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Random Graph Generation Based p-Method and Box Method for the Evaluation of Power-Aware Routing Protocols of Ad hoc Networks

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Abstract: The objective of this paper is to investigate the best solution such that on which decision should be made to forward a wireless packet. The decision should be made in such a way to keep the node alive by choosing an alternate path, through those nodes that have more power reserve. Minimizing the consumption of the reserve power will results in an increase in the number of hops the packet must travel. A hybrid solution can be utilized which is a combination of power-aware and minimizing the number of hops to be traveled. Recent research suggests that it should select the node with high power reserve than based on the shortest path. A question arises which is more critical for ad hoc networks the power-aware solution or the shortest path based on the number of hops. This research will investigate these solutions aiming on minimizing power consumption for wireless packets networks and the number of hops to be traveled. Through rigorous empirical analysis based on the p-method and box-space method, we were able to derive critical global properties with respect to end-to-end minimum power consumption routes. Finally, a simulation results are presented to verify the performance of the proposed algorithms.

Key words: Box Method, p-method, power-aware routing, wireless communications, ad hoc networks

INTRODUCTION

With the increasing dependence on the Internet in many aspects of their daily lives, users demand ubiquitous, high performance Internet access whether they are at work, at home, or on the move. Moreover, users on the move are often interested in forming ad hoc networks to collaborate with colleagues for class related work, or more generally to interconnect all their personal devices. An example of an ad hoc network is shown in Fig. 1.

Ad hoc networks are collections of nodes with capability of both sending and receiving at the same time act as a router. The cluster of such mobile nodes will virtually eliminate the needed wiring to connect individual devices, thus creating the possibility of using mobile data in a variety of applications[1]. There are different usage for such networks, such as students using laptop or PDAs to participate in an interactive lecture or military usage where soldiers relaying information for situational awareness on the battle field, Fig. 2.

Mobility support of such network can be achieved by Mobile IP[1] and further advances achieved by the introduction of Mobile IPv6 for added security and an increase in the address space. Due to the mobile node mobility the status of the communication links between the nodes heavily depends on the position, speed, transmission power and reserve battery power. Unfortunately, the advances in the CPU technologies do not match the advances in batteries technology, in the sense of being capable of operating for longer hours.

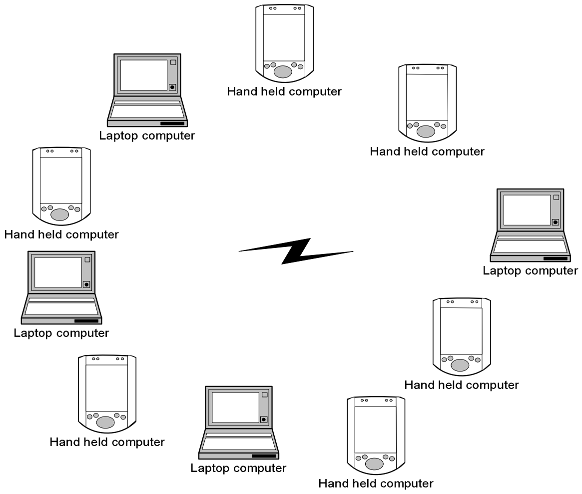


Fig. 1: Ad hoc network

One way to maximize the number of hours a mobile devise can operate is by designing an efficient routing technique. A major power dissipation of the

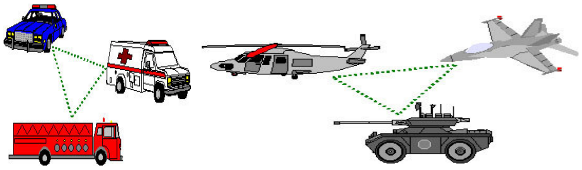


Fig. 2: Ad hoc for Military communication and commercial usage[2]

mobile devise is the transmission power. A mobile node can be either transmits its own data or forward data as an intermediate node. In the following we will investigate the major three techniques that have been proposed recently to address the lifetime of mobile devise battery[3-4].

LITERATURE REVIEW

Minimum Total transmission power Routing (MTPR)[3-7]. The MTPR (Minimum Total Transmission Power Routing), in wireless communications, radio signals transmit power can be best modeled as proportion to d^{-n}. In[7] the MTP characterized by P_l, where P_l represent the total transmission power along the rout l , which can be derived from:

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

Then the optimal rout with minimum transmission power P_k, can be found by:

$$P_k = \min_{l \in A} P_l \tag{2}$$

where, A is the set of all possible routes from source to destination.

The solution with the distributed Bellman-Ford algorithm is:

$$\begin{aligned} C_{i,j} = {} & P_{\text{transmit}}(n_i, n_j) + \\ & P_{\text{transceiver}}(n_j) + \text{Cost}(n_j) \end{aligned} \tag{3}$$

(Calculation at j; i – next node on route; Cost – total power cost from source to j), whereby the power, which will be used when receiving data, is considered. This value is sent to node i and then the path with the minimum cost is selected:

$$\text{Cost}(n_i) = \min_{j \in NH(i)} C_{i,j} \tag{4}$$

(NH – set of neighbors). The procedure is repeated until destination is reached[7].

If the objective of selecting a path based on the MTP, then we expect the MTP rout (MTPR), will have longer number of hops. As indicated in[7] the number of intermediate nodes will be larger as a result probability of having more path request will increase. Adopting MTPR strategies as indicated by[7] will results in more number of hops. Increasing the number of hops will affect another performance metric which is the end-to-end delay. It also noted that[9] having an objective of minimum transmission power will result on overloading specific host that leads to fast drainage of mobile node battery power. As a result, a new technique has been proposed which is minimum battery cost routing (MBCR).

In[9] the MTPR was modified such that only along the route from source to destination nodes were chosen based on the maximum power to be include in the packet forward decision. As a result a minim battery cost routing, MBCR, was selected. In this scheme data forwarding by mobile nodes using MBCR will have longer battery life. Even though MBCR relief certain node of being exhausted there is no guaranteeing that the total transmission power guaranteed to be a minimum.

In[7] proposed a new technique where the author used the battery level instead of the cost metric used in[9] called conditional max-min battery capacity routing, CMMCBR. At each node to select the next node to forward the data packet, the CMMBCR consider the max battery level and minimum transmission power, as a condition to select that node. To prove the performance of the CMMCBR a simulation has been conducted. The simulation is similar to ns-2 network simulator. It was concluded that using the CMMCBR will result in a shortest path taking into account other factors such as min transmission power and maximum battery reserve only when all the node along the selected rout have sufficient battery reserve. CMMCBR show a significant improvement in elongated the lifetime of mobile node battery.

Previous research on this problem fail to fully simulate the best method since the variables in the selection process such as transmission power, shortest path and battery level interrelated in such a way optimizing one factor affect the other. In this work, we use rigorous simulation approach using the p-method and box method to select the best route such that we optimized all three factors[10-13].

THE P-METHOD

The P-Method can be used to generate random coordinate in the Euclidean space of a mobile node based upon the probabilistic construction of a mobile node Boolean incident matrix. The incident matrix whose elements, a_{ij} where $0 \leq i < m$ and $0 \leq j < m$ are defined to be $a_{ij} = 1$ if there is a directed data transmission link/control dependency directed from mobile node M_i to mobile node M_j and $a_{ij} = 0$ if no link (out of range) between mobile node M_i to mobile node M_j.

To generate a random acyclic structures, the incident matrix is first constructed with all its lower triangular and diagonal elements set to zero ($a_{ij} = 0, \forall i \geq j$). Then each of the remaining upper triangular elements of the matrix are examined individually as part of Bernoulli process with the parameter p, representing the probability of a success. For each element examined ($a_{ij}, \forall i \geq j$) when the Bernoulli trial is a success, then the element is assigned a value of one ($a_{ij} = 1$); in case of a failure the element is given the value of zero ($a_{ij} = 0$). The parameter p can also be considered to be the sparsity of the nodes graph since it represents the expected portion of the possible $\binom{m}{2} = m(m-1)/2$ datalink/control dependencies represented by the edges of the acyclic directed nodes graph. With this method the probability parameter of p = 1 creates a totally sequential Task Graph (chain) and a parameter of p = 0 creates fully disconnected nodes graph; values of p that lie in between these two extremes generally produce mobile cluster graphs that possess intermediate structure.

The longest link set that a packet must travel through the resultant graph that must travel on average is α. Alpha is an important parameter that is associated with a given Directed Acyclic Graph (DAG). The exact expression that describe this relationship is difficult to derive for the P-method but some insight can be gained into its behavior by carefully observing empirical data taken from multiple applications of the P-method. Such data are shown in a previous work[8] where it is clear that the expected longest link set of a resultant DAG is an almost linear function of its sparsity parameter p and it is variance is greatest for the cases of p which are in the middle range. Combined with the fact that the maximum number of hops on average is bounded by α. It has also been observed that in cases where the weighting is not unity (using Poisson and uniform weightings) that α is somewhat less linear function of p but is still very linear in the range of high sparsity. It worth mentioning here sparsity of nodes, will acquire more transmission power. For the sake of fairness in evaluating different power-aware routing techniques, p was selected to be in the middle range. Nevertheless, we run the simulation with different value of p's to indicate the total power loss as a function of p. From the results we can build a better understanding of the relationships between range of p and the total transmission power.

BOX METHOD

The Box-method[10-13] is another technique that can be employed to generate random DAG which can be used to quantify the differences that exit between a set of random generation of links status (in range/out of range) as the computer nodes move. It is defined as fellows:

Let m random points been chosen independently from Uniform distribution on the unit square in the Euclidean k-space. Construct a partially ordered set P_k (m) such that the points from the underlying set of random order, with partial ordering given by x (i)<x (j) whenever $X_l(i) < X_l(j)$ for all random generated coordinates $1 < l \leq k$.

This method has been studied extensively by other researchers[10-13] to determine the longest chain among random points in Euclidean space which is directly related to the amount of sequentially present within the task graph. It has been shown by Bollobas and Winkler[13] that the longest chain divided by m tends to a set of constant C_k as m approaches infinity. Thus the expected sequentially parameter α can be given by Eq. 5 as

$$\lim_{m \to \infty} \alpha_k(m) \to \sqrt[k]{m^{1-k}}\, C_k \tag{5}$$

where, $0 \leq C_k < e$ for the uniform distribution and unknown for other distribution.

Values of C_2 (i.e. k = 2 Euclidean space of Dimension 2, Unit box) have been found empirically and are listed in Table 1 for both the uniform and Poisson distributions assuming both unit and randomly-generated tasks weights (with a range from 1 to 100 units for the random weights).

When the values of Table 1 are used for C_2 then Eq. 1 is a very good approximation for α. The structure of the task graphs produced by the Box method are very predictable and can be made to produce graphs with the same sparsity (by varying the dimension k) as that produced by the p-method and many real world systems[10].

Table 1: Empirical Estimates of C_2

Distribution	Unit Weight	Random Weights
Uniform	1.709	100.14
Poisson	0.9090	58.27

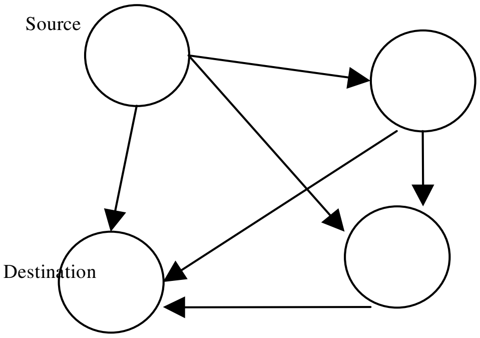


Fig. 3: Direct Graph Example.

GRAPH GEODESIC

Let G = (V, E) be a graph which consists of a finite nonempty set of vertices V of n nodes where n is the number of vertices in the graph G and E is the set of Edges in the graph G. A walk in the graph G is an alternating sequence of nodes and edges $v_0, e_1, v_1, e_2, v_2, \ldots$, such that every $e_i = (v_{i-1}, v_i)$ is an edge in the graph G, where $1 \le i \le n$ [14]. A walk is a trail if all edges are distinct. The length of the trail (path) is the number of edges in the trail. The graph bellow Fig. 3 show an example of DAG, as shown there is multiple walk between the source and destination.

Graph Geodesic is an NP-complete problem, which is finding the shortest path connecting two specific vertices (u, v) of a directed acyclic graph (DAG). The number of hops (number of edges) between the two vertices (u, v) is denoted by d(u, v). Two well know algorithms the Bellman-Ford algorithm and Dijkstra's algorithm are known for solving the shortest path problem[14]. In most of the algorithms the number of steps to solve the shortest problem is of $O(n)$ in the n-edge graph[15].

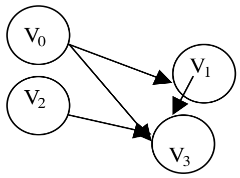
Showed[12] that in every DAG (directed acyclic graph) with n nodes we can generate a count of the number of labeled graph n is given by the following recurrence equation:

$$a_n = \sum_{k=1}^{n} (-1)^{k-1} \binom{n}{k} 2^{k(n-k)} a_{n-k} \qquad (6)$$

with $a_0 = 1$[14]. It is evident from McKay *et al.* work[15], evaluating proposed power-aware routing in the literature is a difficult task. For that in this work we utilized the p-method and box method to fairly evaluate the proposed algorithms in the literature as well as propose an alternate method (discussed in the following section).

Adjacency matrix: In a graph G we say two vertices (v_I, v_j) are adjacent if they are joined by a directed edge. The adjacency matrix of a graph G is a matrix with a 1 or 0 in position of (v_i, v_j). Inserting a one in (v_i, v_j) position indicate a connection between the two vertices while if a zero inserted indicate otherwise. To have a cyclic graph the diagonal of the adjacency matrix must be zeros. And for directed graph the lower triangle of the adjacency matrix must be zeros as well. In the following we showed an example of simple acyclic directed graph. For the adjacency matrix A given bellow:

$$A = \begin{bmatrix} 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$ The DAG for A is



SIMULATION MODEL BASED ON BOX METHOD

In this research we use the p-method and box method as an algorithm to generate a fair simulation domain of an ad hoc environment. The vertex of the graph represent a mobile node (MN) where the edge between the two vertices (v_i, v_j) indicates that MN_i is in the range of MN_j. As explained earlier the p-method and box method will be used to generate the random adjacency matrix. New parameters were added to the adjacency matrix to take into account the transmission power as well as the battery level indicator. The first parameter is the transmission power or link cost. The second parameter will indicate the battery level in the MN. The range of the battery level from 0% to 100%, where 0% indicates an empty battery, while a 100 indicate a 100% full battery.

Let R be a relation on a set of n elements. Let $v_1, v_2, \ldots, v_n$ be an arbitrary listing of these n elements. The concept of interior vertices of a path is used. If (a, b) is a path such that $a, x_1, x_2, \ldots, x_{m-1}, b$, it is interior vertices is $x_1, x_2, \ldots, x_{m-1}$, that is, all the vertices of the path that occur somewhere other than as the first and the last vertices in the path. Each vertex in the DAG is given a random variable to indicate it is power level. And the incident edges were given a value to indicate the transmission cost.

A C++ code has been written to implement the p-method and box-method to buildup (generate) an ad-hoc network according to either the uniform distribution or the Poisson distribution. In the following we will describe the three main components of the simulation code of this study.

Minimum cost links: The minimum cost path (MCP) calculate all the walks from a source to the rest of the nodes in the randomly generated graph for all the interior vertices in G. The walks will select the edge based on the link cost ignoring the battery level of the forwarding mobile node. Based on the selected path, the average power of the intermediate nodes was calculated. To simulate the movement of the nodes, we created 100 instances; we generated the graphs randomly 100 times and average out our calculations per instance. This approach also will give us a fair calculation of the average power consumed as well as the length of the paths. The simulation results was provided in this form:

Source	Destination	Cost Required	# of Hops	Next Hop	Average Power

And at the end of each iteration (total of 100 iterations) the average number of hop was calculated as well as the average power left in each node in the path selected.

Maximum reserved power level path; In this part, the path between any two nodes in the network was selected based on the node which holds maximum battery level (i.e. the maximum weight of the interior vertices). As a result the selected path contains the maximum power levels between them. Also, the average power on the selected path will be calculated as well as the average number of hops. The results were provided in this form:

Source	Destination	Power Consumed	No. of Hops	Next Hop	Average Power

Minimum cost link maximum reserved power level: In this part, the path between any two nodes in the network will be selected such that it satisfy the minimum transmission cost link and maximum reserved power level. The results will be provided in this form:

Source	Destination	Average Power	No. of Hops	Next Hop

At the end of this part, the average number of hops will be calculated.

SIMULATION MODEL

In order to evaluate the previous three methodologies and it is impact on the total power consumption and the average number of hops, it is simulated using a C++ code. In the simulation, the number of nodes is kept constant in order to have fair comparison between the three methodologies. The mobility of nodes is simulated by regenerating the adjacency matrix using the p-method and box method. The transmission power cost (link cost) as well as the reserved battery level are randomly selected.

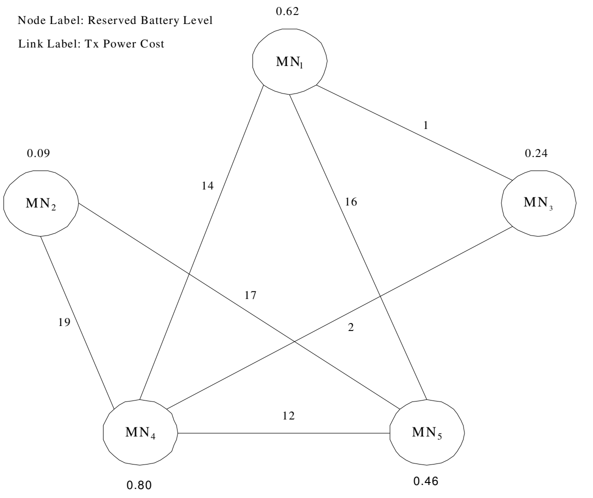


Fig. 4: Random generated graph using p-method

Simulation example: The simulation of the preceding parts can be repeated to find out which part is the best among the others. It will be repeated for the same set of parameters specified by the user. However, the difference will be due to the edge creation by either the uniform distribution or the Poisson distribution. Now, we build this generated graph in order to justify the results in each part. The generated graph will appear as illustrated in Fig. 4:

Let's examine the path from node MN_1 to MN_2.

Using the criteria for using the path minimum link cost (MLC), MN1 will examine all possible paths to MN2. It results in choosing the path {(MN1) (MN3) (MN4) (MN2)} , the minimum cost links (edges) is 22. Then, we calculate the number of hops, which is 3 and sets MN3 as the next hop on its path to MN2 in its routing table. This can be found clearly Table 1.

Source Node	Destination node	Cost	No. of Hops	Next Hops	Average Power
1	2	22	3	3	0.55

After finding the minimum cost path, it will calculate the average power on this path. First, it will accumulate the power levels of each node along the transmission rout, which are for node (MN1), node (MN3) and node (MN4). Then, it will divide the accumulated power levels by the number of hops on the traverse path, which is (0.62+0.24+0.80)/3 = 0.55

For the second criterion which is based on the Maximum reserved power (MRP) from MN1 as a source and MN2 as a destination. Since there is no direct link (edge) to Node (MN2), we will look for a next hop (node) with the maximum power level, which is MN4, with the power level (0.80). Now, MN4 will forward packets to the final destination MN2. As a result the path from node MN1 to MN2 will be {(MN1) (MN4) (MN2)} and the power consumed for transmission is (0.62) + (0.80) = 1.42. The results of the simulation are depicted in Table 2.

Source Node	Destination node	Cost	No. of Hops	Next Hops	Average Power
1	2	1.42	2	4	0.71

Actually, the power consumed for transmission on the path corresponds to the accumulated power on the path. So by dividing the power consumed by the number of hops on the path, we get the average power on the path, i.e. 1.42/2=0.71.

For the hybrid method in which we select the next hob based on Minimum transmission cost link and Maximum Reserved Power (MLC_MRP) by comparing the average power on the path found in the first methodology (the minimum cost path) and the second methodology (the maximum power level path). We found that the average power on the path found in MRP is greater, which is (0.71). For that, the path from node (MN1) to node (MN2) in this part will be chosen to be the maximum power level path. The results are summarized in Table 3.:

Source Node	Destination node	No. of Hops	Next Hops	Average Power
1	2	2	4	0.71

Simulation results: Through rigorous simulation, we run the simulation for 20 mobile nodes and regenerate the graph 100 times to simulate the mobile nodes movements. The results of the simulation using the MLC are shown in Table 2.

In Table 3 we summarize the results of the simulation based on the Maximum Reserved Battery Level (MRP). While Table 3, depict the results of the hybrid solution which based on Maximum Reserved Battery Level and Minimum Link Cost (MLC_MRP.)

Table 1: Minimum Cost Path for different source and destination (routing table)

Source Node	Destination node	Cost	No. of Hops	Next Hop Hops	Average Power
1	2	22	3	3	0.55
1	3	1	1	3	0.62
1	4	3	2	3	0.43
1	5	15	3	3	0.55
2	1	22	3	4	0.38
2	3	21	2	4	0.45
2	4	19	1	4	0.09
2	5	17	1	5	0.09
3	1	1	1	1	0.24
3	2	21	2	4	0.52
3	4	2	1	4	0.24
3	5	14	2	4	0.52
4	1	3	2	3	0.52
4	2	19	1	2	0.80
4	3	2	1	3	0.80
4	5	12	1	5	0.80
5	1	15	3	4	0.50
5	2	17	1	2	0.46
5	3	14	2	4	0.63
5	4	12	1	4	0.46

Table 2: Maximum reserved Battery Level Cost Path for different source and destination routing table

Source Node	Destination node	Cost	No. of Hops	Next Hops	Average power
1	2	1.42	2	4	0.71
1	3	0.62	1	3	0.62
1	4	0.62	1	4	0.62
1	5	0.62	1	5	0.62
2	1	0.89	2	4	0.44
2	3	0.89	2	4	0.45
2	4	0.09	1	4	0.09
2	5	0.09	1	5	0.09
3	1	0.24	1	1	0.24
3	2	1.04	2	4	0.52
3	4	0.24	1	4	0.24
3	5	1.04	2	4	0.52
4	1	0.80	1	1	0.80
4	2	0.80	1	2	0.80
4	3	0.80	1	3	0.80
4	5	0.80	1	5	0.80
5	1	0.46	1	1	0.46
5	2	0.46	1	2	0.46
5	3	1.26	2	4	0.63
5	4	0.46	1	4	0.46

As shown in Table 4, selecting a path of minimum link cost produced the lowest battery level values along the path and worse than that it has more hops count. For the case of MRP it shows better value for the battery reserved power as compared to MLC as wells as less hop counts. Though MLC_MRP has the best result in terms of battery reserve power along the transverse path, but it shows more hop counts as compared to MRP, but the difference is not of large value as compared to MLC.

CONCLUSIONS

Due to the unique characteristics of wireless networks such as user mobility, limited battery lifetime and dynamic topology lead to have an ad hoc nodes that might be overused with packets to be forwarded due to

Table 3: Maximum Reserved Battery Level with Minimum Cost Link

Source node	Destination node	No. of hops	Next hop	Average power
1	2	2	4	0.71
1	3	1	3	0.62
1	4	1	4	0.62
1	5	1	5	0.62
2	1	2	4	0.44
2	3	2	4	0.45
2	4	1	4	0.09
2	5	1	5	0.09
3	1	1	1	0.24
3	2	2	4	0.52
3	4	1	4	0.24
3	5	2	4	0.52
4	1	1	1	0.80
4	2	1	2	0.80
4	3	1	3	0.80
4	5	1	5	0.80
5	1	3	4	0.50
5	2	1	2	0.46
5	3	2	4	0.63
5	4	1	4	0.46

Table 4: Three methodologies simulation results

Methodology	Average power consumption	Average No. of hops
MLC	0.4825	34
MRP	0.5185	26
MLC_MRP	0.5205	28

the limited range of an ad hoc node antenna. The intermediate role to forward packets decrease the battery level of a node which lead to a decrease in the network life time. For that, a numerous research have be been done to overcome such problem in order to prolong the life time of ad hoc networks. In this research, a rigorous simulation runs have been done in order to evaluate and have better understanding of the protocols under study. In this research a stochastic approach have been conducted using p-method and box method to randomly generate a random graph to emulate the ad hoc interconnection topology. We concluded that though previous researcher thought that selecting a routing path based on the battery level or combined with link cost will lead to more hop counts. Such increase in the hop count will lead to an increment of end-to-end delay. Our approach revealed that such an assumption is not valid as proven by our simulation results.

For example, for the MLC case (as shown in Table 4), the number of hops is higher compared with MRP and MLC_MRP protocols. And the battery reserve power along the inter-vertices is the lowest. For both MRP and MLC_MRP simulation runs show almost equal hop count which results in lower end-to-end delay. The MLC_MRP protocol shows a higher reserved batter level than MRP, but the difference is not significant. Such higher battery level result in prolong of the life time of the ad hoc nodes. For that selecting the rout based on the maximum reserved battery power or based on the available reserved combined with link cost has no effect on the total end-to-end delay nor on the life time of the ad hoc network, while making the decision only based on the link cost will definitely lead to higher end-to-end delay and as a result will degrade the life time span of the ad hoc network.

Selecting a path of minimum link cost produced the lowest battery level values along the path and worse than that it has more hops count. For the case of MRP it shows better value for the battery reserved power as compared to MLC as wells as less hop counts. Though MLC_MRP has the best result in terms of battery reserve power along the transverse path, but it shows more hop counts as compared to MRP, but the difference is not of large value as compared to MLC.

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