A Heuristic Approach to Energy Saving in Ad Hoc Networks[1]

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Abstract. This paper presents a new algorithm, Extra, for extending the lifetime of ad hoc networks. Extra tries to conserve energy by identifying and switching off nodes that are momentarily redundant for message routing in the network. Extra is independent of the underlying routing protocol and uses solely information that is collected locally. Simulation studies conducted have shown promising results.

1 Introduction

In recent years, computer ad hoc networks have been receiving more attention. These are networks without defined topology, whose nodes are moving and they communicate through radio channels. As it does not have a centralized element, all the nodes in network should cooperate to permit messages routing. Several routing protocols in ad hoc networks were proposed in the literature, e.g., DSDV [1], DSR [2], TORA [3] and AODV [4].

An important characteristic of mobile devices in an ad hoc network is the energy consumption, because they usually depend on battery. In that way, besides the traditional metric to evaluate a protocol like packet delay and drop rate, lifetime of the network is important. The nodes in a ad hoc network consumes energy not only when they are transmitting or receiving messages, but also when they listen for any data (idle). That happens because the electronics of the radio can be energized to maintain the capacity to receive messages. Several studies indicate that the necessary power for transmission, reception and listen is, typically, in the order of 1,60W, 1,20W and 1,0W, respectively[5]. However, if the radio goes in sleeping state, the consumption falls to 0,025W. Those values indicate that, to be an effective decrease in the battery consumption the radio should be put in sleeping state by a certain period of time, during the operation of the network.

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An interesting comparison on the consumption of energy of several ad hoc network protocols was showed in [6]. In this study, the authors observed the energy consumption of AODV, DSR, DSDV and TORA protocols presents approximate the same value of energy consumption when the idle state consumption is considered. Then, we noticed the importance of minimizing such periods, although we have to guarantee the connectivity in the network or, at least, try to maintain the metrics in acceptable values compared to the value when all nodes are energized.

The BECA (Basic-Energy Conserving Algorithm) algorithm[7], minimize the energy consumption maintaining the radio turned off by the maximum possible period, supporting a higher latency, but having a smaller energy consumption. Another algorithm, GAF (Geography-informed Energy Conservation for Ad Hoc Routing) [6], uses the geographical positioning information (e.g., using a GPS) to support the mechanism of energy conservation.

Several works discussed the conditions what a node should put to sleep and maintaining the network connectivity using only locally information, are all based in heuristics, without a formal proof[8]. In this work, the authors show and demonstrate a theorem of necessary and sufficient conditions for a node to turn off its radio, maintaining the connectivity of the network.

In this paper, we will present the Extra algorithm to deal the problem of the coordination of the entrance in sleeping state of nodes in ad hoc network. This algorithm allows to each node in the network to make decisions in an autonomous way, based only on local information. Additionally, it can work together with any ad hoc routing protocol.

3 The Extra Algorithm

The Extra algorithm implements an energy saving mechanism in ad hoc networks. It can be implemented on any reactive protocol, demanding few changes in routing protocol. Another important point is that the mechanism only uses locally information in each node, and it is not also necessary any communication.

The energy saving procedure is based on put network nodes in sleeping state. In other words, the node radio is turned off to avoid listens in idle mode, that consumes as many energy as the transmission and the reception of messages.

The main characteristic of this energy saving mechanism, and what differs it from other proposals, is the decision to sleep and the duration of sleeping state. In this algorithm, each node will have a probability P, chosen based on heuristics, to start sleeping. In highly populated networks, where there is more active nodes to maintain network connectivity, P is high. When the density decreases, we have to take care to avoid disconnection, reducing the probability.

3.1 Algorithm Operation

During its operation, a node can be in one of three states: Active, Listening and Sleeping, as showed in Figure 1. A node starts operation sending a hello message, reporting its neighbors that it is in the Active state, i.e., the radio is on and ready to transmit. It will stay in this state during Ta seconds. If during this period it receives a data packet (as the destination or is part of a route) or a route response, the counting of Ta time is restarted. Elapsed this time, and not having received any message, the node decide, with probability P, if it will sleep or it will stay active. If the node stays active, another cycle of Ta seconds is started.

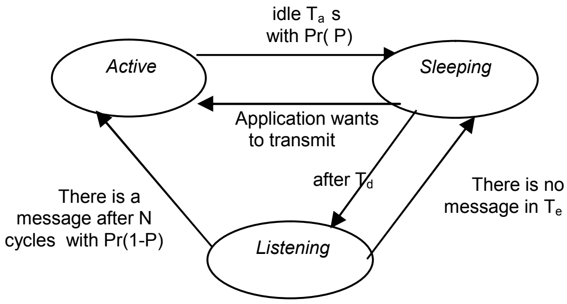

Fig. 1. Node state transition in Extra

A node stays in the Sleeping state for Td seconds. At the end of this time, the node changes its state for Listening. In this situation, the radio is turn on to listen the medium to verify if there is some message destined to him. If it is true, the node restarts the whole cycle, going to the Active state. In case there are no messages during a period of Te seconds, the node goes back to the Sleeping state. This procedure is repeated N times, after that starts the cycle. In order to control neighbors' state, each node has a cache mechanism updated when a packet is received. If, after an interval, no new message be received from a certain neighbor, its information is considered obsolete and it will be withdrawn from the cache.

3.2 Obtaining Probability P

The procedure to calculates the probability P is responsible for the decision to start the energy saving mechanism. The P value is varied to adjust the energy saving mechanism in agreement with the network conditions in the moment. For the first implementation of the algorithm, only information regarding the connectivity and energy level is considered. Simply, P should be higher when the node energy level is high and also when the number of neighbors is high. Based on this comment, some heuristics were developed.

Heuristic 1**:** its characteristic is to try to preserve the network connectivity. Then, greater value of P and, i.e., high probability to sleeping, is attributed to the nodes in high density area. Smaller value of P is attributed in low density area. The value of P is defined by the product of the number of neighbors by a constant K. However, to avoid that all the nodes in a very populated region go asleep at the same time, the P value is limited by the constant, L. In that way:

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P(h1) = K * neighbor_number ()
If (P(h1)> L), then P(h1) = L
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where neighbor_number() is the quantity of neighbors of this node. In the tests accomplished for that work the values chosen were K = 0,1 and L = 0,9.

Heuristic 2**:** its characteristic is also to try to preserve the network connectivity. In this case, the value of P will be the division of the number of active neighbors by the total number of neighbors of the node.

Heuristic 3**:** the main objective of this heuristics is to save energy when it is insufficient, in spite of the effect that can produce in the connectivity. Here, the value of P is obtained by the relation between level of current energy and the level of initial energy of the node. This heuristics can be seen as a selfish behavior. In that way:
P(h3) = 1 - current_energy() / initial_energy()
where current_energy() is a the amount of energy remaining in the node and initial_energy() is the initial energy of the node.

Heuristics 4**:** this heuristics is a combination of the heuristics 1 and heuristics 3. In other words, it try to save energy balancing the network connectivity and energy conservation in the node. Its definition is the following:
if (P(h1) = ref) and (P(h3) = ref) => P(h4) = max(P(h1), P(h3))
if (P(h1) = ref) and (P(h3) <ref) => P(h4) = P(h1)
if (P(h1) <ref) and (P(h3) = ref) => P(h4) = P(h3)
if (P(h1) <ref) and (P(h3) <ref) => P(h4) = min(P(h1), P(h3))
where P(h1), P(h3) and P(h4) are the values of P returned by the heuristics 1, 3 and 4, respectively, and ref is an adjustable parameter, whose value attributed in the implementations was 0,5.

Heuristics 5**:** has similar objective to the heuristics 4. It is the combination of the heuristics 2 and heuristics 3, also looking for save energy where it is in shortage, although trying to maintain the network connectivity. Its definition is the following:
if (P(h2) = ref) and (P(h3) = ref) => P(h5) = max(P(h2), P(h3))
if (P(h2) = ref) and (P(h3) <ref) => P(h5) = P(h2)
if (P(h2) <ref) and (P(h3) = ref) => P(h5) = P(h3)
if (P(h2) <ref) and (P(h3) <ref) => P(h5) = min(P(h2), P(h3))

Finally, in all the accomplished tests, the attributed values N, Ta, Te and Td were, respectively, 15, 4s, 0,05s and 0,5s.

4 Performance Evaluation

The Extra algorithm was evaluated through simulation methodology. The goal was validate the algorithm in a great number of ad hoc network scenarios. To evaluate the performance it was compared with basic AODV protocol, as the reference protocol, and with GAF algorithm with AODV protocol. To validate the simulation model, each metric was measured in 10 different scenarios, and the average value was presented with confidence interval of 95%.

The simulator used in the tests was the Network Simulator - ns-2, version 2.26 [9]. To create the simulation scenario, it was used the BonnMotion version 1.1 [10].

The simulation scenario used 60 nodes, moving in a random way (random way-point model) in a 1200 m by 600m area. There were defined 4 static nodes on the edges of simulation plane acting as source and sink of traffic. The nodes speed were 0 m/s, a static network used as reference, 1 m/s, equivalent to a person walking, and 10 m/s, a vehicle in urban environment (36 Km/h).

The simulation time was 900 seconds, to permit a comparison with measures accomplished for GAF algorithm in [6]. In all scenarios, we use pause times of 0, 30, 60, 120, 300, 600 and 900 seconds. The radio has 250m range, and the propagation model was the two-ray-ground. For traffic model we choose two sources and two sinks implemented in fixed nodes, with CBR traffic over UDP transport. The packet size was 512 bytes. The evaluated rates were 1 pkt/s, 10 pkts/s and 20 pkts/s, producing in each simulation rates of 2, 20 and 40 pkts/s, respectively.

The energy model chosen is based on the measures from [5] of WaveLAN 2 Mb/s board. The values obtained in this work were 1,6W for transmission, 1,2W for reception, 1,0W in idle (listen) and 0,025W in sleeping state. The initial energy attributed to each node was 500 J, enough to maintain the network working for about 450s with AODV protocol. As the simulation time was 900s, we can observe the behavior of energy saving mechanism.

4.2 Results

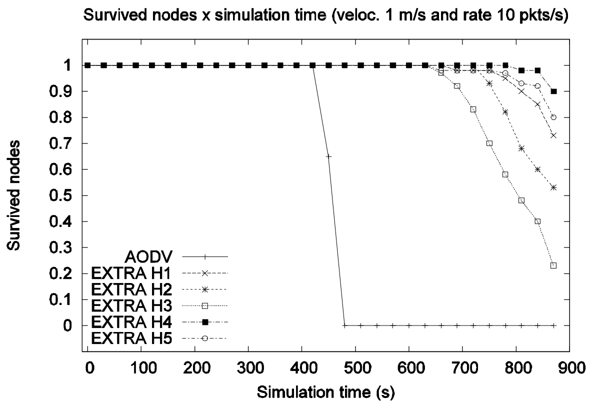

Fig. 2. Lifetime: AODV, GAF and Extra (for several heuristics)

In the results presented here none control of energy is considered for AODV protocol and GAF is assumed running with AODV. The first measure indicates the network lifetime obtained by Extra algorithm. In Figure 4 we show a comparison among the performance of AODV, GAF and all Extra heuristics. For this graph it was used a pause time of 0s, the mobile nodes had speed of 1m/s and a rate of 10 pkts/s was maintained for each fonts. On this figure, we can see the benefit of Extra algorithm.

The results of packet drop rate and percentile 90 of the delay with variation in pause time, transmission rate and node speed, for GAF and Extra (using heuristic 4) shows that Extra doesn't produce degradation in QoS metrics.

5 Conclusions and Future Works

This work presents a new algorithm, Extra, for energy conservation of nodes in ad hoc networks. As well several other algorithms, its objective is maximize the lifetime of the network, but trying to maintain the connectivity. Its operation is controlled by a function that defines when the node should enter in sleeping state. Against other algorithms, the entrance in this state happens with a certain probability. This probability is calculated in execution time and heuristics are used to calculate. We tested five different heuristics, all of them with very simple structure. As seen in the work, in all heuristics are used only information obtained locally.

As future works, it can be appraised solutions where the neighboring nodes change information about its current energy and the neighbors' density can be more explored. In that last case, for instance, it can be obtained a notion of who are (or how many are) the neighbors of the neighboring nodes. Obviously, this will cause an increase in control messages, what produces more energy consumption. However, it is possible that this negative effect is not enough to degrade the performance.

In any way, the accomplished tests show the importance of maintaining the simplicity of the control parameters. A larger number of parameters implicates in larger complexity in get information and also in the algorithm structure.

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