency

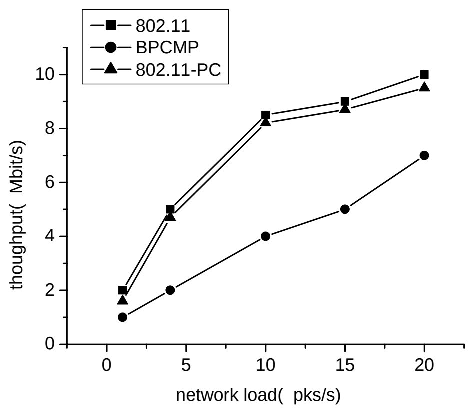

Fig 9: The effect of network load on throughput

Also from Fig 8, 9, and 10 we can see that 802.11-PC consumes much less energy to successfully deliver one bit data than 802.11 and BPCMP. Along with the increasing of network load, the power consumption and throughput are increasing gradually, the goodput ratio is reducing. But the throughput of 802.11-PC is not descendable greatly and the goodput ratio is improved.

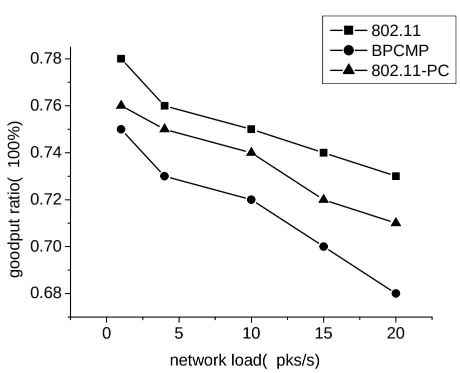

Fig10: The effect of network load on goodput ratio

Ⅴ. CONCLUSION

In this paper, IEEE 802.11 MAC protocol and basic power control MAC protocol for MANETs have been introduced. We proposed a power controlled MAC protocol for wireless ad hoc networks based on IEEE 802.11, in which transmitting power can be estimated with the signal to noise ratio and the distance between source destination pairs. The proposed protocol optimized the network topology through controlling the number of neighbor nodes. The simulation results indicates that compared to 802.11 protocol and basic power control protocol, 802.11-PC protocol offers a very good energy efficiency under various scenarios. Our future work will focus on enhancing the throughput and tuning the parameters of 802.11-PC.

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