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Dynamic Power Management in Multi Path Mobile ADHOC Networks

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Abstract- A Mobile Ad-Hoc Network (MANET) is a collection of mobile nodes (such as laptops, PDAs) forming as arbitrary networks without the support of any fixed infrastructure such as base station or access point. There is no fixed topology due to the node mobility, which results in interference, multipath propagation and path loss. Mobile nodes are constraints to battery power, computation capacity, bandwidth, and wireless channel leading to number of challenges while design routing procedures. In a mobile ad hoc network, nodes are often powered by batteries. The power level of a battery is finite and limits the lifetime of a node. Every message sent and every computation performed drains the battery. In this paper we present a case for using new power-aware metrics for determining routes in wireless mobile ad hoc networks. We present different metrics based on battery power consumption at nodes. We show that using these metrics in shortest-cost routing algorithms reduces the cost/packet of routing packets by significant percentage.

Index Terms- **MANET, Power Aware Metrics, Power Aware Routing, Route Discovery, Route Maintenance.**

I. INTRODUCTION

A Mobile network is a radio cellular network distributed over land areas called cells, each served by at least one fixed-location transceiver known as a cell site or base station. When joined together these cells provide radio coverage over a wide geographic area. This enables a large number of portable transceivers (e.g., mobile phones, pagers, etc.) to communicate with each other and with fixed transceivers and telephones anywhere in the network, via base stations, even if some of the transceivers are moving through more than one cell during transmission. Mobile networks offer advantages for both the military and the civilian world. While they were originally meant for enhancing military communications in the battlefield or in areas hit by natural catastrophes, wireless networks have found their way into civilian life. Today People are using these networks in cafes, restaurants, malls, universities, and public Gatherings, such as audio and video conferences. While wireless networks have expanded and their technology has been advanced considerably, there are still issues that need to be looked at more closely. These issues include throughput, delay, channel capacity, and power consumption. Regarding throughput and delay, the throughput and delay in wireless networks lag behind that of wired ones.[7]-[8]-[9]-[10] Power is also crucial in wireless networks, especially in mobile ad hoc networks, as it is the "fuel" that keeps the network alive. Thus, conserving power helps prolong network life. Moreover, energy conservation leads to smaller, more lightweight devices and helps reduce environmental hazards by minimizing discarded batteries [11].

A. Mobile Ad-hoc Network:

The increasing use of wireless portable devices such as mobile phones and laptops is leading to the possibility for spontaneous or ad hoc wireless communication known as Mobile Ad Hoc Networks (MANET). In contrary to infrastructure networks, an ad-hoc network lacks any infrastructure. There are no base stations, no fixed routers and no centralized administration. All nodes may move randomly and are connecting dynamically to each other. Therefore all nodes are operating as routers and need to be capable to discover and maintain routes to every other node in the network and to propagate packets accordingly. MANET may be used in areas with little or no communication infrastructure: think of emergency searches, rescue operations, or places where people wish to quickly share information, like meetings etc. fig.1. A mobile ad hoc network (MANET) [12] is an autonomous system of mobile routers connected by wireless links, the union of which forms an arbitrary graph. The routers are free to move randomly and organize themselves arbitrarily; thus, the network's wireless topology may change rapidly and unpredictably. Such a network may operate in a stand-alone fashion, or may be connected to the larger Internet. In general, MANET is formed dynamically by a set of mobile nodes that are connected via wireless links without using an existing network infrastructure or centralized administration. These nodes are free to move randomly and organize themselves arbitrarily thus the topology of the network may change rapidly and unpredictably.

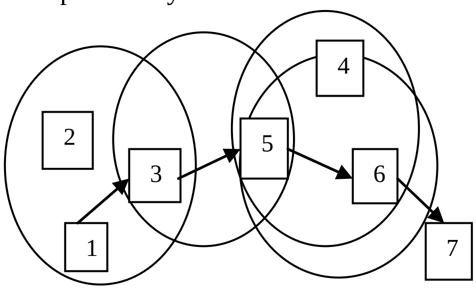

Fig.1 Communication between Nodes in Infrastructure-Less Networks

MANET is an infrastructure-less network because it does not require any fixed infrastructure support such as a base station for its operation. Nodes participating in the

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mobile ad hoc networks manage routing without the use of existing infrastructure; these mobile nodes will typically have limited transmission range, which mean that packets might have to forward to another nodes to reach its destination. Fig.2 below illustrate how the node A uses a route through node D, B, E to get Data to node C, because C is out of node A transmission range.

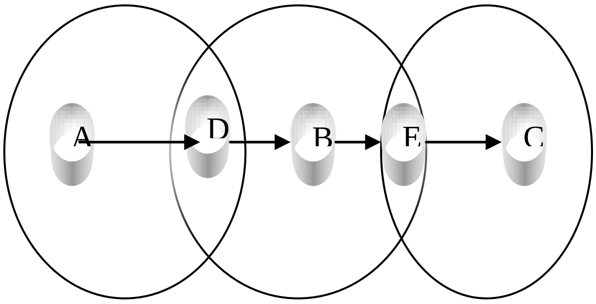

Fig.2 Communication between node A and C via intermediate node D, B, E

II. POWER AWARE ROUTING IN MOBILE AD-HOC NETWORKS

Power conservation in wireless mobile ad hoc networks is a critical issue as energy resources are limited at the electronic devices used. Power-aware routing protocols are essentially route selection strategies built on existing ad hoc routing protocols. A survey is conducted on a series of power-aware routing protocols around energy efficient metrics, as discussed in subsequent sections:

A. Power awareness in Routing:

Mobile ad hoc networks (MANETs) are characterized by dynamic topology, limited channel bandwidth and limited power at the nodes. Because of these characteristics, paths connecting to the source nodes with destinations may very unstable and go down at any time, making communication over ad hoc networks difficult. Energy efficiency is the limiting factor in the successful deployment of MANETs, because nodes are expected to rely on portable, limited power sources. Moreover, energy conservation is extremely challenging in multi-hop environments, where the mobile nodes should also consume energy to route packets for other nodes and to guarantee the connectivity of the network.

B. Approaches to Power Awareness in Routing:

In a mobile ad hoc network nodes are often powered by batteries. The power level of a battery is finite and limits the lifetime of a node. Every message sent/received and every computation performed drains the battery. The main goal of power awareness routing in an ad hoc network is to optimize the lifetime of the nodes and network. In mobile ad hoc networks the power consumption of a node can be divided according to functionality into:

- The power utilized for the transmission of a message;
- The power utilized for the reception of a message;
- The power utilized while the system is idle.

This suggests two complementary levels at which power consumption can be optimized in wireless communication:

- Minimizing power consumption during the idle time by switching to sleep mode; Known as **Power Management**;
- Minimizing power consumption during communication, that is, while the system is transmitting and receiving messages; known as **Power Control**.

An effective routing protocol should not only focus on individual nodes in the system but also focus on the system as a whole, otherwise this might quickly lead to a system in which nodes have high residual power but the system is not connected because some critical nodes have been depleted of power. This can be optimized by focusing on a global metric in the routing path calculation to maximize the lifetime of the network. An effective routing scheme should consume less energy and should avoid nodes with small residual energy in the selected route since we would like to maximize the minimum lifetime of all nodes. Different routing schemes can be utilized, but the two most extreme solutions to power Awareness routing for a message are:

- Compute a path that maximizes the minimal power consumption; that is, use the path that requires the least power to transmit and receive a message, here by keeping the power consumption needed to communicate as low as possible;
- Compute a path that maximizes the minimal residual power in the network; that is, use a path according to the residual energy of the nodes, here by maximizing the lifetime of all nodes and the lifetime of the network as well.

Obviously, both of these cannot be optimized at the same time, which means there is a tradeoff between the two. In the beginning when all the nodes have plenty of energy, the minimum total consumed energy path is better off, whereas towards the end avoiding the small residual energy node becomes more important. Ideally, the link cost function should be such that when the nodes have plenty of residual energy, the power consumption term should be applied, while if the residual energy of a node becomes small the residual energy term should be applied. [19]

III. POWER AWARE METRICS

The problem of routing in mobile ad hoc networks is difficult because of node mobility. Thus, we encounter two conflicting goals: on the one hand,, in order to optimize routes, frequent topology updates are required ,while on the other hand, frequent topology updates results in higher message overheads. Several authors have presented routing algorithms for these networks that attempt to optimize routes while attempting to keeps message overhead small. In this section we briefly discuss the different metrics used for routing and then examine their effect on node and network life.

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Different routing protocols use one or more of a small set of metrics to determine optimal paths. The most common metrics used are DSR, DSDV, TORA, WRP and DARPA etc. but in power control routing protocols several metrics can be used to optimize power awareness routing as discussed in subsequent sections:

A. Minimize Energy consumed per packet:

The most intuitive metric, however not optimal for maximum lifetime. This is one of the more obvious metrics. To conserve energy, we want to minimize the amount of energy consumed by all packets traversing from the source node to the destination node. That is, we want to know the total amount of energy the packet consumes when it travels from each and every node on the route to the next node. The energy consumed for one packet is thus given by the equation:

$$E = \sum_{i=1}^{k-1} T(n_i, n_{i+1})$$

Where n_1 to n_k are nodes in the route while T denotes the energy consumed in transmitting and receiving a packet over one hop. Then we find the minimum E (energy) consumed for all packets. However, this metric has a drawback and that is nodes will tend to have widely differing energy consumption profiles resulting in early death for some nodes.

B. Maximize Time to Network Partition:

Important for mission critical applications, hard to maintain low delay and high throughput simultaneously. For this metric, the basic criterion is that given a network topology, we can find a minimal set of nodes whereby the removal of it will cause the network to partition. A routing procedure must therefore divide the work among nodes to maximize the life of the network. However, optimizing this metric is extremely difficult as finding the nodes that will partition the network is non-trivial and the "load balancing" problem is known to be an NP-complete problem.

C. Minimize Variance in Node Power Levels: [22]

Balance the power consumption for the entire node in the network. i.e., all nodes in the network have the same importance; this metric ensures that all the nodes in the network remain up and running together for as long as possible. It achieves the objective by using a routing procedure where each node sends packets through a neighbor with the least amount of packets waiting to be transmitted. In this way, the traffic load of the network is shared among the nodes with each node relaying about equal number of packets. Therefore, each node spends about the same amount of power in transmission.

D. Minimize Cost per packets: *[22]*

Try to maximize the life of all the nodes. For this metric, the idea is such that paths selected do not contain nodes with depleted energy reserves. In other words, this metric is a measurement of the amount of power or the level of battery capacity remaining at a node and that those nodes with a low value of this metric are not chosen (unnecessarily) for a route. This metric is defined as the total cost of sending one packet over the nodes, which in turn can be used to calculate the remaining power. It is given by the equation:

$$C = \sum_{i=1}^{k-1} f_i(x_i),$$

Where x_i represents the total energy consumed by node *i* so far and *f* is the function that denotes the cost. Then we find the minimum C for all packets. This metric is by far one of the more deployed metric as it can incorporates the battery characteristics directly into the routing protocol as shown in the introduction of MMBCR

E. Minimize Maximum Node Cost:

Try to delay the node failures. The idea here is to find the minimum value from a list of costs of routing a packet through a node. The costs themselves are maximized value of the costs of routing a packet at a specific time. The equation for this metric is:

$$\text{Minimize } \hat{C}(t), \text{ for all } t > 0,$$

Where $\hat{C}(t)$ denote the maximum of the $C_i(t)$s and $C_i(t)$ is the cost of routing a packet through node *i* at time *t*.
Side effects:

a. Delays node failure
b. Reduces variance in node power levels.

IV. POWER AWARE ROUTING PROTOCOLS

Power aware routing schemes make routing decisions to optimize performance of power or energy related evaluation metric(s). The route selections are made solely with regards to performance requirement policies, independent of the underlying ad-hoc routing protocols deployed. Therefore the power-aware routing schemes are transferable from one underlying ad-hoc routing protocol to another, the observed relative merits and drawbacks remain valid.

A. Power-Aware Source Routing (PSR): *[16]*

This is a Reactive (On demand) protocol based on DSR. The objective of Power-aware Source Routing (PSR) is to extend the useful service life of a MANET. This is highly desirable in the network since death of certain nodes leads to a possibility of network partitions, rendering other live nodes unreachable. Power aware source routing solves the problem of finding a route *p* at route discovery time *t* such that the following cost function is minimized:

Cost Function

The cost of route π at time t is C (π,t)

$$C(\pi, t) = \Sigma i \in \pi \; C_i(t)$$

Where $C_i(t)$ is the cost of node i at time t

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$$Ci(t) = \rho i \cdot \left[\frac{Fi}{\square} Ri(t)\right] \alpha$$

- ρi : transmit power of node i
- Fi : full-charge battery capacity of node i
- $Ri(t)$: remaining battery power of node i at time t
- α : a positive weighting factor

This Cost function takes into account both transmission power and remaining battery power in PSR, both the node mobility and the node energy depletion may cause a path to become invalid. Since the route discovery and route maintenance in PSR are more complicated compared to their counterparts in DSR. Also, since PSR is derived from DSR, the PSR description will often be contrasted with that of DSR.

PSR – Route Discovery

RREQ broadcast initiated by source. Intermediate nodes can reply to RREQ from cache as in DSR if there is no cache entry, receiving a new RREQ an intermediate node does the following:

- Starts a timer
- Keeps the path cost in the header as Min-cost
- Adds its own cost to the path cost in the header and broadcast

On receiving duplicate RREQ an intermediate node re-broadcasts it only if the following is true:

- The timer for that RREQ has not expired
- The new path cost in the header is less than Min-cost

Destination also waits for a specific time after the first RREQ arrives It then replies to the best seen path in that period and ignores others that come later .The path cost is added to the reply and is cached by all nodes that hear the reply.

PSR Route Maintenance

Route maintenance is needed for two reasons:

- **Mobility**: Connections between some nodes on the path are lost due to their movement,
- **Energy Depletion**: The energy resources of some nodes on the path may be depleting too quickly.
  In the first case, a new RREQ is sent out and the entry in the route cache corresponding to the node that has moved out of range is purged. In the second case, there are two possible approaches: semi-global and local.
- **Semi-global Approach:** The source node periodically polls the remaining energy levels of all nodes in the path and purges the corresponding entry in its route cache when the path cost increases by a fixed percentage. Notice that this results in very high overhead because it generates extra traffic.
- **Local Approach:** Each intermediate node in the path monitors the decrease in its remaining energy level (and hence increase in its link cost) from the time of route discovery as a result of forwarding packets along this route. When this link cost increase goes beyond a threshold level, the node sends a route error back to the source as if the route was rendered invalid. This route error message forces the source to initiate route discovery again. This decision is only dependent on the remaining battery

$$Ci(t) - Ci(t0) \geq \delta$$

t : current time

$t0$: route discovery time

PSR Route Cache Invalidation

- Once the cost of a node has increased beyond the threshold for a particular route, all cache entries to various destinations are invalidated
- However if a path was newly added to the cache, the node makes some allowance by lowering the threshold by some normalized amount for forwarding packets only in that path
- Invalidated routes are purged from cache after some time
- A node can use an invalidated route for its own message initiations but not for relaying other node's packets

B. Minimum Total Transmission Power Routing (MTPR): [2]

In wireless communications, radio propagation can be modeled with a $1/dn$ transmit power roll off (usually, n = 2 for short distance and n = 4 for longer distance). For successful transmissions, the signal-to-noise ratio (SNR) received at a host nj should be greater than a specified predilection threshold *ψj*. This threshold *ψj* is closely related to the bit error rate (BER) of the received signal. For successful transmissions from a host *ni* to *nj*, the SNR at host *nj* should satisfy the following equation:

$$SNR_j = \frac{P_i G_{i,j}}{\sum_{k \neq i} P_K G_{k,j} + \eta_j} \psi_j(BER), \qquad (1)$$

Where *Pi* is the transmission power of host *ni*, *Gi,j* is the path gain between hosts *ni* and *nj* and *ψj* is the thermal noise at host *nj*. Therefore, the minimum transmission power is dependent on interference noise, distance between hosts, and desired BER. To obtain the route with the minimum total power, the transmission power *P* (*ni*, *nj*) between hosts *nj* and *nj* can be used as a metric [13]. The total transmission power for route *l*, *Pl*, can be derived from

$$P_l = \sum_{i=0}^{D-1} P(n_i, n_{n+1}) \qquad (2)$$

For all node $ni \in$ route

Where *n*0 and *nD* are the source and destination nodes, respectively. Therefore, the desired route k can be obtained from

$$P_k = \min P_l$$

Where "A" is the set of all possible routes. The above function can be solved by a standard shortest path algorithm such as Dijkstra or Bellman-Ford. In [17], Dijkstra's shortest path algorithm was modified to obtain the minimum total power route. However, since

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transmission power depends on distance1 (proportional to *dn)*, this algorithm will select routes with more hops than other routing algorithms. In general, the more nodes involved in routing packets, the greater the end-to-end delay. In addition, a route consisting of more nodes is more likely to be unstable, because the probability that intermediate nodes will move away is higher. Hence, from the standpoint of minimum hops, the route obtained from the above algorithm is not attractive. To overcome this problem, transceiver power (the power used when receiving data) as well as transmission power were considered as a cost metric, and the distributed Bellman-Ford algorithm [14] was used. At node *nj*, it computes

$$C_{ij} = P_{transmit}\left(n_i, n_j\right) + P_{transceiver}(n_j) + \text{Cost}\ (n_j) \qquad (3)$$

Where *ni* is a neighboring node of *nj*, *P*transceiver(*nj*) is the transceiver power at node *nj*, and *Cost* (*nj*) is the total power cost from the source node to node *nj*.
This value is sent to node *ni*. Subsequently, at node *ni* it computes its power cost by using the following equation:

$$Cost(n_i) = min_{j \in NH(i)} C_{ij},\ where$$
$$j;\ n_j \text{ is a neighbor node of } n_i \qquad (4)$$

The path with minimum cost from the source node to node *ni* is selected. This procedure is repeated until the destination node is reached. In this algorithm, *P*transceiver (*nj*) helps the algorithm find routes with fewer hops than the MTPR algorithm because generally the transceiver power is identical for hosts using the same transceiver. However, it has a critical disadvantage. Although this metric can reduce the total power consumption of the overall network, it does not reflect directly on the lifetime of each host. If the minimum total transmission power routes are via a specific host, the battery of this host will be exhausted quickly, and this host will die of battery exhaustion soon.

C. Minimum Battery Cost Routing: *[14]-[2]*

This routing scheme proposed that the remaining battery capacity of each host is a more accurate metric to describe the lifetime of each host [14]. Let *ct i* be the battery capacity of a host *ni* at time *t* ranging between 0 and 100. We define *fi* as a battery cost function of a host *ni*. Now, suppose a node's willingness to forward packets is a function of its remaining battery capacity. The less capacity it has, the more reluctant it is. As proposed, one possible choice for *fi* is:

$$f_i\left(c_i^t\right) = \frac{1}{c_i^t} \qquad (1)$$

As the battery capacity decreases, the value of cost function for node *ni* will increase. The battery cost *Rj* for route *i*, consisting of *D* nodes, is

$$R_j = \sum_{i=0}^{D_j-1} f_i\left(c_i^t\right). \qquad (2)$$

Therefore, to find a route with the maximum remaining battery capacity, we should select a route *i* that has the minimum battery cost

$$R_i(i) = \min\{R_i j \mid j \in A\}, \qquad (3)$$

Where "*A"* is the set of containing all possible routes. Since battery capacity is directly incorporated into the routing protocol, this metric prevents hosts from being overused, thereby increasing their lifetime and the time until the network is partitioned [14]. If all nodes have similar battery capacity, this metric will select a shorter-hop route. However, because only the summation of values of battery cost functions is considered, a route containing nodes with little remaining battery capacity may still be selected. Initially, it seems that the lifetime of all nodes will be elongated. However, on closer examination, since there is no guarantee that minimum total transmission power paths will be selected under all circumstances, it can consume more power to transmit user traffic from a source to a destination, which actually reduces the lifetime of all nodes.

D. Min-Max Battery Cost Routing: *[2]*

Recall that the cost function used in MBCR to measure the remaining residual power and hence to determine the willingness of a node to receive and forward a packet is $f_i(C_i) = \frac{1}{C_i}$. when a node's remaining battery capacity ci drops, the cost to include this node into the routing path rises. However, due to the overall viewpoint of battery costs, some weak links may still exist in the paths. Instead of considering the summation of battery costs, MMBCR emphasizes on the weakest link along a path. Its route selection strategy is redefined as:

$$R_j = \max_{i \in route_j} f_i(c_i)$$
$$R_i = \min\{R_j, \in A\}$$

Where the battery cost of a path Rj is measured as the maximum battery cost, i.e., the minimum residual power, involved from a single node on the path; and a path Ri is selected if its path cost is the minimum among all possible routes A.MMBCR circumvents the inclusion of weakest links and prolongs the duration before network partitioning. It attempts to maintain nodes' battery capacity at approximately a fair level by restraining workload allocation to nodes with low power. However, it suffers from lacking an overview of the network's total power consumption and may select routes with more hops. As a whole, packets consume more power to transmit from source to destination than necessary; and on average, nodes effectively have their lifetime shortened, which is undesirable

E. Transmit Power Aware Routing:

Such algorithms minimize the transmit power required for packet transmission or adjust the transmit power of nodes with varying network traffic and remaining node energy. In [2], Toh et al. propose the conditional max-min battery capacity routing algorithm which chooses the route with minimal total transmission power if all nodes in the route have remaining battery capacities higher than a threshold; otherwise, routes that consist of nodes with the lowest remaining battery capacities are avoided. In [3], Tarique et al. integrate two common energy management approaches: they use a load sharing approach for routing decisions and a transmit power control approach for link by link power adjustments. They employ their approach to enhance DSR [1]. Such algorithms in general select the minimum transmit power cost routes. Though some of them take the node residual energy into account, but mostly nodes along the least transmit power cost routes tend to die soon since these routes now become the most heavily used ones instead of the min-hop ones. This is harmful since the nodes which die early are precisely the ones that are needed most to maintain network connectivity. The proposed protocol does find the optimal route not only based on a metric like min-hop, but also a second metric (reliability). It finds multiple stable routes for a particular pair of source and sinks nodes and thus maintains the network connectivity.

F. Residual Energy Aware Routing:

Such algorithms minimize the residual energy of the nodes and select the most residual energy or least battery cost routes. In [4], Marbukh et al. aim at preserving network connectivity by choosing routes according to the remaining battery life of nodes along the route. They use a power draining factor to accurately predict the residual battery life time. In [5], Venugopal et al. study various ad-hoc network protocols in terms of robustness and conclude that the robustness of a routing protocol is restricted by its remaining energy. Further, they present a Max-Min Energy DSR (MME-DSR) route selection algorithm to select the optimal energy route. In [18], Maleki et al. propose a lifetime prediction routing protocol for MANETs that maximizes the network lifetime by selecting routes that minimize the variance of the residual energies of the nodes in the network and include the rate of energy discharge into the cost function to improve network lifetime. They argue that mobility of nodes can affect the traffic pattern through the nodes and the recent history is a good indicator of this traffic. These works assume that it is better to use a higher transmit-power cost route if the least transmit-power cost route consists of nodes with small amount of residual energy. Nodes usually do idle listening when there is no significant traffic. Such algorithms never completely turn off the nodes in absence of traffic.

V. CONCLUSION AND FUTURE WORK

In this paper we present the necessity to make routing protocols power aware. Thus, rather than using traditional metrics such as delay, distance and hop-count for finding routes, we believe that is more important to use cost/packet and maximum node cost (which are functions of remaining battery power and residual battery power or energy level) as metrics. Our discussion demonstrates that significant reduction in cost can be obtained by using shortest-cost routing as opposed to shortest-hop routing. The features of our discussed metrics are that they can be easily incorporated for use in existing routing protocols for mobile and other ad-hoc networks. Discussed metrics helps in predicting the energy level of the nodes, this feature can be used in future to design efficient and reliable stability aware routing protocols to improve significant packet delivery ratio for the ad-hoc networks.

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