Maximum Lifetime Routing in Wireless Sensor Network by Minimizing Rate Capacity Effect

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Abstract

Capacity of the battery is usually specified in Ampere-Hour. So far, while designing a routing protocol people are considering that if C is the capacity of the battery and the current drawn out of it is at rate R then total time to evacuate is T=C/R. On contrary, the batteries show Rate Capacity Effect. That is, Capacity of a battery decreases with increase in discharge current. Thus lifetime of the battery also decreases significantly with increase in discharge current. Researcher have been minimizing this effect using proper pulse shape and traffic shaping, all at physical layer of communication protocol. Our present work deals with these limitations of realistic battery model at network layer in routing protocols itself. We are presenting here two types of power aware algorithms to overcome this issue. In our algorithm Rate Capacity Effect, Minimum Drain Rate and Minimum Transmission Power Constraints are exploited altogether as a metric to design a routing protocol, which minimizes Rate Capacity effect and ultimately gives improved lifetime of the sensor network. This is to be noted that this improvement in lifetime of the battery used in sensor nodes is in addition to the improvement done at physical layer by other researchers.

1. Introduction

Wireless sensor network (WSN) is a network of sensor nodes. The main constituents of the WSN nodes are the communication devices (i.e. receiver and transmitter), a small CPU, a sensing device and a battery. The sensor node senses and gathers information from the surroundings; the CPU executes some control instructions and the communication units send the information to the base station through the network of such a large number of nodes.

There are many applications of wireless sensor network (WSN). It can monitor an agricultural field, it can create a network of home appliance or it can create network of medical instruments and supply data to a remote doctor. It can track the postal packets or a train on railway track. Its range can also be extended to monitor an atomic reactor or monitor any intruder on the border of any country. Broadly application of sensor network can be categorized in two parts: the application of sensor network in a *convenience place* and its application on a *hazardous location*. Keeping

in mind the battery model of a sensor node, the same classification is valid. Because, at convenience location we can recharge or change the battery as it gets discharged. But in hazardous location such as battlefield or borders of a country (summarily all defense use) sensor nodes are not easily accessible for changing it or recharging it. This is why, while designing a routing protocol for sensor network, all other issues like shortest path or minimum hop count becomes trivial. What is more important here is optimal use of battery power. Efforts are being made to utilize the fundamental characteristics of the battery for designing a routing protocol.

There are many power aware routing available in existing literature [1, 2, 3, 4, 5, 6, 7 and 12]. One of such routing protocol is Minimum Total Transmission Power Routing (MTPR) [3], which minimizes the total power necessary for transmission throughout the routing. Since the Transmission power is directly proportional to d^2 or d^4 , where *d* is the distance between the intermediate nodes of the route [13]. Therefore this protocol try to minimize the distance, hence choose more number of intermediate nodes, without caring for the delay and number of nodes involved in route formation. Therefore this is not the minimum hop count routing protocol.

Lifetime of a route can be defined as time up to whch a worst node of a route can survive with its residual battery power. S. Singh et. al. [14] proposed Min-Max Battery Cost Routing (MMBCR) scheme, which considers the residual battery capacity of nodes as the metric in order to enhance the lifetime of the nodes. Let $c_i(t)$ be the battery capacity of the node n_i at time t, the metric for route selection in this protocol is based on the route cost, where $f_i(t) = 1/c_i(t)$. This protocol defines 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 $R(r_o) = \min_{r_j \in n} R(r_j)$ where

 r_* is the set of all routes. Thus this algorithm MMBCR tries to choose a path whose weakest node has maximum remaining power among the weakest nodes in other possible routes to the same destination. Though in this process a route of maximum possible lifetime has been discovered but it doesn't guaranty minimum transmission power node. Authors in

[15] solved this problem by combining the two concepts described above, i.e. ideas behind MTPR and MMBCR and produced the "Conditional Max-Min Battery Capacity routing (CMMBCR).

There are more literatures available on maximum lifetime routing considering the battery power. Authors in [6] applied different cost metric to determine maximum lifetime routing scheme. Parameters like maximum residual battery power etc. has been used as a metric to determine the best route dynamically and on each step they proposed to increment the flow through best route detected. Authors in [5] developed a distributed algorithm based on flow based routing, where flow through each node is optimized and adjusted to get maximum life of the battery.

Authors in [7] used a new metric, the drain rate to find the best route. They defined a new cost function $C_i = (RBP_i)/DR_i$ where RBP_i is the residual battery power of the i_{th} node and DR_i indicates how much average energy is consumed by i_{th} node per unit time. This protocol is called minimum drain rate (MDR) routing.

1.1 Motivation:

Capacity of the battery is measured in Ampere-Hour. All of the power aware routing protocols in existing literature consider capacity of a battery like water in a bucket. If the capacity of the battery is c_i and I is the current drawn through it then it will last till c_i / I time. However the realistic battery behaves otherwise. As the current drawn out of the battery increases, the corresponding capacity and lifetime of the battery decreases. This phenomenon can be observed in following plots, which is taken directly from [10].

As current increases, the capacity of the battery decreases. Though at high temperature (say 55^{0} C) there is less variation in the capacity of the battery but at normal temperature (say 10^{0} C) the capacity decreases significantly. Capacity of the battery at room temperature can be expressed as an empirical formula [16]:

$$C = \frac{C_0}{(i/A)^n} \left(\frac{e^{(i/A)^n} - e^{-(i/A)^n}}{e^{(i/A)^n} + e^{-(i/A)^n}} \right) = C_0 \frac{\tanh(i/A)^n}{(i/A)^n}$$
(1)

Where C_0 is theoretical capacity of a battery *i* is the current drawn from battery and *A* and *n* are empirical parameters.

Along with the capacity the lifetime of the battery also decreases. Thus, as the current drawn out of battery increases, lifetime of the battery decreases. This relation can be given by "*Peukert's Formula*" [9, 10, 11, 16] as following:

$$T = C / I^{Z} \tag{2}$$

Where C is *theoretical* capacity (in amp-hours, equal to actual capacity at one amp), I is current (in amps), T is time (in hours), and Z is the **Peukert Number** for the battery. The *Peukert Number* shows how well the battery holds up under high rates of discharge - most range from 1.1 to 1.3 and

depends upon the temperature of operation. Typically at room temperature value of 'z' is 1.28 for Lithium Battery [16].



Figure-0 : Behavior of Lithium Battery used in most of the mobile device. This plot is taken directly from [10].

Review of the literature (given above) and [8] can be summarized as the following:

- Capacity of the battery is not independent of the current drawn out of it.
- Capacity of the battery decreases, as current drain out of it increases. This is known as Rate Capacity effect.
- Lifetime of the battery decreases with increase in current drawn out of it.
- At higher temperature the variation in lifetime of a battery and capacity is not so significant for moderate values of current but at room temperature and lower than it, the variation of capacity and lifetime that is given by *Peukert's Formula* must not be ignored while designing a routing protocol.

1.2 Related Work

Researchers have been aware of these chemical limitations of the battery. One of the early works has been done by Rao et. al. in [8] and [19]. They have used a specific pulse shaping technique to minimize this particular effect. They proposed that if pulsed current discharge technique is used instead of constant current discharge then this effect can be minimized. Moreover, they propose that to minimize the rate capacity effect, bursty discharge pattern must be used. Thus they optimize the parameters at physical layers to minimize Rate Capacity Effect.

Recently authors in [20] proposed a scheme to minimize one of the chemical limitations of the battery, known as charge recovery effect. But their work is entirely different from ours in the sense that while they have exploited "Charge Recovery effect" but we are exploiting "Rate Capacity Effect" of the battery for maximum lifetime routing. Their assumptions are rather intuitive, they don't give results that quantify the degree of improvements and their results are based on simulation with their own intuitive battery model rather than well established Puekert's Model which can be applied to battery.

1.3 Contribution:

As mentioned in last subsection the researchers have been aware of the chemical limitations of the battery used in mobile devices. But their work are either concentrated on Physical layer or they addressed relevant but entirely different issue like Charge Recovery Effect. With the insight of these works in mind we have following contribution:

- Our work is concentrated on Network layer and we minimize the rate capacity effect by routing algorithm itself.
- b) We give exact mathematical analyses that specifically quantify the degree of minimization of rate capacity effect.
- c) Our simulation studies show that our algorithm is simple and it can be implemented in the sensor nodes either placed on grid or spread randomly in a geographical area.
- d) We have shown with analyses and simulation studies that using the same battery capacities for the sensor nodes, our routing protocols assure increased lifetime of a route, and for a specified lifetime, these algorithms require a battery with lower capacity.

In what follows we are presenting our core algorithms of maximum lifetime routing and its analysis in section-2. The experimental results using simulation studies on Glomosim Network Simulator [18] is presented in section-3. We conclude in section-4.

2. Maximum Lifetime Routing Considering **Rate Capacity Effect of Realistic Battery Model** Here, we are using the DSR algorithm [17] for route discovery. In DSR, to discover a route, a ROUTE REQUEST packet is broadcasted by the source. The broadcast packet travel through all possible nodes to the destination. When a broadcast packet reaches the destination node, a ROUTE REPLY packet is returned to the source node through the same path through which request come and whose information is being stored in the packet itself. Therefore in this process there will be many ROUTE REQUEST packets reaching to the destination node, through distinct routes and hence all distinct ROUTE REPLY packets are returned to the source node. The delay experienced by a ROUTE REPLY packet is directly proportional to the number of hops in the route. Therefore, more will be the length of the route (hop count) more delay will be experienced by the ROUTE REPLY packets and latency in reaching to the source will be more. Thus the first ROUTE REPLY packet received by source will be through shortest path (minimum hop count) and other ROUTE REPLY packets will be reaching to the source node in order of the number of hop counts (length of the route).

Let us consider that there are N sensor nodes. Each source node generate data at the rate of DR_s which is needed to be shipped to the destination node. There are K numbers of such source sink pair. Let us define a cost function

$$C_i = \frac{RBC_i}{I^Z} \tag{3}$$

Where RBC_i is the Residual Battery Capacity of i_{th} node, I is the current drawn out of it and 'Z' is the *Peukert's Number* defined earlier. If we observe this cost function then we 'll find that this cost function actually represents the lifetime of a node from equation-2. In next subsection we are presenting two algorithms for Maximum Lifetime Routing.

2.1 The m Max-Z_p Min Algorithm for Maximum Lifetime Routing (mMzMR):

Following are the steps of the algorithm we propose here:

DEFINE: Worst node \leftarrow Lowest Battery Cost Function

Step-1: Source Node broadcast a ROUTE REQUEST.

Step-2: Source Node wait till Z_p number of delayed "ROUTE REPLY"s are received one after another. Let us consider that route discovered have following set of member nodes:

 $r_{1} = \{ n_{S}, n_{1-1}, n_{1-2}, n_{1-3}, \dots, n_{D} \}$ $r_{2} = \{ n_{S}, n_{2-1}, n_{2-2}, n_{2-3}, \dots, n_{D} \}$ $r_{3} = \{ n_{S}, n_{3-1}, n_{3-2}, n_{3-3}, \dots, n_{D} \}$ \dots

$$r_{Z_p} = \{ n_S, n_{Z_p-1}, n_{Z_p-2}, n_{Z_p-3}, \dots, n_D \}$$

Here we consider only those routes which satisfy $r_j \cap r_{j+q} = \{n_S, n_D\}, \forall q, j$. Let us consider that $C_{j,p}$ be the cost function of p_{th} node of j_{th} route.

Step-3: Calculate the cost function $C_{j,p}$ of each node and find the $\min_{\forall p \in r_j} C_{j,p}$ of j_{th} route and designate it as C_j^w .

Step-4: Sort the values of C_j^w for all j in descending order and take 'm' values and corresponding routes from top of this list, where $m \ll Z_p$ in general. If $Z_p \leq m$ then, then take Z_p values and corresponding routes from top of this list. Here 'm' is a control parameter to be chosen by the routing protocol designer.

Step-5: Divide and route the data produced per second by the source, into all chosen routes in such a proportion so that it induces effective currents through the worst nodes of all routes, resulting in the equal lifetime to the worst nodes of every route. This will further ensure that all chosen routes will have equal lifetime.



Figure-1 (a). Fracement of sensor nodes on a grid. Node numbers are marked in increasing order in a row from left to right. Thus the number written in first column indicates the node number of the first node in that row. The arrow indicates a particular connection with tail of the arrow as source and head as its destination.



Figure-1 (b): Random deployment of sensor nodes in a geographical area. All two adjacent sensor nodes may not have equal distance. Therefore energy consumed in transmitting a bit of information will be different for different node. Our second algorithm is most important for this type of orientation.

The summary of this given algorithm is: First of all $\min(m, Z_p)$ best routes in the terms of lifetime is selected among Z_p shortest route and the data generated per second is divided and routed into all chosen routes in such a way that lifetime of each route is equal.



Figure-2: This picture describes the delayed route discovered by DSR algorithm and number of hop counts of a route consists.

2.2 The Conditional m Max-Z_p Min Algorithm for Maximum Lifetime Routing (CmMzMR)

In this algorithm we are also considering the transmitted power as one of the metric. In this theorem all steps of the "mMzMR" algorithm remains same, but step-2 is modified and divided into two parts and it is written as:

Step-2(a): Source Node wait till Z_S number of delayed "ROUTE REPLY"S are received, Satisfying $r_j \cap r_{j+q} = \{n_S, n_D\}, \forall q, j$.

Step-2(b): Out of Z_S number of discovered routes for each route i calculate $\sum_{\forall i \in i} \left\| (d_{j,i} - d_{j,i+1}) \right\|^2$ $\left\| (d_{j,i} - d_{j,i+1}) \right\|^2$ where is calculated as the square of the Euclidian distance from i_{th} node to $(i+1)_{th}$ node in jth route and $d_{i,i}$ is the distance vector of ith node of the jth route from origin. Sort these numbers in ascending order. Take Z_p of these values and corresponding routes from top of this list, where \boldsymbol{Z}_p is a control parameter to be chosen by the routing protocol designer. (Step 1, 3, 4 and 5 of this algorithm

(Step 1, 3, 4 and 5 of this algorithm remains same as those of the algorithm we described in previous subsection)

Thus from above description it is clear that we have chosen the best route which takes minimum power to transmit packet from source node to destination node among the discovered delayed routes as given in figure-2. Finally $\min(m, Z_n, Z_s)$

number of new routes will be chosen and data generated is divided into all these routes to produce current for the worst node of a route in such a way that all chosen routes will have same lifetime.

2.3 The effect of distributed flow in elementary paths on the lifetime:

A heavy current drawn out of a battery degrade its capacity and lifetime. At lower discharge current battery shows effectively high performance. We are exploiting this property of a realistic battery model given by Peukert's formula in equation-1 and equation-2 in a way that if the current is divided into elementary paths then the effective lifetime of the nodes will be more than what undivided current flow will achieve. This effect can be visualized better by Lemma-2. Let us first describe how this current can be distributed and associated with data rate.

Let us consider that DR_i is rate at which data is generated by the source node and that is to be shipped to the sink node. If any particular route is selected, all nodes in that route will have to transmit and receive data with average rate of DR_i . Thus if the current drained out of battery of i_{th} node in a route is *I* for DR_i data rate, then for a data rate of (DR_i/m) the current needed will be I/m. Let us state it as a Lemma.

Lemma-1: Current drawn from the battery of a node is directly proportional to the rate at which that node transmits and receives data.

Let us consider that C_j^w be the capacity of the battery of the worst node of j_{th} route. To show the effect of distribution of data in elementary paths we want to compare here the two cases: (i) When routes are deployed one after another and each route has to bear the data rate DR_i thus the current I is drawn from the worst node of each routes one after another and (ii) For our algorithm, when data produced per second is divided into all elementary paths in such a way that currents drawn from the worst nodes of all routes make the lifetime of worst nodes of each route equal to T^* . This is to be noted that following analyses are carried out when only one source-sink pair is considered. As the number of source-sink pair will increase communication load on the nodes will increase but ultimately flow distribution will lead to minimization of Rate Capacity Effect.

Theorem-1: Let T be the sum of the lifetime of m routes under case-(i). If flow is distributed as given in our algorithm of mMzMR and CmMzMR the effective lifetime is increased to T^* which can be given as:

$$T^* = T\{\sum_{j=1}^m (C_j^w)^{1/z}\}^Z / \sum_{j=1}^m C_j^w$$

Where C_j^w be the capacity of the battery of the worst node of j_{th} route.

Proof: For the first case if current *I* is drawn out of the worst node, according to Peukert's formula the lifetime of the worst node of j_{th} route will be $T_j = C_j^w / I^Z$, where *Z* is the Peukert's number. Being a lifetime of the worst node, this will also be the lifetime of j_{th} route. Thus total lifetime of *m* routes can be expressed as:

$$T = \sum_{j=1}^{m} T_j = \sum_{j=1}^{m} \frac{C_j^w}{I^Z} = \frac{\sum_{j=1}^{m} C_j^w}{I^Z}$$
(4)

In the second case from Lemma-1, according to the data rate assigned to a particular elementary path current will also distributed proportionally. Thus the sum of the total data sent to all elementary paths per second will be equal to DR_i and sum of total current will be *I*. As stated in our algorithm, due to particular distribution of data, every elementary routes have same lifetime i.e. T^* . Thus relationship of current I_j drawn from the worst node of j_{th} route is related to T^* by

following formula $T^* = C_j^w / (I_j)^Z$. This is further simplified as:

$$(I_{j})^{Z} = C_{j}^{w} / T^{*} \Rightarrow I_{j} = \left(\frac{C_{j}^{w}}{T^{*}}\right)^{\frac{1}{Z}}$$
$$\Rightarrow I = \sum_{j=1}^{m} I_{j} = \sum_{j=1}^{m} \left(\frac{C_{j}^{w}}{T^{*}}\right)^{\frac{1}{Z}}$$
(5)

From equation-4

$$I = (\frac{\sum_{j=1}^{m} C_{j}^{w}}{T})^{\frac{1}{Z}}$$
(6)

Since for a same data rate both current in equation-5 and equation-6 will be equal hence

$$\Rightarrow T^* = \frac{T\left(\sum_{j=1}^m (C_j^w)^{1/Z}\right)^Z}{\left(\{\sum_{j=1}^m C_j^w\}^{1/Z}\right)^Z} = \frac{T\left(\sum_{j=1}^m (C_j^w)^{1/Z}\right)^Z}{\sum_{j=1}^m C_j^w} \quad (7)$$

If we analyze then we find that the numerator of the last term of above equation is much greater than the denominator, which assures that lifetime of the route after distribution of data in elementary flow paths is much greater than when data is carried out to each route separately one after another.

A novel example: Let us consider m=6, $C_1^w = 4$, $C_2^w = 10$, $C_3^w = 6$, $C_4^w = 8$, $C_5^w = 12$, $C_6^w = 9$ and Z for realistic battery model at room temperature is **1.28**. For this case suppose total lifetime of route without distribution of data in elementary flow paths i.e. T = 10. Putting these numerical value in equation-7, $T^* = 16.649$. Further, to visualize the effect of distribution of data in elementary flow paths properly let us consider a case when $C = C_j^w$, i.e. when $\forall J$

all worst nodes of all routes have same battery capacity. Then $T^* = T \frac{(mC^{1/Z})^Z}{mC} = T \cdot m^{Z-1}$. Let us state this result as a

Lemma.

Lemma-2: Due to Rate Capacity Effect lifetime of the distributed flow is m^{Z-1} times the same of undistributed flow, and can be expressed as $T^* = T \cdot m^{Z-1}$, where T is the sum of lifetime of all routes which are put into service one after another.

2.4 Implementation Issues:

The analyses given in last subsection identifies a fact that **distributed flows minimize** *Rate Capacity Effect* and **increase the lifetime**. But in sensor network scenario, topology changes rapidly and any node can begin transmitting data whenever an event of interest occurs. Therefore fixed elementary flow paths discovered cannot be

considered to be dedicated to a single sink-source pair. Any node will have to accept a ROUTE REQUEST any time and therefore at the same time topology and constraints will change. To overcome this issue we are proposing that in both the proposed algorithm route discovery process is updated after every sample time of T_s second, $(T_s << T^*)$ to accommodate the updated topology.

In our experimental setup, we have two types of placement of sensor nodes. In case one we have placed the sensor nodes on a grid (as shown in figure-1(a)) and in second case we have placed the sensor nodes randomly in given geographical location. Placement of nodes on a grid can be an example of a sensor network which is being deployed at a convenience location where human access is easy. Random placement of nodes can be considered as an example where sensor nodes are spread from the aeroplane to monitor a hazardous location which is not easily accessible like deep forest or Warfield. In grid based sensor we have considered that the distance between two neighbor nodes is always same. Therefore it always takes same amount of power to transmit between neighbor nodes. So fewer will be the number of nodes in a route (hop count) lesser will be the power required to transmit. However, for the case of random orientation and distribution of sensor nodes in a geographical region the distance between two nodes depends upon its coordinates and may not be always same. Therefore the energy consumed in transmitting a bit of information may vary from one node to other. Our second algorithm i.e. CmMzMR takes care of this effect of this non-uniformity in distribution of the sensor node.

3. Simulation Studies for A Grid Based Sensor Network with Multiple source sink pairs.

3.1 Simulation Set up:

We are using Global Mobile Information System Simulator (GLOMOSIM-2.0) [18] for our experimental simulation. We modified the DSR algorithm to discover routes. Modification is done to wait till Z_p numbers of routes are discovered. Here we have fixed $T_s = 20$ second. We have studies the performance of our routing protocols for two types of localization of sensor nodes in a geographical area. In first scheme sensor nodes are place on a grid as in figure-1(a). This is motivated with the fact that sensor nodes are deployed in a relatively convenient location to monitor that area. The example of such a location can be an agricultural field. In second scheme we are motivated with the fact that sensor nodes are deployed in an area not-so-accessible by human. Here sensor nodes can be spread from an aeroplane. In either case of fgure-1(a) or figure-1(b) the dimension of the area in which sensor nodes are spread is (500m X 500m). Each sensor node is capable of communicating up to 100 meters. We have 18 connections as shown in figure-1. A detail of the

connections in our experimental set up is also given in table-1 with their source-sink pairs.

Additionally we have considered the energy consumption model as $E(p) = I.V.T_p$. Where E(p) is the energy consumed in transmitting a packet p. I is the current value, Vis the voltage and T_p is the time taken to transmit a packet p. Here T_p is calculated as , $T_p = L/DR_p$ where L= length of packet and DR_p is the rate at which any source generate data.. For our simulation study we have fixed length of packets of 512 bytes and $DR_p = 2$ mbps and V=5v. Here one important point is to be noted that this is the rate at which data is being generated. In our algorithm when multiple elementary flow paths are used data rate is divided and hence current will also be divided. Note that we will have 'm' number of elementary flow paths for a single source sink pair. MDR [7] has single route at a time which may or may not follow the shortest paths. Here we have considered that battery of each node have a fixed initial capacity of 0.25 Ampere-Hour. Current required to transmit a packet in our simulation is 300mA and to receive is 200mA. We are not considering the power dissipated due to overhearing. Since in [7] it has already been shown that Minimum Drain Rate Routing (MDR) outperforms Minimum Total Transmission Power routing (MTTPR) [15], and Min-Max Battery Cost routing (MMBCR) [14] and Conditional Min-Max Battery Cost routing (CMMBCR) [15]. Thus it will be sufficient to show that our proposed algorithm out-perform MDR algorithm. Therefore in what follows, we have compared the various performance metrics of our algorithms with the same of MDR

3.2 Results for Grid based node deployment:

We have considered 18 pairs of source and sink. Thus in figure-1(a) the arrows are indicating, the minimum hop count route from source to sink.

Conn. No.	Source- Sink Pairs	Conn. No.	Source- Sink Pairs	Conn. No.	Source- Sink Pairs
1	1-8	7	49-56	13	5-61
2	9-16	8	57-64	14	6-62
3	17-24	9	1-57	15	7-63
4	25-32	10	2-58	16	8-64
5	33-40	11	3-59	17	8-57
6	41-48	12	4-60	18	1-64

Table-1: Description of connection number with their Source-Sink pair.

In figure-3 we have shown, how the nodes are running out of energy and at a particular moment of time how many nodes remain alive. In figure-3 it is clearly visible that under our proposed algorithm mMzMR number of nodes alive at a particular moment of time is greater than the same of MDR. However, numbers of nodes that are alive in CmMzMR are still higher than the both of them. Thus it is giving us a conclusion that CmMzMR is the best algorithm for routing, when our purpose is to maximize the battery lifetime in the sensor network.



Figure-3: Number of alive nodes vs Simulation time considered when all 18 source-sink pairs are communication with each other. Here we have kept m=5.



Figure-4: Here on Y-axis we put Ratio of the average lifetime of all nodes in our proposed algorithms to the average lifetime in the case of MDR. Along X-axis value of m is varied. The two plots are respectively for mMzMR and CmMzMR.

In figure-4 we demonstrate most important result of our algorithms. Typically without the Rate Capacity Effect of the battery the ratio of the lifetime in our algorithms with that of MDR should have been one. But due to this effect flow of data through elementary flow paths reduces the current and hence the capacity and lifetime of the batteries increase. On Y-axis, ratio of the average lifetime of all nodes in our algorithms and that of MDR is taken. This result is taken when all 18 source sink pairs are communicating. Here we find that for m=1, our algorithm converges to the MDR. Therefore ratios of lifetimes is 1. But as 'm' increases, the number of flow paths increases and due to distribution of data rate and hence current, Rate capacity Effect is minimized. Hence we get more lifetime and this leads to the ratio of lifetimes T^*/T increasing beyond 1. Here we find that in the case of mMzMR the after m=6 this ratio starts decreasing. Because in mMzMR as the number 'm' increases length of paths also increases which costs more transmission power. Hence after a particular value of m the ratio of T^*/T starts decreasing. However in CmMzMR Maximum Transmission Power is one of the initial constraints therefore this ratio T^*/T always increases. However at high value of '*m*' system is not able to identify the better routes due to the limited number of nodes in our case.



Figure-5: Variation of average lifetime with increasing battery Capacity.

In figure-5 we have plotted the variation of average lifetime of all 64 nodes with increasing capacity of the battery, here m=5. We note that as the capacity of the battery increases the average lifetime of the node also increases linearly. However one of the important result we find that for each capacities of the battery the lifetime under our proposed algorithm is much higher than the same under MDR. For example, for battery capacity of 0.50Ah MDR gives lifetime of 370 sec (approx) while our algorithms assure 430 sec (approx) and 485 sec (approx) respectively. This concludes two results: (i) With the same Capacity of the battery we can assure more lifetime and (ii) For a specified lifetime for a connection we need battery with less capacities.

3.3 Results for randomly orientated sensor nodes.

We have again 18 pairs of source and sink. But we have here randomly oriented sensor nodes in a geographical location as shown in figure-1(b). Source and sink both are chosen randomly among 64 nodes we placed in this geographical location. Any source node can be sink node of other source node.

In figure-6 we have taken the similar result like the result shown in figure-3. All 18 pairs of sources and sinks start communicating at the same time. As the time elapses we start observing how many nodes remain alive at a particular epoch of time. Here we find that at the beginning 64 nodes are alive and as time elapsed nodes are running out of energy and number of alive nodes remain fewer and fewer. But at each epoch of time number of alive nodes in our case is much greater than the case when MDR algorithm is being used.

In figure-7 we have compared the ratio of average lifetime of all 64 nodes in our case to the average lifetime of the nodes while using MDR algorithm. We find that as the number of distributed flow paths increases, the rate capacity effect is minimized and so the ratio of average lifetime of the nodes in our case and average lifetime of the nodes in MDR algorithm also increases. However due to limited number of nodes in the network, number of best discovered path is limited and so beyond m=5 ratio of lifetimes doesn't increases. Since in this case of random distribution of sensor nodes we are using CmMzMR algorithm in which distance between two nodes is taken as one of the metric. Therefore for greater value of m lengths of paths doesn't increase heavily and unlike in figure-4 ratio of average lifetime doesn't decrease after its peak value. Rather it remains almost constant.



Figure-6: Number of alive nodes vs Simulation time considered when all 18 source-sink pairs are communication with each other. Here we have kept m=5.



Figure-7: Here on Y-axis we put Ratio of the average lifetime of all nodes in our proposed algorithms to the average lifetime in the case of MDR. Along X-axis value of m is varied.

4. Conclusion

We have presented here two algorithms for routing to minimize the *rate capacity effect* of a battery, due to which the practical capacity of a battery remains far below the theoretical capacity when a large current is drawn out of it. Further, we have suggested that instead of sending a bulk of data through a best lifetime route, send the data through multiple routes, which are best among all available routes. This will result in a distributed flow of data. It further proves that distribution of data results in minimization of rate capacity effect and maximization of lifetime.

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