Reception-Aware Power Control in Ad Hoc Mobile Networks

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Abstract. Energy is a scarce resource in ad hoc mobile networks, making power control a popular, yet crucial, technique. The network is however characterized by the absence of a central controlling entity, which makes the problem of power control non-trivial. For sake of simplicity, most existing power control protocols only consider the energy cost of transmissions. In this paper, we consider a more realistic model of power control in ad hoc networks in which the energy cost of the receiving nodes is also taken into account. This paper presents protocols that can not only achieve considerable energy savings (comparable to existing techniques using only transmission power control in small networks) but can, in larger networks, actually increase the effectiveness by bringing significant energy savings per successful packet.

1 Introduction

A Mobile Ad Hoc Network (MANET) is a distributed, infrastructure-less wireless communication network, in which the mobile nodes communicate directly with nodes that are within their transmission range and forward packets for other nodes. The nodes in MANET are usually powered by batteries which provide limited energy resources. Wireless communications, however consume lot of energy not just by transmitting and receiving packets for themselves, or forwarding packets for others, but also by overhearing (unnecessary) packets from their neighbors. By default, nodes use maximum power to transmit packets. Although large transmission ranges can reduce the number of hops required to transmit a packet (thus the required cost for retransmissions), they may create excessive interference in the shared medium. Reduced transmission power results in increased spatial reuse, less interference and has also been proven to increase the overall network throughput and energy consumption [1–7] but may lead to partitioned networks. Designing effective power control techniques managing the power of transmission locally in the nodes is a critical issue in increasing the performance and lifetime of the network. Most of the existing power control methodologies only consider the cost of transmission and are based on minimum power neighborhood protocols: they decide on the lowest possible power to be used for communication while ensuring the connectivity of the network. Direct communication links are removed if found to cost more than communicating through an intermediate node. Protocols in [2–4] use topological and/or geometric properties of the network like connectivity, node degree, coverage over an angle, etc., to decide on the minimum transmission power neighbors of a node. In [5], a MAC layer protocol increases channel reuse and minimizes the power consumption by using a min-power connectivity set and introducing a signal-to-noise margin for more concurrent transmissions. In [1] a protocol for finding the common lowest transmit power for all the nodes in the network, while maintaining network connectivity, is presented. In [6, 7] "per packet transmission" power control is introduced, where the control packets like RTS, CTS sent at maximum power are used to determine the power for data and ACK packets.

Unfortunately, energy costs associated to receptions may be comparable to the transmission costs (see [8]) and this emphasizes the need for advanced protocols in a more realistic model that also consider receptions costs. (Notice that optimal routing may not be tractable, as it was proved in [9] that finding a simple unicast path that guarantees enough remaining energy locally at each node is an NP-complete problem even when all the nodes transmit at the same power.) Initial investigations have highlighted the difficulties. In [10] an analytical model for optimal transmission range for energy minimization while considering the costs of reception at the destination and the interfering nodes was presented. In [11] the protocol is also based on minimum power network maintaining connectivity, but it also considers the reception energy in the control of transmission power (the paper however only analyzes the energy savings for different ratio of electronic and transmission powers, and does not evaluate the effect of the protocol on the throughput of the network). Finally, it is worth noting that little analysis has been done on the efficiency of the power-aware protocols towards the energy vs. throughput costs (i.e., the number of Joules required per successfully delivered packet). Energy savings can be inadequate as they could be arbitrarily achieved by substantially increasing the length or number of back-offs and thus reducing the number of packets successfully received.

This paper aims to include reception power so that transmission power control takes care of minimizing the number of receptions. We investigate the impact of power control on energy and throughput of the network when reception as well as transmission costs are considered. We also take into account the impact of the routing protocol used on the throughput of the network. We show that reception-aware power control not only saves energy, but also requires less average energy to send packets in the network. In section 2, we present the method used for considering reception costs in power control. Then we analyze the performance of the protocol through our simulation settings and results in section 3 and through further discussions in section 4.

2 Reception-Aware Power Control

The main aim of power control is to maintain a minimum power neighborhood, with only the neighboring nodes which require less energy through direct communication than via indirect communication. Both the communication costs

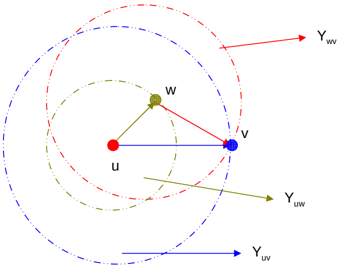


Fig. 1. Power Control and Interference Regions.

will include the transmission cost of the transmitter(s), reception cost of the receiver(s) and reception costs at the overhearing nodes.

Nodes use hello packets transmitted periodically to disseminate information about their neighborhood. Since some periodic transmission of information is essential to disseminate information for power control, we are using a proactive routing protocol and have elected to use OLSR as it is one of most efficient (and widely used for comparison) IETF protocol [12]. (A similar analysis can be done easily with any other protocol.) In OLSR, the multipoint relay (MPR) selection used effectively reduces the overhead of disseminating topology information throughout the network. Each hello packet, sent at maximum transmission power, will contain the power of transmission of this hello packet, a list of the issuing node's immediate neighbors and their current transmission powers.

For each hello packet received from its neighbor v, the receiving node u measures the power of reception P_{R_u} and also calculates the path gain G using the transmission power $P_{T(vu)}$ indicated in the packet. Using this information, Signal to Interference Ratio (SIR) measured during packet reception SIR_u, the SIR threshold parameter SIR_{th}, which is by default 10dB in 802.11 networks, and the minimum reception threshold $P_{R_{th}}$, the minimum transmission power required to reach to this neighbor $P_{T_{\min(uv)}}$ is calculated as in [13] and shown in equation 1. The calculated power is stored in the neighborhood table while the powers of the two-hop nodes from the hello packets are stored in the two-hop neighborhood table.

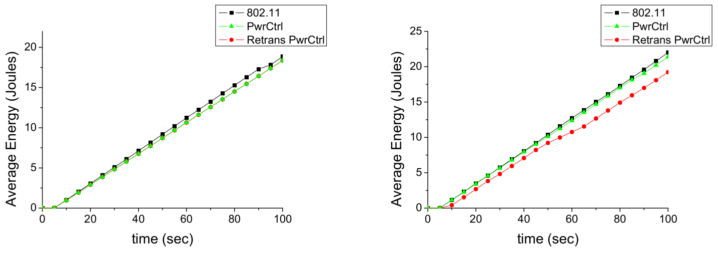
$$P_{T_{\min(uv)}} = \max(\frac{SIR_{th}}{SIR_u} \times P_{T(vu)}, \frac{P_{T(uv)}}{P_{R_u}} \times P_{R_{th}}) \tag{1}$$

For each neighbor w already in its list, it then calculates if going through this new neighbor to reach the existing neighbor will cost less energy as follows:

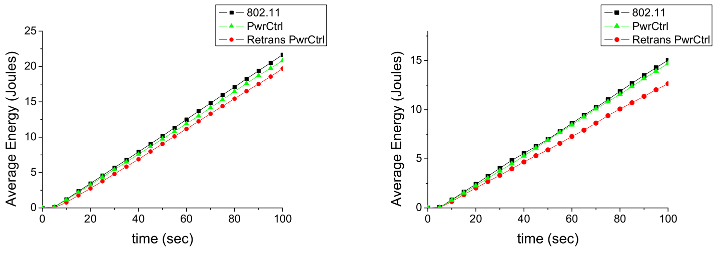
The energy consumed $E_T(xy)$ while transmitting from node x to node y is given by

$$E_T(xy) = (P_T(xy) + P_R \times I) \times t \tag{2}$$

where, $P_T(xy)$ is the transmission power required to transmit from any node x to y, P_R is the power required to receive a packet, I is the number of nodes in the interference region of this transmission, including the receiving node and t is the transmission time of the packet. If the energy to transmit directly from u to v is greater than to transmit through w, ie., $E_T(uv) > E_T(uw) + E_T(wv)$, then neighbor v is marked and added to 2-hop neighborhood, with node w as its 1-hop precedent. For example, in figure 1, $P_{T(uw)}$ and $P_{T(uv)}$ are taken from the neighborhood table of node u, and $P_{T(wv)}$ from the two-hop table. The interference region I for link uv is given by Y_{uv} in the figure, which is given by the number of neighbors of node u with transmission power less than $P_{T(uv)}$. Similarly, for link uw, nodes in interference zone Y_{uw} is found out. The exact number of nodes in the interference region for link wv (Y_{wv}), can be found from the power stored of 2-hop neighbors. This will be the number of 2-hop neighbors of neighbor w for which the transmission power is less than or equal to $P_{T(wv)}$.



(a) Network with 10 nodes, 2 flows (b) Network with 32 nodes, 3 flows



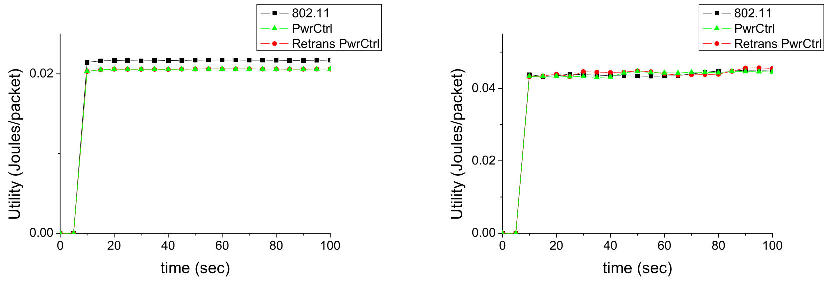
(c) Network with 50 nodes, 3 flows (d) Network with 200 nodes, 4 flows

Fig. 2. Average Energy Consumption of Nodes.

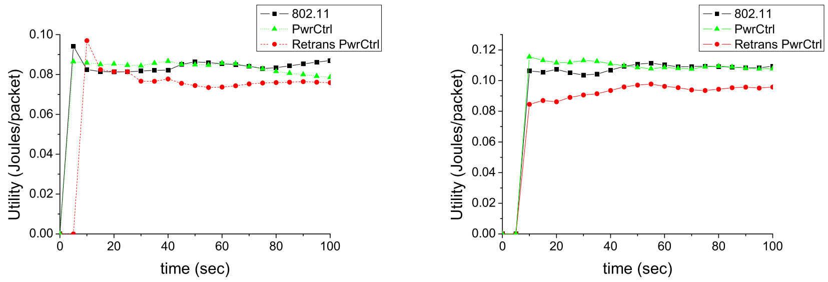
The required transmission power is still stored for each neighbor but marked nodes will not be considered as immediate 1-hop neighbors. Thus, hello packets are used to measure the transmission power required to reach each neighboring nodes, and calculate the power for indirect links. This is used to recalculate the neighborhood in a power efficient way. With the node's new neighborhood, the OLSR protocol is then used to find the MPR sets and routes for the node.

3 Performance Evaluation

3.1 Simulation Setup



(a) Network with 10 nodes, 2 flows (b) Network with 32 nodes, 3 flows



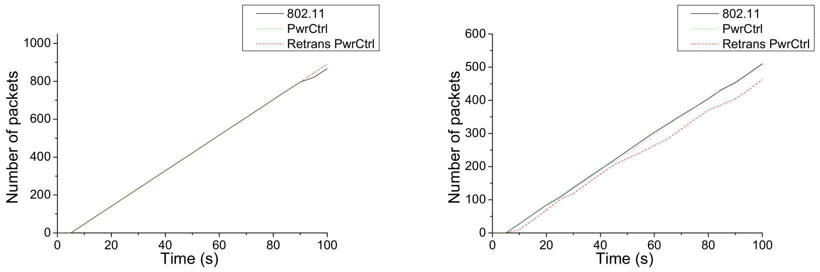
(c) Network with 50 nodes, 3 flows (d) Network with 200 nodes, 4 flows

Fig. 3. Average Energy Consumption per Successful Packet Transfer (Utility).

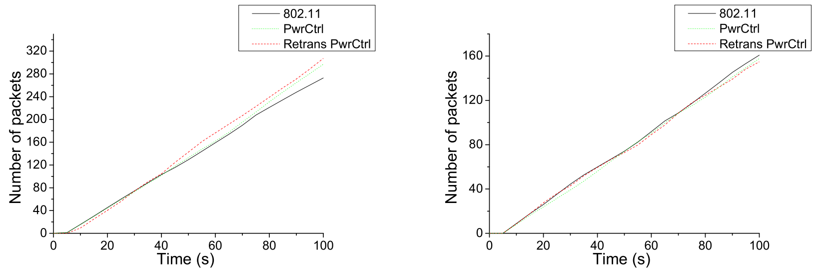
The reception-aware power control scheme was implemented in NS2 simulator to evaluate the efficiency of the protocol. For these simulations, 10 to 200 nodes were randomly placed in a square field of 1000 × 1000m with default transmission radius of 250m. Two to four Constant Bit Rate (CBR) flows were generated for 100 seconds of the simulation time. The performance of retransmission aware power control (Retrans PwrCtrl) was compared to general IEEE802.11 type of networks without any power control and conventional power control without reception energy (PwrCtrl), where minimum power to reach the existing neighbors was used for transmission (i.e., there is no change in the neighborhood). The power consumption was separated into electronic consumption (constant) and power amplifier consumption (variable part) as in [11]. Thus, equation 2 becomes:

$$E_T(xy) = (P_{Tx}(xy) + P_{Telec} + P_{Relec} \times I) \times t \tag{3}$$

Here, P_{Telec}, P_{Relec} represent the difference between total transmission,reception cost and the idle energy consumption, and were both set to 250mW, while idle energy was set to 0. Each node had six discrete transmission power levels (P_{Tx}) similar to the six power levels available in the Cisco Aironet 350 series of wireless cards [14].



(a) Network with 10 nodes, 2 flows (b) Network with 32 nodes, 3 flows



(c) Network with 50 nodes, 3 flows (d) Network with 200 nodes, 4 flows

Fig. 4. Average Number of CBR Packets Sent.

3.2 Simulation Results

For all the settings of the simulations, the average energy consumption was measured for both reception-aware and non reception-aware power control, as well as for non power-aware networks. The results are shown in Figure 2. Both the power control schemes were found to consume less energy than the network without power control, saving up to almost 50% energy for some nodes. Reception-aware protocol was found to perform comparatively better in larger network, with an energy saving of upto 16% on average compared to about 4% average savings in conventional power control protocol. In smaller networks, the energy consumption of the two techniques were found to be almost the same.

Besides the energy consumption, the effect of power control in the transmission of packets was also evaluated. Figure 3 shows the average energy consumption per successful packet sent (utility). Figure 4 shows the number of CBR packets that were sent for the different protocols and network sizes. It was observed that the average number of packets that were sent were mostly comparatively lower for power control techniques, but the difference was not very high at about 9% in average. The number of these packets that were successfully received also followed a similar pattern, with loss of up to about 13% in average. The interesting observation was that the average energy spent for each packet that were successfully sent showed a general decrease for the power control schemes. Retransmission aware power control scheme showed the utility of up to 12% in average meaning such schemes took 12% less energy to send a successful packet compared to networks with no power control. General power control scheme showed only up to 9% average gain in utility.

4 Discussions and concluding remarks

As seen in the results, the average energy consumption was decreased with power control techniques, and the reception-aware power control showed better energy conservation in a larger more dense network as expected. Denser networks have shorter hops, and more interference with neighbors, so there are more chances of re-routing for reception-aware power control. It was also observed that though the average packets sent and successfully received were comparable for different protocols for all network sizes, the utility remained better for reception-aware power control, showing that less energy is required for transmitting successful packets with this protocol.

This power control technique however just controls the topology of the network, reducing the neighborhood if it is more efficient. The MPR selection and the route computation process can affect the final route chosen, and the path may not always be the most cost effective energy-wise. More improvement is expected to be achieved if these processes were also made power-aware. (Although as pointed at in [9], it is NP-hard to find such an optimal path.) The evaluation also uses a more realistic six discrete power levels instead of allowing the nodes to transmit at any power (as many of the power-aware protocols assume). This also reduces the actual efficiency evaluated, but is more realistic.

In order to reduce the overhead in the packets required to transmit powers of the neighbors, indirect links and power required for equation 2 can be calculated using Angle of Arrival (AOA) method as in [2, 5]. Using this method, the exact interference region Y_{wv} for transmission from w to v in Figure 1 is not known, so the entire neighborhood of w is used and $P_{T(wv)}$ is calculated using AOA and the known values of $P_{T(uv)}$ and $P_{T(uw)}$.

Thus, in this paper, a reception-aware power control scheme was evaluated. It was found that the scheme showed similar efficiency in energy conservation compared to power control without reception-awareness in sparse networks, but showed better performance in denser networks. The energy needed to send a successful packet with the scheme was however found to be always less than other power-aware and non power-control schemes, showing that such a scheme is an effective way to reduce energy of the nodes in the network.

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