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Adaptive power-aware metric in mobile Ad hoc networks

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Abstract

Mobile Ad hoc networks consist of sets of mobile nodes that have batteries as sources of power. In addition to high error rates, constantly varying channels and limited bandwidth, a new constraint is imposed: limited energy supplies. Due to the limited transmission range of wireless network interfaces, multiple hops may be needed for nodes to exchange data across the network. Using multiple hops may lead to over-using some nodes in the network which leads to early node death and shorter network lifetime.

At this point of our research we concentrated on conservation of power in wireless ad-hoc networks by applying various metrics. Since one of the objectives of projecting wireless ad hoc networks is to obtain high throughput with optimal transmission power with lowest cost we exploited the best properties of power- and cost-aware routing to derive the new power-cost aware algorithm. The new power-cost aware algorithm significantly increases lifetime of nodes in the network and increases the overall lifetime of mobile network.

I Internship objectives

The objective of this internship was to:

- propose solutions for improving of existing MRDC (Multicast Routing with Dynamic Core) protocol;
- Propose a new routing or power-efficient algorithm.

The main part of the work was concentrated in the area of power-aware routing. Significant part of time was spent in research of performance of existing routing protocols. The final work was in the area of adaptive power-aware metrics in ad hoc networks. One part of the work was dedicated to implementation of power-aware metric in routing protocols. However, we were confronted with many arising problems in that area and concentrated on finding optimal algorithms in the first phase of our research. The proposed algorithm gave satisfying performance and the next step is to implement power control in routing algorithms.

II Introduction - Properties of Ad hoc networks

Ideally we expect an ad-hoc routing protocol to have following properties:

- it should be distributed in order to increase reliability. Where all nodes are mobile, it is unacceptable to have a centralized routing protocol. Each node should be intelligent enough to make routing decisions using other collaborative nodes. A distributed but virtually centralized protocol is a good idea;
- it should assume routes as unidirectional links. Wireless medium may cause a wireless link to be opened in one direction only due to physical factors. It may not be possible to communicate bidirectionally. Thus a routing protocol must be designed considering unidirectional links also;
- it should be power efficient. Protocol should consider everything to save power, if power is very important, for such as palm computers, or other small battery powered devices. Protocol should distribute load considering this, otherwise shut-off nodes may cause partitioned topologies which may result in unaccessible idle routes. Thus it must consider multiple routes.
- it should consider its security. Ad-hoc routing protocols lack security. A wireless medium is very vulnerable. At physical layer, denial of service attacks may be avoided using coded or frequency hopping spread spectrum, however at routing level, we need authentication for communicating nodes, non-repudiation and encryption for private networking to avoid routing deceptors.

- Hybrid protocols can be preferred. A protocol should be much more reactive than proactive to avoid protocol overhead.
- A routing protocol should be aware of Quality of Service.
  It should know about the delay and throughput for a source destination pair, and must be able to verify its longevity so that a real-time application may rely on it.

II.1 Mobile Ad hoc networks

A Mobile Ad hoc network (MANET) 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 MANETs include battlefield coordination and on site disaster relief and management. The links of the network are dynamic and are based on the proximity of one node to another node. These links are likely to break and change as the nodes move about the network. Because of the temporal nature of the network links, and because of the additional constraints implied by mobile nodes, such as limited bandwidth and power, conventional routing protocols are not appropriate for ad-hoc mobile networks.

Some of the main restrictions of MANETs include:

- Dynamic topology
  Nodes are mobile and can be connected dynamically in an arbitrary manner. Links of the network vary with time and are based on the proximity of one node to another node. They are also subject to frequent disconnection due to node's mobility;
- Bandwidth constrains
  Wireless links have significantly lower capacity than the wired links; they are affected by several error sources that result in degradation of the received signal and high bit error rate in the range of 10-4 and 10-5;
- Energy constrained
  Mobile nodes rely on battery power, which is a scarce resource; the most important system design criteria for optimization may be energy conservation;
- Limited physical security
  Mobility implies higher security risks than static operation because portable devices may be stolen or their traffic may cross insecurely wireless links. Eavesdropping, spoofing and denial of-service attacks should be considered.

A mobile ad hoc network includes several advantages over traditional wireless networks, including: ease of deployment, speed of deployment, and decreased dependence on a fixed infrastructure. MANET is attractive because it provides an instant network formation without the presence of fixed base stations and system administrators. MANETS are viewed as suitable systems which can support some specific applications including:

- Personal communication like cell phones, laptops, PDA;
- Group communication such as communication set-up in exhibitions, conferences, presentations, meetings, lectures;
- Military, emergency, discovery, civil communication, ...

II.2 Secure routing

There are several issues that arise in the area of security of ad hoc networks such as:

- Availability
  Routing protocols may be open to denial-of-service attacks, since any mobile node would try to answer any query of an hostile node. It is possible to flood all nodes, and decrease routing protocol performance by misusing protocol messaging. Reactive protocols are more vulnerable than proactive ones, on the other hand they can recover faster.
- Confidentiality
  All queries and neighborhood discoveries are done, trusting whomever the routing protocol talks to. There are no authentication methods embedded in routing protocols, except IMEP.
- Integrity
  This guarantees that the message being forwarded is never corrupted intentionally or unintentionally. Latter case is assumed to be taken care by the MAC standard. First case requires an authentication method which could be checked by all neighbor and route nodes. Thus ignoring such packets can slow down denial-of-service attacks.
- Authentication
  Authorization system is required, to ensure that the peer is the real one, and not masquerading.

III Overview of routing protocols

In contrast to infrastructure based networks, in ad hoc networks all nodes are mobile and can be connected dynamically in an arbitrary manner. All nodes of these networks behave as routers and take part in discovery and maintenance of routes to other nodes in the network. Ad hoc networks are very useful in emergency search-and-rescue operations, meetings or conventions in which persons wish to quickly share information, and data acquisition operations in inhospitable terrain. Proposed protocols for those networks can be divided into two categories: table-driven and on-demand routing based on when and how the routes are discovered. In table driven routing protocols consistent and up-to-date routing information to all nodes is maintained at each node whereas in on-demand routing the routes are created only when desired by the source host. Table driven routing protocols can be divided into:

- Dynamic Destination-Sequenced Distance-Vector Routing Protocol (DSDV)
- The Wireless Routing Protocol (WRP)
- Global State Routing (GSR)
- Fisheye State Routing (FSR)
- Hierarchical State Routing (ZHLS)
- Zone-based Hierarchical Link State Routing Protocol (CGSR)
- Clusterhead Gateway Switch Routing Protocol (CGSR)

On-demand routing protocols can be divided into:

- Cluster based routing protocols (CBRP)
- Ad hoc On-demand Distance Vector Routing (AODV)
- Dynamic Source Routing Protocol (DSRP)
- Temporally Ordered Routing Algorithm (TORA)
- Associativity Based Routing (ABR)
- Signal Stability Routing (SSR)

We conducted our research in areas of Zone-based routing and Ad hoc On-demand Distance Vector Routing. Some solutions for power-aware routing were found, but there were some unsolved problems that need further work. Routing protocols are very vulnerable since they can reveal topology information. Listening few DSR messages in promiscuous mode gives valuable information. A GPS based routing algorithm may give exact node locations. ZRP would inform about number and size of enemy regions. Typically, an attacker can playback routing information and easily collapse the network. Denial of service attack could break whole communication between two networks. Therefore protocols which are capable of finding multiple paths ie., AODV, TORA, DSR, have an advantage.

IV Introduction to power-efficient algorithms

Since MANETs consist 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: limited energy supplies is imposed. One of the objectives of projecting wireless ad hoc networks is to obtain high throughput with optimal transmission power with lowest cost. In this paper we concentrate on conservation of power in wireless ad-hoc networks. The power saving algorithm is based on using both energy consumption and cost aware algorithms. When we only minimize energy-consumption algorithm it will always route messages over the path that needs minimum power for transmission. 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. Some metrics have the negative impact on node's lifetime by preferring some paths to the others and thus over using the energy resources of a small set of nodes in favor of other nodes. Also, since this metric doesn't have automatic loading balance capacity, there is a possibility that some paths in the network are heavily utilized and act as bottlenecks while the others consist of lightly used nodes. Another negative impact is faster network partition as a consequence of early node death. When we use only cost-aware metric it results in favoring links that are not heavily utilized and consist of nodes that have high residual capacity [1]. It tries to spread the offered traffic evenly over all paths. Since most existing routing algorithms do not consider the power consumption and cost in their routing decisions we propose a new power and cost aware algorithm in order to increase lifetime of the network. When algorithm that is based on minimizing energy consumption is used alone, the goal is to minimize the total power that is needed for routing the message from source to destination. In case of using only cost-aware algorithm, the main goal 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 whole duration of the process and is based on normalization of functions. The rest of the paper is organized as follows. First we present a short overview of the previous work that has been done in this field, then we present our system model along with imposed constraints and assumptions and precisely define the problem and the proposed metric. Finally, we present the results and conclusions about the proposed metric performance.

V Overview of previous work

In this section we present some relevant work that has been done in this area.

[1] capacity means node's residual capacity in the rest of the text

V.1 Cost-aware algorithm

Protocol proposed in [1] 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 cost and x_i represents the total energy expanded by node i. As a particular choice for f the authors have two solutions. The first one is to define f_i as battery's remaining lifetime and the second one is to define it as

$$f(x_i) = \frac{1}{1 - g(x_i)} \ , \tag{1}$$

where x_i is measured voltage and $g(x_i)$ 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 suggest to use shortest-hop routing while energy resources are higher than a certain threshold. When they fall below the threshold they suggest to use power-aware metric.

V.2 Minimum energy consumption algorithms

In [2], Rodoplu and Meng considered the model with $u(d) = d^4 + 2 * 10^8$ and a general model represented as $u(d) = d^{\alpha} + c$. 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 destination runs a loop free non-locked Bellman-Ford shortest path algorithm using power consumption as the cost metric. Each node broadcasts its cost to its neighbors and each node calculates the minimum cost it can attain given the cost of its neighbors. In [3], Stojmenovic and Lin use GPS to provide location information to nodes that allows nodes to use the least transmission power for reception. Each node is able to make decisions which neighbors to forward packets to based on the location of itself, its neighboring nodes and some additional information that i constantly provided. Also destination locations are needed in case of routing.It is assumed that every node contains the geographic location of all other nodes in the network in its routing table. They generalize the model proposed by Rodoplu and Meng in [2] by assuming that the power needed for transmission and reception of a signal is $u(d) = ad^{\alpha} + bd + c$ which includes models described in [2] and [3]. $u(d)$ is referred to as the weight of the edge and the algorithm is referred to as SP-power algorithm.

VI System model and Problem formulation

In this section we present the system model and the overview of our proposed solution.

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 20% of maximal battery capacity. When the node has capacity that is less than 20% of initial capacity, it is considered to be $logically\ dead$ for the rest of the network. It cannot forward packets any more, but it can send the packets to the rest of the network. Technically, the node is considered to be logically dead when it still has enough energy to send packets and enough energy to forward only one packet and after that it is considered to be $physically\ dead$. The only packet that the logically dead node can forward is the packet that is marked as a high priority packet and this node is the only node that can forward the packet to destination node. We also assume that all nodes keep track of their residual capacity at all times and have a large number of bandwidth resources. Also, the following assumption is used in the remaining part of the paper: if the cost of using link (i, j) is denoted as $D_{i,j}$, the cost of using a path n that consists of N nodes will be given by

$$C_n = \sum_{(i,j)\in n} D_{i,j} \tag{2}$$

Most of algorithms proposed so far either minimize 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 node's worst case lifetime. However, minimizing energy consumption does 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 power-aware 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 proposed solution consists of using the algorithm that combines both energy consumption (G) and cost-aware (C) algorithms and it also adds the weight factors that depend on node's residual capacity. Thus we encourage usage of paths that consist of nodes that have residual capacity that is larger than some predefined threshold. When node's residual capacity reaches 20% of the initial capacity the node cannot take part in any more transmissions and is considered dead for the rest of the network. The only situation when it can take part in transmission is in case when a high priority message arrives and it is the only node that can receive it. The goal of applying both energy-consumption and cost-aware algorithms is to minimize the total power needed and to avoid nodes with short battery lifetimes at the same time. We propose 4 different battery's residual capacity ranges in which power weight factor (W_G) and cost weight factor (W_C) change:

- battery power is in the range of 100%-80% of full battery capacity and energy consumption part (G) is far more important than cost-aware part (C): $G \gg C$. This is the initial case in every network. In this period all batteries have their full power available and there is no need for using cost-aware metric since every node has enough energy to route every message. However, this is the period when some routes start being preferred to the others and some nodes (most often the central ones) are preferred to the others and hence have faster decrease in residual power;

- 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 factors W_G and 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%-20% of full battery capacity and battery is considered to be old and $G \ll C$. In this period most of nodes have low power reserves and thus the cost-aware algorithm has much higher weight than the power-aware, which is 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 20% of full battery capacity and battery is considered to be $dead$ for the rest of the network because it cannot transmit any more messages. The only case when it takes part in routing is when a high priority message arrives and the only path from source to destination is through the given node (the nature of that message will be discussed in the next step, when we will implement this power- and cost-aware algorithm in a routing protocol).

VII Metric

In this section we define variables that are going to be used in the simulations. Since we are using both capacity and power to define our metric, we need to normalize both variables in order to make them comparable. for normalizing power we use the value P_0 that represents the minimal power that a node needs to transmit a message to another node. For normalizing capacity we use the value C_{max}, that represents the maximal capacity of the node (capacity that node has in the beginning of the transmission).

VII.1 Minimization of energy consumption

To define energy consumption part of the metric we first need to define the value G that represents the ratio between current power level of the node and the minimal value of power, P_b. We define the variable G as:

$$G_{ij} = \frac{P_t}{P_b} \tag{3}$$

where P_t is the minimal power at which node j can successfully receive the packet sent by node i and the range of P_t should be between P_{max} and P_b.

VII.2 Cost-aware metric

As previously mentioned in introduction, the main problem in metric that minimizes energy consumption is the possibility of giving advantage to certain paths compared to the others, which results in early power depletion of nodes that lie on given paths, leaving many of them without further possibility to transmit or receive messages. The solution is to use cost-aware metric in addition to power-aware metric that was already proposed in some protocols. We want to construct a new algorithm that would give preference to either power or cost metric in the system, depending on the residual capacity x of the node.

$$C_i = f(\frac{x_i}{C_{max}}), \tag{4}$$

VII.3 Power-cost-aware algorithm

In defining our new power-cost-aware algorithm we take 4 approaches and compare their performance. The approaches are: shortest-path in terms of number of hops, power-aware, cost-aware metric and power-cost-aware metric. Since the main goal of our algorithm is to implement power and cost aware algorithm, we propose using a unique formula to calculate the weight of link from node i to node$j$:

$$W_{ij} = G_{ij} + C_i \tag{5}$$

VIII Performance analysis

In this section we present the simulation model, implement power-cost-aware algorithm and compare its performance with other 3 algorithms and finally analyze its performance.

VIII.1 Short overview of ns-2

NS is a discrete event simulator developed for networking research. It provides support for wired wireless networking with multicast capabilities and satellite networks. It has limitations, such as 2D terrain with two way ground reflection model is used. Simulator is written in C++, accompanying OTCL script language based on Tcl/Tk. The researcher defines the network components such as nodes, links, protocols and traffic using OTCL script. Simulator uses this script and outputs the trace at different selective layers. We used this output to calculate delays, throughput, power consumption and other metrics.

We have used simplified NS simulator to simulate ad-hoc environment.

VIII.2 Simulation model

The radio model of the simulation used characteristics similar to Lucent's WaveLAN with a nominal bit rate of 2Mb/sec and a nominal radio range of 250 meters. Traffic sources were CBR (continuous bit-rate). Sources generated 512-byte data packets per period.

The tools used for simulating the environment represent a simplified version of ns2. It's discrete event-driven. In this simulator, a node is an instance of mobile node class. All nodes are connected to an object called network. This object is in charge of distributing the packets from one node to all its neighbors (for broadcast case) or one special neighbor (for unicast case). Since the aim of simulation is to evaluate the performance of algorithm in network layer, the simulator doesn't consider the MAC layer problem but the physical layer, for radio propagation, it used Friss-space attenuation at near distance and an approximation to Two ray Ground at far distance, as ns2. If a CBR agent in a node sent periodically a traffic packet to udp agent attached in that node. At destination, a sink agent recorded the information when it received a packet.

In the simulations we used random topology graph with 10 nodes to 100 nodes. The random topology graphs were generated as follows. Firstly, we randomly created a topology with 10 nodes distributed in the area of 1000m*1000m, as shown in figure 1. Then we arbitrarily added ten nodes to the 10-node graph to get a 20-node graph. Adding another 10 nodes into a 20-node graph, we created a 30-node graph and so on until a 100-node graph is created. In this paper we only evaluated performances of different power-aware metrics and, hence, we did not account for mobility. Each node had a budget of energy to forward a packet (forwarding a packet includes processing, routing and sending a packet). When the budget for a node reaches zero, we define that node as dead for packet relaying. The network is dead when the topology is partitioned because of the node's death. Node knows the position of its one-hop neighboring nodes. That permits a node to estimate the energy consumption when it wants to forward a packet to one of its neighbors. In the simulation, different metrics only affect the weight links between nodes. nodes use link state routing to calculate the "shortest-path" to the destination. There are two source-destination pairs in the network: nodes 3 and 9; nodes 8 and 2. when a packet passes a node, the node sends the packet to the next hop on the path, and at the same time, the node decreases the energy from its budget for forwarding this packet. The simulation stops when the network is dead.

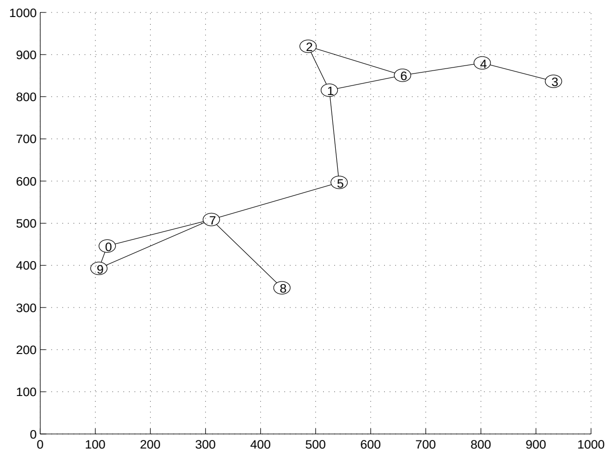

Figure 1: 10-node basic topology.

We ran simulations for 4 algorithms:

- shortest-path algorithm (in terms of number of hops);
- minimal energy consumption algorithm;
- cost-aware algorithm and
- power-cost-aware algorithm

According to the parameters of WaveLAN, we choose $P_{max} = 281mW$ and $P_b = 1mW$. 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 became:

$$e_j = k - 1; \tag{6}$$

For minimum energy consumption algorithm the path weight becomes:

$$e_j = \sum_{i=1}^{k-1} G_{n_i,n_{i+1}} \tag{7}$$

For cost-aware algorithm, the path weight becomes:

$$e_j = \sum_{i=1}^{k-1} 1.05 - \frac{x_i}{C_{max}} \tag{8}$$

For the cost-aware part of our power-cost-aware algorithm, we used the curve as shown in figure 2.

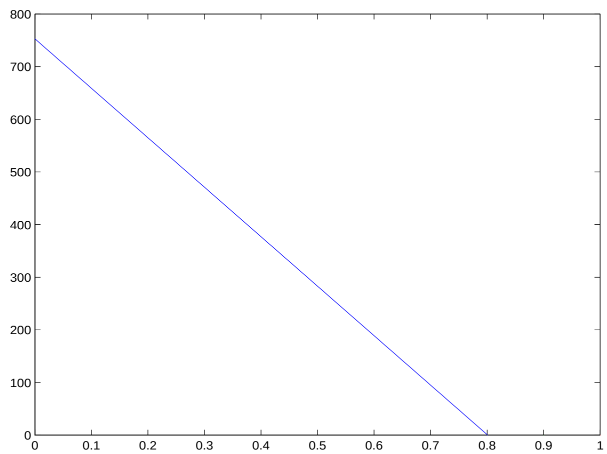

Figure 2: Cost-aware part of energy consumption and cost-aware algorithm

The idea was already described in Section 3. When there is more than 80% of residual power, the value of the cost part of metric is much smaller than minimal transmission power, so that the algorithm behaves like minimal energy consumption algorithm; when there is 50% of residual power, the value of cost part of metric is a little bigger than energy consumption part. When residual energy becomes smaller than this threshold (50%), the algorithm switches to cost-aware. The formula that represents this curve is:

$$C_i = \begin{cases} 753.0 - 940 * \frac{x_i}{C_{max}} & \text{if } \frac{x_i}{C_{max}} < 0.8; \\ 0.05 & \text{otherwise}. \end{cases} \tag{9}$$

Hence, the expression for the path weight becomes:

$$e_j = \sum_{i=1}^{k-1} G_{n_i, n_{i+1}} + C_i \tag{10}$$

Then distributed Bellman-Ford algorithm chooses the path that minimizes e_j for all packets j. Two key performance metrics were evaluated:

1. 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;

2. First node death time - the moment when the first node used its power budget.

VIII.3 Simulation results

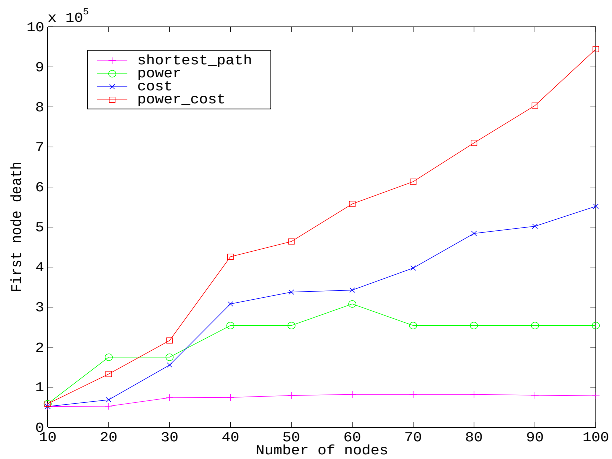

Figure 3: First node death time

For the first performance metric, the graph 4 shows that minimal energy consumption and power-cost-aware metrics have almost the same performance in small networks. As the network size grows, the power-cost-aware metric outperforms the minimal energy consumption metric and the cost-aware metric performs worse than either of previously mentioned metrics. The results show that as the network size grows, the minimal energy consumption metric behaves far worse than cost-aware and power-cost-aware metrics. On the other hand, while the network size is small, the performance of all 4 metrics is about the same. This may be explained with the fact that in the beginning of the process all nodes have maximum amount of energy and paths are not heavily utilized. As time passes, some nodes may be over used for routing, while the others will remain idle for longer intervals, due to the topology characteristics. Such an unfair utilization causes certain nodes to exhaust their energy reserves faster and be considered "physically dead" by the network faster, which leads to performance degradation and network partitioning. Cost-aware metric assigns higher costs to heavily utilized paths and that gives much better

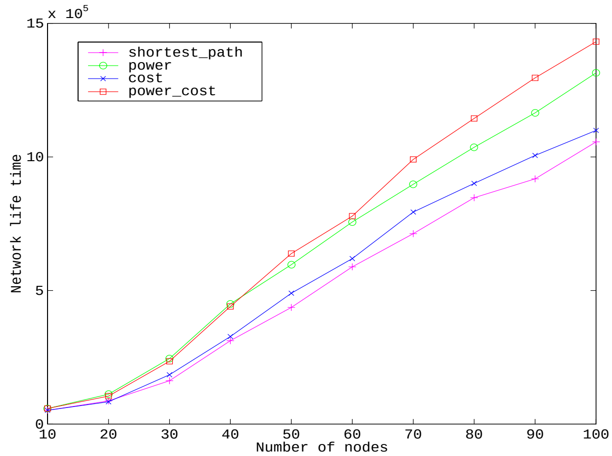

Figure 4: Network lifetime

performance than the power-aware metric. Naturally, power-cost-aware metric use both previously mentioned approaches and behaves much better in dense networks.

In the second performance metric, the results are almost the same and behave in favor of power-cost-aware metric. The simulation results also show that the power-cost-aware algorithm will outperform the energy consumption and cost based algorithms as the network becomes more dense.

Obviously, power-aware algorithm will always provide the minimum power path available, which may not always be advantageous in terms of overall network performance. A minimum power path will always consist of multiple short hops and will occupy more network resources for packet processing, which can be seen on both graphs and it may result in shorter network lifetime.

For the first performance metric, the graph 4 shows that minimal energy consumption and power-cost-aware metrics have almost the same performance in sparse networks. As the network density grows, the power-cost-aware metric outperforms the minimal energy consumption metric and the cost aware metric performs worse than either of previously mentioned metrics. The minimal energy consumption metric chooses the minimum energy consumption in air interface per packet. Therefore a node can forward more packets than that of cost-aware metric. The total energy consumption for forwarding contains also packet processing power. A minimum power path will always consist of multiple short hops and will occupy more network resources for packet processing. The cost part of power-cost-aware metric increases as number of hops increasing, that reflects indirectly the packet processing power of a path. Therefore power-cost-aware metric provides a path with the optimization of the total power consumption and node's battery, and consequently prolongs the life time of network.

The graph 3 shows the second performance metric. The results show that as the network density grows, the power-cost-aware algorithm will outperform the cost aware algorithms and the minimal energy consumption metric behaves far worse than cost-aware and power-cost-aware metrics. On the other hand, while the network size is sparse, the performance of all 4 metrics is about the same. This may be explained with the fact that in the beginning of the process all nodes have maximum amount of energy and paths are not heavily utilized. As the time passes, some nodes may be overused for routing, while others will remain idle for longer intervals, due to the topology characteristics. Such an unfair utilization causes certain nodes to exhaust their energy reserves faster and be considered ”physically dead” by the network faster, which leads to performance degradation and network partitioning. Cost-aware metric assigns higher costs to heavily utilized paths and that gives much better performance than the power-aware metric. Naturally, power-cost aware metric uses both previously mentioned approaches and behaves much better in dense networks.

The shortest-path metric always provides the minimum hop number path avaible. It cannot optimize the power consumption neither node utilization. Therefore it has the worst performance in both two graphs. We can see that the second best metric in this case of node lifetime is cost-aware metric. In case when we need to optimize the lifetime of nodes, cost-aware metric outperforms power-aware because it takes into account the residual capacity of nodes and hence uses nodes with more capacity for routing. The consequence is that nodes die more slowly than in the case of power-aware metric. In case of network lifetime power and power-cost metrics perform very similar until the network becomes larger, when power-cost metric outperforms the power-aware.

From our results we can draw the following conclusions. Both in terms of network lifetime and in terms of first node death the proposed metric outperforms the existing ones. The performance is much better in terms of node lifetime, where the proposed metric outperforms the second best one (cost-aware metric) by around 40%. In case of network lifetime the proposed metric outperforms the second best metric (power-aware) by 15%.

IX Conclusions and future work

We have proposed a new metric, power-cost-aware metric, to maximize the lifetime of mobile ad hoc network and mobile nodes 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 the same time. Our results indicate that the proposed power-cost-aware metric outperforms both power and cost-aware metrics as the network becomes larger.

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