Ad Hoc네트워크의 Cross-Layer설계를 위한 Opportunistic Scheduling과 Power Control기법

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Opportunistic Scheduling and Power Control for Cross-Layer Design of Ad Hoc Networks

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ABSTRACT

This paper proposes a new algorithm for opportunistic scheduling that take advantage of both multiuser diversity and power control. Motivated by the multicast RTS and priority-based CTS mechanism of OSMA protocol, we propose an opportunistic packet scheduling with power control scheme based on IEEE 802.11 MAC protocol. The scheduling scheme chooses the best candidate receiver for transmission by considering the SINR at the nodes. This mechanism ensures that the transmission would be successful. The power control algorithm on the other hand, helps reduce interference between links and could maximize spatial reuse of the bandwidth. We then formulate a convex optimization problem for minimizing power consumption and maximizing net utility of the system. We showed that if a transmission power vector satisfying the maximum transmission power and SINR constraints of all nodes exist, then there exists an optimal solution that minimizes overall transmission power and maximizes utility of the system.

Key Words : Opportunistic Scheduling, Power Control, IEEE 802.11 DCF, Ad hoc Networks

Ⅰ. INTRODUCTION

Wireless communication systems have unique characteristics such as time-varying channel conditions and multiuser diversity. As a result, different opportunistic scheduling schemes are developed to exploit the channel conditions. The term opportunistic[1] denotes the ability to schedule users based on favorable channel conditions. Various opportunistic scheduling schemes have been studied and their common objective is to improve or maximize system performance or throughput under various fairness and QoS constraints. Most of the current researches on opportunistic scheduling focus on cellular systems, and less attention is given to ad hoc networks. Hence, the researchers are motivated to explore opportunistic scheduling in ad hoc wireless networks.

The IEEE 802.11 DCF (Distributed Coordination Function) mode is the most dominant MAC protocol for ad hoc networks. It follows the CSMA/CA with RTS/CTS (Request-To-Send and Clear-To-Send) handshake between the transmitter and receiver which reserves the floor for data transmission. These control packets and data packets are usually transmitted at a fixed or maximum power level to prevent all other potentially interfering nodes from starting their own

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transmissions. Any node that hears the RTS or CTS message defers its transmission to avoid collision. However, the fixed-power approach has a negative impact on channel utilization by not allowing concurrent transmissions to take place over the reserved floor. Also, the received power from a sender may be more than what is needed to achieve the required SINR, (signal-to-interference and noise ratio) and hence, there is a waste of energy.

Usually, ad hoc wireless network systems contain nodes of various types, of which many can have limited power capabilities. Hence, power management in ad hoc networks is very important. The authors in[7] pose certain issues in power management in ad hoc wireless networks. According to them, as the transmission power is reduced, the communication range is also reduced and there is a risk of losing network connectivity. Likewise, as the communication range is reduced, the number of hops per packet may also increase and consequently, may increase system latency and decrease throughput. Finally, as the transmission power is being increase or decrease, more collisions may occur due to incorrect assumptions about the usage of the channel.

One of the advantages of a power control in ad hoc networks is that it allows a greater number of simultaneous transmissions which enhance spectral reuse. As shown in Fig. 1 below, if nodes C and D will use a transmission power which is enough only to transmit a data packet to the other node; without interfering the transmission between nodes A and B, nodes C and D can have their own transmission while nodes A and B can have their own transmission too.

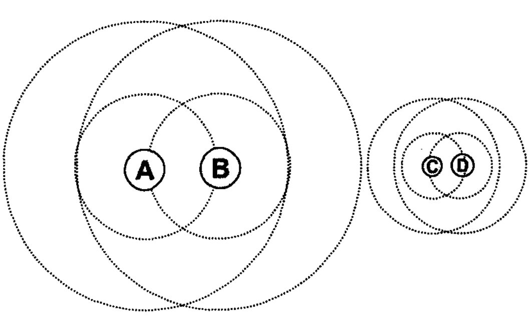


Fig. 1. Transmission powers with power control.

This paper has two main objectives: to design an opportunistic packet scheduling scheme with power control based on IEEE 802.11 MAC protocol, and to derive energy-constrained optimization problem that if there exists a transmission power vector satisfying the maximum transmission power constraint and SINR constraints of all nodes, then there exists an optimal solution that minimizes overall transmission power and maximizes net-utility of the system.

The rest of the paper is organized as follows. Section 2 reviews the related work and section 3 describes the proposed opportunistic scheduling and power control algorithm. In section 4 we show through convex optimization that if there exist an optimal transmission power vector that satisfies SINR and power constraints it converges to optimal or minimum energy consumption of the system. Since a trade-off exists between throughput and power consumption, we show that the net utility [3] of the system can be also maximized.

II. RELATED WORKS

In ad hoc networks, it is usual that a node communicates with several neighbors concurrently. Since the channel quality is normally time-varying and independent across different neighbors, the node has an opportunity to choose one of its neighbors with good channel quality to transmit data before those with bad channel quality. Presently, there are few studies of opportunistic scheduling in ad hoc networks and some of them are[2-4], and[5]. These papers exploit durations of high-quality channel conditions through rate adaptation while others exploit frequency diversity of multirate WLANs and multi-hop ad hoc networks.

There are also several power control algorithms in the literature but most of them have appeared in the context of cellular radio systems. In the study made by authors in[10], they divided the data reception area of IEEE 802.11 DCF into two zones based on the characteristics of wireless propagation model. These zones are the decoding

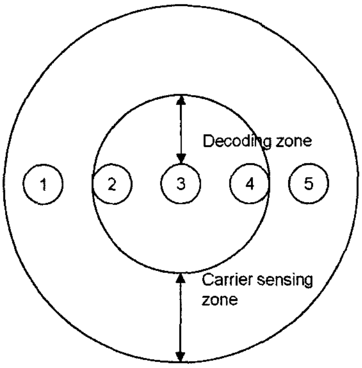


Fig.2. Data reception area of IEEE 802.11: decoding zone and carrier sensing zone.

zones and carrier sensing zone as shown in Fig. 2 below. If node 3 is the sender, nodes 2 and 4 are within the decoding zone while nodes 1 and 5 are within the carrier sensing zone. As the name implies, the decoding zone is the area where a node can receive and correctly decode a packet while a node within the carrier sensing zone, can only sense the signal but cannot decode it correctly.

In [8], they introduce PCM, a Power Control MAC protocol for ad hoc networks which is similar to BASIC scheme that uses maximum power level for RTS-CTS and minimum necessary transmit power for DATA-ACK. Only that during data transmission, the sender periodically raises the power level to the maximum level. This way, the battery power is saved but the throughput is not totally enhanced. PCMA, a Power Controlled Multiple Access wireless MAC protocol within the collision avoidance framework was proposed in[9]. Their protocol generalizes the on/off collision avoidance into a flexible variable bounded power collision suppression. PCMA uses two channels, one for the packets and the other one for the busy tone. The busy tone is used to overcome the hidden terminal problem such that while the node receives data packet, the node periodically sends a busy tone. The PCMAC on the other hand, proposed by Lin et al[10] improves the handshake mechanism of IEEE 802.11 by adding a separate power control channel and a transmission table. This way, they have tackled the asymmetrical link problem.

Liu et al, [6] studied the interference management in cellular networks through a joint scheduling and power allocation schemes. Using stochastic methods they solved an optimization problem in minimizing transmission powers and maximizing net utility. The authors in[12] propose a joint scheduling and power control for wireless ad hoc networks in TDMA and TDMA/CDMA systems. Their scheduling and power control algorithm first determine the set of users who can attempt transmission simultaneously in a given slot and then specify the set of powers needed in order to satisfy SINR constraints at their respective receivers. Another joint scheduling and power control algorithm was studied in[12] but in the context of unicast transmissions only, hence the authors in[13] proposes a distributed joint scheduling and power control algorithm for multicast traffic in TDMA/CDMA scheme.

Our paper differs from related works in the following ways. Our paper exploits multiuser diversity in ad hoc networks considering the physical condition specifically the SINR at the nodes. In the case there is a transmitter node which has several packets to send to a set of receivers, the best candidate receiver is chosen for data transmission. The power control algorithm is based on CSMA/CA framework. We have made some modifications such that the system uses two channels: control channel and data channel. The control channel is where the RTS-CTS and the noise tolerance of the node are transmitted. Instead of ACK, the receiver will just send a NACK if the data is corrupted and need retransmission. The details of the algorithm are described in Section 3. Moreover, we presented an optimization problem that minimizes overall transmission power and net-utility of the system.

Ⅲ. PROPOSED ALGORITHM

3.1 System model

We assume a system of ad hoc networks consisting of M numbers of active source-destination pairs. We let $\mathbf{P}=(P_1,P_2,...,P_M)$ be a power vector where Pi is the transmit power of a node i. We also let $N_i=\eta_O B_T$ be the noise signal at node i, where η_O and BT denotes the noise density and bandwidth respectively. Then, we define a noise power vector $\mathbf{N}=(N_1,N_2,...,N_M)$, for every node i in every source destination pair. We let Gi (i) be the link gain of transmitter node i and its intended receiver node (i) and Gk(i) as the link gain of an interfering node k at the intended receiver of node i. A transmitter node i can only have a successful transmission if the corresponding SINR at its intended receiver node (i) is greater than or equal to a given threshold γ_i.

$$\Gamma_i(\mathbf{P})=\frac{P_i}{I_{(i)}(\mathbf{P})}\geq\gamma_i \qquad (1)$$

In equation (1), $\Gamma_i(\mathbf{P})$ denotes the computed SINR where $I_{(i)}(\mathbf{P})$ is the effective interference [12] of node i's intended receiver from other transmitters other than node i, given as

$$I_{(i)}(\mathbf{P})=\frac{\sum_{i\neq k}P_k G_{k(i)}+N_i}{G_{i(i)}}$$

In addition, we let $Pn_{(i)}$ as the total noise observed at the receiver node of node i.

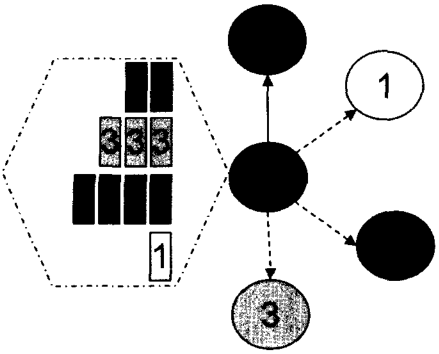
$$Pn_{(i)}=\sum_{i\neq k}P_k G_{k(i)}+N_{(i)}$$

The assumptions and constraints of our algorithm are as follows. The transmit power of any node should be within the range, 0≤ Pi ≤ PMAX which is upper bounded by a maximum power level, PMAX. The channel gain between two nodes is approximately the same in both directions. The gain between transmitter node i and its intended receiver (i) can be computed as $G_{i(i)}=1/d_{i(i)}^{\beta}$ where β is the path loss exponent and $d_{i(i)}$ is the distance between node i and its intended receiver (i). We define RXTHRESH<RXREQ and $\gamma_i<\gamma_{REQ}$ where RXTHRESH is the minimum required signal power needed for receiving a valid packet. The reason we incorporate RXREQ and γREQ is to take transmission reliability into account, that is, the values should be larger than the thresholds. The bandwidth is divided into two channels: control (ch.1) and data (ch.2) channels. The power control channel has no interference with the data channel and both of them share the same propagation gain. Moreover, the transmission ranges are same if using the same power level.

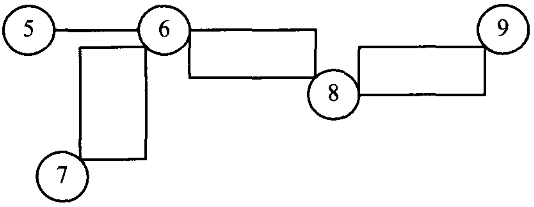
3.2 Scheduling Framework

The scheduling framework of OSMA (Opportunistic Packet Scheduling and Media Access Control) protocol given in[1] is adopted in the study. In order to exploit the multiuser diversity, a multicast RTS and a prioritized CTS mechanism is implemented. The focus is on the next neighborhood transmission which is sending packet traffic to the specified neighbors while meeting constraints on the SINR at the intended receivers.

At the sender node, one separate queue is maintained for each next hop (Fig. 3a). If the sender has several packets in its queue waiting for transmissions, the scheduler will choose a set of receivers based on weight of the HOL (head of line) packet. Suppose that node 6 is transmitting to node 5 (Fig. 3b), and node 8 has four packets in its queue, two of them are intended to node 6 and two for node 9, if node 8 follows a FIFO scheme, it has to wait for node 6 to finish its transmission since the packet at the head of its queue is intended for node 6. However, using the proposed scheduling scheme with the power control mechanism as described in the next section, node 8 can transmit the packets intended for node 9 without interfering node 6's transmission. It will then wait for node 6 to be available. In this way, channel utilization is further enhanced.



(a) Scheduling scheme



(b) A wireless ad hoc network with 5 nodes

Fig.3. Scheduling Framework

In this study, the WFQ (Weighted Fair Queuing) algorithm is used. By default, WFQ schedules low-volume traffic first, while letting high-volume traffic share the remaining bandwidth. This is handled by assigning a weight to each flow, where lower weights are the first to be serviced.

3.3 Proposed Opportunistic Packet Scheduling

As shown in Fig.1, if a power control mechanism is implemented such that a node only uses enough transmission power which at the same time maintains network connectivity and reduces interference, spatial reuse could be maximized. In our proposed algorithm, we let a transmission to be successful only if the received SINR, $\Gamma_i(\mathbf{P})$ at the receiving node is above the preset threshold γ_i. Firstly, the channel will check whether the channel is busy. If the channel is busy, the transmitting node will double its back off window and defer its transmission. This back-off algorithm is similar to that 802.11. If the channel is idle for a duration equal to DIFS (Distributed Inter Frame Spacing), NAV (Network Allocation Vector) is zero and the received power (Pri) of sender i is less than the carrier sensing range threshold, Pri<CSTHRESH, then node i can send the multicast RTS at a power level Pi .The multicast RTS will include the noise level Pni at the sender's node and transmission power Pi at which RTS is transmitted. Also, it includes a duration which is used to specify the time that the channel will still be occupied. The other nodes in the neighborhood would adjust their NAVs upon receiving the multicast RTS whose format could be like as shown in Fig 4.

Frame Control	Pn$_i$	Pi	RA(1)	Duration	···	RA(M)	Duration	TA	FCS

Fig.4. Multicast RTS

Upon receiving the RTS, the candidate receivers will analyze the channel condition by computing the SINR of the link from the transmitter to the receiver itself. The received power at the receiver must be at least equal to RXTHRESH . The candidate receiver with SINR above its SINR threshold $(\Gamma_i(\mathbf{P}) \geq \gamma_i)$is allowed to access the channel and will reply CTS at a power level Pj given in (2). This equation includes the noise $Pn_{(i)}$observed at the transmitter and satisfies both minimum received power and the SINR thresholds[9].

$$P_j = \max\left[\frac{RX_{REQ}}{G_{(i)i}}, \frac{\gamma_{REQ}Pn_i}{G_{(i)i}}\right] \qquad (2)$$

Similar to [2], if there is more than one receiver that will be qualified to transmit CTS, different IFSs (Inter-Frame Spacings) will be employed such that the IFS of the ith receiver will be IFS=SIFS+(n-1)*time-slot where n is the number of candidate receivers. The order of the receivers in the candidate receiver's list will be the basis of prioritization. The closer the receiver address to the top of the receiver list, the higher the priority to access media and hence the high priority to reply CTS first.

The receiver will include in the CTS(Fig.5) the minimum transmission power PDATA, needed by node i to transmit the data successfully. The duration included in each frame, predefined the time it would take for node i to receive an ACK from its receiver.

$$P_{DATA} = \max\left[\frac{RX_{REQ}}{G_{(i)i}}, \frac{\gamma_{REQ} Pn_{(i)}}{G_{(i)i}}\right] \qquad (3)$$

Frame Control	Duration	Receiver address(RA)	P_{DATA}	FCS

Fig.5. Prioritized CTS

Before the sender node transmits data to its destined receiver at the required power level PDATA, node i should perform collision computation [10] first at a nearby current receiver node, say j. This will ensure whether node i's transmission to its intended receiver might cause collision to other nearby receiver. The symbol $\Delta > 0$ is a constant that will ensure that the power level is slightly below the threshold.

$$P_i G_{ij} \le \Delta\left(\frac{\Pr_j}{\gamma_j} - Pn_j\right) \qquad (4)$$

The left side of the above equation denotes the noise given by node i to a nearby receiver node j while the right side is the noise tolerance of node j. If node i satisfies the constraint above, it could send the intended data for its receiver. Otherwise, it should defer the transmission. When the receiver begins to receive data packet from node i, it estimates its signal and noise strength, by computing the noise level it can endure by

$$\frac{\Pr_{(i)}}{\gamma_{(i)}} - Pn_{(i)} \qquad (5)$$

and broadcast this information through the power control channel at a normal level. This will inform other nodes that a transmission is going on and other nodes must perform collision computation first before initiating a transmission to ensure that they will not interfere the current transmission. Otherwise, they should defer their transmission too. This mechanism solves the asymmetrical link problem observed in IEEE 802.11 DCF.

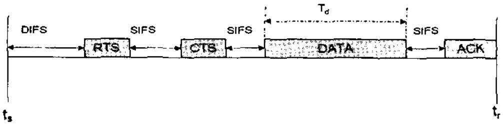
If the receiver has not received the correct data packet within a time period, the receiver will send NACK to let the sender initiate retransmissions. If the receiver received the data packets successfully, the channel will return into IDLE mode. The power control algorithm is summarized in a flowchart as shown in Fig. 6 where we denote node i as the transmitter and node j as the intended receiver of node i.

One of the objectives of power control is to maximize spatial reuse of bandwidth. To measure the effectiveness of bandwidth spatial reuse, an end to end throughput could be an appropriate metric. We can say that spatial reuse of bandwidth is maximized if we can show that throughput is also maximized. The throughput capacity is the average number of bits transmitted per unit time by every node to its destination. Hence, throughput is concerned of the transmission rate per node.

In IEEE 802.11 unicast packet transmission sequence[11], the throughput could be measure using the equation below.

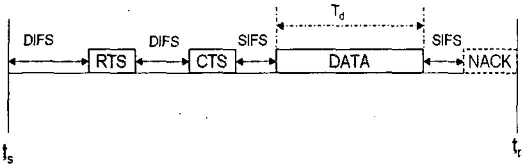
$$TP = \frac{S}{t_r - t_s}$$

where S is the packet size of the packet, ts is the time stamp that packet is ready and tr is the time stamp that ACK has been received.



$$T_{TOTAL1} = DIFS + \frac{S_{RTS}}{BW} + SIFS + \frac{S_{CTS}}{BW} + SIFS + \frac{S_{DATA}}{BW} + SIFS + \frac{S_{ACK}}{BW}$$

The total transmission time needed in IEEE 802.11 for a successful packet transmission when there are no transmission errors due to collisions is given by TTOTAL1. Note that we assume that there are no collisions to all the packets for simplicity of analysis. In the proposed algorithm, DIFS duration is allotted for the scheduling scheme which is the selection of the best candidate receiver i.e. upon transmitting multicast RTS a DIFS duration is given to the set of candidate receivers to reply the CTS. If we let S be the size of the packets, then the total time for a node's transmission is



$$T_{TOTAL2} = DIFS + \frac{S_{RTS}}{BW_{CH1}} + DIFS + \frac{S_{CTS}}{BW_{CH1}} +$$

$$SIFS + \frac{S_{DATA}}{BW_{CH2}} + SIFS + \left(\frac{S_{NACK}}{BW_{CH2}}\right)$$

where

Control channel bit rate = BWCH1

Data channel bit rate = BWCH2

Total bit rate of the channel bandwidth BWCH = BWCH1+BWCH2

Based on the equations, we can say that the IEEE 802.11 has a shorter time for transmission than the proposed protocol. However, as already known, there are problems in hidden and exposed problems in IEEE 802.11 MAC. We must show then that though the total time for transmission for IEEE 802.11 is shorter than our proposed protocol, IEEE 802.11 is more prone to collision and retransmissions; hence, there is a drawback on throughput.

Ⅳ. MATHEMATICAL ANALYSIS

4.1 Minimizing Transmission Powers

The power control problem aims to minimize the overall transmission powers while satisfying the SINR requirements and the power constraints at all nodes. The first objective of the power control problem is to find an optimal transmission power vector, satisfying the SINR requirement at the receiving nodes. The power control problem is a linear programming (LP) problem where the objective function could be stated as

$$\text{Minimize} \quad \sum_{i=1}^{M} \alpha_i P_i \tag{6}$$

$$\text{Subject to} \quad 0 \le P_i \le P_{\max} \tag{7}$$

$$\frac{P_i G_{i(i)}}{\sum_{i \ne k} P_k G_{k(i)} + N_{(i)}} \ge \gamma_i \quad i=1,\ 2,..,M \tag{8}$$

where α_i is a vector which denotes the cost or weight assigned for each transmission power Pi and $\sum_{i=1}^{M} \alpha_i = 1$. The second constraint (8) can be written in the form of $A\mathbf{P} \ge b$, where A is a receiver x transmitter matrix

$$\mathbf{A} = \begin{bmatrix} 1 & \frac{-\gamma_1 G_{12}}{G_{11}} & \cdots & -\frac{\gamma_1 G_{1k}}{G_{11}} \\ \frac{-\gamma_2 G_{21}}{G_{22}} & 1 & \cdots & \frac{-\gamma_2 G_{2k}}{G_{22}} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{-\gamma_{(i)} G_{(i)1}}{G_{(i)i}} & \frac{-\gamma_{(i)} G_{(i)2}}{G_{(i)i}} & \cdots & 1 \end{bmatrix}$$

$$\mathbf{b} = \begin{bmatrix} \frac{\gamma_1 N_1}{G_{11}} \\ \frac{\gamma_2 N_2}{G_{22}} \\ \vdots \\ \frac{\gamma_{(i)} N_{(i)}}{G_{(i)i}} \end{bmatrix}$$

Our primal problem can be formally written as

$$\text{Minimize} \quad \sum_{i=1}^{M} \alpha_i P_i$$

$$\text{Subject to} \quad 0 \le P_i \le P_{\max}$$

$$A\mathbf{P} \ge \mathbf{b}$$

The first objective of the joint scheduling and power control problem is to find an optimal transmission power satisfying the SINR requirement as well as the transmission power constraint at all nodes. There may or may not exist a network power vector P that satisfies the constraints. If there is a solution, the objective function converges to a minimum power vector. The SINR requirement may not be satisfied when some elements in the converged minimum power vector are larger than Pmax or there is really no solution. If a solution to the minimization problem (6) exists, this provides an optimal transmission power vector such that the total power expenditure of the system is minimized. An optimal solution to the problem in (6) exists if and only if there is a solution to the constraints given by equations (7) to (8) i.e. there is at least one set of transmission powers which ensures the successful reception at all receiver nodes which at the same time satisfies maximum node's transmission power and SINR constraints respectively.

Observe that, the transmit power is bounded by $0 \le P_i \le P_{\max}$ for all nodes; hence, an optimal solution exists by virtue of Theorem 3.4 in [19]. The optimal solution or minimizer $(\mathbf{P}^*)$ can be solved using simplex method or any other simple means. Likewise, there exists a feasible region Rf which contains the feasible solution that satisfies the given constraints. Multicasting is one application of this minimization problem.

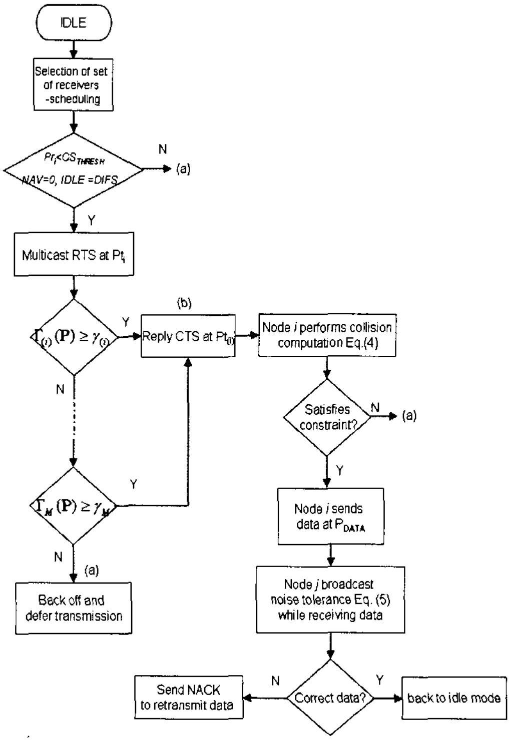


Fig.6. Flowchart of the proposed opportunistic packet scheduling with power control.

4.2 Maximizing Utility

The second objective of the power control problem is to maximize throughput. According to Shannon capacity formula[16], the capacity or the maximum rate at which data can be transmitted over a given communication path or channel with bandwidth W is given by

$$R_i(\mathbf{P}) = \mathrm{W}\log_2(1+\Gamma_i(\mathbf{P}))$$

To maximize throughput, nodes should transmit at high power as possible since $\Gamma_i(\mathbf{P})$ is an increasing function of Pi. However, high power transmission could cause interference to other nodes. Thus, to evaluate network performance of the network, power consumption should also be considered just as what the authors in[3] did. They introduce the notion of "net utility" which is the difference between the value of throughput and the cost of power consumption.

We let Ri(P) as the achievable instantaneous data rate of node i under the maximum transmission power constraint (7) and SINR constraint (8). Ri(P) denotes the instantaneous capacity of the system associated to Pi and we let Ci(P) be the power cost of node i's transmission. We also denote $R_i(\mathbf{P}) - C_i(\mathbf{P})$ as the net utility of a node i and $T(\mathbf{P}) = \frac{\sum_{i=1}^{N} R_i(\mathbf{P}) - C_i(\mathbf{P})}{N}$ is the average net utility of user i for N transmissions.

The objective problem is to maximize the net utility given the maximum power constraint and the data rate requirement. Hence, the maximization problem can be written as

$$Maximize_{P_i \in [0, P_{\max}]}\ T(\mathbf{P}) \tag{9}$$

$$\text{Subject to } R_i(\mathbf{P}) \ge Dr_i \tag{10}$$

The constraint (10) simply says that the achievable data rate of node i associated with its transmission power Pi must be greater than or equal to the required data rate of the receiver node which is denoted by Dri. Using the

Lagrange multiplier λ, $\lambda \geq 0$ the maximization problem is relaxed as shown below

$$L(\mathbf{P},\lambda)=T(\mathbf{P})+\lambda^{T}(R_i(\mathbf{P})-Dr_i)$$

The Lagrange dual function is given by $g(\lambda)=\max_{P\in R_F} L(\mathbf{P},\lambda)=\max_{P\in R_F} T(\mathbf{P})+\lambda^{T}R_i(P)-\lambda^{T}Dr_i$. There may exists a maximizer or transmission power vector P*which maximizes the net-utility if there is a solution to the constraint given by(10).

Lemma 1 : If $g(p)$ is the cost of the objective function in(9) and $\lambda \geq 0$, then $g(\lambda)\geq g(p)$.

Proof : Suppose P^{*} is a transmission power vector which satisfies the maximum transmission power constraint and data rate constraint, and $\lambda \geq 0$, then

$$g(\lambda)=\max\left[T(\mathbf{P}^{*})+\lambda(R_i(\mathbf{P}^{*})-Dr_i)\right]$$
$$\geq T(\mathbf{P}^{*})+\lambda(R_i(\mathbf{P}^{*})-Dr_i)$$
$$\geq T(\mathbf{P}^{*})\geq T(\mathbf{P})=g(\eta)$$

This completes the proof.

V. NUMERICAL EXAMPLE

A simple chain topology as shown in Figure 7 was investigated. This will explain the power control over interfering links using equation 1 where node i is the transmitter and node j is its intended receiver. Node k is the hidden terminal and an interfering node in the transmission between node i and node j.

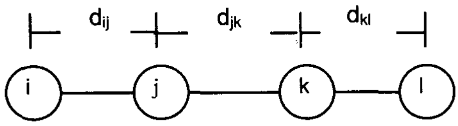


Fig.7. Simple Topology.

In the figure above, we set dkl<djk to avoid collision, and to maximize spatial reuse of the bandwidth. We fixed dij, the distance between node i and node j and also dkl, the distance between node k and node l. We then varied djk, the distance between node j and node k, to determine its relationship on power transmission of node i. The path loss between each link is given by Gij=1/dij4 and we assume that the peak transmission power of each node is 1Watt. We set the thermal noise n= -104dBm, while the required SINR and required power are set as 10dB and -64dBm respectively for all nodes. We then determine the needed transmission power, Pij of node i to have a successful transmission to node j, based on equation 1. We also determined the transmission power Pji needed by node j to reply CTS to node i (2), and the transmission power, PijDATA needed by node i to transmit data to node j (3).

Fig.9 illustrates the transmission power specifically the required transmission power Pij for node i to have a successful transmission to node j as djk is varied. The graph shows that as the distance between node j and node k increases, the transmission power required for node i to transmit to node j successfully decreases. This holds because the nearer the interfering node, the higher the transmission power is needed to satisfy the required SINR γREQ. Likewise, using our power control algorithm, in the previous section, we obtained that as the distance between interfering nodes is increased, the total transmission power decreases, as shown in Fig. 10.

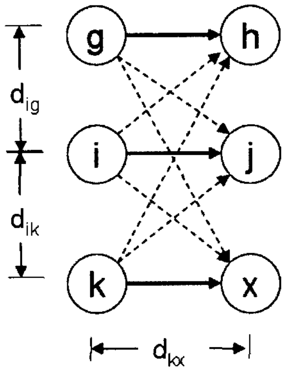


Fig.8. Parallel Links

In addition, we considered power transmissions in parallel links. In Fig. 8, there are three parallel links that transmit in the same direction: g → h, i → j, k → x. The transmission is as shown by the bold lines while the dashed lines are the transmissions made by the interfering nodes. We set dkx=dij=dgh and dig=dik. To avoid collisions between nodes, we also set dig>dkx. In this example, we varied dig and dik where dkx is fixed and is equal to 50meters. We plot the minimum (optimal) transmission power at each link with increasing distance as shown in Fig. 11.

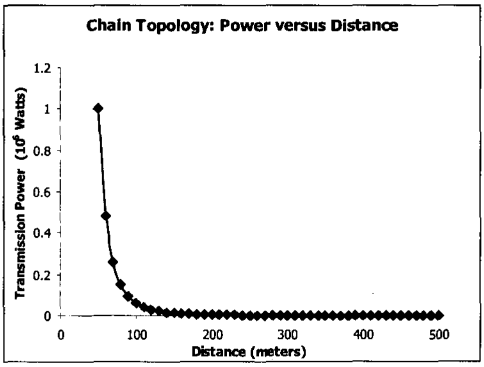


Fig.9. The required transmission power Pij for node i to have a successful transmission to node j as djk is varied.

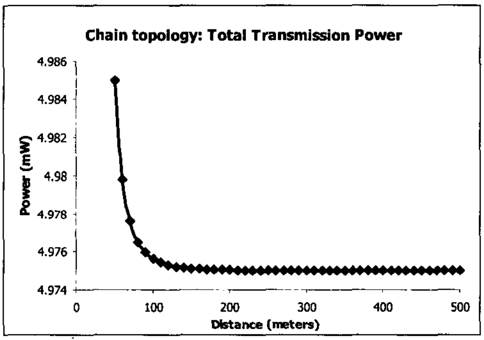


Fig.10. The total transmission power of node i to node j transmission as djk is varied.

In the first case, same target SINR is assumed for all users. As can be seen in the graph, if the distance between parallel links is less than twice the distance between each source-destination pair, the transmission power is still increasing. However, as the distance between parallel links is greater than 100 meters, the transmission power decreases continuously. For the parallel links in our example, we can say that 100 meters is a threshold distance. If the links are near to each other, there is more interference generated in the network and therefore more power is needed to overcome the interference and satisfy the SIR requirement at the receiving nodes. But as a general, we can say that as distance between links increases, the network tends to become energy-efficient, i.e. the optimal transmission power of the transmitting nodes and the minimum total power of the whole network decreases while satisfying the SINR and maximum transmission power constraints of all nodes. Only when the interfering nodes are far from the active transmitter that a lower transmission power could be used and still the SINR constraint is satisfied.

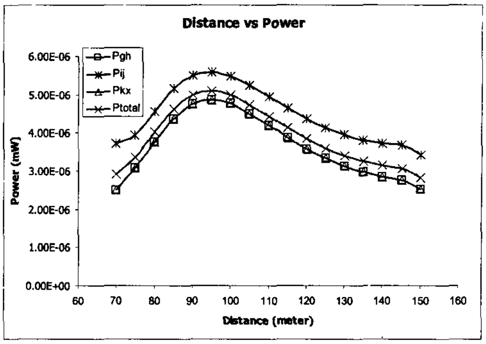


Fig.11. Minimum transmission power at each link as the distance between parallel links is varied. (dkx=dij=dgh=50meters)

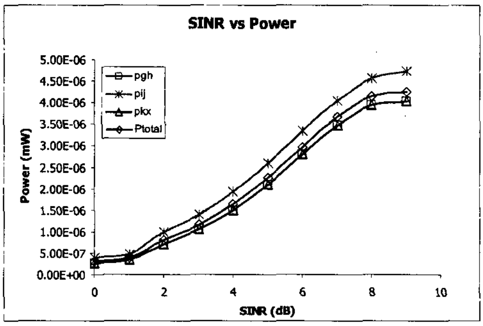


Fig.12. Minimum transmission power at each link as the SINR requirement at each receiving node is varied.

In Fig. 12, we fixed dkx= 50meters and dig=80 meters as we vary the SINR requirements at each node. As you can see in the graph, as the SINR requirement of the receiving nodes increases, the transmission power needed for successful transmission also increases. From the above examples, the farther the transmitter from other nodes that could interfere its transmission, the lower is the minimum transmission power needed for a successful transmission which also satisfies the SINR constraint and the maximum transmission power constraint. Hence, a lower transmission power could be used if the two nodes are just close to each other and away from other interfering nodes. In this way, the power consumption of the node is minimized and this further enhances spatial reuse of the bandwidth. The ideas obtained from our examples are important consideration in our power control and scheduling scheme, since we consider a valid transmission only if the nodes satisfies its SINR constraints in the first place.

Ⅵ. CONCLUSION AND FUTURE WORKS

In this paper we have proposed an opportunistic packet scheduling and power control algorithm in ad hoc wireless networks based on IEEE 802.11 MAC. In our study, we provided the scheduling scheme and the power control algorithm. We have also shown that if there exists a transmission power vector satisfying the power and SINR constraints of all nodes, then there exists an optimal solution that minimizes overall transmission power and maximizes utility of the system. As a supplement, from previous studies, power controlled MAC achieves higher throughput than IEEE 802.11 MAC protocol since interference with other nodes is avoided. Unlike in IEEE 802.11 hidden and exposed nodes exist. Moreover, the opportunistic scheduling scheme proposed by[2] obtains throughput gains several times better as compared to 802.11 MAC. Hence, we are confident that our proposed scheduling and power control scheme will perform better than IEEE 802.11 MAC. For our future work, further simulation and a comparison between our proposed protocol with other protocols will be conducted.

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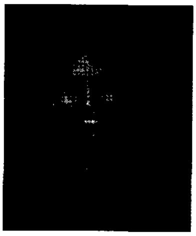

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