JOINT OPPORTUNISTIC SCHEDULING AND POWER CONTROL FOR AD HOC NETWORKS

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ABSTRACT

This paper proposes an 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. 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, would help 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 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.

Keywords: Opportunistic Scheduling, Power Control, IEEE 802.11 DCF, Ad hoc Networks.

1. INTRODUCTION

Wireless communications systems have unique characteristics such as time-varying channel conditions and multiuser diversity. As a result, different opportunistic scheduling schemes are developed by exploiting 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.

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 [5]. 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 Figure 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.

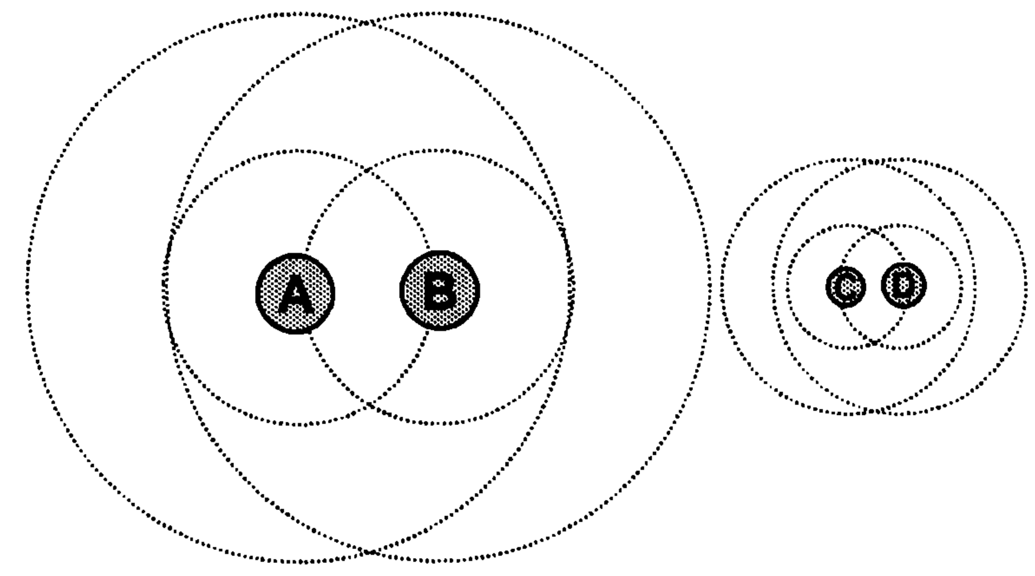

Figure 1. Transmission powers with power control.

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] and reference herein. There are also several power control algorithms in the literature but most of them have appeared in the context of cellular radio systems with TDMA/CDMA scheme [4] and [7]. There are also some papers pertaining to power control in ad hoc networks based on IEEE 802.11 RTS-CTS scheme like in [6] and reference herein.

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 on the other hand, 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 2. Moreover, an optimization problem that minimizes overall transmission power and *net-utility* of the system is presented.

2. PROPOSED ALGORITHM

2.1 System Model

We presume a system of ad hoc network consisting of M nodes. Let $\mathbf{P}=(Pt_1,Pt_2,...,Pt_M)$ be a power vector where Pt_i is the transmit power of node *i*. Let $N_{(i)}=\eta_O B_T$ be the noise signal at the intended receiver of node *i*, where η_O the noise density and B_T is the bandwidth. Then, we define a noise power vector $\mathbf{N}=(N_1,N_2,...,N_M)$, for every receiver node *(i)*. Let $G_{(i)k}$ be the link gain between the intended receiver *(i)* of node *i* and a transmitter *k* - an interfering node. $G_{(i)i}$ is the link gain of node *i* to its intended receiver node *(i)*. Let $\Gamma_{(i)i}(\mathbf{P})$ be the SINR of the receiver of node *i* and γ_i is its target SINR.

$$\Gamma_{(i)i}(\mathbf{P})=\frac{P_{(i)i}G_{(i)i}}{\sum_{i\neq k}G_{(i)k}P_{(i)k}+N_{(i)}}\geq\gamma_{(i)} \quad (1)$$

and let $Pn_{(i)}$ be the total noise observed at the intended receiver of node i.

$$Pn_{(i)}=\sum_{i\neq k}G_{(i)k}Pt_k+N_{(i)} \quad (2)$$

2.2 Scheduling Framework

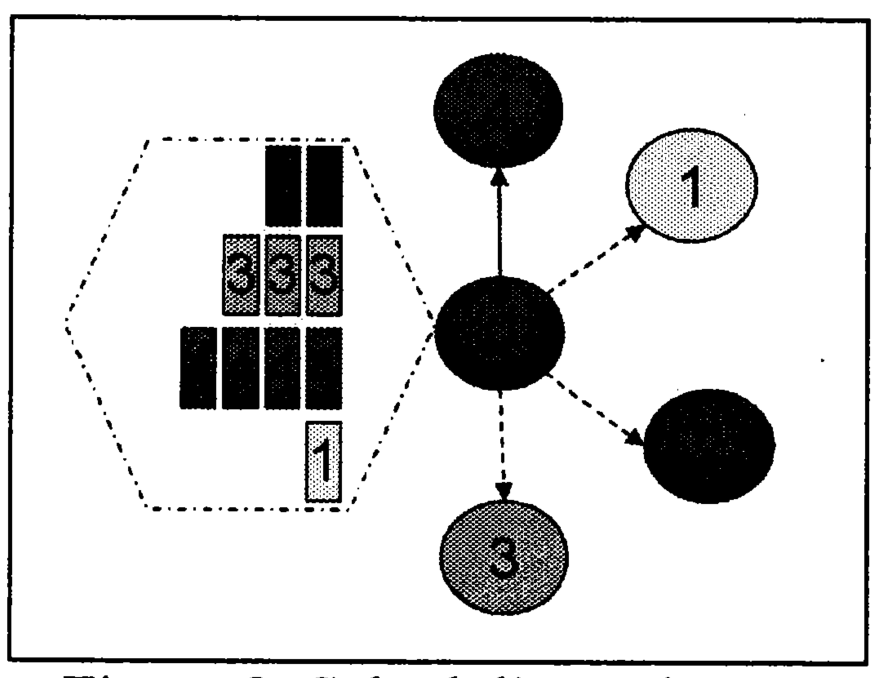

Figure 2. Scheduling scheme.

The scheduling framework of OSMA (Opportunistic Packet Scheduling and Media Access Control) protocol given in [2] 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 (Figure 2). 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.

2.3 Opportunistic Packet Scheduling with Power Control

The scheduling and power control algorithm is summarized in a flowchart shown in Figure 3 where we denote node *i* as the transmitter and node *j* as the intended receiver of node *i*.

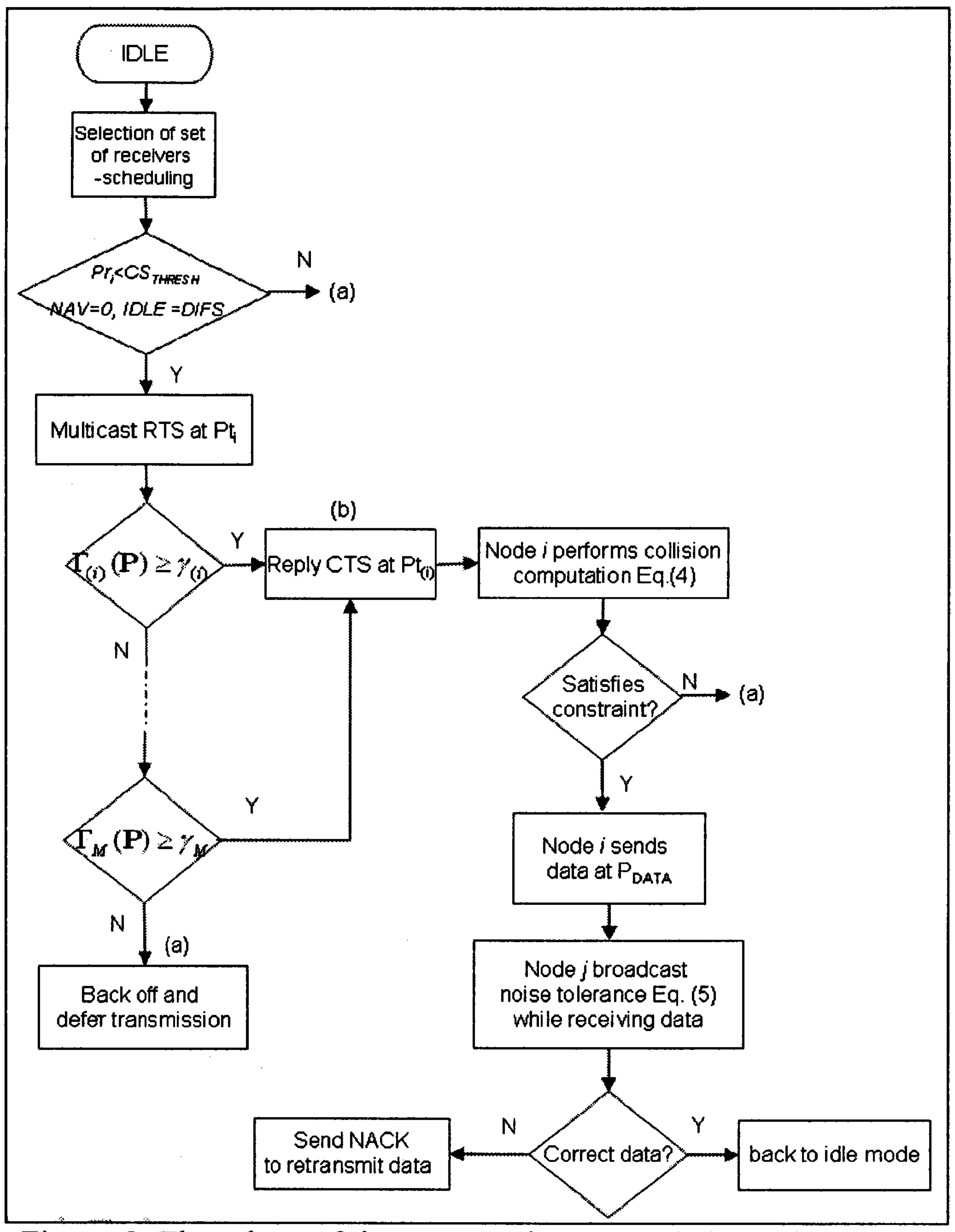

Figure 3. Flowchart of the proposed opportunistic packet scheduling with power control.

The following are the equations involved in the power control algorithm [8] which considers the SINR constraints and the maximum power constraints.

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

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

$$G_{ik}Pt_i\leq\Delta\left(\frac{\Pr_k}{\gamma_k}-Pn_k\right) \quad (4)$$

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

3. MATHEMATICAL ANALYSIS

3.1 Minimizing Overall Transmission Power

The power control problem aims to minimize the overall transmission power while satisfying the SINR requirements of all nodes. The first objective of the power control problem aims to find an optimal transmission power vector, satisfying the SINR requirement of all users. The power control problem is a linear programming problem where the objective function could be formally stated as

$$\text{minimize} \quad \sum_{i=1}^{M} Pt_i \tag{6}$$

$$\text{subject to} \quad 0 \le Pt_i \le P_{\max} \tag{7}$$

$$\frac{G_{(i)i} Pt_i}{\sum_{i \ne k} G_{ik} Pt_k + N_i} \ge \gamma_i \qquad i = 1, 2, .., M \tag{8}$$

3.2 Maximizing Utility

According to Shannon capacity formula, the capacity or the maximum rate at which data can be transmitted over a given communication path or channel with bandwidth W under the power vector **P** 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 Pt_i. 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 [4] 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 $R_i(\mathbf{P})$ as the achievable instantaneous data rate of node *i* under the maximum transmission power constraint (7) and SINR constraint (8). $R_i(\mathbf{P})$ denotes the instantaneous capacity of the system associated to Pt_i and we let $C_i(\mathbf{P})$ be the power cost of node *i*'s transmission. Thus, $R_i(\mathbf{P}) - C_i(\mathbf{P})$ is the net utility of node *i*. Also we let $T(\mathbf{P}) = \frac{\sum_{i=1}^{M} R_i(\mathbf{P}) - C_i(\mathbf{P})}{M}$ be the average net utility of user *i*.

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

$$\text{maximize} \quad T(\mathbf{P}) \tag{9}$$

$$\text{subject to} \quad 0 \le Pt_i \le P_{\max} \tag{10}$$

$$R_i(\mathbf{P}) \ge Dr_i \tag{11}$$

The second constraint (11) simply says that the achievable data rate of node *i* associated with its transmission power Pt_i must be greater than of equal to the required data rate of node *i* which is denoted by Dr_i.

4. NUMERICAL EXAMPLES

A simple chain topology as shown in Figure 5(a) was investigated. This will explain the power control over interfering links where node *i* is the transmitter and node *j* is its intended receiver. Hence, node *k* acts as the interfering node in the transmission between node *i* and node *j*. Also, node *k* is the hidden terminal from node *i*.

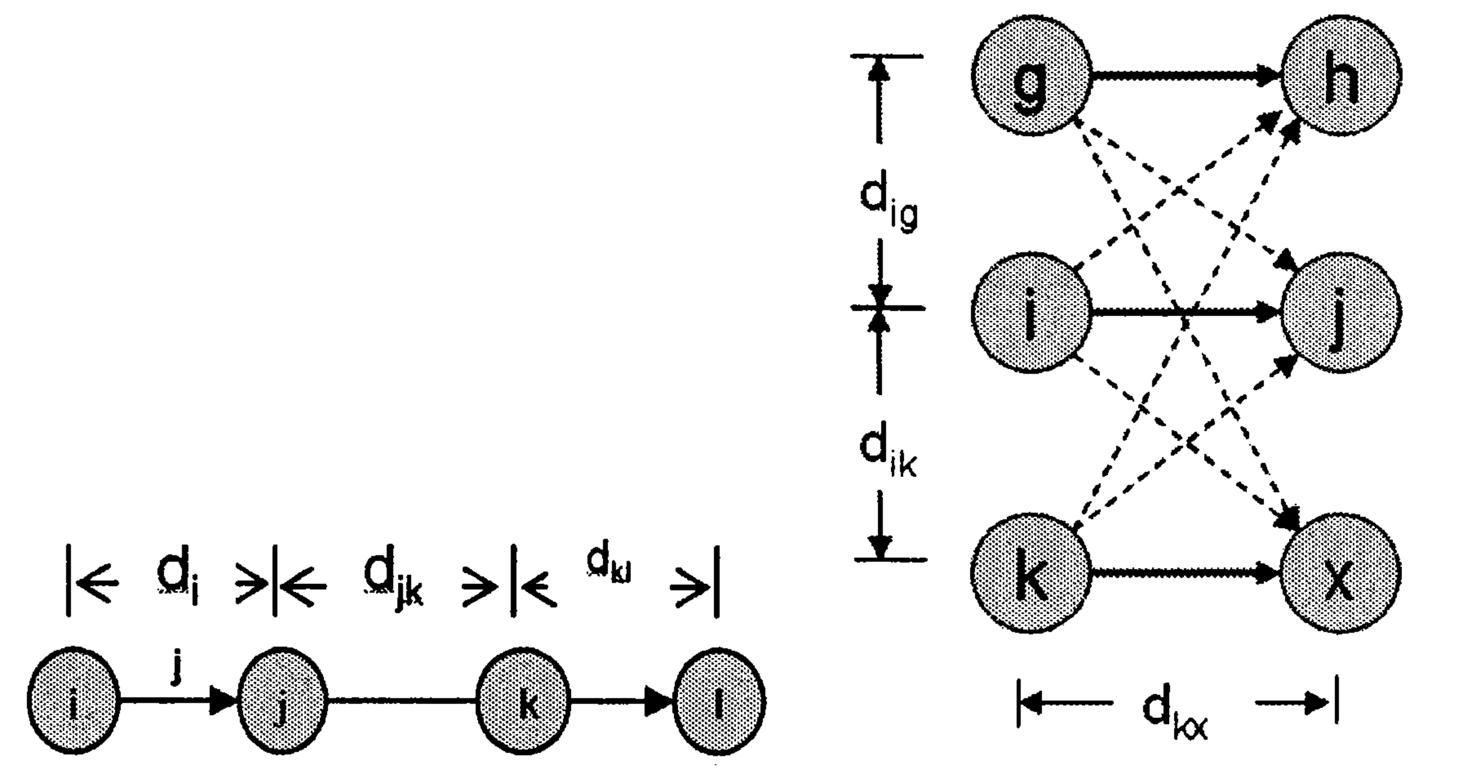

Figure 5. a) Simple Chain Topology b) Parallel Links

In figure 5(a) above, we set $d_{kl}<d_{jk}$ to avoid collision, and to maximize spatial reuse of the bandwidth. We fixed d_{ij}, the distance between node *i* and node *j* and also d_{kl}, the distance between node *k* and node *l*. We then varied d_{jk}, the distance between node *j* and node *k*, to determine its relationship on power transmission of node *i*. We then determine the needed transmission power, Pt_{ji} of node *i* to node *j*, from equation (1). We determined the transmission power Pt_{ij} needed by node *j* to reply CTS to node *i* (2), and the transmission power, Pt_{jiDATA} needed by node i to transmit data to node j (3).

Figure 6(a) and 6(b) simply states that as the distance between node *j* and node *k* increases the transmission power required for node *i* decreases. Likewise, the total power used also decreases. This holds because the nearer the interfering node the higher transmission power is needed for node *i* to satisfy the required SINR γ_{REQ} of its receiver.

In addition, we considered power transmissions in parallel links. In Figure 5(b), we consider three 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 $d_{kx}=d_{ij}=d_{gh}$ and $d_{ig}=d_{ik}$. To avoid collisions between nodes, we also set $d_{ig}>d_{kx}$. In this example, we varied d_{ig} and d_{ik} to determine its relationship with the transmission power of the nodes. As the distance between links is increased the needed transmission power of transmitting nodes as well as the total power used decreases, as shown in Figure 7(a) and 7(b) respectively. Usually, when interfering nodes are near to the active transmitters, the transmitters are required to transmit at a higher power since they must satisfy the SINR constraint.

In the above examples, the farther the transmitter from other nodes that could interfere its transmission, the lower is the transmission power required for it to perform its transmission which at the same time satisfies the SINR constraint. This is important consideration in our power control and scheduling scheme, since we consider a valid transmission only if the nodes satisfies the SINR constraint in the first place.

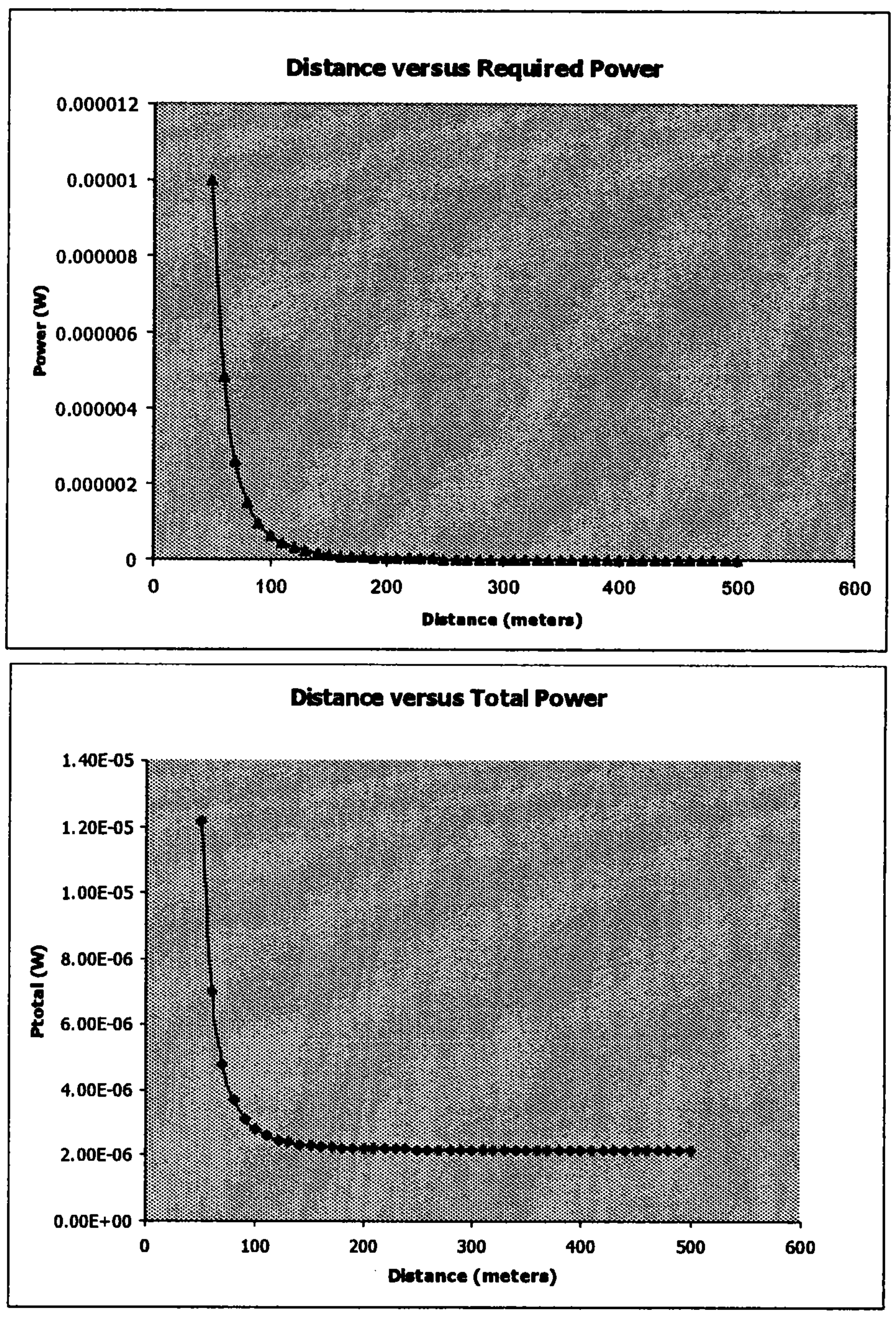

Figure 6. a) The required transmission power for node i as d_{jk} is varied. b) Total transmission power for node i as d_{jk} is varied.

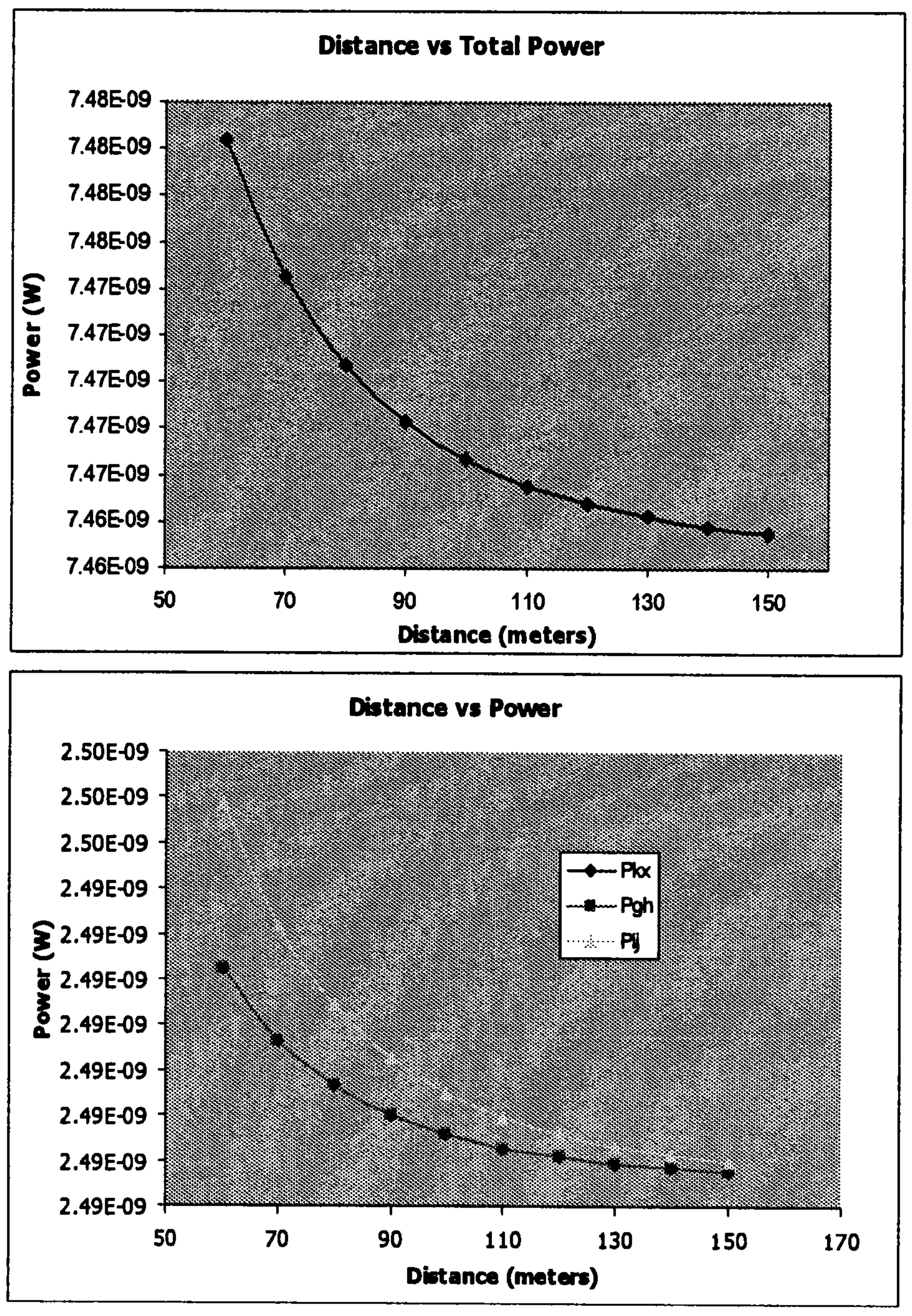

Figure 7. a) Transmission power as the distance between parallel links is varied. b) Total transmission power as the distance between parallel links is varied.

5. 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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