Adaptive power-aware metric for Mobile Ad-hoc Networks[1]

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Abstract: Energy efficiency routing is required to well use limited power resources in wireless ad hoc networks,. In this paper, we investigate problems of minimizing transmission power routing, which depends on distance between nodes, and cost aware routing, which depends on remaining battery power of nodes, as reference algorithm. As the result of our research we propose a new linear algorithm, called power-cost-aware algorithm, that uses both power consumption and cost metric depending on the battery's residual capacity, to maximize the lifetime of both network and node. Our simulation results indicate that the proposed power-cost-aware metric performs as good as minimization transmission power and cost aware metrics in sparse networks and outperforms those metrics as the network becomes more dense.

Keywords: Ad hoc networks, energy efficient

1 Introduction

A Wireless ad hoc network is a collection of wireless mobile nodes, which dynamically form a temporary network, without using any existing network infrastructure or centralized administration. Current typical applications of wireless ad hoc network include battlefield coordination and on site disaster relief and management.

Wireless ad hoc network is becoming increasingly popular in the communications research due to the projected demand for and easily deployable high-speed connections. Since this type of networks consists of sets of mobile nodes that have batteries as sources of power, energy becomes a scarce resource. In addition to high error rates, constantly varying channels and limited bandwidth, a new constraint is imposed, which is limited energy supplies. One of the objectives of projecting wireless ad hoc networks is to obtain high throughput with optimal transmission power.

In this paper we concentrate on conservation of power in wireless ad-hoc networks since most existing routing algorithms do not consider energy efficient transmission in their routing decisions. The power saving routing algorithm is based on using either energy consumption or cost-aware metrics. When we use only minimal energy consumption algorithm, it will always route messages over the path that needs minimum transmission power. This may not always be advantageous in case of overall network performance because this path will usually be multi-hop path and hence occupy more network resources. Energy consumption metric does not consider residual battery power at nodes. Therefore, it has impact on node's lifetime by preferring some paths to the others and thus overusing the energy resources of a small set of nodes in favor of other nodes.

Cost-aware metric is based on residual battery power at nodes and attempts to extend the lifetime of node. It assigns high cost to nodes with low residual battery power and low cost to nodes with high reaming battery power. Thus, the possibility of using nodes with lower remaining battery is reduced. Cost-aware metric results in favoring links that are not heavily utilized and consist of nodes that have high residual capacity. Cost-aware metrics assume that nodes transmit packets in same power level. So, it does not optimise transmission power for a packet.

In this paper, we propose a new power-cost-aware algorithm in order to increase lifetime of both network and node. Minimal energy consumption algorithm can minimize the total power consumption for routing the message from source to destination. Cost-aware algorithm is to extend node's lifetime by distributing the traffic over all possible paths. We tried to find an optimal solution by employing both algorithms by adding weight factors that are dependent on the battery's remaining capacity. The proposed metric employs a unique formula throughout the

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whole duration of the process and is based on normalization of functions.

The rest of this paper is organized as follows. In the next section (section 2), we present a short overview of the previous work that has been done in this field. Section 3 presents our system model along with imposed constraints and assumptions. And then, we precisely define the problem and the proposed metric in section 4. In section 5, we present the performance comparison results. Section 6 is our conclusions.

2 Overview of previous work

Most of routing protocols use hop number or delay as metric for paths computation. However some work has been done in energy efficient routing. This section gives an overview of most relevant works in this area.

2.1 Minimal energy consumption algorithm

In [2] Heizelman, Chandrakasan and Balakrishnan proposed an energy efficient routing protocol for wireless microsensor networks, where nodes are fixed and known to all nodes. They used a simple signal attenuation radio model for power consumption computation. Both transceiver and receiver consume E_0 to transmit one bit between them. Transceiver should consume further E_1d^2 to allow signal to arrive at receiver at distance d. Therefore the normalized power needed to transmit and receive a bit at distance d is $u(d)=d^2+2E$, where $E = E_0/E_1$. They propose to utilize 2-level hierarchy of forwarding nodes, where sensors form clusters and elect a random cluster head, which forwards transmissions from each sensor within its own cluster. This scheme is shown to save energy under certain conditions.

In [3], Rodoplu and Meng considered a general model represented as $u(d)=d^{\alpha}+c$ to estimate normalized power consumption, where d is the distance between two nodes, α and c are some constants that can be measured by physical experiments. The proposed power-aware algorithm runs in two phases. In the first phase each node searches for its neighbors and chooses those neighbors for which direct transmission requires less power than if intermediate nodes were used. In the second phase each nodes runs a distributed loop free non-locked Bellman-Ford shortest path algorithm using power consumption as the "distance" and calculates the shortest path for each attainable node. Rodoplu and Meng used $u(d)=d^4+2*10^8$ in their experiments.

In [5], Stojmenovic and Lin generalize the model proposed by Rodoplu and Meng in [3] by assuming that the power needed for transmission and reception of a bit is $u(d)=ad^{\alpha}+bd+c$ which includes models described in [3] and [2], which is represented as $u(d)=e+(1+d)^2$, where d is the distance between nodes and e is a constant that depends on the kind of equipment. They use GPS to provide location information to nodes. A localized routing algorithm is introduced to select shortest weighted path. The authors also prove this routing algorithm is loop-free.

2.2 Cost-aware algorithm

Protocol proposed in [4] is involved in solving the problem of energy critical nodes and the proposed solution maximizes the life of all nodes in the network by selecting paths on which nodes with depleted energy reserves do not lie on many paths. They propose to use function $f_i(x_i)$, which denotes the node i' s reluctance to forward packets and x_i represents the total energy expanded by node i. The less residual power, the higher value function f_i gives. After studying batteries discharge curve, as a particular choice for f the authors have two solutions based on measured voltage z_i. The first one is to define f_i as $f_i(z_i) = 1/(z_i-2.8)$. And the second one is to define the function as $f_i(z_i) = 1/(1-g(z_i))$ where $g(z_i)$ is the normalized remaining lifetime (or capacity) of the battery. This ensures that the cost of forwarding packet is tied in closely with the power resources deployed in the network. The algorithm works in the way which minimizes the sum of $f(x_i)$ for nodes on the desired path. The authors suggest that this metric may not be used for routing at all times. They propose to use shortest-hop routing while energy resources are higher than a certain threshold. When they fall below the threshold they suggest power-aware metric.

3 System model and Problem formulation

In this section, we present the system model and an overview of our proposition.

We consider a network consisting of N nodes randomly deployed over a given area. We assume that all nodes may transmit at any power level $P \leq P_{max}$. All nodes that want to take part in a certain session must have residual capacity that is larger than 10% of maximal battery capacity. Otherwise the node is considered to be *logically dead* for the rest of the network. It cannot forward packets any more, but it can receive packet form the network. A node is *physically dead* when it has no battery. We also assume that all nodes keep track of their residual capacity at all times. Also, the following assumption is used in the remaining part of the paper: if the "distance" of link *(i,j)* is denoted as $D_{i,j}$, the "distance" of a path that consists of N nodes will be given by:

$$DP = \sum_{i \leq N}^{i=1} D_{n_i n_{i+1}} \tag{1}$$

Most of algorithms proposed so far are either minimal energy consumption per packet and thus have the role to minimize the total power needed to route a traffic packet, or cost-aware where the goal is to extend nodes worst case lifetime. However, minimal energy consumption algorithms do not take into account the residual capacity of nodes, which decreases with time and decreases faster when the traffic through the node is higher. Using minimal energy consumption algorithm we may come to the point when some paths are preferred to the others and nodes that are found on those paths drain out all their energy very fast and die within a short period of time. On the other hand, when only cost-aware algorithm is used the main consideration is to minimize the cost of routing, not taking into account the power consumed during transmissions.

The solution that we propose consists of using the algorithm that combines both energy consumption (G) and cost-aware (C) metrics and it also adds the weight factors for cost-aware (W_C) that depends on nodes residual capacity. So, the "distance" from node i to node j, $D_{i,j}$, in our proposition can be defined as $D_{i,j} = G(d) + W_c(x_i)C(x_i)$, where d is the distance between node i and j, x_i is the residual battery at node i. Thus we encourage usage of paths that consist of nodes that have residual capacity that is larger than some predefined threshold. The goal of applying both energy consumption and cost-aware algorithms is to minimize the total power needed and at same time to do the best to avoid nodes with short battery lifetimes. We propose 4 different battery residual capacity ranges in which cost weight factor (W_C) changes:

battery power is in the range of 100%-80% of full battery capacity and energy consumption part (G) is much more important than cost-aware part (C). In this period there is no need for using cost-aware metric since node has enough energy to route every message;

battery power is in the range of 80%-50% of full battery capacity, battery may be considered as *mature*. In this case G and C should be in the same range and we need to adjust the weight factor W_C so that G and C are comparable. In this period most of nodes that are on preferred paths have mature batteries and hence have need for using both power and cost aware algorithms in order to prolong the lifetime of the network and increase time to network partition by assigning higher costs to paths that consist of nodes with lower power.

battery power is in the range of 50%-10% of full battery capacity and battery is considered to be *old* and G <<C. In this case, nodes have low power reserves and thus the cost-aware part has much higher weight than the power-aware, which is nearly negligible in this case. This is also accomplished by using the appropriate weight factors that give advantage to the cost-aware metric.

battery power is lower than 10% of full battery capacity and battery is considered to be *dead* for the rest of the network because it cannot forward any more messages.

4 Metric

In this section we define variables that are going to be used in the simulations.

4.1 Minimal energy consumption metric

To define energy consumption part of the metric we first need to define the function *G*. We define that P_{ij} is the estimated minimal power at which node j can successfully receive the packet sent by node i. The function *G* is the ratio between P_{ij}, plus a constant E and a standard power level, P_b. We define the function *G* as:

$$G_{ij} = (P_{ij} + E)/P_b \quad (2)$$

where E stands for the power used for packet processing and reception. The interval of P_{ij} should be between P_{max}, which is defined by radio interface and P_{min}, which is the minimum power needed for the transmission. For normalizing power, we use the value P_b that could be 1mW for example.

To get P_{ij}, we can use this procedure. Node i sends hello message with full power P_{max}. Its neighbor, node j, receives this hello message and calculates the difference between receive power level and the minimum power level for correct reception, ΔP. Then node j tells node i ΔP in its hello message or other routing messages. So that node i can estimate that $P_{ij} = P_{max} - \Delta P$.

4.2 Cost-aware metric

Here we discuss how to calculate cost of a node based on residual battery capacity $x_i=g(z_i)$, where $g(z_i)$ is normalized to be in the interval [0,1][2]. The aim is to have a cost near to zero when node' s battery is full and have a large value when node' s battery is low. We define C_i [3] as:

$$C_i = 1/(x_i + 0.001) \quad (3)$$

4.3 Power-cost-aware algorithm

There are two possible ways to combine power and cost aware metrics, product or sum of two metrics. The sum is more reasonable, where node cost and power consumption are both looked as link weight and taken into account in shortest path selection. Therefore the formula to calculate the weight of link from node i to node j is:

$$D_{ij} = G_{ij} + W_c(x_i)C_i \quad (4)$$

5 Performance analyze

In this section, we implement power-cost-aware algorithm and analyze its performance by comparing with other 3 metrics (minimal energy consumption, cost-aware and number of hop)

5.1 Simulation model

The radio interface of the simulations used characteristics similar to Lucent' s WaveLAN with a nominal bit-rate of

[2] The measured voltage of battery z_i can be read directly. Node can get residual capacity by using battery discharge curve.

[3] Adding 0.001 into formula is to prevent C_i become too large when x_i tends to zero

2Mb/sec and P_{max} = *281mW* for a maximal radio range of 250 meters. The signal propagation model is same as that in ns2 [1]. This model uses Friss free space attenuation equation at near distances and an approximation to Two ray Ground at far distance. We introduce a power control mechanism, which permits a node to send a packet with $P_t = L*RXThresh \leq P_{max}$, where L is signal attenuation at distance *d*, RXThresh is the receive threshold at receiver. which is defined in radio interface. Each node has a battery budget. Transceiver and receiver consume 1mW for packet processing. When a packet passes a node, the node sends the packet to the next hop, and at the same time, it decreases the energy used for forwarding this packet from its battery budget. There are two unicast CBR (continuous bit-rate) traffic. Sources generate 40 data packets of 512 bytes per second until the end of the simulation. So, the lifetime of network reflects the throughput of the network.

In the simulations, we use random topology graph with 10 nodes to 100 nodes without network partition. The random topology graphs are generated as follows. Firstly, we randomly create a topology with 10 nodes distribute in 1000m*1000m. Then, we arbitrarily add ten nodes to the 10-node graph to get a 20-node graph. Adding another 10 nodes into 20-node graph, we get 30-node graph. Continuing this procedure, we create 100-node graph. This treatment guarantees number of paths augment when network becomes denser. Because in this paper we only evaluate the performances of different metrics, we do not account for mobility. The network is considered dead when the topology is partitioned due to node' s death.The simulation stops as soon as the network is dead.

In the simulation, different metrics have effect only on the weight of links between nodes. Nodes use distance vector based on distributed Bellman-Ford algorithm as routing protocol. The routing protocol is a little modified according to section IV to help nodes estimate transmission power consumption. We run simulations for 4 algorithms:

- shortest-path algorithm (which use hop-number as weight);
- minimize energy consumption algorithm (which use transmission power as weight);
- cost-aware algorithm (which use cost as weight) and
- power-cost-aware algorithm (which use power-cost as weight).

Assume that packet j traverses nodes n_1, ..., n_k, where n_1 is the source and n_k the destination. Therefore, for shortest-path algorithm, the path weight becomes: $e_j = k-1$;

For minimal energy consumption algorithm, the path weight becomes:

$$e_j = \sum_{i=1}^{k-1} G_{n_i n_{i+1}} = \sum_{i=1}^{k-1} (P_{n_i n_{i+1}} + E) \big/ P_b \qquad (5)$$

where P_b=*1mW* and *E=2mW*. For cost-aware algorithm, the path weight is:

$$e_j = \sum_{i=1}^{k-1} C_{n_i} = \sum_{i=1}^{k-1} 1\big/(x_{n_i} + 0.001) \qquad (6)$$

And for power-cost-aware algorithm, we choose a linear formula to calculate $W_c(x_i)$ to realise the idea as described. From equation(5), we can get $2 \leq G_{ij} \leq 283$. When there is more than 80% of residual power ($0.8 \leq x_i \leq 1$), we should have $W_c(x_i)*C(x_i) << 2$, so that the algorithm behaves like minimal energy consumption algorithm; when there is more than 50% of residual power ($0.5 \leq x_i \leq 0.8$), the value of cost part of metric varies in the same interval as G_{ij}, that is $2 \leq W_c(x_i)*C(x_i) \leq 283$. So we have $1.6 \leq W_c(x_i) \leq 141.5$. When the residual power fall below 50% ($x_i < 0.5$) the algorithm switches to cost-aware. The formula is:

$$W_c(x_i) = \begin{cases} 375 - 466 * x_i & x_i < 0.8 \\ 0.05 & x_i \geq 0.8 \end{cases} \qquad (7)$$

The path weight in power-cost-aware metric becomes:

$$e_j = \sum_{i=1}^{k-1} C_{n_i} + G_{n_i n_{i+1}} \qquad (8)$$

Two key performance metrics were evaluated:

(i) Network life time - the time when no route could be found for one of two source-destination pairs, that also means the network was partitioned because of node' s death;

(ii) First node death time - the moment when the first node used out of its power budget.

5.2 Simulation Results

For the network lifetime, the figure 1 shows that minimal energy consumption and power-cost-aware algorithms have almost the same performance in small networks. As the network size grows, the power-cost-aware algorithm and the minimal energy consumption algorithm outperform other two algorithms. That is because minimal energy consumption algorithm optimises energy consumption in air interface per packet. Therefore a node could forward more packets than that of cost-aware and shortest path algorithm. The power-cost-aware algorithm has better performance than the minimal energy consumption algorithm. This may be explained with the fact that two traffic flows intersect at central area. One traffic has path could bypass the central area but with higher total transmission power, while the other traffic does not have. The minimal energy consumption algorithm forces both traffic flows to use path going through central area, which results in the network partition. In power-cost-aware algorithm, traffic is switched to other path to bypass the central area before overusing nodes. Hence both two traffic flows can last longer than that in the minimal energy consumption algorithm.

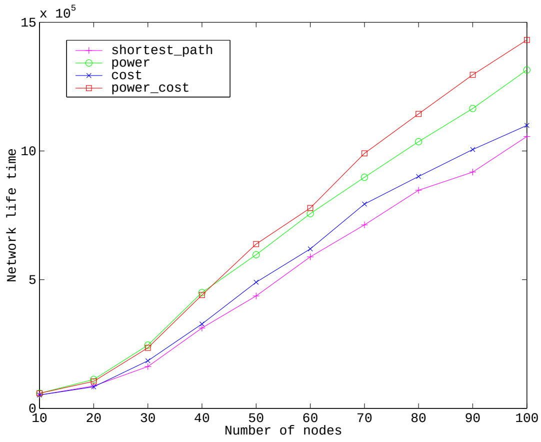

Figure 1 : Network life time

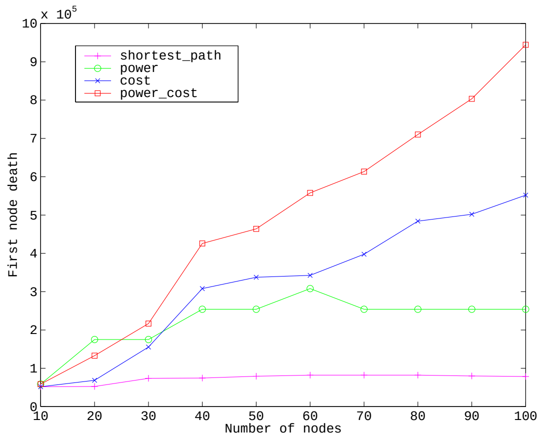

Figure 2 : First node death time

The figure 2 shows the comparison of the first node death time. The results show that while the network is sparse, the performance of all 4 algorithms is about the same because there are not many paths to be chosen from. When the network density grows, the power-cost-aware algorithm will outperform the cost aware algorithm. The minimal energy consumption algorithm and the shortest path algorithm behave far worse than other algorithms because these two algorithms continue to use same set of nodes until battery power of one of those nodes falls below the threshold. The minimal energy consumption algorithm saves power for transmission so its performance is better than that of the shortest path algorithm. The more paths between sources-destination pairs, the better performance the cost-aware metric can give. The minimal energy consumption part of power-cost-aware metric can improve the performance of cost-aware part by augmenting the throughput of a node. So, the power-cost-aware algorithm gives the best performance among four algorithms.

The power-cost-aware algorithm takes the advantages of the cost-aware and the minimal energy consumption algorithms. When nodes have nearly the same residual battery power, this metric gives the smallest transmission power path to increase throughput of nodes. While the difference of remaining power level of nodes becomes significant, this metric tries to switch traffic to another path in order to avoid overuse of certain nodes. That' s why power-cost-aware algorithm has the best performance in two criteria.

6 Conclusions

In this paper we have proposed a new metric, power-cost-aware metric, to maximize the lifetime of mobile ad hoc network and mobile nodes especially in central area. The traditional metrics such as hop-count, minimal energy consumption and cost-aware do not consider the lifetime of network and mobile nodes at same time. We believe it is important to switch between point of view of network and point of view of node level so that the throughput of network can be improved and nodes will be fairly used. Consequently, the lifetimes of both network and nodes can be prolonged. The performance results demonstrated that the proposed power-cost-aware metric outperforms both power and cost aware metrics as the network becomes larger.

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