# PERFORMANCE ANALYSIS OF POWER-AWARE ROUTE SELECTION PROTOCOLS IN MOBILE AD HOC NETWORKS

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Recently, several efficient power-aware routing protocols have been developed for Mobile Ad Hoc Networks. While the MTPR (Minimum Total Transmission Power Routing) scheme attempts to reduce the total transmission power per packet, the MMBCR (Min-Max Battery Cost Routing) scheme tries to consider the remaining battery power of nodes to prolong the lifetime of each node. Since it is difficult for just one protocol to meet both goals simultaneously, a hybrid protocol like the CMMBCR (Conditional Max-Min Battery Capacity Routing) mechanism has been devised. However, to the best of our knowledge, this is the first simulation study to compare the three protocols subject to a range of MANET scenarios including mobility and network density. Moreover, in this study, we also consider energy consumption due to overhearing of packets and show its importance when developing power-aware protocols.

## 1 Introduction

Mobile ad-hoc networks (MANET) [1] have no fixed infrastructure, where all nodes communicate in all wireless links with their transmission ranges. Especially, some intermediate nodes should participate in forwarding packets when the source and destination nodes are not directly within the transmission range of each other. Developing core protocols (at different layers, e.g., MAC and network layers) for MANETs has been an area of extensive research in the past few years. Some critical issue in MANETs is that nodes are often power-constrained. More recently, several efforts have focused on developing power-aware protocols used in MANETs [2 3 4 6]. Furthermore, some routing protocols focusing on efficient power utilization have been proposed [4 7 8 9].

The *Minimum Total Transmission Power Routing* (MTPR) [7] was initially developed to minimize the total transmission power consumed per packet, regardless of the remaining battery power of nodes. Since the transmission power required is proportional to $d^{\alpha}$, where $d$ is the distance between two nodes and $\alpha$ between 2 and 4 [5], MTPR prefers routes with more hops having short transmission ranges to those with fewer hops but having long transmission ranges, with the understanding that more nodes involved in forwarding packets can increase the end-to-end delay. Moreover, since it fails to consider the remaining power of nodes, it might not succeed in extending the lifetime of each host.

S. Singh et al. [8] proposed the *Min-Max Battery Cost Routing* (MMBCR), which considers the residual battery power capacity of nodes as the metric in order to extend the nodes lifetime. MMBCR allows the nodes with high residual capacity to participate in the routing process more often than the nodes with low residual capacity. In every possible path, there exists a weakest node which has the minimum residual battery capacity. Hence, MMBCR tries to choose a path whose weakest node has the maximum remaining power among the weakest nodes in other possible routes to the same destination. However, MMBCR does not guarantee that the total transmission power is minimized over a chosen route.

Finally, a hybrid approach was devised by C.K Toh [9] which relies on the residual battery capacity of nodes.

However, to the best of our knowledge, this is the first simulation study based on ns-2 simulator [10] to compare the three protocols subject to a range of MANET scenarios including mobility and network density. Moreover, the protocols suggested in the literature overlook the energy consumption caused by overhearing the packet transmitted by some neighboring nodes. Therefore, we also observed the performance when the energy consumption model includes the energy dissipation due to overhearing.

The rest of this paper is organized as follows. In Section 2, we provide brief descriptions of three power-aware routing protocols we studied. The performance evaluation with simulation results will be presented in Section 3. Finally, some concluding remark is made in Section 4.

## 2 Route Selection Protocols

### *2.1 The Minimum Total Transmission Power Routing*

The Minimum Total Transmission Power Routing (MTPR) [9] mechanism makes use of a simple energy metric which represents the total energy consumed along the route. If we consider a generic route $r_d = n_0, n_1, ..., n_d$, where $n_0$ is the source node and $n_d$ is the destination node and a function T($n_i$,$n_j$) which denotes the energy consumed in transmitting over the hop $(n_i,\ n_j)$, the total transmission power for the route is calculated as: $P(r_d) = \sum_{i=0}^{d-1} T(n_i, n_{i+1})$. The optimal route $r_O$ is the one which verifies the following condition: $P(r_O) = \min_{r_j \in r_*} P(r_j)$, where $r_*$ is the set of all possible routes.

### *2.2 Min-Max Battery Cost Routing (MMBCR)*

Although MTPR can reduce the total power consumption of the overall network, it does not reflect directly on the lifetime of each host. In other words, the remaining battery capacity of each host is a more accurate metric to describe the lifetime of each host. Let $c_i(t)$ be the battery capacity of host $n_i$ at time t. We define $f_i(t)$ as a battery cost function of host $n_i$. The less capacity it has, the more reluctant it is to forward packets; the proposed value is: $f_i(t) = 1/c_i(t)$. If only the summation of the values of battery cost function is considered, a route containing nodes with little remaining battery capacity may still be selected. The Min-Max Battery Cost Routing (MMBCR) [8], defines the route cost as: $R(r_j) = \max_{\forall n_i \in r_j} f_i(t)$. The desired route $r_O$ is obtained so that $R(r_O) = \min_{r_j \in r_*} R(r_j)$, where $r_*$ is the set of all possible routes. Since MMBCR considers the weakest and crucial node over the path, a route with the best condition among paths impacted by each crucial node over each path is selected. However, in MMBCR, there is no guarantee that the total transmission power is minimized over a chosen route.

### *2.3 Conditional Max-Min Battery Capacity Routing (CMMBCR)*

The Conditional Max-Min Battery Capacity Routing (CMMBCR) [9] considers both the total transmission energy consumption of routes and the remaining power of nodes. When all nodes in some possible routes have sufficient remaining battery capacity (i.e., above a threshold $\gamma$), a route with minimum total transmission power among these routes is chosen. Since less total power is required to forward packets for each connection, the relaying load for most nodes must be reduced, and their lifetime will be extended. However, if all routes have nodes with low battery capacity (i.e., below the threshold), a route including nodes with the lowest battery capacity must be avoided to extend the lifetime of these nodes. We define the battery capacity for route $r_j$ at time $t$ as: $R_j(t) = \min_{\forall n_i \in r_j} c_i(t)$.

Given two nodes, $n_a$ and $n_b$, this mechanism considers two sets $Q$ and $A$, where $Q$ is the set of all possible routes between $n_a$ and $n_b$ at time $t$, and $A$

is the set of all possible routes between any two nodes at time $t$ for which the condition $R_j(t) \geq \gamma$ holds. The route selection scheme operates as follows: if all nodes in a given paths have remaining battery capacity higher than $\gamma$, choose a path in $\mathrm{A} \cap \mathrm{Q} \neq \emptyset$ by applying the MTPR scheme; otherwise select a route $r_i$ with the maximum battery capacity (i.e., MMBCR is applied).

## 3 Performance Evaluation

### *3.1 Energy Consumption Model*

We assume all mobile nodes to be equipped with IEEE 802.11 network interface card with data rates of 2 Mbps. The energy expenditure needed to transmit a packet $p$ is: $E(p) = i * v * t_p$ Joules, where $i$ is the current value, $v$ the voltage, and $t_p$ the time taken to transmit the packet $p$. In our simulation, the voltage, $v$ is chosen as 5 V and we assume the packet transmission time $t_p$ is calculated by $(p_h/2 * 10^6 + p_d/2 * 10^6)sec$, where $p_h$ is the packet header size in bits and $p_d$ the payload size. The currents required to transmit and receive the packet used in the simulations are 280mA and 240mA, respectively. Moreover, we account for energy spent by nodes overhearing packets. As shown in [6], we assume the energy consumption caused by overhearing data transmission is the same as that consumed by actually receiving the packet.

For the purpose of evaluating the effect of overhearing, we modified the ns-2 energy model to account for overhearing. The total amount of energy, $E(n_i)$, consumed at a node $n_i$ is determined as:

$$E(n_i) = E_{tx}(n_i) + E_{rx}(n_i) + (N - 1) * E_o(n_i) \tag{1}$$

, where $E_{tx}$, $E_{rx}$, and $E_o$ denote the amount of energy expenditure by transmission, reception, and overhearing of a packet, respectively. $N$ represents the average number of neighboring nodes affected by a transmission from node $n_i$. Eq.(1) implies that when the network is more dense, the packet overhearing causes more energy consumption.

### *3.2 Simulation Environment*

Ns-2 simulator was used in our simulations. We modified the DSR (Dynamic Source Routing) protocol [11] to implement MTPR, MMBCR and CMMBCR [a]. It is the source node that selects the best route while gathering all route

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[a] For the CMMBCR protocol, we studied two different configurations: $\gamma$ values set to 25% and 75% of the initial energy.

replies transmitted by the destination node. For route maintenance, although we follow the basic DSR route maintenance scheme, the source node periodically refreshes its cache and triggers a new route recovery process (in this simulation, we used 10 seconds for the period). Moreover, if some intermediate nodes respond to the route requests with their cached routes when performing the route discovery, we cannot obtain the expected route because the cached routes do not represent the current state of power consumption of nodes. Hence, we avoided some route cache optimization techniques performed by intermediate nodes as in DSR.

Particularly, since only a few actual network interface cards allow a limited number of discrete power levels, in this study we implemented a fixed transmission range (250 meters) of nodes, which is supported by most of current network cards. Hence, it means that MTPR selects the shortest path among possible routes, thus behaves exactly like the protocol using minimum-hop paths. Theoretically, only when all nodes are capable of adjusting their transmission ranges according to the distance between nodes, MTPR can reduce the total transmission power by utilizing routes with more hops having short transmission ranges. We run all simulations for 800 seconds.

When we consider node movement, "random waypoint" model is used with two factors: (a) maximum speed and (b) pause time. During simulation, each node starts moving from its initial position to a random target point selected inside the simulation area. The motion speed value is uniformly distributed between 0 and the maximum speed. When a node reaches the target point, it waits for the pause time, then selects another random target point and moves again.

### *3.3 Simulation Methodology*

We evaluate the protocols by using a scenario of dense network as well as a randomly generated scenario of sparse network. In the scenarios, we use the traffic sources of constant bit rate (CBR) connections with 3 packets/seconds and a packet size of 512 bytes.

We analyze the time when each node die due to lack of remaining battery (i.e., expiration time of nodes) as well as the lifetime of connection which captures the effects of disconnections due to lack of possible routes (i.e., expiration time of connections). In addition, we measure the average number of hops with different number of connections.

For investigating the energy consumption, all nodes have their initial energy values which are randomly selected, but are very similar. In addition, since in realistic scenarios some nodes don't attempt to start the commu-

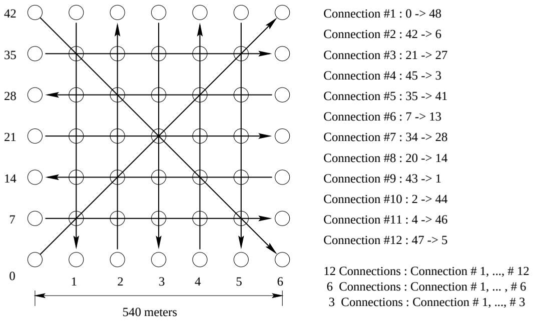

Figure 1. Example Scenario: 49 nodes.

nication with low energy, we assign more initial energy to the source and destination nodes than the others.

### *3.4 Observed Results with Example Scenario*

First, we evaluated the performance by using the example dense network scenario consisting of 49 mobile nodes equally distributed over a 540 m x 540 m area as shown in Figure 1.

Figure 2 shows how many nodes have died over time due to lack of battery when node movement is not allowed. We can definitely observe different results between two cases, namely when the energy consumption by overhearing is excluded and when it is included.

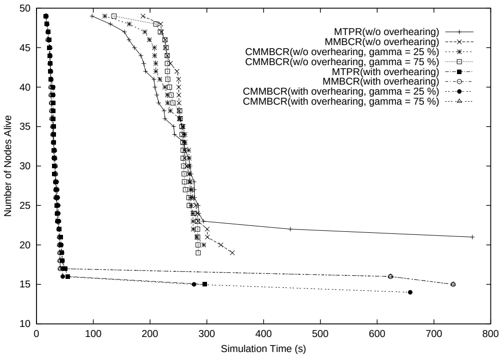

Figure 2. Example Scenario, 12 connections, No mobility.

When we excluded overhearing, MMBCR outperforms the others because

MMBCR distributes energy consumption among different routes by taking into account the remaining power of intermediate nodes in terms of the lifetime of nodes. Note that CMMBCR behaves in between of the MTPR and MMBCR protocol. A $\gamma$ equal to 25% derived a similar behaviour to MTPR, while a $\gamma$ of 75% makes the protocol behave as MMBCR does.

However, MMBCR increases their total energy consumption by using longer paths than MTPR. In other words, when finding new paths, it is possible that the acquired paths consist of the nodes with low energy, resulting in the early expiration time of connections (see Table 1). However, from the aspect of expiration time of connections, since there exist many other possible paths in dense networks when finding new routes, MTPR allows the connections to survive longer than MMBCR. This is why Table 1 shows that MTPR have higher total energy expenditure than MMBCR is that MTPR can continue to spend the energy of nodes because the connections survive longer than MMBCR.

|  | MTPR(w/o) | MMBCR(w/o) | MTPR(w) | MMBCR(w) |
|---|---|---|---|---|
| Total Energy(J) | 378.88 | 372.33 | 401.94 | 401.66 |
| Mean CET(s) | 257.06 | 237.37 | 73.23 | 70.38 |

Table 1. Total Energy Consumption; CET is the connection expiration time. w/o and w represent without and with overhearing, respectively.

In addition, Table 2 shows the average number of hops in the example scenario with different number of connections. The connections selected for 3, 6 and 12 connections are shown in Figure 1. For all cases, the average number of hops in MTPR remains around 6% longer than in MMBCR, because MTPR prefers shorter routes in terms of hops.

|  | # of Connections |  |  |
|---|---|---|---|
|  | 3 | 6 | 12 |
| MTPR | 4.72 | 4.30 | 4.70 |
| MMBCR | 4.90 | 4.60 | 4.96 |
| CMMBCR ( $\gamma = 25$ % ) | 4.88 | 4.47 | 4.72 |
| CMMBCR ( $\gamma = 75$ % ) | 4.96 | 4.56 | 4.77 |

Table 2. Average Number of Hops (Without Overhearing).

Besides, when we consider the overhearing activity, all approaches behave similarly, because the nodes that are close to a transmitting node consume their energy even though we attempt to balance the energy consumption by using more stable route in terms of residual capacity (see Figure 2 and Table 1).

Therefore, we investigated the amount of energy consumed by the participating nodes according to the network card activities. We observed that most of energy expenditure is caused by the overhearing activity (see Figure 3). It implies that some techniques are required to reduce this energy expenditure by, for example, switching the network interface cards into the sleep mode.

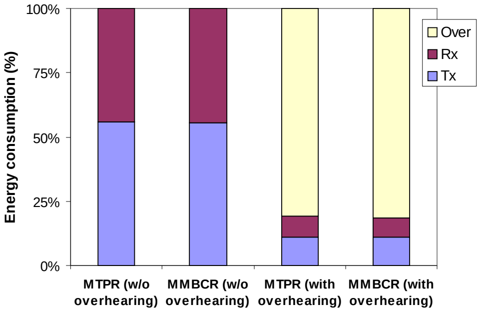

Figure 3. Investigating the Percentage of Energy Consumption.

Now, we evaluate how node mobility can affect the performance. We used pause time of 30 seconds and the maximum speed of nodes is selected to 5, 10, and 15 m/s. Since we obtained similar results for all simulations with the varied maximum speed of nodes, we present the results for 15 m/s. Moreover, when considering overhearing, we increased the nodes' initial energy in order to better observe the behaviour of the different protocols.

Figure 4 shows the number of operational nodes over time without and with overhearing. MMBCR produced the best performance when overhearing is not considered (Figure 4.a). When considering overhearing, all protocols have similar performance (Figure 4.b). From Figure 2 and 4.b, we can say that when considering overhearing, all protocols are similar, regardless of the amount of initial energy.

Figure 5 shows the lifetime of connections with different speeds of nodes[b].

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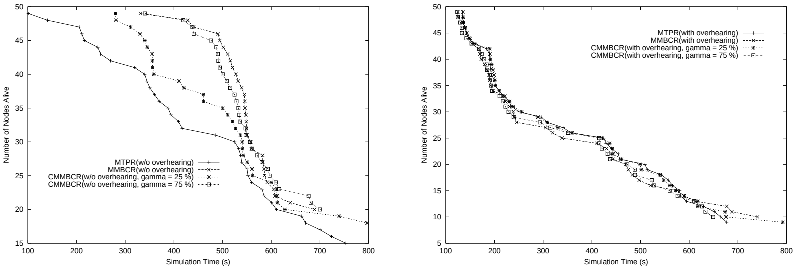
[b] Note that when compared to the static network, the lifetime of connections significantly increases. In the static network, some connections cannot progress when network partition occurs. However, in the dynamic network, the node mobility allows new paths to appear after network partition is resolved.



(a) Without Overhearing (Low Energy) (b) With Overhearing (High Energy)

Figure 4. Example Scenario, 12 connections, Mobility(15 m/s).

MTPR experiences better performance over MMBCR for all scenarios, because in dense networks, many other nodes can still act as forwarding nodes for the connections. In the context, MTPR selecting the shortest paths behaves better than MMBCR delaying the expiration time of nodes but wasting more energy due to longer routes.

### *3.5 Observed Results with Random Scenario*

We evaluated the behaviour of the route selection protocols in some sparse network. A MANET consisting of 75 mobile nodes with their random positions in the area of 1 km x 1 km is generated in this simulation. The maximum speed of nodes is set to 10 m/s with the pause time of 30 seconds. We considered a total of 12 CBR traffic sources with a sending rate of 3 packets/sec (a packet size of 512 bytes). All the connections start at random time to emulate some real network environment.

Figure 6.a shows when the node die due to the lack of battery in the scenario with 10 m/s. On the other hand, Figure 6.b shows some results when the energy model considers the energy dissipation caused by overhearing.

As for the expiration time of nodes, the result shows similar behaviour to the dense scenario. In other words, the protocols selecting the route based on the remaining energy can have advantage of delaying the time of nodes passing away. As expected, when considering overhearing, all protocols behave similarly. However, as for the expiration time of connections, both protocols have similar results irrespective of overhearing (Figure 7). In this scenario, the reduced number of available routes allows the two protocols to select the same route. Even more, when a node die, there exists a high probability that

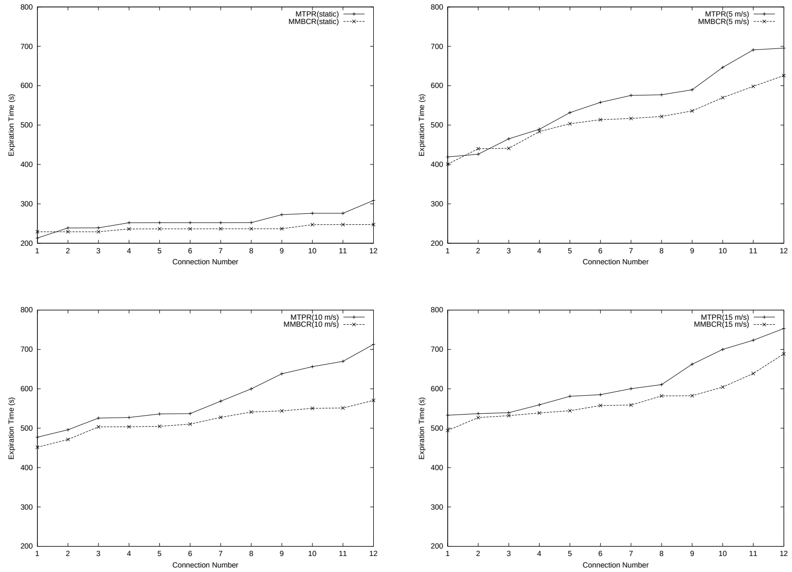
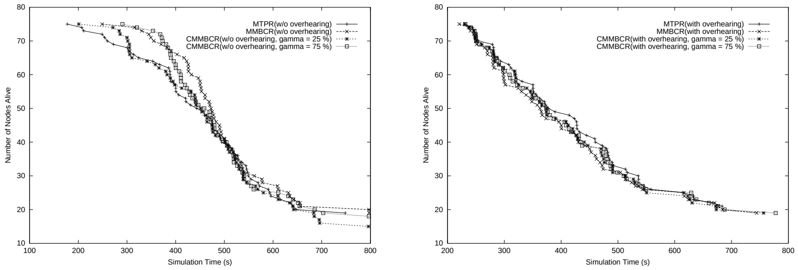


Figure 5. Connection Expiration Time. Maximum speeds of nodes are 0 m/s, 5 m/s, 10 m/s and 15 m/s.



(a) Without Overhearing (Low Energy) (b) With Overhearing (High Energy)

Figure 6. Random Scenario, 75 nodes, 12 connections, Mobility(10 m/s).

the network becomes partitioned, specially in static scenario or network with low mobility of nodes. Thus, in sparse networks, the later the node dies, the better performance we get.

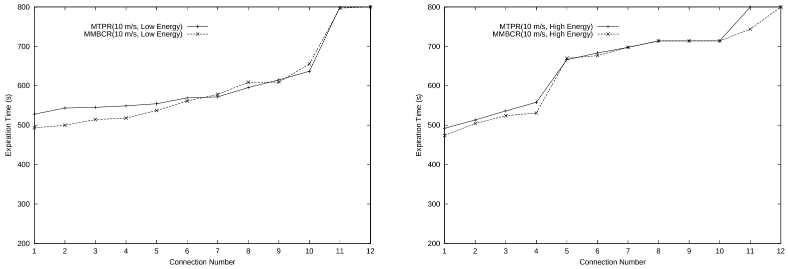


Figure 7. Connection expiration time. Maximum speed of nodes is 10 m/s. Low and High Energy

## 4 Conclusions

We compared the energy consumption behaviour of three power-aware route selection protocols, namely Minimum Total Transmission Power Routing (MTPR), Min-Max Battery Cost Routing (MMBCR) and Conditional Max-Min Battery Capacity Routing (CMMBCR). Extensive simulations under different MANET scenarios (e.g., mobility, node density) show the importance of considering overhearing as part of the energy model when evaluating power-aware mechanisms. Another key result of this study is the importance of network density in route selection when trying to prolong the lifetime of both nodes and connections. When considering overhearing, all protocols behave similar with respect to the expiration time of connections as well as that of nodes. When we do not consider the overhearing activity, we can expect the different performance according to network density. In dense networks, because of the availability of several routes, it seem to be more important to reduce the overall energy consumption so as to prolong the lifetime of each individual node. Simulation results show that MTPR allows the connections to live longer. As for sparse networks, the role of nodes for avoiding the network partition is more crucial. To conclude, since network interface cards in near future could allow nodes to switch themselves into on and off states with low cost in terms of energy consumption and transition time, some approaches that combine the sleeping mode with the appropriate route selection mechanisms should be developed to extend the lifetime of both nodes and connections.

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