ADAPTIVE CONTENTION CONTROL FOR IMPROVING POWER CONTROL FOR END-TO-END THROUGHPUT PERFORMANCE OF ADHOC NETWORKS

[1]R.Tamilselvi, [2]S.Gayathiri, [3]V.S.Arulmurugan

[1]PG Scholar, Department of Electronics and Communication Engineering, Shree Venkateshwara Hi-tech Engineering College, Gobi

[2]PG Scholar, Department of Electronics and Communication Engineering, Shree Venkateshwara Hi-tech Engineering College, Gobi

[3]HOD, Department of Electrical and Electronics Engineering, Shree Venkateshwara Hi-tech Engineering College, Gobi

[1]tamil20r@gmail.com, [2]sheelangayu@gmail.com, [3]arulpvp@gmail.com

Abstract: A fully distributed contention window adaptation mechanism, which adjusts the channel access probability depending on the difference between the incoming and outgoing traffic at each node, in order to equate the traffic forwarding capabilities among all the nodes in the path to improve the throughput of wireless networks And providing maximum transmit power is used for RTS-CTS, and the minimum required transmit power is used for DATA-ACK transmissions in order to save energy. These schemes can degrade network throughput and can result in higher energy consumption than when using IEEE 802.11 without power control to consider the following issues: 1) to estimate the traffic forwarding capability at each node 2) to differentiate the contention window size depending on the traffic forwarding capability 3) to increase the end-to-end throughput by regulating the throughput of traffic relayed at each hop in a distributed and scalable manner.

1. INTRODUCTION

Ad-hoc wireless networking is receiving renewed attention. It enables many interesting usage scenarios but poses several challenges. Traditionally, wireless networking has been applied to cellular telephony and Internet connectivity via radio modems. These systems provide single hop connectivity to a fixed, wired base station. Ad-hoc wireless network systems attempt to form multi-hop networks without pre-configured network topologies. There is peer-to-peer interaction among nodes, unlike in cellular networks where nodes communicate with a centralized base station. Ad-hoc networks are characterized by dynamically changing topologies, a direct result of the mobility of the nodes. Such systems can offer many advantages. They do not rely on extensive and expensive installations of fixed base stations throughout the usage area. With the availability of multiple routes to the same node or base station, they can perform route selection, based on various metrics such as robustness and energy cost. Nodes can communicate directly with each other when possible, rather than using a distant, intermediate base station. This can help conserve energy and improve throughput. These systems enable various applications, ranging from the monitoring of herds of animals to supporting communication in military battlefields [1] and civilian disaster recovery scenarios.

Many of these applications require that nodes be mobile and be deployed with little network planning. The mobility of nodes limits their size, which in turn limits the energy reserves available to them. Thus energy conservation is a key requirement in the design of ad-hoc networks. In wireless networks, bandwidth is precious and scarce. Simultaneous transmissions in domains which use the same bandwidth interfere with each other. Thus bandwidth re-use is also important.

Power control helps combat long term fading effects and interference. When power control is administered, a transmitter will use the minimum transmit power level that is required to communicate with the desired receiver. This ensures that the necessary and sufficient transmit power is used to establish link closure. This minimizes interference caused by this transmission to others in the vicinity. This improves both bandwidth and energy consumption. However, unlike in cellular networks where base stations make centralized decisions about power control settings, in ad-hoc networks power control needs to be managed in a distributed fashion. In this paper, we present a power control loop for ad-hoc wireless networks. We describe the details of this algorithm in Section II. In Section III we describe the simulation infrastructure that we have built to simulate realistic ad-hoc networks. We have made an effort to model the node mobility, communication traffic and environment likely to be experienced in typical scenarios. We evaluate our power control loop in Section IV. Our power control loop improves energy consumption and throughput by 10-20% and 15% respectively in our simulation models.

2. DISTRIBUTED POWER CONTROL FOR AD-HOC COMMUNICATION

In this section, we describe an energy conservation technique at the MAC layer. The goal here is to minimize the energy cost of communication between any given pair of neighboring nodes if such communication is possible. Ad-hoc networks can contain nodes of various types, of which many can have limited power capabilities and may not be able to scavenge energy from sources such as solar energy. Furthermore, many of the data gathering applications for which these networks are deployed are latency tolerant. Thus, energy efficiency rather than latency should be the principle design goal in MAC communication. One main mechanism for energy conservation at the MAC layer is power control. Power control loops for various cellular telephony systems have been studied extensively in the past and are used in commercially deployed systems [2], [3]. They are especially important in ad-hoc networks due to the higher levels of interference. We have applied power control extensions to the IEEE 802.11 MAC 1 specification [5], thereby achieving lower energy consumption and higher throughput. In this section, we begin by describing the general concept behind power control and refer to related work. In a following subsection, we describe the IEEE 802.11 MAC protocol, which is the MAC protocol we use for implementing power control. We then describe our distributed power control loop.

A. Power Control

In cellular systems, a base station tells mobile units to adjust their transmit powers by measuring the power received from them. Cellular systems are used for applications such as telephony where the pre-installation of a fixed base station infrastructure is feasible. Cellular systems have star topologies and every mobile unit communicates exclusively with an associated base station.

An ad-hoc network on the other hand does not have a centralized arbiter which can tell each node the transmit power to use to communicate with a particular receiver. Furthermore, well defined cells or domains do not exist. Thus power control in an ad-hoc network is not trivial and needs to be administered in a distributed manner. However, the benefits of power control remain. Instead of every node using the same transmit power, if a node uses only the power level that is required to communicate with a desired receiver, it might extend its battery life. Furthermore, it will reduce interference seen by other simultaneous transmissions in the network.

B. Related Work: Power Control Loops in Cellular Networks

Power control loops for various cellular telephony systems have been studied extensively in the past and are used in commercially deployed systems [2], [3]. The related literature is vast, and we will not attempt a complete survey. Instead, we describe the basic concept behind power control loops in CDMA systems. One of the main goals of power control is to avoid the nearfar effect. Since transmitted signals experience propagation loss, signals received by a base station from a closer mobile station will be stronger than those received from one that is further away. Thus distant mobile stations will not experience a fair share of the available throughput to the base station. Similarly, another goal of power control is to reduce the interference that a mobile station experiences from different base stations near the edge of a cell. In spread spectrum networks, especially in CDMA networks, power control is necessary to reduce the average noise level so that it is possible to recover the spread signal.

Both open loop and closed loop power control mechanisms have been explored in CDMA systems. Open loop control attempts to measure, at the mobile station, the path loss between itself and the base station. Using the received signal strength of messages and various control parameters transmitted by the base station, the mobile station can set its transmit power level. This mechanism does not always achieve the best transmit power level because the path loss experienced on the uplink and downlink may differ (especially if different frequencies are used for the uplink and downlink). Closed loop power control treats uplink and downlink power control separately. The base station measures the received signal to interference ratio (SIR) over a short time period and decides whether the mobile station should raise or drop its transmission power level by comparing the received SIR to the appropriate SIR value. This decision is transmitted to the mobile station on the downlink. The mobile station then adjusts its transmit power levels accordingly. The base station determines the optimal SIR value by an outer control loop that considers the error rate experienced on the uplink. CDMA systems use a similar closed loop power control to adjust the downlink transmit power levels.

The base station periodically reduces its transmit power levels. The mobile station measures the error rate experienced on the downlink and requests additional power from the base station if the experienced error rate is unacceptable. The downlink control loop iterates at a frequency that is at least an order of magnitude lower than the uplink control loop. Reference [6] in particular describes an adaptive closed loop power control algorithm for cellular CDMA networks that is similar to the one we propose in this paper for ad-hoc networks. Their simulations of cellular CDMA networks consist of hexagonal cell layouts with each cell consisting of randomly moving nodes that communicate only with base stations.

3. POWER CONTROL PROTOCOL MECHANSIM

Protocol Description power control can reduce energy consumption power control may introduce different transmit power levels at different hosts, creating an asymmetric situation where a node A can reach node B, but B cannot reach A. Different transmit powers used at different nodes may also result in increased collisions, unless some precautions are taken. Suppose nodes A and B lower powerthan nodes C and D. When A is transmitting a packet to B, this transmission may not be sensed by C and D. when C and D transmit to each other using a higher power, their transmissions will collide with the on-going transmission from A to B. to transmit RTS and CTS at the highest possible power level but transmit DATA and ACK at the minimum powerlevel necessary to communicate. In nodes A and B send RTS and CTS, respectively, with the highest power level so that node C receives the CTS and defers its transmission. By using a lower power for DATA and ACK packets, nodes can conserve energy. In the BASIC scheme, the RTS-CTS handshake is used to decide the transmission power for subsequent DATA and ACK packets. This can be done in two different ways as described below. Let pmax denote the maximum possible transmit power level.

Suppose that node A wants to send a packet to node B. Node A transmits the RTS at power level pmax . When B receives the RTS from A with signal level pr B can calculate the minimum necessary transmission power level, pdesired , for the DATA packet based on received power level pr , the transmitted power level, pmax , and noise level at the receiver B. This procedure determines pdesired taking into account the current noise level at node B. Node B then specifies pdesired in its CTS to node A. After receiving CTS, node A sends DATA using power level pdesired . Since the signal-to-noise ratio at the receiver B is taken into consideration, this method can be accurate in estimating the appropriate transmit power level for DATA a destination node receives an RTS, it responds by sending a CTS as usual (at power level pmax). When the source node receives the CTS, it calculates pdesired based on received power level, pr , and transmitted power level pdesired = pmax/pr × Rxthresh × c

4. PERFORMANCE EVALUATION

To measure the effectiveness of Span, we simulated Span, with geographic forwarding, on several static and mobile topologies. Simulation results show that Span not only performs well by extending network lifetime, it out-performs unmodified 802.11 power saving network in handling heavy load, per-packet delivery latency, and network lifetime.

4.1 Simulation environment

We simulated Span in the ns-2 [17] network simulator using the CMU wireless extensions [5]. The geographic forwarding algorithm, as described in section 4.1, routes packets from source to destination. Span runs on top of the 802.11 MAC layer with power saving support and modifications described in section 4.3. In this section, we compare performance of Span against both unmodified 802.11 MAC in power saving mode and unmodified 802.11 MAC not in power saving mode. For convenience,we will refer to them as Span, 802.11 PSM, and 802.11. To evaluate Span in different node densities, we simulate 120-node networks in square regions of different sizes. Nodes in our simulations use radios with a 2 Mbps bandwidth and 250 m nominal radio range. Twenty nodes send and receive traffic. Each of these nodes send a CBR flow to another node, and each CBR flow sends 128 byte packets. In section 5.2 we vary the rate of the CBR traffic to measure performance of Span under different traffic load. In other experiments, each sender sends three packets per second, for a total of 60 Kbps of traffic. To ensure that the packets of each CBR flow go through multiple hops before reaching the destination node, 10 source and destination nodes are placed, uniformly at random, on each of two 50 m wide, full-height strips located at the left and right of the simulated region. A source must send packets to a destination node on the other strip. The initial positions of the remaining 100 nodes are chosen uniformly at random in the entire simulated region. Thus, the square root of the area of the simulated region and the number of hops needed by each packet are approximately proportional. Source and destination nodes never move. They stay awake at all times so they can send and receive packets at higher throughputs. However, they do not participate in coordinator elections. Thus, only 100 nodes can become coordinators. In mobile experiments, the motion of the remaining 100 nodes follows the random waypoint model [2]: initially, each node chooses a destination uniformly at random in the simulated region, chooses a speed uniformly at random between 0 and 20 m/s, and moves there with the chosen speed. The node then pauses for an adjustable period of time before repeating the same process. The degree of mobility is reflected in the pause time. By default, we used a pause time of 60 s. For simplicity, we did not use a location service in our simulations. Instead, a router obtains the location of the destination node from the GOD module in ns. Since the location lookup is only required once per flow at the sender, we believe the overhead produced by the location service is not likely to change our results. Nevertheless, location services such as GLS [15] can be used with Span.

Coordinator election Ideally, Span would choose just enough coordinators to preserve connectivity and capacity, but no more; any coordinators above this minimum just waste power. This section compares the number of coordinators Span chooses with the number that would be required to form a hexagonal grid layout, shown in figure 7; the hex grid layout of nodes, while perhaps not optimal, produces a connected backbone in every direction with very few coordinators. The hexagonal grid layout of coordinators places a coordinator at each vertex of a hexagon. Every coordinator can communicate with the three coordinators that it is connected to through an edge of a hexagon, which is 250 m long (the radio range). Each hexagon has six coordinators, but each coordinator is shared by three hexagons. Therefore, each hexagon is only responsible for two coordinators. Each hexagon has an area of 162,380 m2. Thus, given a simulation area of d2 meters, the number of coordinators expected in this area Cideal is

$$C_{\text{ideal}} = 2 \cdot \frac{d^2}{162380}.$$

Energy consumption

This section evaluates Span's ability to save energy. The potential for savings depends on node density, since the fraction of sleeping nodes depends on the number of nodes per radio coverage area. The energy savings also depend on a radio's power consumption in sleep mode and the amount of time that sleeping nodes must turn on their receivers to listen for 802.11 beacons and Span HELLO messages.

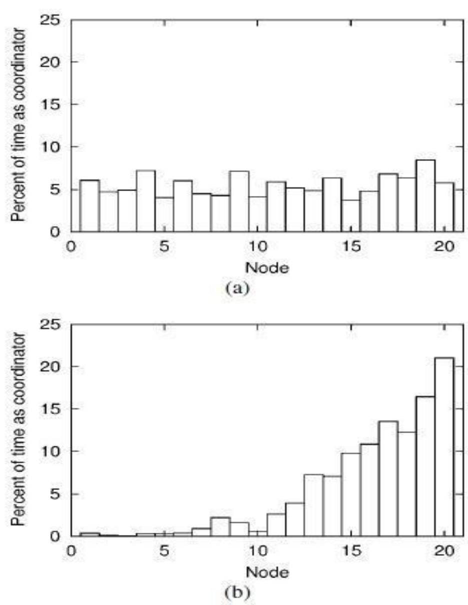


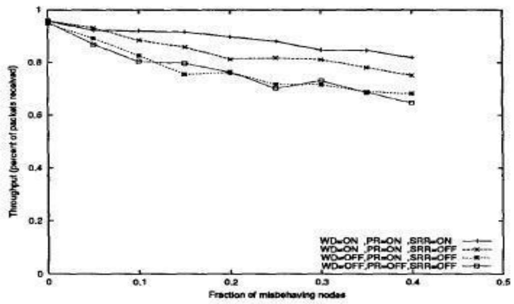
Figure 1: Percent of time each node in a 20 node, 100 m × 100 m network spent as a coordinator during 7200 s of simulation. In (a), each node starts with 10,000 J of energy. This graph shows that Span rotates coordinators equally among all the nodes. In (b), each node starts with 2000 + 400i J of energy where i is the node ID. This graph shows that Span is more likely to elect coordinators with more energy.

5. SIMULATION RESULTS

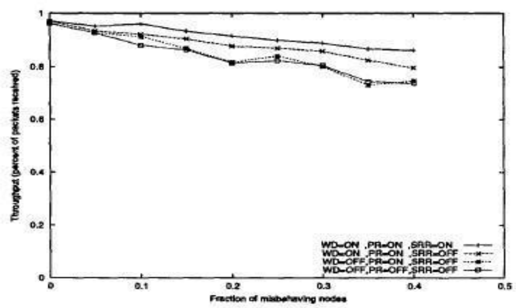
In this section we present the results of our simulations. We focus on three metrics of evaluation: network throughput, routing overhead, and the effects of false positives on throughput. We test the utility of various combinations of our extensions:

watchdog (WD), pathrater (PR), and send (extra) route request (S paths when all known paths include a suspected misbehaving node. Each of the following sections includes two graphs of simulation results for two separate pause times. The first graph is for a pause time of 0 (the nodes are in constant motion) and the second is for a pause time of 60 seconds before and in between node movement. We simulate two different node mobility patterns using four different pseudo-random number generator seeds. The seeds determine which nodes misbehave. We plot the average of the eight simulations.RP~). We use the SRR extension to find throughput we graph four curves for network throughput: everything enabled, watchdog and pathrater enabled, only pathrater enabled, and everything disabled. We choose to graph both everything enabled and everything enabled except SRR, because we want to isolate performance gains or problems caused by extra route requests. Since the pathrater is not strictly a tool to be used for circumventing is behaving nodes, we choose to include the graph where only pathrater is enabled to determine if it increases network throughput without any knowledge of suspected misbehaving nodes. We do not graph watchdog and St~ activated without pathrater, since without pathrater the information about misbehaving nodes would not be used for routing decisions. Figure 5 shows the total network throughputs, calculated as the fraction of data packets generated that are received, versus the fraction of misbehaving nodes in the network for the combinations of extensions. In the case where the network contains no misbehaving nodes, all four curves achieve around 95% throughput. After the 0% misbehaving node case, the graphs diverge.

As expected, the simulations with all three extensions active perform the best by a considerable margin as misbehaving nodes are added to the network. The mechanisms increase the throughput by up to 27% compared to the basic protocol, maintaining a throughput greater than 80% for both pause times, even with 40% misbehaving nodes. Table 1 lists the maximum and minumum throuput achieved in any simulation run at 40% misbehaving nodes with all options enabled. When a subset of the extensions is active, performance does not increase as much over the simulations with no extensions. Watchdog alone does not affect routing decisions, but it supplies pathrater with extra information to combat misbehaving nodes more effectively. When watchdog is deactivated, new



(a) 0 second pause time



(b) 60 second pause time

Overall network throughput as a function of the fraction of misbehaving nodes in the network, the source node has no way of detecting the misbehaving node in its path to the destination, and so its transmission flow suffers total packet loss. Pathrater alone cannot detect a path with misbehaving nodes to decrement its rate (see Section 7). One effect of the randomness of ns is that nodes may receive route replies to their route requests in a different order in one simulation than in another simulation with slightly varied parameters. This change can result in a node choosing a path with a misbehaving node in one run, but not choosing that path in a simulation with more misbehaving nodes in the network. This may actually result in slight increases in network throughput when the number of misbehaving nodes increases. For instance, this is noticeable in the pathrateronly curve of Figure 5 (b) where the throughput raises from 82% to 84% between 20% and 25% misbehaving nodes. In both throughput graphs, the everything disabled curve and the pathrater only curves closely follow each other. From the graphs we conclude that the pathrater alone does not significantly affect performance. In Section 7 we suggest some improvements to the pathrater that may increase its utility in the absence of the other extensions.

6. CONCLUSION

A Power Control MAC protocol, which periodically increases the transmit power during DATA transmission. Simulation results show that PCM achieves energy savings without causing throughput degradation. One possible concern with PCM is that it requires a fre quent increase and decrease in the transmit power which may make the implementation difficult. An alternative approach is to replace this higher power level for data by a busy tone at pmax in a separate channel, with one channel being used for the busy tone and another channel for RTS-CTS-DATA-ACK. Another concern is that fading may adversely affect the PCM performance. As a variation of PCM, a different time interval can also be used between the transmissions at pmax during a packet transmission. In this variation, there is a tradeoff between performance and energy savings. Although PCM provides energy saving it does not yield improved spatial reuse as compared to IEEE 802.11.

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