ISSN No. 0976-5697

Volume 2, No. 1, Jan-Feb 2011

International Journal of Advanced Research in Computer Science

RESEARCH PAPER

Available Online at www.ijarcs.info

A New Protocol for Power Saving in Mobile Ad Hoc Networks

V.Ramesh*
Research Scholar, Sathyabama University, Chennai,
TamilNadu, India
v2ramesh634@yahoo.co.in

N.Koteswar Rao & B.Mohan
Associate Professor, Narayana Engg. College,
Gudur, AP, India
rao0007@gmail.com

Dr.P.Subbaiah
Principal, VBIT, Badvel, Kadapa,
AP, India.
subbaiah_nani@sify.com

Abstract: For mobile ad hoc networks (MANET) optimization of energy consumption has greater impact as it corresponds directly to lifetime of a network. A Mobile Ad Hoc network (MANET) is a collection of digital data terminals that can communicate with one another without any fixed networking infrastructure. Since the nodes in a MANET are mobile, the routing and power management become critical issues. Due to the slow advancement in battery technology, battery power continues to be a constrained resource and so power management in wireless networks remains to be an important issue. Power conservation in wireless 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. Among which, Conditional Maximum Residual Packet Capacity (CMRPC) Protocol most comprehensively captures tradeoffs of network lifetime, energy efficiency and reliability in packet delivery. CMRPC is simulated using NS-2 to analyze its performance gains. Through this study, we lay a foundation for further research on enhancements in extending the operational lifetime of an ad hoc wireless network.

Keywords: DSR, TORA, Power Aware Routing, MRPC, CMRPC, Min-Max Battery Cost Routing.

I. INTRODUCTION

Ad hoc networks are dynamically-formed networks whereby computing or electronic devices join together to facilitate the transmitting of information from one device to another device through relaying of data packets. The computing or electronic devices (hereby referred to as 'nodes'), cooperatively maintain network connectivity by forwarding packets to each other in a multi-hop fashion.

So what gives rise to an ad hoc network? An ad hoc network arises in the situation where information needs to be relayed from one point to another point in the absence of a base station for centralized administration. Such situations like military maneuvers and search-and-rescue operations in disasters require a network on-the-fly whenever needed and setting up a base station in such instances is not possible. Building an ad hoc network immediately can be likening to the scenario of forming a bucket-chain in the event of a fire.

However, maintaining an ad hoc network is a significant technical challenge, especially in ensuring the life-span of the network. This is because the nodes are limited in terms of resources and power capacity, and are mobile from being wireless in nature. These characteristics [13] impose restrictions on the network, such as the connectivity of the nodes and the efficiency of packet transmissions. Of all characteristics, the limiting capacity of battery power of nodes can be counted as the most critical issue as a downed node can mean the partitioning of the network.

Since the need to conserve energy so that battery life is maximized is important, it is obvious that energy efficient algorithms should be implemented in place of the conventional routing algorithm. In the conventional routing algorithm, connections between two nodes are established between nodes through the shortest path routes. It is unaware of energy budget and thus results in a quick depletion of the battery energy of the nodes along the most heavily used routes in the network. Therefore to conserve battery energy of the nodes, there are various routing algorithms and schemes designed to select alternative routes. These algorithms and schemes are collectively known as 'power-aware routing protocols' and an example of a better choice of routes selected is one where packets get routed through paths that may be longer but that pass through nodes that have plenty of energy reserves. One point to note is that the power-aware routing protocols are not necessary new routing protocols but just modifications to or incorporated in the current ad hoc network routing protocols like DSR [7], TORA [11], and AODV [14].

Besides modifying routing protocols as a way of incorporating power awareness in ad hoc networks, there are other methods such as scheduling the sleep/awake periods of network nodes to conserve energy and varying the transmission power according to the distance betweens nodes. However, they are as yet deemed impractical because of their complexities and inaccuracies for implementation. The former needs a flexible hardware substrate in which the application requirements of the microsensor domain are anticipated [20]. The latter has issues in determining the distances between nodes (especially when nodes are mobile) and often requires external hardware (such as a GPS receiver) or algorithm to be location-aware [19].

The contribution given by this paper is two-fold. In the first part of this paper, we give a survey of the different metrics used for power-aware routing and the different protocols presented so far in related works. We focus in depth on the newer protocol called Maximum Residual Packet Capacity (MRPC) and its conditional variant (CMRPC) [9], devoting a small discussion to it. For the second part of the paper, we evaluate and analyze CMRPC based on results obtained through simulations done on Network Simulator 2. The simulations are done with varying parameters for the threshold, and size of network.

Hence the paper is organized as follows: Section 2 is about the types of power-aware metrics. Section 3 is about the common power-aware routing protocols presented so far. Section 4 gives the analysis on the CMRPC simulation results. We then conclude the paper with findings on CMRPC and how it compares with the other protocols.

II. POWER-AWARE METRICS

Before the discussion and emergence of the types of metrics used for measurements in power-aware routing protocols, the main performance metrics widely used in networks are end-to-end throughput and delay. They belong to a small set of metrics used in different routing protocols for determining optimal paths, with the most common one being the shortest-hop routing in DSR and WRP [10]. Beside these, link quality and location stability are other performance metrics, as used in SSA [3]. Such metrics influence the design of protocols and we need to optimize them by balancing the trade-offs between them. The following is a list of metrics worthy of consideration for optimization as discussed in [17]:

[a] Maximum end-to-end throughput
[b] Minimum end-to-end delay
[c] Shortest path/minimum hop
[d] Minimum total power (battery capacity)
[d] Load balancing (least congested path)
[e] Minimum overhead (bandwidth)
[f] Adaptability to the changing topology
[g] Association stability [16]
[h] Route relaying load [16]

However, some of these metrics have a negative impact on node and network life by inadvertently overusing the energy resources of a small set of nodes in favor of others. Hence we need to use appropriate metrics to help us design power-aware protocols which can select optimized paths that are power-saving for nodes with lower battery capacities and higher traffic loads. In the next few subsections, we give brief introductions to several power-aware metrics that do result in energy-efficient routes as presented in [15].

A. *Minimize Energy consumed/packet*

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 packets consumed 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 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*

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*

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/Packet*

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 in 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 expended 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 and CMMBCR [17][8]. These two protocols are discussed in more details in the next section.

E. *Minimize Maximum Node Cost*

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:

Minimize $\hat{C}(t)$, 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*.

III. 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.

The two routing objectives of "minimum total transmission energy" and "total operational lifetime of the network" can be mutually contradictory. For example, when several minimum energy routes share a common node, the battery power of this node will quickly run into depletion, shortening the network lifetime.

Minimum total transmission energy, such as *Minimum Total Transmission Power Routing (MTPR)*, focuses on end-to-end energy efficiency. Generally, the route selected by conserving energy is the shortest distance path or minimum hop path. Even though some nodes may be dissipating more energy due to dynamics of link characteristics such as distance or error rate, the end-to-end shortest path naturally leads to conservation of energy in transmission.

Route selection schemes that maximize operational network lifetime, such as *Minimum Total Transmission Power Routing (MTPR)* and *Maximum Residual Packet Capacity (MRPC)*, attempt to distribute the transmission load over the nodes in a more egalitarian fashion in the route selection process, even if such distribution may drive up the overall energy expenditure. Individual nodes have their residual battery capacities monitored to delay network partitioning. Route selection is determined by node level constraints. As the power consumption and residual should be evenly distributed, the nodes in the shortest path with low power are deliberately avoided. A chosen path is characterized by larger number of hops with shorter inter hop distance, compared to an energy efficient path.

Excessively conserving energy neglects power consumption at individual nodes, which speeds up network partition by draining batteries of the nodes critical in the network topology one by one. In effect, it shortens the network lifetime. On the other hand, overly conserving power expels energy consideration, which commits to paths with large number of hops and longer total distance. Consequently, the total energy dissipated is high and on average, the battery power decays faster. In effect, it also shortens the network lifetime. The above observations suggest that both battery level and transmission energy shall be considered when designing power-aware routing schemes, and that an anchor point should be drawn to balance the minimum energy and the maximum network lifetime requirements.

A series of power-aware schemes are in place for ad hoc network routings which incorporate both minimum energy and maximum network lifetime considerations. Among these, *Conditional Maximum-Minimum Battery Capacity Routing (CMMBCR)* and *Conditional Maximum Residual Packet Capacity (CMRPC)* are two dominant ones. CMMBCR is the conditional variant MMBCR; and CMRPC is the conditional variant of MRPC.

Conventional minimum total energy or maximum lifetime power-aware protocols simplify the energy consumption model by ignoring the costs of potential retransmissions across error-prone wireless links. In wireless communication, link layer retransmissions are typically performed multiple times to achieve reliable packet delivery. Link characteristics, such as channel error rate, can significantly affect energy requirements for packet transmission. Choosing a path with large number of short hops can be counter-productive. *Maximum Residual Packet Capacity (MRPC)* and *Conditional Maximum Residual Packet Capacity (CMRPC)* improve over conventional power-aware algorithms in that it selects routes not only by identifying residual node battery power, but also by estimating the energy spent in reliable packet transmission over specific links.

A. Minimum Total Transmission Power Routing (MTPR)

In a non-partitioned ad-hoc network, there exists at least one path for a node to communicate with any other node. So theoretically, any node can reach any other node through a random forwarding path. However, the power consumption along different paths varies, due to its dependence on variations of distance between directly communicating nodes and noise interference levels. The greater the values these parameters hold, the larger amount of power is demanded to transmit. Successfully delivering packets from node n_i to n_j requires the Signal-to-Noise Ratio (SNR) at the receiver n_j to be greater than a predetermined threshold ψ_j that is closely related to the Bit Error Rate (BER). Mathematically, this requirement is expressed as:

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

where P_i is the transmission power of node n_i, $G_{i,j}$ is the path gain, inversely proportional to the distance d between nodes n_i and n_j (i.e., $G_{i,j} = 1 / d_{i,j}^n$, usually $n = 2$ for short distance and $n = 4$ for longer distance) and η_j is the thermal noise at n_j.

Selecting a routing path with minimum total transmission power, achieves minimization of the power consumed per packet, intending to entertain more packets before the network runs into depletion. The transmission power $P(n_i, n_j)$ between nodes n_i and n_j are used as the metric to construct such routing path. The total transmission power for a possible path l, P_l can be obtained from:

$$P_l = \sum_{i=0}^{D-1} P(n_i, n_{i+1}) \text{ for all node } n_i \text{ in route } l.$$

where n_0 and n_D are the source and destination nodes. Therefore, a path k will be selected if it satisfies:

$$P_k = \min_{l \in A} P_l$$

where A is the set of all possible routing paths.

However, merely accumulating power needed to transmit a packet at the initiating nodes and thus selecting the minimum power path has neglected the receiving end's power consumption. This demerit can be amended by augmenting the transceiver's power consumption, i.e., the power consumed while a node is receiving data, into the objective function. After modification, a transceiver node n_i now computes

$$C_{i,j} = P_{transmit}(n_i, n_j) + P_{transceiver}(n_i) + \text{Cost}(n_i)$$

where n_j is a downstream neighbor of n_i and Cost (n_i) is the minimum power required for a packet to traverse from the source to node n_i, which is based on the information passed down from n_i's upstream nodes n_k and evaluated as Cost (n_i) = min $C_{k,i}$.

Eventually, the iterative process reaches the destination node, where the total power consumption is evaluated and the path demanding the minimum is selected.

PAMAS [15] is a routing protocol that realizes the minimum energy routing. PARO [6] caters for variable transmission energy network. Essentially, an intermediate node inserts itself to the routing path if it potentially leads to energy savings for the transmission.

B. Minimum Battery Cost Routing (MBCR)

Although path transmission power is an important metric to consider, if multiple minimum total power paths pass through some critical node, this node will soon experience battery exhaustion. MTPR has a drawback in violating fair distribution of power consumption among nodes. It does not reflect the lifetime of individual nodes, which leads to potentially shortening of the time before network partition. The undesirability of the MTPR scheme roots in that individual node's power consumption levels are undistinguished. It suggests, as an alternative, that the node's residual power can be used as a cost metric in route selection. MBCR [17] is such a scheme that minimizes the path battery cost so as to maximize the total remaining battery capacity. The cost function f in MBCR is defined such that the lower the remaining battery capacity c of a node i, the more reluctant the node is to receive and forward a packet. One possible f is

$$f_i(c_i) = \frac{1}{c_i}.$$

It reflects that as a node's battery capacity decreases, the cost to include the node into the routing path proportionally increases. A full routing path is determined by accumulating the costs along the path, and selecting the path incurring minimum total battery cost.

$$R_j = \sum_{i=0}^{D_j - 1} f_i(c_i)$$

$$R_i = \min\{R_j \mid j \in A\}$$

By using residual power as a cost metric, MBCR prevents abusive usage of network nodes, and attempts to evenly distribute battery capacity over the network to delay network partitioning. It is capable of selecting a route with fewer hops when all nodes have similar battery capacities. However, it has a drawback, again because only the end-to-end consideration is taken. Although the total battery cost achieves minimum, some weak links where nodes have little residual power can still exist in the paths, which may lead to early network partitioning.

C. Min-Max Battery Cost Routing (MMBCR)

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 c_i 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 [18] emphasizes on the weakest link along a path. Its route selection strategy is redefined as

$$R_j = \max_{i \in route\_j} f_i(c_i)$$

$$R_i = \min\{R_j \mid j \in A\}$$

where the battery cost of a path R_j is measured as the maximum battery cost, i.e., the minimum residual power, involved from a single node on the path; and a path R_i 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.

D. Conditional Min-Max Battery Cost Routing (CMMBCR)

Minimizing each node's battery consumption and maximizing network lifetime are two goals in designing power-aware routing schemes. Instead of disregarding one or the other as in the schemes discussed above, CMMBCR [18] combines both in route selection criteria.

It is observed that MMBCR should lead to higher energy per packet than incurred by minimum energy routing. Performing MMBCR from the outset is unwise since nodes may "evenly" lose battery capacity more rapidly.

CMMBCR measures cost directly using remaining battery capacity, and the cost of a path R_j is estimated by the minimum residual power among its nodes.

$$R_j = \min_{i \in route\_j} c_i$$

where c_i is the residual battery capacity of node i on the route j.

If a set of routes Q between a source and destination pair have each node's residual power above a threshold value γ, i.e.,

$$R_j \geq \gamma$$

a path is selected from Q by applying MTPR for optimal total transmission power. In this case, all nodes along the paths in Q are expected to have sufficient remaining battery capacity, hence minimizing the overall transmission power for each packet and reducing the end-to-end latency are the focus. Reducing the overall power consumption for packets transmission effectively extends the network lifetime of most nodes.

If for all possible paths, there is at least some node on each having energy level below γ, then the routing path is determined by choosing

$$R_i = \max\{R_j \mid j \in Q\}$$

a route whose minimum remaining battery capacity is the maximum among all paths, similar to MMBCR.

In this later situation, maintaining weak nodes' battery capacity is critical. The routing path selection criterion avoids path assignments involving weak nodes, instead, it allocates the workload to nodes with more remaining battery capacities, so that the weak nodes can sustain longer and therefore prolonging the node and network lifetime. Note that the threshold γ acts as a protection margin. It implicitly assigns network level and node level weight distribution in determining routes. If γ gives total emphasis on network level consideration, CMMBCR reverts back to MTPR. On the other extreme, if γ gives total emphasis on node level consideration, CMMBCR degenerates to MMBCR. Therefore the performance of CMMBCR depends greatly on the chosen value of γ.

E. Maximum Residual Packet Capacity (MRPC)

The aforementioned route selection schemes either focus on minimizing total energy consumption, or maximizing the network operational lifetime; but none takes into account the varying transmission error probabilities across links. For reliable communication, packets transmitted over error prone links potentially entail multiple retransmissions. It is observed that the effect of energy reduction achieved by choosing a route with short range but large number of hops can be negated as the number of hops increases, due to increased number of retransmissions.

Since link characteristics significantly affect the energy consumption for reliable packet delivery, power-aware routing protocols must not only concern with node specific parameters, e.g., residual battery energy, but must also take into consideration the link specific parameters, e.g., error rate of the channel, in order to increase the operational lifetime of the network.

MRPC [1][9] suggests a notion of measuring idealized maximum amount of data transmittable with consideration of link characteristics, where the number of packets that can be ideally transmitted over a path is maximized with parameters of link error rate and current battery power levels at the constituent nodes, assuming independence of other flows which may share partial route. MRPC accommodates dynamic adaptation of transmission power from nodes based on distance between the nodes, as well as incorporates packet retransmission effects caused by link layer transmission error controls.

In MRPC, the cost metric for a link *(i, j)* is

$$C_{i,j} = \frac{B_i}{E_{i,j}}$$

$C_{i,j}$ contains both a node specific parameter, i.e., the node's residual battery power B_i and a link specific parameter $E_{i,j}$, i.e., the effective packet transmission energy over the link. $E_{i,j}$ includes the energy spent in one or more retransmissions necessary in the face of link errors, which is measured as

$$E_{i,j} = \frac{T_{i,j}}{(1-p_{i,j})^L}$$

where $p_{i,j}$ is the packet error probability, L is 1 if link layer hop by hop retransmission is present or {3, 4, 5} otherwise. $T_{i,j}$ is the energy involved in a single packet transmission. $T_{i,j}$ remains constant for radio technology where transmission power is a constant, and varies reflecting a transmitter's capability of dynamic adjustment of power release to link distance changes.

The maximum lifetime associated with a routing path *P* is determined by its weakest intermediate node

$Life_P = \min \{Ci,j \mid (i,j) \in P\}$

Since the weakest node has the smallest ratio of residual battery power to effective transmission energy, it practically limits the idealized maximum number of packets transmittable through the route. MRPC selects the route with maximum $Life_P$ for packet delivery.

F. Conditional Maximum Residual Packet Capacity (CMRPC)

Analogous to CMMBCR, which is a conditional variant of MMBCR, CMRPC [1][9] is a conditional variant built on minimum total energy routing and MRPC. Since minimum energy routes are more energy efficient, CMRPC chooses a minimum energy route as long as the remaining battery power at the constituent nodes lies above a specified threshold; when the threshold level is crossed, routes are chosen with MRPC, which equitably distributes battery consumption among different nodes, to protect against early exhaustion of a few critical nodes.

The CMRPC algorithm can be formulated as follows. Let Ψ be the set of all possible paths between a source and a destination pair, and Ω denote the set of paths having lifetime $Life_P$ no less than a specified threshold γ. If $\Omega \cap \Psi \neq \Phi$, indicating there is at least one path whose lifetime is above the threshold, CMRPC selects a path that minimizes the total transmission energy. Otherwise, the scheme switches to MRPC based max-min route selection. It selects a path *R* that maximizes the route lifetime computed based on the most constrained node-link cost metric.

$R = \arg\max \{ Life_P \mid P \in \Psi \}$.

CMRPC is equivalent to MRPC if the threshold γ value is set to 1. Battery consumptions are evenly distributed and minimizing total transmission energy is never attempted. Then MRPC degenerates to MMBCR only if all nodes are incapable of dynamically adapting their power based on the transmission range, and only if all links have the same intrinsic error rates. Otherwise, MRPC makes a more intelligent choice by taking into account the potential variability in the energy needed for reliable packet transfer. CMRPC is equivalent to MTPR if the protection threshold γ value is set to 0. Transmission energy of each packet is minimized throughout the network lifetime, though some nodes may have their batteries run into exhaustion way earlier than the others.

A lower threshold value implies a smaller protection margin for nodes nearing battery power exhaustion. Clearly, the performance of CMRPC depends on the predefined threshold value.

G. Power-aware protocols with Metrics at a glance

Table 1 below reflects the correspondence of each major design focus and the power-aware routing protocols derived to optimize it.

Table 1 Summary of power-aware protocols with respect to dominating metrics.

Dominating Metrics	*Power-aware routing protocols*
Total energy per packet	*MTPR* – Minimum total transmission power routing
Total Battery consumption per packet	*MBCR* – Minimum battery cost routing
Critical node's residual battery power	*MMBCR* – Max-min battery capacity routing *CMMBCR* – Conditional max-min battery capacity routing
(MRPC and CMRPC consider link error rates in addition.)	*MRPC* – Maximum residual packet capacity *CMRPC* – Conditional maximum residual packet capacity

Table 1 summarizes the power-aware metrics used in the protocols described in the previous sub-sections. Assuming a small threshold value is specified in CMMBCR and CMRPC, their performances are dominated by their non-conditional variants, and hence dominated by the metrics optimized in their non-conditional variants. In the event that CMMBCR and CMRPC have large protection threshold for saving total transmission energy, in the expense of shortened network lifetime, *total energy per packet* shall be their major metrics as well.

IV. SIMULATIONS AND ANALYSIS

As mentioned earlier, power-aware wireless ad hoc routing protocols are essentially energy efficient route selection strategies built on top of existing ad hoc network routing protocols. The underlying ad hoc routing protocols provide functionalities of periodical and distributed route re-computation to facilitate maintenance of optimality in the computed paths both at the time of path setup and after random communication traffics.

In the simulations that follow, Dynamic Source Routing (DSR) [7] is employed as the base routing protocol. DSR is chosen because it displays a number of desirable features among popular ad hoc routing protocols, including Destination-Sequenced Distance-Vector routing (DSDV) [13], Temporally-Ordered Routing Algorithm (TORA) [12][11] and Ad-Hoc On Demand Distance Vector routing (AODV). DSR requires minimum routing overhead, and discovers routes very close to the optimal. With increasing node mobility, no significant degradation of route optimality is incurred. It is able to react quickly to network topological changes while continue to successfully deliver data packets to their destinations. The packet delivery ratio is independent of the offered traffic load. In short, DSR performs very well at all mobility rates and movement speeds [2].

In power-aware protocols, prolonging network lifetime is always an attractive primary goal. The interpretation of network lifetime, however, is situation dependent. Some defines network lifetime as the length of time before the first node battery runs into exhaustion. This applies when the network nodes are sparsely situated, any node is a critical transceiver in providing network connectivity. Some accumulates the time as long as there is one node in operation. This applies when the power usage is fair enough among network nodes, so when the network nodes expire at similar time. Others considers node topology, network lifetime is counted till k nodes having their batteries completely drained, resulting in network partition or communication failure.

A. *Simulation model*

Our simulation model has five major components: ad hoc mobile network formation, packet delivery event generator, mobile nodes migration engine, routing protocol engine and statistics analyzer, as illustrated in Figure 1.

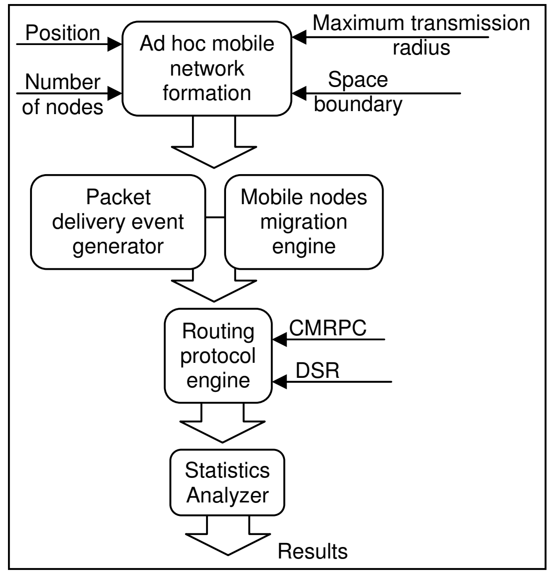

Figure 1 An ad hoc mobile network simulation model.

The module of ad hoc mobile network formation takes in parameters of the space boundary, number of network nodes, their positions in space and their maximum transmission radius. This module is implemented using Tcl script.

The network formation is the simulation ground for packet delivery and mobile node migration events. The number of active communicating flows can be varied and the mobile nodes' migration speed and pause interval is node dependent. These are parameters inputted at simulation setup. Both events are generated using Tcl script and are subsequently handled by the routing protocol engine.

The routing protocol engine employs CMRPC on top of DSR, in which CMRPC handles route selection, DSR manages route discovery, route maintenance, route refreshments and through cooperating with MAC and physical layers in the TCP/IP stack, it achieves reliable packet delivery. This module is realized through C++ codes.

When the routing protocol engine processes packet transmission or node migration events, statistics such as energy consumption, node expiration are recorded. It is the duty of the statistics analyzer to examine the recorded data and draw out interesting analysis results. The analyzer is implemented using both C++ code and Tcl script.

Our protocol analysis is based on the simulation of 50 randomly placed wireless nodes forming an ad hoc network, moving within a 670m by 670m flat space for 350 seconds of simulated time. The network contains 20 connections and the nodes are moving around at a speed of maximum 20m/s with average pause time of 600s. Each node has an Omni-Antenna on its sensor and the physical radio characteristics of each wireless node are that it has initial energy capacity of 0.5 Joules and spends 0.3 Watts of energy each time when a packet transmitted and 0.6 Watts when a packet received.

B. *Discussion on Simulation results*

The Figure 2 shows how the mean network lifetime is changing with changing threshold value in CMRPC protocol. Intuitively, the bigger is the mean value of lifetime the better is protocol performance. As it is shown on the Figure 2, the protocol is stable and appropriate when threshold value is between 20%-45%. With low threshold values the protocol performs not so stable, with high values the lifetime decreases. From the above follows the advice for practical implementing power-aware CMRPC protocol. In shirt, the threshold value for protocol should be chosen in that area where mean lifetime value is stable and high, thus 20%-45%. The mean value shows such behavior since the lifetime is the function of threshold value of CMRPC. The higher the threshold, the higher the probability that the average lifetime of the nodes will decrease.

The deviation of each node lifetime against the mean value is shown on Figure 3. The deviation behavior pattern leads to similar conclusions, the threshold value should be chosen approximately from 20%-40% since the less the deviation the better is the performance.

The changes in values plotted in on the Figure 2 and Figure 3 are not so significant due to the two reasons. The first is that threshold after some value is not playing important role because the underlying MRPC protocol (on top of which the CMRPC is implemented) is still performs very well. MRPC selects links with lower error rates and consequently, smaller energy expenditure on packet re-transmission. The second reason is that have significant changing in the mean network lifetime value and deviation the protocol should run for long time to show high difference in behavior. We run our experiments for time of 350 sec. which is not very long compare to practical working time. Still the values of range of 20-40% for threshold are noticeable, which give the best performance in combination CMRPC with RPC.

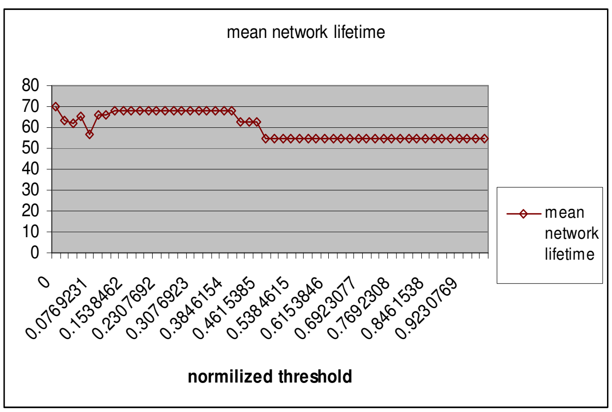

Figure 2: The expectation of network life time depending on CMRPC threshold.

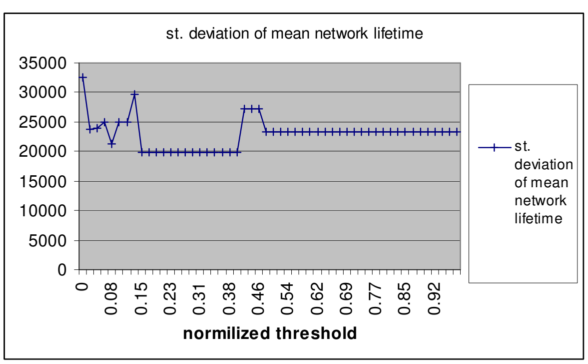

Figure 3: The standard deviation of expectation of network life time depending on CMRPC threshold.

V. CONCLUSIONS

We have presented in this paper descriptions of the various power-aware metrics and power-aware routing protocols that are prominent in the research community. The ones we have listed include *Minimum Total Transmission Power Routing (MTPR)* and *Conditional Min-Max Battery Cost Routing (CMMBCR)* with the latest being *Conditional Maximum Residual Packet Capacity (CMRPC)*. Then we conducted simulations on CMRPC to investigate the performance it provides on energy saving. The simulation suggests the threshold value of CMRPC protocol to be set approximately in range of 20-40%. With such values the protocol shows its best performance because of the combination of MRPC and minimum total energy routing.

Power-aware routing protocols are energy-saving strategies designed at the network layer. Though being effective in power saving, they are still limited in the ability of maximizing the total amount of power savable. Incorporation of power saving strategies designed at the MAC and physical layers with the network layer strategies are expected to bring improvements. Therefore, by tapping into correlating various energy-efficient metrics and logically combining cooperative multi-layer power-aware designs, enhancements in extending the operational lifetime of an ad hoc wireless network are possible.

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