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Performance evaluation of power control routing for ad-hoc networks.

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Abstract - **Wireless adhoc networks are infrastructureless networks that consist of a number of autonomous, wireless devices. The data exchange through the nodes is coordinated by routing algorithms like DSDV so that any node may forward data from a sender to a receiver. Because the network resources such as bandwidth and energy are scarce, power control algorithms have been developed in order to reduce the interference and the contention among the nodes, as well as to save energy. However, a power control algorithm should be thoroughly examined in order to verify if and when these goals are achieved. We ran simulations comparing the performance of DSDV and DSDV-based CLUSTERPOW control algorithm and found that CLUSTERPOW presents scalability issues and enhances network performance only under specific conditions.**

1. Introduction

The advance of technology has enabled the creation of infrastructureless wireless networks, or wider known as ad hoc networks. Originally they were developed in defence applications like the DARPA (Defence Advance Research Projects Agency) and academics, Packet Radio Network (PRNet) project in 1972 [1]. They appear useful in a large number of applications, especially for outdoor deployment where no infrastructure exists. They form an arbitrary topology, where the nodes are free to arrange themselves as required. The devices communicate directly with each other through radio links and without the aid of access points or any wiring.

New routing algorithms had to be developed in order to support ad-hoc communication. The ad-hoc routing algorithms are classified the following categories: i) On-Demand or Reactive. The major representative protocols are AODV [2] and DSR [3]. ii) Table-driven or proactive protocols. DSDV [4] is the main representative. Comparisons using simulation [5,6] show that for networks with low mobility, proactive protocols achieve a lower delay and a higher packet delivery ratio, while in higher mobility situations the reactive protocols are performing better. In the case of a conference, or an educational session, where the participants are quite immobile, a proactive protocol would be ideal to support an ad hoc network created from the participants' devices. Furthermore, as long as the number of participants is relatively small, a proactive protocol would be more suitable for multimedia communication. DSDV is the most widely known and supported proactive protocol, however it presents a problem of scalability, due to the produced overhead, which is O(n3), where n the number of nodes in a network.

Additionally, ad-hoc networks cannot achieve the performance of wired networks. Interference, low bandwidth and noise pose a number of problems. There is a number of techniques that we can use to improve wireless performance, such as using directional antennas, using more effective schemes of modulation, etc. Power control is a technique that, when properly used, benefits the performance of the network. By adapting the transmission range to the minimum required, we can decrease the interference between the nodes, decrease the channel contention, and thus increase the spatial reuse and throughput [7], and finally save energy.

In [8] the authors suggest that power control is a network layer problem and propose a set of power control algorithms: COMPOW is an algorithm that presumes that the network interface of the nodes can transmit data in a predefined number of discrete power levels. Several instances of the routing protocol run, each for a different range of transmission. A common range is selected for transmission, which is the minimum range that provides routes for the same number of nodes that have available routes with the maximum range. CLUSTERPOW executes the same procedure, several routing agents run and construct several routing tables, one for each transmission range, with the exception that no common transmission power level is applied throughout the network. A final routing table consisting every route is constructed, but each indicating the lowest possible transmission range, so each transmission is carried out with the lowest possible power level. MINPOW is combining the transmission power level and energy consumption to use as a cost metric, so that it can save energy. Finally LOADPOW is a power control algorithm that takes into account the network load and accordingly may transmit in a higher power level, in order to minimise delay.

However, there are some issues concerning power control. The first is that if the range is too short, the network will disconnect and a number of nodes might be isolated. The second is that by decreasing the transmission power, the signal is more vulnerable to interference, so errors and retransmissions might occur. The third issue, and most neglected, is that in order to determine and control the transmission range we exchange control overhead, a great part of which is generated from packets transmitted at the highest power. Finally, there are issues including delay, since more hops would delay data transportation, and uneven power levels among nodes, that could induce hidden terminal problems.

Regarding the first issue, CLUSTERPOW and its similar algorithms choose ranges that keep the network connected. The second issue concerns the choice and design of carrier-sense and reception thresholds, of modulation schemes, and must be examined in a cross-layer manner. We have seen no research about the overhead production of network layer-power control mechanisms, so we studied the behaviour and performance of networks using DSDV-based CLUSTERPOW in comparison to DSDV without power control. The results show that it does enhance the network performance, presenting better throughput and even smaller delays; however it increases extensively the routing overhead and suffers from scalability issues and degrading performance when the number of network nodes increases. Knowing this, we can use power control more efficiently and modify our algorithms accordingly.

2. Preliminaries

There is an ongoing work [13,14,15] concerning the estimation of the capacity of ad-hoc networks, but it is a very hard problem to solve, e.g. the case of two interfering links has not been fully solved, so most of the results so far come from simulations. In [7], an analysis is presented for the capacity of very large networks, that derives bounds on the achievable capacity with very high probability.

The practical results from the analysis are that the per-node available throughput in a random network, when all nodes transmit, is $\Theta(\frac{1}{\sqrt{n \log n}})$ where n is the number of the network nodes. A perfect network would achieve a capacity that is $\Theta(\frac{1}{\sqrt{n}})$. In the same analysis it is also shown that the capacity is inversely proportional to the transmission range, as long as it is greater than $\sqrt{\frac{\log n}{\pi n}}$ to guarantee connectivity.

Other studies indicating the benefits of power control are presented in [16] and [17], while more than 50 papers have been edited in journals and conferences so far, analysing the problem.

DSDV is a proactive protocol, according to which each node constructs and uses a routing table to every destination in the network. All nodes transmit hello packets to discover their neighbours. The neighbours of a node are the first entries to be registered in its routing table. On a defined periodic interval the nodes exchange their routing tables and so they fill up the tables with all the destinations. When a node detects a change in the topology, it transmits a triggered routing update including only the entry of the change to all its neighbours, who in turn update their tables and retransmit this change to their neighbours, and so on. A report to determine the amount of the overhead produced from proactive protocols is presented in [18]: Let h be the average frequency of triggered routing updates, S the size of the periodically broadcast table, Δ the average number of neighbours for each node, N the nodes of the network and b the size of a routing table entry. If E denotes the average number of emissions to achieve a topology broadcast, we denote by o the broadcast optimization factor, i.e. the average number of per node routing transmissions for a topology broadcast, $o = E/N$, $(1/\Delta \leq o \leq 1)$, then the consumed bandwidth is $B= h\cdot b\cdot N + o_l\cdot S\cdot N^2/T$ bytes/sec (1).

Knowing that $S=b\cdot N$, the total bandwidth consumed is $B= h\cdot b\cdot N + o\cdot b\cdot N^3/T$ (2).

In CLUSTERPOW algorithm, each node runs a routing protocol daemon at each power level. In case of a proactive protocol, it independently builds a routing table for every power level by exchanging hello messages at only that power level. To forward a packet for a destination, a node consults the lowest power routing table in which the destination is present, and forwards the packet at the minimum power level to the next hop. For a reactive or on-demand routing protocol, route discovery requests can be sent out at all the available power levels. The lowest power level which results in a successful route discovery can then be used for routing the packet. So, in the case of proactive routing, for each transmission power level l we have the total routing overhead of the construction and maintenance of its table, substituting in (2) yields

$$B = \sum_{i=1}^{l} (\mathrm{h}_i \cdot \mathrm{b} \cdot \mathrm{N} + \frac{\mathrm{o}_i \cdot \mathrm{b} \cdot \mathrm{N}^3}{T}) \text{ bytes/sec (3).}$$

This means that although power control improves the network performance, it increases the overhead. The consequences are collisions, retransmissions, delays, waste of energy and scalability issues. We use simulation in order to estimate the real overhead and performance of DSDV and CLUSTERPOW.

3. Related work

Various algorithms have been proposed for power control and it is not within the scope of this paper to present the list exhaustively. Most of these algorithms operate at the Medium Access Control Layer. Very little work has been done for the network layer. BASIC [9] is a MAC algorithm that performs the RTS/CTS handshake at the highest power level to avoid packet collisions from the hidden nodes. Then the sender and the receiver negotiate a lower transmission power level for sending the DATA packets. Power Control MAC (PCM) [10] uses the BASIC scheme but the power level during transmission is periodically increased to its maximum to inhibit hidden node transmission. ELPCM [11] is another modification of BASIC, where the RTS/CTS handshake takes place with the smallest possible power. If unsuccessful, the transmitting power increases, until the handshake is successful, at which point the transmission power is defined. Finally, Power Controlled Multiple Access (PCMA) [12] allows nodes to have different transmission power levels and uses two channels, one to inform nearby nodes of the packet transmission with busy tones, and the other for all the other packets.

One of the very few algorithms besides [8] that operate on the network layer is Power Aware Routing Optimisation (PARO) [13]. PARO presupposes the network can initially operate in single-hop mode and every node is within the reach of each other. When a node decides to transmit, other nodes can overhear the handshake, calculate the distances from each node and offer to become intermediate nodes for the transmission. So, each single-hop route breaks down to a larger number of short hops were each hop utilises the minimum possible transmission power. Some other cross - layer design solutions have also been proposed [19] that combine MAC layer Power Control and Network layer routing.

4. Method of simulation

We have run simulations for various scenarios using DSDV with CLUSTERPOW, and DSDV. For our simulations we have used ns2, the Network Simulator [21] with Vikas Kawadia’s modifications for CLUSTERPOW [20]. Initially we have simulated random networks of static nodes in 400*400m^2 and 600*600m^2 areas. 1 up to 15 nodes in the network, in various simulations, communicate by sending TCP packets that cross the whole network topology, that is all the sources are randomly located in a zone at the first 50m of the network longitude and the destinations are located in a zone at the last 50m, the rest nodes are scattered randomly throughout the area.

Beginning from networks of 40 nodes, we gradually increase the number of nodes up to 80. Each scenario runs for different random topologies. The details of our simulation are listed in Table 1.

Simulator	NS2 v2.26
Simulation Time	1000s
Traffic	TCP
MAC	IEEE 802.11
Link Data Rate	2 Mbps
Number of power levels used in CLUSTERPOW	6 , 3
Transmission Range per power level (6 levels)	250, 210, 170, 130, 90, 50 meters.
Transmission Range per power level (3 levels)	250, 170, 50 meters
Transmission power per level (6 levels)	281 mW, 140 mW, 60 mW, 20 mW, 4.73 mW, 0.45 mW
Transmission power per level (3 levels)	281 mW, 60 mW, 0.45 mW
Routing Protocol Warm-Up time	180 sec

Table 1: Simulation Parameters

5. Experimental results

The results of the overhead, delay and throughput are depicted in the following figures. Fig. 1 exposes total control overhead in Mbytes. As expected CLUSTERPOW$_6$ (we will use the subscripted number to declare the power levels) exhibits the highest overhead production.

The figures show that the overhead follows a polynomial function that is not just O(n^3) but O(n^p), with p>3, which means that either the optimization factor in (3) is a function of n, or that the data transmission across the network react with the control data causing also retransmissions and useless traffic

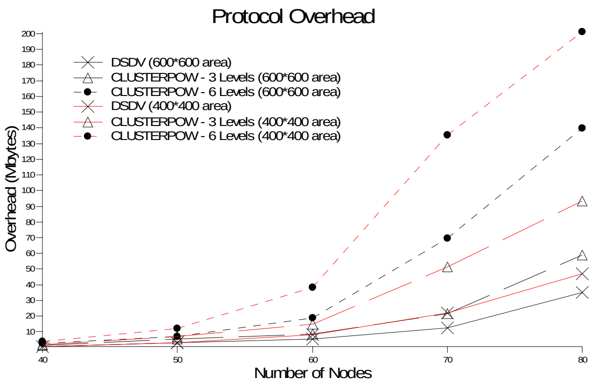

Figure 1: Protocol overhead in scenarios of 600*600m^2 and 400*400m^2

To clear this, we ran simulations of the 80 node network in the 600*600m^2 area with a) no data exchange, b) 1 TCP flow crossing the whole area of the network, c) 5 TCP Flows, d) 10 TCP Flows, and e) 15 TCP flows, in order to clarify this.

The results are given in Fig. 2, where we see that the overhead generated when no TCP data are exchanged through the hosts is the solution of eq. (3), with optimization factor o=0.003. Even a single flow almost doubles the routing overhead of CLUSTEPROW. However, the overhead of DSDV starts increasing only after 5 flows. At 15 TCP flows running through the network DSDV shows an increase of 1312.7%. We would expect a reduction in the performance of DSDV as the data flows increase in comparison to the performance of CLUSTERPOW that is appears quite steady on any number of flows.

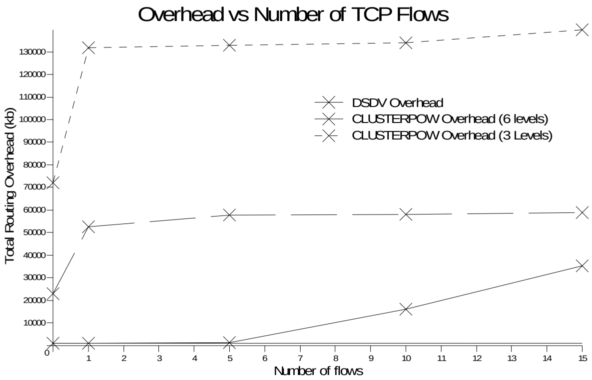

Figure 2 : . Impact of network traffic on the control overhead

Fig. 3 shows the aggregate throughput (in kbit/s) as a function of the amount of data exchange. It is clear that the DSDV throughput reduces, while the CLUSTERPOW$_6$ throughput increases. Of course, the aggregate throughput is not analogous to the number of flows and so the per-node throughput is always diminishing.

Fig. 4 shows throughput as a function of the total number of nodes in the network. Here, we clearly see the scalability problem of CLUSTERPOW. The rate of reduction of the CLUSTERPOW$_6$ is the highest of all three. In all results with more than 60 nodes, DSDV performs better.

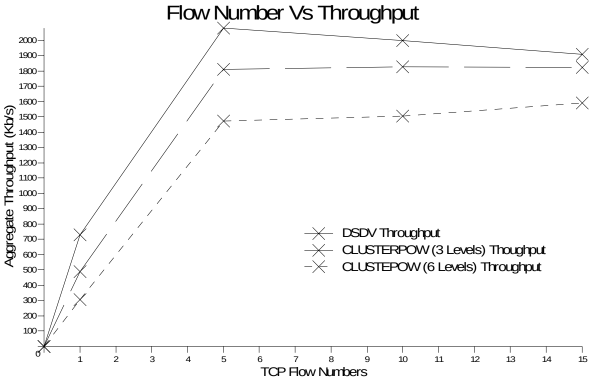

Figure 3 : Throughput vs. Number of TCP Flows

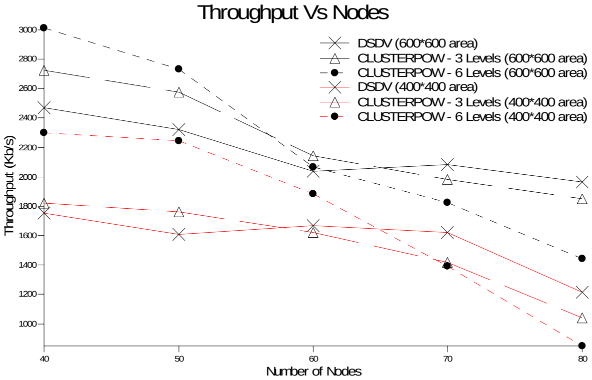

Figure 4 : Throughput vs. Nodes Number in a 600*600m^2 and a 400*400m^2 area.

This is an important result because it shows the limits of CLUSTERPOW in a random network with a uniform distribution of nodes, regarding throughput. In the 400*400 network, for a node population up to 70, DSDV has a constant performance, that introduces only minor fluctuations.

We also see that the lower density a network has, the more probable is to achieve a higher throughput under CLUSTERPOW. In the 400*400m^2 area CLUSTERPOW$_6$ begins with a throughput of about 2300 kb/s with 40 nodes, which quickly degrades to a 900 kb/s throughput when having 80 nodes, and the decrease is 255%. On the other hand DSDV begins at 1750 kb/s and remains steady with minor deviations up to 70 nodes.

At 80 nodes the heavy density and scalability influence becomes apparent, resulting in an aggregate throughput of 1250 kb/s, a much better than CLUSTERPOW$_6$ performance. The DSDV throughput decrease from 40 to 80 nodes is only 140%.

At the 600*600m^2 scenarios, CLUSTERPOW$_6$ aggregate throughput decreases from 3 Mbit/s to 1,5 Mbit/s, that is a 200% decrease, while DSDV throughput has a 126% decrease, from 2,45 Mbit/s to 1,95 Mbit/s. Lower densities tend to give a slower decrease of the throughput when increasing the nodes.

CLUSTERPOW$_3$ in the 400*400 scenario is performing just a little bit better than DSDV and again at 70 nodes its performance becomes only a little worse than DSDV. This happens because of the choice of power levels, in CLUSTERPOW$_6$ a 36% of next-hop entries of the final routing table indicate the use of power level 3 , a 49% the use of power level 2 and only a 15% the rest power levels. CLUSTERPOW$_3$ level 2 corresponds to CLUSTERPOW$_6$ level 4, not 3 which if had been chosen would yield theoretically much better results. On the other hand in the random scenarios of 600*600m^2 areas, CLUSTERPOW$_6$ final routing table consists of 37% Level 3 entries, a 43% level 2 entries, 11% level 4 entries and 10% level 1 entries, which is why CLUSTERPOW$_3$ shows such a better performance in this set.

Next, we study the average end-to-end delay with respect to the number of nodes. As we see in Fig. 5 in all occasions, DSDV presents the worst delay, which sometimes has the size of a second.

Given that with power control, each route includes more hops of smaller transmission power, we would expect the opposite. Fig. 6 clarifies things

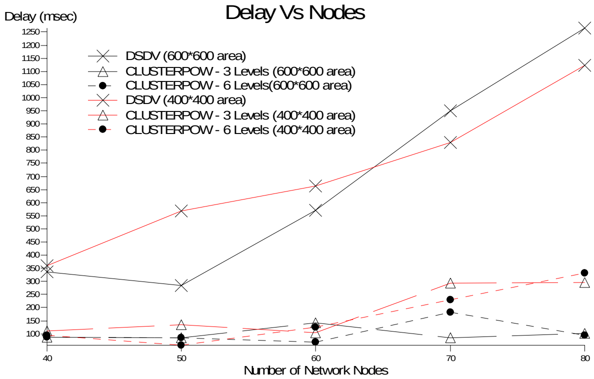

Figure 5 : Delay vs. Nodes in a 600*600 and a 400*400 m^2 area

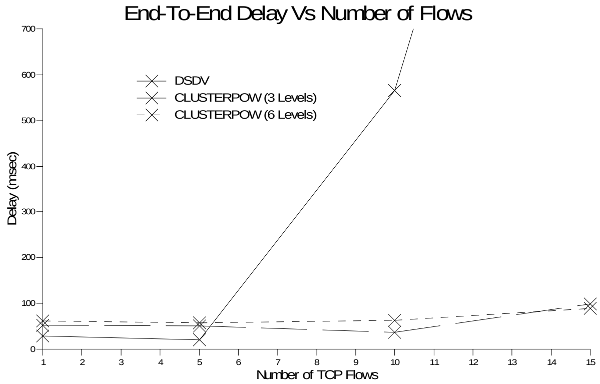

Figure 6: Delay vs. Number of TCP Flows

DSDV end-to-end delay is much shorter than CLUSTERPOW end-to-end delay for a small number of flows. However, when 10 sources transmit simultaneously, DSDV introduces a very large delay. The range of the transmission of a node inhibits the circulation of data through its neighbors, causing collisions, retransmissions and delay. CLUSTERPOW using power control does not let nodes interfere with each other causing delays.

Finally we investigated another parameter, the node distribution and topology. We additionally ran simulations of a perfectly homogeneous and ordered network consisting of 60 nodes in a 600*600 area with 15 TCP flows. DSDV yields an aggregate throughput of 521.92 Kb/s, CLUSTERPOW_3 286.13 Kb/s and CLUSTERPOW_6 just 161.48 Kb/s. On the other hand the authors of CLUSTERPOW simulate a variety of non uniform distributed topologies where CLUSTERPOW prevails. This means that in topologies that include both dense and sparse areas of node distribution, the use of dynamic power control is much more suitable than homogeneous networks. In summary, the topology of the network has a crucial influence.

These results pose some issues that we have to investigate before implementing a power control scheme. First we have to see if the size of our network can stand a network-layer power control mechanism such as CLUSTERPOW. CLUSTERPOW overhead is produced mostly due to the inheritance of the mechanics of DSDV that produce overhead. In fact it is the same overhead, just that it is produced for every power level. If we implement CLUSTERPOW based an on-demand routing algorithm, then the problem will be the broadcast storm of the route request for every power level. As CLUSTERPOW can be implemented based on any routing algorithm, it should be implemented based on scalable algorithms.

Second we have to examine the number of power levels that we should use when deploying an ad-hoc network with power control. The topology of the network also has a crucial influence, as well as mobility. In topologies that include both dense and sparse areas, or where there is mobility, the use of dynamic power control is much more suitable. Homogeneous networks on the other could be benefited by a predefined common communication range.

Third, we have to take into account the amount and the nature of traffic in our network. As we saw in Fig. 6 and Fig. 3, power control proves its worth when a high load of data exchange is taking place. CLUSTERPOW can be beneficial in conjunction with multicast and broadcast transmission, as long as the minimum spanning tree construction follows a distributed mechanism. Further research could take place for a proper creation of a multicast-power control scheme.

Finally a full parametric analysis of the algorithm and a careful study and review of its design should be conducted before implementation. For example, routing tables of the lower power levels could be updated more frequently while those of the higher power more infrequently, since the higher power level tables obviously carry most of the overhead. The update frequency is also dependent on the mobility of the nodes. Static networks that have no mobility can have a very long updating period and save a lot of overhead.

6. Conlcusion

We have shown that CLUSTERPOW reaches the peak of its performance and keeps delay at a minimum amount when network load is high. Also it provides a good throughput for small networks. However it multiplies routing overhead and surcharges the DSDV scalability problems. So the use of CLUSTERPOW power control has no benefit results on uniform distributed networks of more than 60 nodes. In order to solve the scalability problem, CLUSTERPOW should be implemented based on a scalable routing algorithm.

7. Future Work

Simulations of CLUSTERPOW based on scalable routing algorithms should be conducted, as well as investigation on the parameters of each power level, e.g. different updating frequencies. Also implementations of power control in multicast routing have not yet been explored.

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