ZONEPOW: A NOVEL APPROACH TO POWER CONTROL IN AD-HOC NETWORKS

SHACHINDRA SHARMA
Department of Computer Science, University of Illinois at Urbana-Champaign

R. S. SREENIVAS
Department of General Engineering, University of Illinois at Urbana-Champaign,
1308 West Main Street, Urbana, IL, 61801, USA

This paper presents an attempt to address the problem of power control at the network layer by proposing a novel protocol called ZONEPOW for Ad Hoc Mobile Networks. The aim of ZONEPOW is primarily to increase the overall traffic carrying capacity of the network. The solution to the power control problem is based on (i) the search for a common power level limited to discrete zones that proactively guarantees connectivity within the zone, and (ii) an appropriate, reactive forwarding procedure for any out of zone traffic. Being a hybrid power control protocol ZONEPOW is suited for ad-hoc networks and it is particularly attractive in networks where communication between hosts is mostly localized and communication across zones is comparatively rare.

1. Introduction

Space and Battery life are two critical resources in ad hoc and sensor networks and hence power control becomes important because it results in: (a) increased spatial reuse and reduced contention for floor acquisition at the data link (MAC) layer, (b) increased community throughput or the bit hauling capacity of the network, (c) less battery consumption. The significant works done to address the issue at the network layer are COMPOW [7], PARO [10], CLUSTERPOW [9] etc. Schemes using topology control include **Rudolpho and Meng** [16], **Bahl, Wang** et al. [11]. Other approaches in [12], [13] take the residual battery capacity into account. Solutions at the MAC layer include PCMA by **Bhargavan, Monks** et al. [14]. **Vaidya** et al. [15].

Our work draws inspiration from the common power level communication approach followed in COMPOW. The advantages of common power level have already been presented in the paper [7]. The need for this work arises from the following infeasibilities in COMPOW. As stated earlier COMPOW employs DSDV [2] network wide whose control overhead offsets the spatial reuse advantage. COMPOW also has the daemons running at different power level granularities, which deteriorates the advantage of having common optimal power level Pathological topologies in sparsely dense networks lead to choosing of much high power levels in COMPOW.

Claim: Power level search is not a cumulative but a discrete approach.

According to ZONEPOW the network is not seen in its holistic pictures but as a cumulative splicing of nodes lying in segregated zones, which forms the network topology. The search for a common power level will hence be limited to these discrete zones and the networks proactive route maintenance traffic will also be pruned to the size of different zones which will be decided by the number of hops at a given power level.

Zone Routing Protocol ZRP [3] methodology strikes us as an alternative to pure proactive routing mechanism in COMPOW. It provides for stable and up to date in-zone routes and reduces the network wide control traffic due to the on demand out of zone routes.

2. Protocol Description

2.1 Phase I Network Discovery Initiation

By the end of this phase we are guaranteed to have an undisputable network discovery initiator node termed as SOURCE who has the onus of commencing the network discovery. For this purpose any existing leader selection mechanism, which guarantees a real time successful leader discovery, can be employed (Suggestions [17], [18]). The protocol needs the discovery of the leader or SOURCE only at the time of network discovery initiation. The leader has no special role to play for the rest of the lifecycle of ZONEPOW run.

2.2 Phase II Route Discovery

This phase is constitutes the discovery of the network routes on the basis of zone radius and optimal zone power level and ensures: (a) the division of network into zones, (b) the assignment of the status to the nodes, (c) the discovery of common and optimal power levels specific to a zone, (d) network connectivity, (e) knowledge of routes at the nodes.

The SOURCE, initiates network discovery by beaconing with the network discovery HELLO packets at the ***minimum power*** granularity and waits for a response from any hosts, who might have been able to hear the packet. A predefined threshold number of nodes are required to acknowledge this request for the SOURCE to decide that the power level is appropriate for zone discovery and declare it as the zonal power level. The SOURCE and discovered nodes will then update their routing tables and zone power level will be followed for all subsequent discoveries in the zone. The discovered nodes set a flag, which tells them that they do not have to respond to any subsequent route discovery requests at greater or equal power and they then proceed to search for the nodes in their single hop vicinity at the zone power level. This process of the discovery of first zone will terminate in two circumstances, either when the host, which had sent the HELLO packet at the zone power level, finds no new neighbor and there is a corresponding time out or when the discovered node lies at the predefined maximum number of hop count (similar to ZRP) in other words the zone radius. This ensures the determination of the first zone boundaries and the corresponding nodes where the search terminated are termed as the zone's PERIPHERIES. They form the interface of the sub-network to the external world and any out of zone traffic in future will be sent to them. Any subsequent intra-zone communication will abide to the zonal common power level. In the other scenario when the threshold number of nodes does not respond to the SOURCE's discovery packet the SOURCE has to **hike up its power granularity** on the request time out. This means if the previous HELLO packet was sent at P_{min} it will now be sent at the next available higher power level i.e. P_{next}. In case the threshold number of nodes responds, the zone discovery proceeds as described otherwise the SOURCE repeatedly hikes up the power granularity. Threshold at maximum power blast can automatically be reset to one to avoid branching.

After the discovery of the first zone the designated PERIPHERIES are required to discover their part of the network. In a sense they now have to play the role of the SOURCE and have to discover their own zones. The PERIPHERIES follow the same process of route discovery as the SOURCE the only difference being that here that any node, which has already been discovered by another PERIPHERY or SOURCE, will stop responding to any future discovery requests at equivalent or higher power. This is a recursive process and the algorithm terminates in case none of the nodes discovered in the previous iteration is able to discover any new node even when they resorted to the maximum power level. It can be seen that here our perspective digresses from ZRP with respect to peripheries and overlapping zones since overlap and power control are two obtuse aspects with respect to each other.

2.3 Phase III Route Maintenance

This phase commences once the network has been discovered, the zones have been formed and routing information has been updated. It ensures the maintenance of up to date low delay intra-zone routes by virtue of the underlying proactive protocol (DSDV with respect to this paper) that requires all the nodes that are a part of the zone to beacon periodically sending their routing information so that the freshest routes are maintained. Besides this the phase takes care of the mobility. We do not expect a large scale movement at small interval of time; so within safe practical limits we assume the network to be pseudo static as is the underlying assumption in most of the routing protocols. The three possible movements are as follows:

2.3.1 MEMBER movement handling

The knowledge of movement of the node comes from the timeout of the periodic update from the node (reference DSDV) and the parent zone adjusts its routing information by sequence number based update information exchange. Now the moving node when it stops can land into situations: a) It hears a periodic beacon from some zone. It will the respond at the beacon's power level and will try to get incorporated in the zone it hears from as a member greedily accepting the invitation from lower power zone. b) In case it moves farther away from a zone than is the zone radius of the nearest zone it will beacon saying "Hello I am new" waiting for response and increasing its power level on timeout. In case of an ACK from host/hosts this node will choose the zone whose zone power is equal or higher than the power level of its request ensure minimum zone distortions.

2.3.2 PERIPHERY movement handling

If the network branch does not terminate at the moving periphery its movement has a larger impact on the network and hence there has to be additional signaling to have a replacement. The hosts within a single hop from that peripheral node ideally should be the candidate to take over as the new periphery. To deal with the movement following scenarios need to be addressed: (a) the zone power in the two bordered zones is different one being higher than the other; (b) the zones have the same power. To address this, the nodes promiscuously hear the beacons broadcasted by the different zone neighbors checking if these hosts are at one hop from the periphery. The nodes realizing that the periphery has moved out of the zone check if they have cached information and whether the other zone is at the higher or lower power. In case the other zone's zone power is more than this zone the node send the beacon at the higher power equivalent to the other zone's power and declare that it is the new periphery. After one node declares that it is the periphery the search terminates. In case the other zone is at the lower power then the nodes wait because it is mostly likely that someone from the other side will contact them due to information cached at those nodes and there is a timer maintained beyond which this zones nodes will themselves send the beacon at the lower power indicating to the other nodes that they want to take over as the periphery. The first node to do so will be chosen as the new periphery. In case both the zones are at the same power level then the first potential periphery to claim that it is the new periphery is assigned the role. In case there is no neighbor of the other zone that has been promiscuously heard the nodes wait for sometime and initiate afresh discovery for the other zone nodes that have the moving periphery as their one-hop neighbor. Nodes in the single hop neighborhood of the moving periphery communicate and inform each other once they have discovered other zone and declare themselves as peripheries.

2.3.3 SOURCE movement handling

If the moving SOURCE is also a periphery to the zone the movement is treated like periphery movement other wise it is considered as member movement.

2.4 Issue Resolution

There is a potential for collision in case the bordering zones have different zone power since there is a possibility of potential disturbers not being silenced by virtual carrier sensing (RTS/CTS did not reach the node). To deal with this the periphery always sends it control messages at the highest power level amongst the bordered zones and data messages at the corresponding zone power level alleviating the possibility of collisions. Moreover other nodes track the number of collisions and promiscuously cache bordering zone's power levels hiking their control message power beyond a threshold. For increasing the efficiency we propose the rule of greedy change of allegiance according to which whenever a host in the network hears a lower power blast from a different zone's periphery it responds back changing its allegiance to the "better claimer". A tradeoff to obtain more even and correct zone distributions and to reduce collisions we suggest bringing in a priority for lower power levels presently incorporated by a delay, which favors the searches at lower power levels. Another issue is in case of biased directional route discovery where there is a possibility of network getting branched in pathological topologies. To deal with this the peripheries and the source is required to maintain information about nodes that can be reached at higher than zone power levels and make checks if all corresponding nodes have been found after allowing appropriate time for network search.

3. Simulation and Analysis

The test-bed consists of the homegrown simulator for running COMPOW and ZONEPOW and the network consists of varying number of nodes being spread randomly in different topologies over a square grid of the area of 550 * 550 square meters. The number of nodes considered for the simulation runs were 15, 25, 35, 50, 65, 90, 100, 120, 140, 175, 200 and 225. For each topology 14 runs are made and the power level is averaged over these. There are two fold savings for ZONEPOW in comparison to COMPOW in terms of power savings and control traffic overhead. Our efficiency metric for power savings is given by:

Average Power-Level in ZONEPOW / Common Power-Level in COMPOW.

The proactive traffic in COMPOW in comparison to ZONEPOW increases with the square of number of nodes because the size of the routing packet is O(N) and every node is required to beacon the control information every periodic time T. The efficiency is measured by:

Total number control traffic packets ZONEPOW / Total number of control traffic packets COMPOW

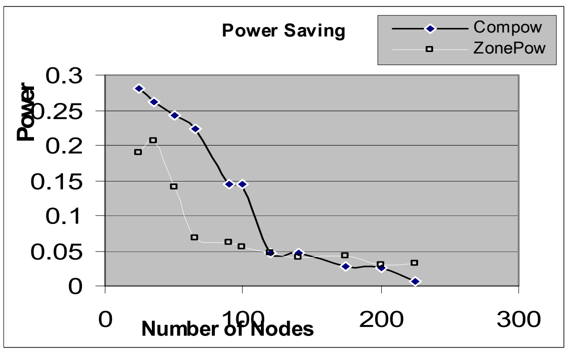

Figure 1 Power saving comparison ZONEPOW and COMPOW

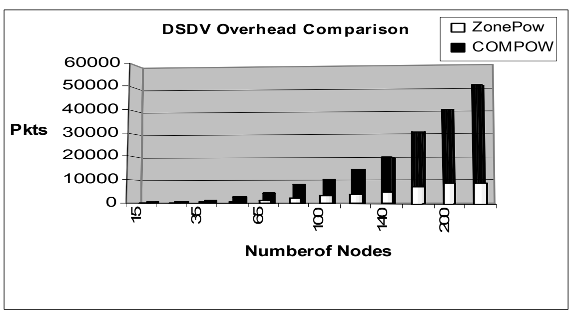

Figure2 Comparison of control traffic overhead in ZONEPOW and COMPOW

As can be seen in the Figure 1 power savings are considerable for ZONEPOW for sparse topologies. Till about 90 nodes for this topology ZONEPOW performs significantly above COMPOW on an average because of the fact that random sparse topologies often result in one or a bunch of nodes being sprayed unevenly from the rest of the network leading COMPOW to choose the higher power level. This is reduced as the number of nodes increases, where COMPOW and ZONEPOW performance tends to converge to a common optimal power level. In fact although theoretically it shouldn't happen towards very high node densities COMPOW even gets better at times because ZONEPOW is subject to issues related to synchronization and experimental errors.

4. Conclusion

ZONEPOW has been inspired by COMPOW, which attempted to come up with a solution by a common power level of transmission for a network but lost the scalability due to high proactive traffic and proclivity of the protocol to choose higher power level in case of networks with uneven density. ZONEPOW for lower node densities leads to considerable savings in terms of space and higher densities saves on overhead of control traffic in comparison to COMPOW. Moreover ZONEPOW follows a hybrid approach whose advantages are already known for Mobile Ad Hoc networks. The special status to PERIPHERIES imparts to ZONEPOW scalability and adaptability tending towards the hierarchical protocols, which are specially suited for the modern day internet architecture. There is an associated overhead but the advantages of the power control are prominent enough to justify the approach for the solution to power control problem.

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