Power Controlled MAC Protocol with Dynamic Neighbor Prediction for Ad hoc Networks

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Abstract — Energy and bandwidth are the scarce resources in ad hoc networks because most of the mobile nodes are battery-supplied and share the exclusive wireless medium. Integrating the power control into MAC protocol is a promising technique to fully exploit these precious resources of ad hoc wireless networks. In this paper, a new intelligent power controlled MAC (iMAC) protocol with dynamic neighbor prediction is proposed. Through the elaborate design on the distributed transmit-receive strategy of mobile nodes, iMAC greatly outperforms the prevailing IEEE 802.11 MAC protocol in not only energy conservation but also network throughput. Using the Dynamic Neighbor Prediction (DNP), iMAC performs well in mobile scenes. To the best of our knowledge, iMAC is the first protocol that considers the performance deterioration of power controlled MAC protocol under the mobile scenes and then proposes a solution. Simulation results indicate that DNP is important and necessary for power controlled MAC protocols in mobile ad hoc networks.

1. Introduction·

Mobile ad hoc network is a set of mobile nodes which form and self-configure the network without the pre-deployed central administrative infrastructure (e.g. base station of WLAN). The demand for ad hoc networks is blooming these years on the commercial and military applications, because only ad hoc networks can be applied on the situations where the central administrative infrastructure can't be pre-installed (e.g. battle fields, disaster rescue) or is not economical to install because of temporary use (e.g. a meeting on the rented room).

MAC (medium access control) protocol is an essential element of ad hoc networks because the contention and collision on the shared wireless channel are more complicated to be solved than that in a wired network and a rough MAC protocol will degrade the network performance a lot [1]. IEEE 802.11 MAC protocol [2] is now a prevailing MAC protocol that has been used extensively not only on the industrial wireless network products but also on the most research works about ad hoc network as the base architecture. Being widely used and further studied, IEEE 802.11 MAC protocol appears to be a good but imperfect MAC protocol fitted in the ad hoc fashion network.

There are some disadvantages on the IEEE 802.11 MAC protocol when applied in the ad hoc fashion network. Among these disadvantages, what we concern most in this paper are energy inefficient consumption and hidden-terminal problem. Mobile nodes using 802.11 MAC protocol will transmit the packets on the identical maximum power level in spite of the distance of intended receivers, which will waste battery energy and bring the unnecessary interference to the neighbor nodes. One way to solve this problem is to introduce the power control into the MAC protocol. A power control MAC protocol adjusts transmissions with the minimum power level that is required to communicate with the intended receiver. This ensures that no unwanted energy will be wasted and minimizes the interference in the vicinity of transmitter. The other disadvantage of 802.11 MAC in the wireless ad hoc network is the hidden-terminal problem. Although the RTS-CTS mechanism may alleviate the hidden-terminal problem in some sense, the loss of RTS or CTS packets in the heavy-load network will make hidden-terminal problem much worse and thus degrade the network capability. Using special signals similar to carrier sense as the supplement of RTS-CTS mechanism will prevent the potential transmitter who is unaware of the earlier RTS-CTS from interrupting the ongoing transmission.

The rest of this paper is organized as follows. Section 2 reviews the research works on the power control MAC protocols. In Section 3, we discuss the basic idea of iMAC and present the detail of iMAC implementation. The simulation consideration and result are discussed on Section 4 and the conclusion on Section 5.

2. Related Works

Though power control under ad hoc network is an emerging solution for energy inefficient consumption, power control for cellular telecommunication systems has been extensively studied in the past and is widely used in commercially deployed systems. In [3] authors use the power control loop, similar to those commonly found in cellular CDMA networks, for ad hoc wireless networks. Loop means that a Require-Adjust feedback procedure must proceed between communication pairs, therefore still waste some unnecessary transmission energy and bring excessive interference to the neighbor nodes. Also the convergent procedure limits this power control algorithm to be used in static topology only. Ref. [4] and [5] propose an energy efficient MAC algorithm based on scheduling and reservation. A pseudo base station (PBS) is elected according to battery power level and controls the behavior of the neighbor nodes.

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Scheduling of the proposed MAC scheme prevents mobile nodes from collisions and retransmissions that cause additive battery energy consumption and also informs nodes of when to receive packets to avoid the unnecessary energy consumption on receiving unwanted packets. The way how PBS switches between nodes isn't presented in the [4] or [5], however it's important since PBS switch during the lifetime of network will certainly happen because PBS cost more energy than common nodes. And the requirement for synchronization is difficult to implement because of the distributed characteristic of ad hoc network.

Authors of [6] and [7] motivate the development of COMPOW protocol in [6] and present the details of COMPOW protocol in [7]. COMPOW protocol uses the identical transmission power level in the entire ad hoc network. Multiple route agents with different power level are running simultaneously to determine the minimum identical transmission power level while still ensuring the connectivity of network. One demerit of COMPOW is that it uses the identical transmission power level in spite of the distance of intended receiving nodes, which wastes the battery energy and brings additional interference as we have discussed above. The other demerit of COMPOW is that the routing daemons bring the significant overhead to the mobile ad hoc network, exhaust the energy of network more quickly.

The schemes for power control in [8], [10] and [12] are the most relevant to our scheme. One similarity among [8-12] is that they divide the original channel into multiple sub-channels and transfer the data and control information on the different sub-channels respectively. Unlike [7], they allow each node to acquire the necessary information from the control sub-channel and then choose different transmit power levels for different neighbor nodes. One important and primary difference between our scheme and [8-12] is that our power control scheme uses the original channel defined in IEEE 802.11 and add nothing but a Busy Beacon signal. One advantage of this additive slight modification is that it's more practicable than [8-12] to implement because a number of transceivers whose amount is equal to the number of sub-channels is required, which is very costly. The other advantage is that the intact data channel makes iMAC compatible with IEEE MAC 802.11. Other advantages include that data rate of the whole data channel is higher than any of the sub-channel under the same modulation method. Another difference between iMAC and [8,10,12] is that they still transmit the RTS-CTS packets with the maximum power but iMAC transmit all packets with the necessary and sufficient[1] power level to reach the intended receiver, thus reduces the energy cost and alleviates the interference in the vicinity of transmitter. Unlike the nodes in [12] only communicate with the neighbor nodes in the connection set, iMAC still allow nodes to communicate with all of their neighbors using desired power level, thus ensures the connectivity of networks.

None of the power control scheme in [3-12] considers the performance deterioration under the mobile scene and then proposes a solution. iMAC use the Dynamic Neighbor Prediction (DNP) to estimate the position change of intended receiver and then tune the transmission power to be necessary and sufficient to reach the intended receiver. This technique makes iMAC perform well in the mobile scenes.

3. intelligent MAC Protocol with Power Control

A. Channel Model and Protocol Assumptions

As in IEEE 802.11 and other multiple access protocols [3-12], we assume that the wireless channel is exclusive and any simultaneous transmission on the vicinity of receiver will result in a collision.

To model the radio propagation characteristic more precisely, an integrated channel propagation model is used [13]. Within the crossover distance, Free space model [14] is used to predict the received signal power of each packet; beyond the crossover distance, so is Two-ray ground reflection model [15].

Defining the gain as the ratio of the receiving power to the initial transmitting power, we assume the following assumptions of channel gain in designing our protocol:

1. The data channel and Busy Beacon signal channel observe the similar gains.

2. Channel reciprocity holds so that the gain between a pair of transmitter-receiver is approximately the same in both directions.

3. The channel gain is stationary during the transmitting duration of a packet.

And we also assume that the frequency spacing between the data channel and Busy Beacon signal is wide enough to ensure that the outgoing signal on one channel isn't interfering with the incoming signal on the other channel, and is narrow enough to ensure the gains on the data channel and Busy Beacon signal channel are approximately the same.

B. Power Control and Busy Beacon Signal

Applying the power control into the MAC protocol under the shared wireless channel will bring many benefits.

One benefit is the energy saving for the transmitter. Suppose that the distribution of distance between transmitter and intended receiver is uniform. It's easy to deduce that the average ratio of energy consumption using power control to energy consumption without power control is $1/_{\alpha+1}$, where α is the path loss exponent (e.g. α equals to 2 in the Free space model and 4 in the Two-ray ground reflection model). Using power control not only saves the energy of transmitters, but also saves the energy of irrelevant receivers (those who are not the intended receivers). Since reducing the transmission range results in the smaller number of nodes overhearing the transmission, less energy will be

[1] Here necessary and sufficient power level means that the transmission power is just right above a certain threshold ensuring the receiver can decode the packet correctly and no other unnecessary interference is introduced into the network

consumed by those irrelevant receivers. Another benefit is that using the necessary and sufficient power level to transmit can simultaneously hold more tighter transmit-receive pairs in network than using the fixed transmitting power level, thus improving the spectral reuse.

These advantages motivate to apply the power control in the MAC protocol that operates on the shared wireless channel. But how does one node choose the necessary and sufficient power level when it wants to commence a transmission? In the following sub-section C, we will present the detail of transmit-receive strategy of iMAC, including how a node decides the appropriate transmission power. Here we want to discuss further the hidden-terminal problem aggravated by applying power control and propose our solution.

IEEE 802.11 MAC protocol develops the RTS-CTS mechanism to alleviate the performance deterioration caused by hidden-terminal problem. Receiving node uses CTS to inform its neighbor that there exists an ongoing transmission, thus avoid the potential collision on receiver. One premise that RTS-CTS can efficiently eliminate the hidden-terminal problem is that all nodes in the network should have the identical transmission range, i.e. the same transmission power level. Otherwise, collision illustrated in Fig. 1 still happens in spite of the presence of RTS-CTS.

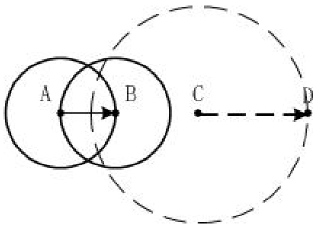

Figure 1

In Fig. 1, node A starts the transmission to node B at the appropriate power level. Node C and D are beyond the transmission range of A and B, thus don't receive the RTS of A or CTS of B and are unaware of the current ongoing transmission between A and B. Now node C wants to communicate with D and have to use a higher power level than A to reach D (transmission range indicated by dashed circles in Fig. 1). Collision on B is inevitable and the transmission from A to B is interrupted. It's easy to see that the asymmetry of transmission range fails the RTS-CTS mechanism and makes the hidden-terminal problem worse.

Our proposal to this problem is using the Busy Beacon signal to indicate the current ongoing transmission. Receiver turns on its Busy Beacon signal at a fixed maximum power level and turns it off while receiving procedure has finished. Because the Busy Beacon signal is sent out at the maximum power level, every potential hidden terminal will receive this signal and then be aware of the existing transmission. Nodes even can estimate the relative distance to the receiver who is sending the Busy Beacon signal and then decide whether to commence a new transmission according to the transmit-receive strategy of iMAC. We will discuss it in detail on the next sub-section C.

C. iMAC Overview

In the scheme of iMAC protocol, any mobile nodes who want to commence a new transmission must obey the following principles:

1. The transmission power level should be high enough to reach the intended receiver, so the receiver can correctly decode the packets.

2. The transmission power level should be so low that no ongoing transmission will be interrupted by the interference of the new transmission.

iMAC uses two variables to represent these two principles respectively: Minimum Power Required and Maximum Power Allowed.

Nodes can estimate the Minimum Power Required from their neighbor list using the Dynamic Neighbor Prediction. Every node of the network contains a list of its neighbor. Once the node receive a correctly decoded packets, regardless of the intended destination of this packet, it will log its neighbor's information into the neighbor list, including the distance between its neighbor and itself, the angle formed by the line stringing these two nodes and the horizon, also the relative time when this node receives that packet. We modify the original head format of control and data packet of IEEE 802.11 MAC and insert the value of current transmission power level into the head field of relevant packet. Thus one node can calculate the distance between transmitter and receiver through the original transmission power level carried in the head of packet and the receiving power level afforded by the physical layer. Note that the techniques for angle of arrival estimation without a positioning system (e.g. GPS) are available (see [16] for details). And the relative time of receiving the packets doesn't require the clock synchronization of all the nodes in the network, which is difficult to implement in a distributed manner network. The neighbor list keeps the two latest records for each neighbor of the node and will update continuously once it get the latest information from the packets sent by its neighbor. Using these information and through the linear estimation[1] on Equation 1 below, node can precisely estimate the current distance between the intended neighbor receiver and itself even under a high mobility circumstance.

$$d_{pre} = \gamma \times \sqrt{X' + Y'} \qquad Equ.1$$

$$X' = \left(x_2 + \frac{t - t_2}{t_2 - t_1} \times \left(x_2 - x_1 \right) \right)^2$$

$$Y' = \left(y_2 + \frac{t - t_2}{t_2 - t_1} \times \left(y_2 - y_1 \right) \right)^2$$

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[1] Through the observation that vehicles and people always move on a straight line, linear estimation can achieve a good result in most circumstances.

and

$$x_1 = d_1 \times \cos\alpha; \quad y_1 = d_1 \times \sin\alpha \quad ,$$
$$x_2 = d_2 \times \cos\beta; \quad y_2 = d_2 \times \sin\beta$$

where d_1, α, t_1 is the distance, angle and logging time of the first record to neighbor node, d_2, β, t_2 is the correspondence in second record; t is the current time and γ is the revision factor to the fluctuation of channel gain. Given the receiving threshold and predicted distance d_{pre}, the Minimum Power Required is easy to estimate.

Maximum Power Allowed is connected with the receiving signal strength of Busy Beacon around the current node. As we have mentioned above, to settle the hidden-terminal problem deteriorated by power control, nodes turn on the Busy Beacon signal when they are entering the receiving phase and turn it off after finish the receiving procedure. Busy Beacon signal is broadcast at the fixed maximum power level to make sure that all potential transmitters can hear. Since the original transmission power level of Busy Beacon signal is fixed, node can easily acquire the channel gain through the receiving signal strength provided by physical layer, and then calculate the upper bound of the transmission power level that won't interrupt the ongoing transmission by the newly induced interference. Then we can get the Maximum Power Allowed by multiplying this upper bound of the transmission power level with a revision factor to gain the robustness. If there are more than one neighbor of current node in the state of receiving, the Busy Beacon signal will overlap and cause the signal strength detected by current node to be stronger than each of the Busy Beacon signal strength if measured respectively. So the Maximum Power Allowed will be lessened and we get a safe approximation to ensure the current ongoing transmission won't be interrupted.

Before the node want to commence a new transmission, it estimates the Minimum Power Required and Maximum Power Allowed as what we have discussed above and compares these two variables to decide whether to start a transmission. If the Minimum Power Required is smaller than Maximum Power Allowed, it indicates that the new transmission won't interrupt the ongoing transmission so the node can start to send the RTS to the intended receiver or directly transmit the data packet while broadcasting. If the Minimum Power Required is bigger than Maximum Power Allowed, it means that the node can't reach the destination without breaking the ongoing receiving procedure. Thus node defers its transmission to obey the second principle.

4. Evaluation of iMAC

We use the NS2 (Network Simulator Version2) to evaluate the performance of iMAC comparing to IEEE 802.11 MAC protocol. NS2 is a discrete event simulator targeted at networking research [17]. It is powerful and has many tunable options so that it has become the prevailing performance evaluating tools in the current research on ad hoc network.

A. Simulation Environment

- 50 nodes distributed randomly on a 670 meters x 670 meters square;
- Maximum transmission range of nodes is 150 meters
- There are at most 10 CBR (Constant Bit Rate) streams simultaneously running in the network. Each CBR streams starts at random time and run till the simulation end. Each pair of CBR stream is randomly designated but all these 20 transmitters and receivers are NOT overlapped.
- Packet size of CBR traffics is 512 bytes.
- Simulation lasts 900 seconds.
- Using AODV as the routing protocol.

We will vary the number of packets per second on the CBR streams and the moving velocity of nodes to study the performance of iMAC under different traffic load and varied mobility. The criterions we use to evaluate the performance are network throughput and energy consumption.

B. Network Throughput

Network throughput is calculated as the total number of CBR packets received by the intended receiver during the simulation period. Because the network throughput is accumulated over time, there are two essential factors of the network will influence the throughput. One is the transmission floor acquired while transmitting. The tighter transmit-receive pairs are, the higher network throughput achieves. The other is energy storage of nodes. The more energy nodes store, the higher network throughput achieves. In order to decouple the impact on network throughput by energy storage of nodes, we give all the nodes sufficient energy to survive until simulation is end.

First we observe the variety of network throughput while packet rate of CBR is increasing by degrees.

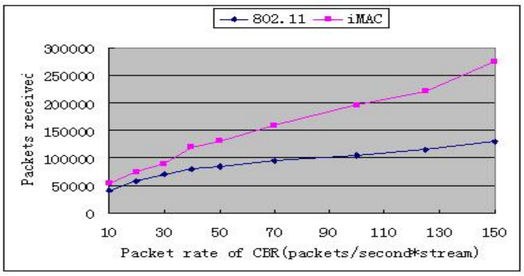

Figure 4.1 Throughput of static topology

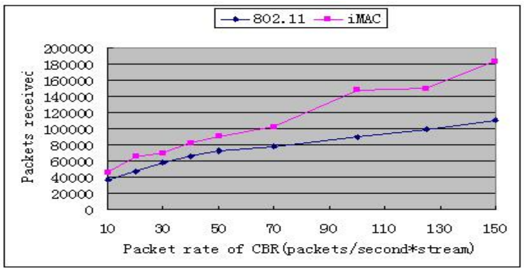

Figure 4.2 Throughput (velocity: 10m/s)

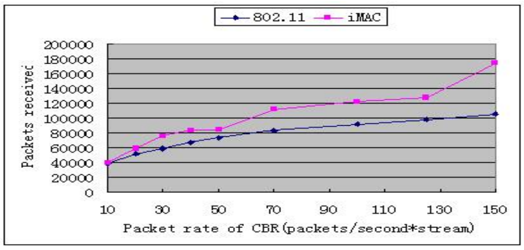

Figure 4.3 Throughput (velocity: 30m/s)

Fig. 4.1-4.3 are the simulation results on network throughput comparing the IEEE 802.11 and iMAC on varied mobility and traffic load. The horizon axis is the number of packets on every CBR stream per second. It is the sign of traffic load of network. The vertical axis presents the number of packets received during the whole simulation period, which we define as the network throughput. The data of Fig. 4.1 are simulated under static topology. Fig. 4.2 and Fig. 4.3 are under velocity of 10 m/s and 30m/s respectively. All of these figure show that iMAC always achieve the higher network throughput than IEEE 802.11 and the gap expands while the network is getting more traffic load. In general, iMAC can outperform 802.11 about 30%~70% on a moderate network load and even 100% while network is crowded under static or mobile network. This gain of throughput, as we have discussed above, come from the power control on the transmission power level to make more transmitter-receiver pairs can proceed simultaneously on the same region.

In order to investigate the benefit that DNP (Dynamic Neighbor Prediction) bring to the power control MAC protocol, we make another iMAC version that is completely the same as the original iMAC except that it doesn't support DNP. We call it *iMAC without DNP*. Through the simulation, we find that under the static topology, two protocols achieve the same throughput (It's obvious since nodes won't move in a static network, thus DNP won't work). When nodes begin to move, both of two protocols degrade the performance as IEEE 802.11 MAC does. But *iMAC without DNP* degrades worse than iMAC. We show the simulation result on Fig. 4.4 and Fig. 4.5 below.

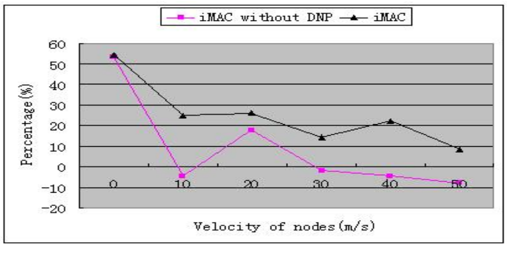

Figure 4.4 Benefit of DNP (packet rate of CBR is 50)

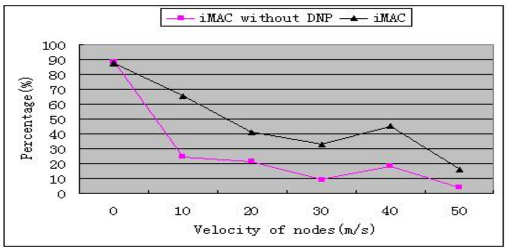

Figure 4.5 Benefit of DNP (packet rate of CBR is 100)

Here the horizon axis of Fig. 4.4 and 4.5 is the moving speed of nodes of ad hoc network. The vertical axis presents the ratio of throughput difference between new protocol and 802.11 to the throughput of 802.11. We can see that iMAC always do better than *iMAC without DNP* under the mobile network and achieve 20%~40% more gain than *iMAC without DNP*. It's because DNP can estimate the distance to intended receiver more precisely, thus select a more appropriate power level to transmit, avoid the loss of packets caused by the departure of receiver and the waste of energy caused by the approach of receiver. Finally we can draw the conclusion that Dynamic Neighbor Prediction (DNP) is necessary for power control MAC protocols in ad hoc network, especially under a high mobility scene.

C. Energy Consumption

We evaluate the total energy consumption of all nodes in the network through the whole simulation period to check what iMAC can bring to us.

First we observe the variety of energy consumption while packet rate of CBR is increasing by degrees.

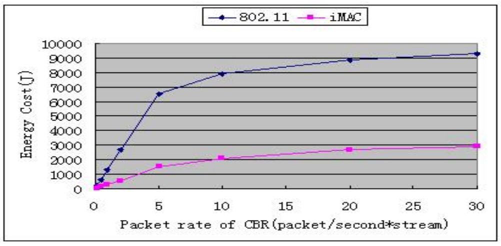

Figure 4.6 Energy Consumption (static topology)

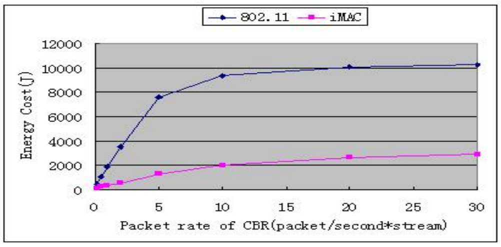

Figure 4.7 Energy Consumption (Velocity: 30m/s)

Fig. 4.6 and 4.7 are the simulation results on energy consumption comparing the IEEE 802.11 and iMAC on varied mobility and traffic load. The horizon axis is the number of packets on every CBR stream per second. The vertical axis presents the total energy consumption of all nodes in the network during the whole simulation period. The data of Fig. 4.6 are simulated under static topology and those of Fig. 4.7 are under velocity of 30 m/s. From both of these figures we can see that iMAC always cost less energy than IEEE 802.11 and the difference extends while more packets are sent.

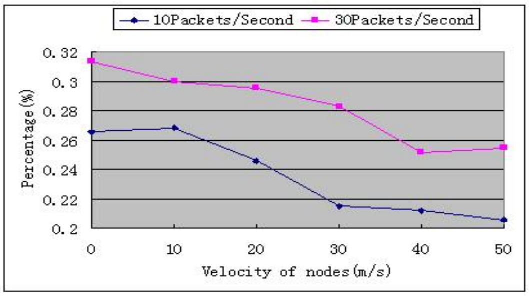

Figure 4.8 Ratio of energy consumption

Fig. 4.8 shows the variation ratio of energy consumption of iMAC to IEEE 802.11. While the nodes are accelerating, ratio of energy consumption is declining. It's because the power control and DNP can avoid the collision at a certain extent while in high mobility scene, thus less energy are used to retransmit the packets. Also the high mobility means lower transmission power when communication pairs are moving closer and stop of unarrivable transmission while communication pairs are leaving beyond the maximum transmission range. In general, iMAC only use 20%~30% amount of energy comparing with 802.11, however achieve higher network throughput as what we have discussed on sub-section B. This gain of energy consumption is congruous with the analytical result we deduce.

5.Conclusion

In this paper, we presented a new intelligent MAC protocol (iMAC) with power control for wireless ad hoc network. Using Busy Beacon signal on the receiving nodes and transmitting packets on the desired power, iMAC can achieve the power control and then reuse the wireless channel by alleviating the interference between transmitting nodes. With the Dynamic Neighbor Prediction (DNP), iMAC performs well even in the high-mobility scenes. To the best of our knowledge, iMAC is the first protocol to consider the performance deterioration of power control MAC protocol under the high mobility scene and propose a solution. An important feature of iMAC is that it's easy to implement in the hardware and compatible with the IEEE 802.11 MAC, thus makes it more practicable than the other power control MAC protocols.

Simulation results indicate that iMAC greatly outperform the prevailing 802.11 MAC protocol in not only energy conservation but also network throughput. In general, iMAC can outperform 802.11 about 30%~70% on a moderate network load and even 100% while network is crowded under static or mobile network. Also iMAC only use 20%~30% amount of energy comparing with 802.11, however achieve higher network throughput. Through the simulation result, we can see that Dynamic Neighbor Prediction is important and necessary to power control MAC protocols under mobile ad hoc network since iMAC can achieve 20%~40% more gain than *iMAC without DNP*. Our future work will consider using the directional antenna instead of the omni antenna and tuning the parameters of iMAC.

REFERENCES

[1] A. Chandra, V. Gummalla, and J. O. Limb, "Wireless Medium Access Control Protocols", In IEEE Surveys and Tutorials, vol. 3, no. 2, Second Quarter 2000.

[2] IEEE Computer Society LAN WAN Standards committee, “Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications”, IEEE Std 802.11-1997. The Institute of Electrical and Electronics Engineers, New York, 1997.

[3] S. Agarwal, et al., “Distributed Power Control in Ad-hoc Wireless Networks”, 2001 12th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, Volume: 2, 30 Sept.-3 Oct. 2001

[4] Kyu-Tae Jin and Dong-Ho Cho, “A MAC Algorithm for Energy-limited Ad-hoc Networks”, Vehicular Technology Conference, 2000. IEEE VTS-Fall VTC 2000. 52nd, Volume: 1, 24-28 Sept. 2000 Page(s): 219 -222 vol.1

[5] Kyu-Tae Jin and Dong-Ho Cho, “Optimal Threshold Energy Level of Energy Efficient MAC for Energy-limited Ad-hoc Networks”, Global Telecommunications Conference, 2001. GLOBECOM '01. IEEE, Volume: 5, 25-29 Nov. 2001

[6] V. Kawadia, et al., “Protocols for Media Access Control and Power Control in Wireless Networks”, Decision and Control, 2001. Proceedings of the 40th IEEE Conference on, Volume: 2, 4-7 Dec. 2001 Page(s): 1935 -1940 vol.2

[7] S. Narayanaswamy, et al., “Power Control in Ad-Hoc Networks: Theory, Architecture, Algorithm and Implementation of the COMPOW Protocol”, In Proceedings of European Wireless Conference, pages 156--162, 2002.

[8] Shih-Lin Wu, Yu-Chee Tseng, and Jang-Ping Sheu. “Intelligent Medium Access for Mobile Ad Hoc Networks with Busy Tones and Power Control.” IEEE Journal on Selected Area in Communications, 18(9): 1647--57, 2000.

[9] Yu-Chee Tseng, et al. “A Multi-channel Mac Protocol with Power Control for Multi-hop Mobile Ad Hoc Networks.” In Proceedings of 21st International Conference on Distributed Computing Systems Workshops, pages 419--424, April 2001.

[10] J. Monks, V. Bharghavan, and W. Hwu, "A power controlled multiple access protocol for wireless packet networks," in Proceedings of IEEE Conference on Computer Communications (INFOCOM), Apr. 2001, vol. 1, pp. 1--11.

[11] J. Monks, V. Bharghavan, and W. Hwu, "Transmission power control for multiple access wireless packet networks," in Proceedings of IEEE Conference on Local Computer Networks LCN, Nov. 2000, vol. 25, pp. 12--21.

[12] A. Muqattash and M. Krunz, “Power Controlled Dual Channel (PCDC) Medium Access Protocol for Wireless Ad Hoc Networks”, INFOCOM 2003. Twenty-Second Annual Joint Conference of the IEEE Computer and Communications Societies. IEEE, Volume: 1, 30 March - 3 April 2003 Page(s): 470 -480

[13] K. Fall and K. Varadhan, The ns Manual. The VINT Project, April 2002.

[14] H.T.Friis, “A note on a simple transmission formula.” Proc.IRE, 34,1946

[15] T.S. Rappaport, “Wireless communications, principles and practice.” Prentice Hall 1996

[16] K. Krizman, T. Biedka, and T. Rappaport, "Wireless position location: Fundamentals, implementation strategies, and sources of error," in IEEE Vehicular Technology Conference, pp. 919--923, 1997.

[17] http://www.isi.edu/nsnam/ns/ index.html