POWER CONTROL IN AD HOC COGNITIVE PACKET NETWORKS

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ABSTRACT

Nodes in ad hoc networks form dynamic topologies typically with scarce resources, such as energy and bandwidth. A main challenge in the operation of such networks is the efficient allocation of resources for radio communications. In this context, the presented paper proposes a power control mechanism created as a network-assisted function of ad hoc cognitive packet-based routing and aimed at reducing both energy consumption in nodes and mutual interference of adjacent communications.

In ad hoc cognitive packet networks (AHCPN) smart packets search for QoS-based routes by exploiting accumulated network knowledge of previous packets. Network information is distributed via acknowledgements and stored via reinforcement learning in random neural networks in nodes involved in a flow. Routes revealed by smart packets are used to transport user's data in dumb packets by means of source routing. To save energy and reduce the interference communications range, dumb packets and acknowledgements are transmitted appropriately with an adjusted transmission power level. Smart packets on the other hand, continue to use full power to explore the network, while the feedback system of AHCPN is extended to support the acquisition and distribution of power information.

Simulation results in NS-2 show significant energy savings after applying the proposed algorithm. In addition, simulation results and a mathematical analysis of interference models, depict a reduction of neighboring radio interference. The reduction of radio interference leads to less collisions and hence, results in a promising increase of network throughput in simulations involving singular or multiple simultaneous flows.

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1. INTRODUCTION

Mobile Ad Hoc Networks (MANET)s are collections of two or more devices - nodes or terminals - with wireless communications and networking capability that communicate with each other without the aid of any centralized infrastructure. Nodes in ad hoc networks in addition to acting as end systems, also act as transit nodes for other communications. Their participation in the process of searching for paths (routing) and forwarding of packets depends on the availability of internal resources. Those resources are typically scarce because of the mobile nature of the nodes. Ad Hoc Cognitive Packet Networks (AHCPN) [1] is a new routing protocol for ad hoc networks. The *Cognitive Packet Network* (CPN) [2, 3, 4, 5] is a fast adaptive routing algorithm that exploits learning to discover and refine routes. Routes are created and maintained by *Cognitive* or *Smart Packets* (SP), which are sent out by source nodes when new destinations are desired. SPs move in the network collecting information and making decisions that also take into consideration what previous packets had learned. Decisions can be tailored to reflect a desired quality of service (QoS) on the path, for example, minimize end-to-end delay or power consumption. An in depth survey of other ad hoc routing protocols can be found in [6].

2. POWER-AWARE ROUTING PROTOCOLS

Power efficient, routing protocols include the work of Singh, et al, [7] who investigated the use of power-aware metrics in the calculation of shortest paths. These metrics describe the power required for transmitting and receiving a packet on a link, so as to minimize the end-to-end power requirements for routing. This proposal did not take into account the remaining energy in the nodes and it can result in a severe drain of energy in the batteries of the nodes on the least-cost route.

Other proposals overcame this problem by using battery lifetime information. Toh [8] proposed a new metric, which calculates the summation of the inverses of the remaining battery capacities of the nodes on the path. In addition, Toh proposed the *Min-Max* algorithm to maintain a fair use of resources by avoiding the use of nodes with the least remaining battery capacity in the network. Li et al. [9] propose an algorithm (denoted by *max-min* zP_{min}) that computes the paths with minimal energy consumption while maximizing the minimal residual power of the network.

Power-aware Source Routing (PSR) [10] is similar to DSR, but the destination calculates the link cost based on the remaining battery capacity and transmission power of the nodes. The drawback of this approach is that the destination needs to wait some time after the arrival of the first route request, so as to receive more than one possible route, and then selects the one with the minimum cost.

An alternative approach is used by the *adaptive fidelity algorithm* (AFA) [11], which operates on top of on-demand ad hoc routing protocols, such as AODV and DSR. AFA saves battery power by turning off certain transceivers whenever the applications allow a reduction in the quality of the connections. The algorithm trades quality for battery lifetime, network bandwidth, or a number of active sensors.

Kawadia et al have worked on several power control algorithms outlined in [12, 13] COMPOW and CLUSTERPOW are the two known algorithms outlined by this paper. The goal of COMPOW is to reduce the transmission power of a given node to the minimum level where the number of neighbors does not change. CLUSTERPOW on the other hand uses the lowest transmit power level *p*, such that the destination is reachable (in multiple hops) using a power level no larger than *p*. COMPOW and CLUSTERPOW both reduce power consumption at the node and increase the Battery life, but no other quality of service goals have been implemented in these algorithms. The CLUSTERPOW algorithm trades battery lifetime for delay.

3. MODELLING AD HOC NETWORKS

3.1. Wireless Communication and Radio Propagation

3.1.1. Path Loss and Attenuation

The path loss phenomena is the ratio of received power to the transmission power. Path loss affects the quality of the received signal and is a function of the

$$P_{rx} = O(\frac{P_{tx}}{d^{\alpha}}) \tag{1}$$

The hidden constants in the big-Oh notation in (1) depend on the physical characteristics of the carrier (ie. the antenna gain, frequency) and α is between 2 - 4, (1), is also known as the Path Attenuation Model. Realistic environments however are not freespace and they might include reflections, scattering and diffraction caused by the obstacles (ie. buildings, terrain and environment characteristics)in the communication zone, hence the α can vary between $2-4$.

3.1.2. Interference Models

In addition to path loss, bit-error rate of a transmission also affects the quality of reception at a given node. The bit-error rate depends on the noise power and transmission powers and the relative locations of the other transmitting nodes (Nodes are assumed to be communicating using the same channel for transmission).

Two of the existing models for interference will be discussed here: The physical model and the protocol model.

3.1.3. The Physical Model

The physical model of interference treats the cumulative power of neighboring nodes as noise, and calculates a Signal to Noise (SNR) or to be more precise Signal to Interference (SIR).
Let X_i denote the set of nodes which are simultaneously transmitting. P_i is the transmission power of a given node X_i, in this case the transmission of X_i is successfully received by Y if:

$$\frac{\frac{P_i}{d(X_i,Y)^{\alpha}}}{N + \sum \frac{P_k}{d(X_k,Y)^{\alpha}}} \geq \beta \tag{2}$$

where β is the minimum acceptable SIR.

3.1.4. The Protocol Model

The protocol model works on the basis that a transmission is received successfully if the received power at the receiver is greater or equal to the received power of other transmissions. Mathematically transmission of X_i is successfully received by Y if for all k

$$\frac{P_i}{d(X_i,Y)^{\alpha}} \geq (1+\Delta)\frac{P_k}{d(X_k,Y)^{\alpha}} \tag{3}$$

Δ in this equation is a protocol-specific guard zone to prevent interference.

4. POWER CONTROL AD HOC COGNITIVE PACKET NETWORK (AHCPN)

Cognitive packet networks use three types of packets to accomplish all routing and forwarding functions: smart packets (SP), dumb packets (DP), and acknowledgments (ACK). SPs are responsible for discovery of routes and for maintenance. DPs employ source routing with the paths discovered by SPs to move payload from source to destination. Finally, ACKs are employed to relay the information acquired by SPs of DPs. There are three elements in the structure of any CPN packet. A header transport source and destination addresses and other useful information for the processing of the packet, such as the packet length. A cognitive map is an area that the packet uses to store network information. Only DPs use the data area to transport payload.[1]

4.1. Unicast Routing

CPN routing decisions are performed with the aid of a random neural network, trained with a reinforcement-learning algorithm. AHCPN employs a procedure virtually identical to CPN to make unicast routing decisions, but with a small difference. CPN replaces a small fraction of decisions with random decisions to avoid trapping the algorithm in local minima. In AHCPN, we replace random decisions with broadcasts to allow the algorithm a better exploration of the mobile network. We will omit further details about CPN as the algorithm is well documented in the literature [2, 3, 4, 5].

4.2. Operation

DPs source route datagrams with *adequate* power to their destinations, using the paths stored in the route cache of the source node. The Network uses full power for SPs and acknowledgements of SPs. Using this methodology the SPs will manage to get to all nodes within the maximum communication range have and the routing decision will be based on the SP acknowledgments. When the destination of datagrams is unknown, they wait in a queue while DPs seek the route. Figure 1 illustrates the logic in the generation of packets at source nodes. Until a route to a requested destination is discovered, source nodes continuously send out smart packets while datagrams arrive from their upper layer and are locally stored.

SPs use either unicast or broadcast to propagate on the network. They decide what method to use depending on the information available in the node where they are located. When the available information is not sufficient to make a unicast (RNN based) decision, then broadcast is preferred (Figure 2). Note that, at least three neighbors are required to use the RNN algorithm at any intermediate node. One of the neighbors is simply the one from which the packet was received and does not participate in the computation (*split-horizon* principle). At the source node at least two neighbors are required.

After a route to a new destination has been established, the received signal power will be used to calculate the attenuation of the signal over the path it has taken at each hop and each node will use this power level which is computed based on information gathered over time from SPs and SP acknowledgments. Smart packets may depart to maintain (or improve) the quality-of-service of the connection. The

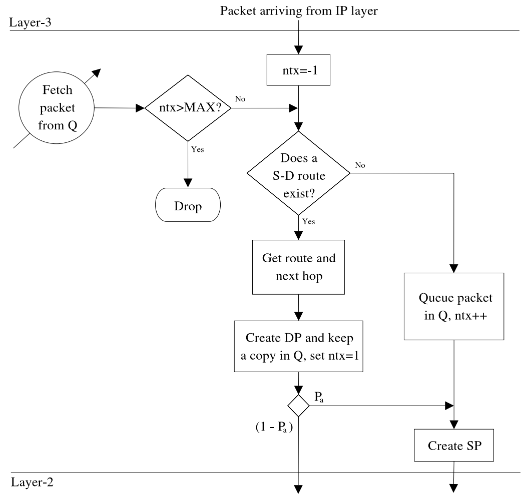

Fig. 1. Generation of packets at source nodes.

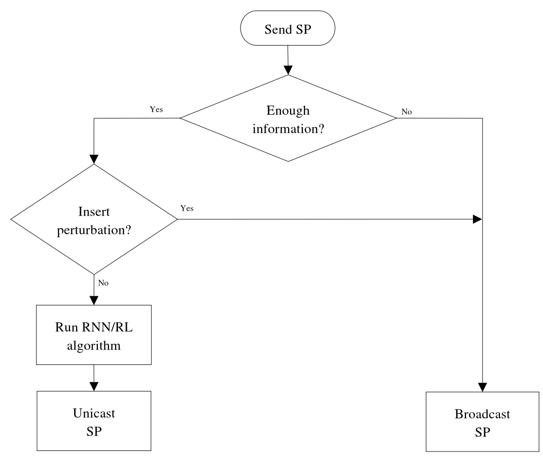

Fig. 2. Decision logic in smart packets.

additional smart packets are generated as a small percentage of dumb packet rate.

AHCPN, will give the complete path to the dumb packets to transport payload (in this case, datagrams). A copy of the original data remains within the source node until the packet is successfully delivered to its destination. The acknowledgments that are originated by dumb packets confirm to the source the delivery of packets and update mailboxes along the path.

Dumb packets collect timestamps as they travel on the network to keep the mailboxes up-to-date whereas their acknowledgments collect battery related and link-quality information on the path.

5. SIMULATION

An implementation of the AHCPN algorithm was developed and integrated into*Network Simulator 2* (NS-2). Our experiments consisted in observing the establishment and use of routes in a the network. Each experiment simulated the operation of the network for 1000 seconds

We employed 45 nodes for the simulation running with the and collected results using the power control algorithm and without the power control algorithm. All nodes are assumed to be static and the topology is illustrated in Figure 3. All nodes are assumed to start with full battery charge.

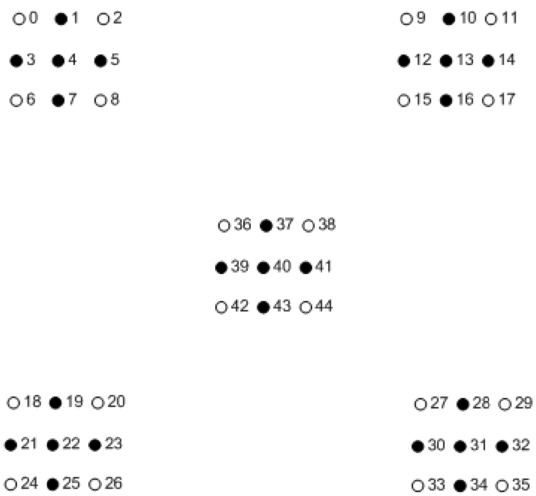

Fig. 3. Simulation Topology

Sixteen connections were established during the simulation between the cornering nodes of the grid and the cornering nodes of the entire network. Nodes 0, 17 also had two flows in opposite directions to add to the traffic. Under AHCPN, smart packets were sent at a ratio of 0.2 (on average, twenty SP every 100 DPs). Their objective function included both round-trip delay and battery information as detailed in Section 4. Figures (4, 5, 6, 7, 8) report an improvement in all aspects of the network after the power control algorithm was introduced. The interesting results are shown in Figure 7 where a reduction in path length can be seen. This can be justified by refereing back to [1] and the notion of " path availability ".

Using power control, in conjunction with energy aware AHCPN, path availability is increased as node energy does not deplete as fast hence paths remain available for longer periods.

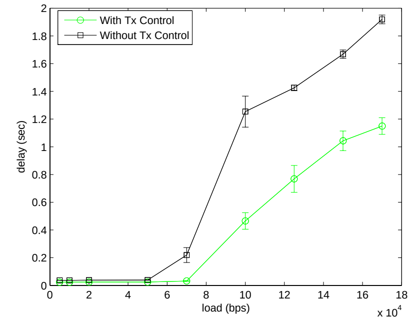

Fig. 4. Delay vs. Rate

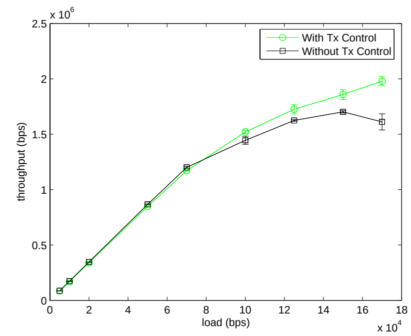

Fig. 5. Throughput vs. Rate

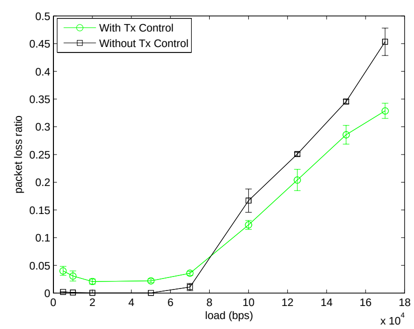

Fig. 6. Loss vs. Rate

6. CONCLUSIONS

This paper has specified and evaluated the AHCPN protocol with a power control algorithm which uses previous research on Cognitive Packet Networks (CPN) and AHCPN to improve the operation of mobile, ad hoc network.

In AHCPN, SPs use full power broadcasts to create a total or partial flooding that allows nodes acquire neighboring information while SPs move on the network since flooding is expensive in terms of resource utilization. Whenever possible, SPs use unicast-based transmissions based on the CPN routing algorithm.

We have introduced a new power control scheme which tries to reduce MAC contention and power usage at nodes. *Path availability*, which models the probability to find avail-

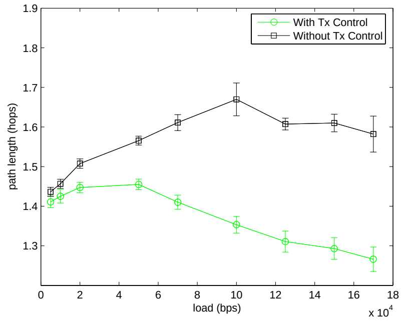

Fig. 7. Path Length vs. Rate

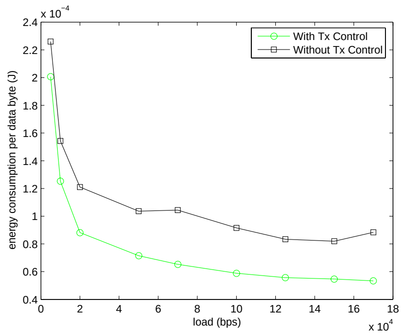

Fig. 8. Energy vs. Rate

able nodes and links on a path, was increased by reducing transmission power at nodes hence the energy available at nodes does not rapidly decrease. The end result is that the packets flow through the network at a power level which is adequate to establish communication without disturbing neighboring nodes. The packets will also choose flows through nodes which have longer remaining battery lifetime with a higher probability, than nodes with shorter remaining lifetime.

We have shown the importance of power control algorithms in the CPN protocol which (1) is able to dynamically discover neighbors and routes, (2) can discover and maintain routes without the need of a large number of broadcasts, (3) will distribute network traffic so as to extend the battery lifetime of the nodes, (4) maintains a comparable performance to more energy consuming, broadcast based approaches.

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