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Energy Efficient Multicast through Acknowledgment based TPC in Adhoc Wireless Networks

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Abstract

The existing energy-aware routing algorithms in ad hoc networks, select a path with a large number of small-distance hops. But such a formulation based solely on the energy spent in a single transmission is misleading —the proper scheme should include the total energy (including that expended for any retransmissions necessary) spent in reliably delivering the packet to its final destination. Our main idea is to find a new routing scheme which is capable of including delay, energy, as well as link reliability factors to increase the operational lifetime of the network. The proposed analytical model successfully captures the key characteristic of a reliable power saving system: the data delivery procedure starts periodically at the previously negotiated time, but ends at a rather random time with its distribution depending on the end time of data delivery in the last delivery period as well as the arrival rate of incoming traffic.

Keywords: Energy aware routing; Markov chain model; Ad hoc networks; reliable routing; routing protocols

1. Introduction

Energy-efficiency and reliable routing are two important requirements in wireless ad hoc networks, where nodes have limited battery power and wireless links are prone to transmission errors. When nodes in the network cooperate to achieve a single goal (e.g., in wireless sensor networks), maximizing the operational lifetime of the network is also an important requirement. While each of these requirements could be achieved separately in ad hoc networks, providing energy-efficiency and reliability in such a way that the network lifetime is maximized is of significance. Presently, there is no such scheme which satisfies both of the above requirements.

The existing energy-efficient routing schemes shown in Section – 3.1, 3.2 and 3.3 can reduce the overall energy consumption in the network. The scheme in 3.1, find routes with the minimum total transmission power required for packet transfer from source to destination. This scheme, however, do not consider the reliability of links in route selection [3]. This may result in choosing less reliable routes, which reduces the quality of service.

Routing schemes proposed in 3.2 aims at increasing the operational lifetime of ad hoc networks [7] by taking into account the residual battery energy of nodes. They try to find routes such that their constituent nodes are likely to have more battery energy. Such schemes can avoid the use of nodes with low battery energy such as relaying nodes, and balance the traffic load in the network. They, however, may fail to find reliable routes, since they also do not consider reliability of wireless links [8] in route selection.

In 3.3, the schemes address the reliability factor but fail to deal about the energy consumption in an optimized manner. The existing routing algorithm in 3.4 takes into account reliability of links and battery energy consumption of nodes in route selection. Nevertheless, it fails to address the power consumption issue appropriately.

2. Problem Definition

In order to attain the co-operation of the nodes in mobile ad hoc networks to facilitate reliable data delivery, the nodes has to be kept active for a longer time. Hence the routing scheme used must be able to increase the operational lifetime of the network and at the same time has to find reliable and energy – efficient routes. The algorithm has to reduce the overall energy consumption in the network by finding minimum energy cost routes. The scheme must be able to find reliable routes in which the constituent links shall require less number of retransmissions due to packet loss. It is also necessary to balance the traffic load in the network.

3. Background and Related Work

Many authors have used different energy aware routing algorithms for multicast services in mobile ad hoc networks. Some of these works are presented in this section.

3.1 MER Algorithm

Energy-aware routing schemes in (1) and (2), define the link weight as the required transmission power for successful signal detection [10] at the receiver side, and finds routes with the minimum accumulated weight. Such a transmission power is proportional to the path-loss exponent power of link distance. If $d_{i,j}$ denotes the distance between nodes i and j, and η denotes the path-loss component ($2 \leq \eta \leq 6$), the weight of path P with h hops in these routing schemes is defined as follows:

$$W_{mer}(\mathcal{P}) = \sum_{i=1}^{h} d_{i,i+1}^{\eta}, \quad (1)$$

which must be minimized. Such a path is called minimum energy path and the routing algorithms which find such paths are called minimum energy routing (MER) algorithms. Since the transmission power decays with the distance exponentially, MER will select routes consisting of many short range links.

3.2 MBCR and MMBCR Algorithm

MBCR (Minimum Battery Cost Routing) and MMBCR (Min-Max Battery Cost Routing) are energy-aware routing schemes which consider the residual battery energy of nodes to avoid them from being overused. MBCR defines the path weight as,

$$W_{mbcr}(\mathcal{P}) = \sum_{i=1}^{h} \frac{1}{B_i}, \quad (2)$$

and finds the path with the minimum weight, where B_i is the is the residual battery energy of node i. On the other hand, MMBCR defined the path weight as,

$$W_{mmbcr}(\mathcal{P}) = min\ \{B_i\}_{i=1}^{h}, \quad (3)$$

and selects the path with the maximum weight. In [2] and [9], other energy-aware routing schemes are proposed for ad hoc networks, which inherit some characteristics of the above mentioned schemes. The main drawback of all these routing schemes is that they do not consider reliability of links in route selection. Less reliable links not only harm the quality of service, but also consume more energy to deliver packets due to more number of retransmissions than such links require [3].

3.3 MRPC and CMRPC Algorithm

In [9], MRPC (Maximum Residual Packet Capacity) and CMRPC (Conditional MRPC) are proposed, which in addition to link reliability consider the residual battery energy of nodes for route selection. MRPC uses a max-min formulation similar to MMBCR. Nevertheless, the path weight in MRPC is the number of packets which can be transmitted ideally through a path when there is no other traffic going through that path. That is,

$$W_{mrpc}(\mathcal{P}) = min\ \{\frac{B_i}{T_{i,i+1}}\}_{i=1}^{h}, \quad (4)$$

where $T_{i,i+1} = \frac{d_{i,i+1}^{\eta}}{p_{i,i+1}}$, is the required power for reliable transmission of a packet over $(i, i + 1)$ link. The path with the maximum weight is then selected. CMRPC is a conditional version of MRPC which finds the minimum energy path among paths that their MRPC weight is above a threshold. If there are no such paths, CMRPC acts similar to MRPC.

3.4 RMECR Algorithm

While MER only considers the required power for packet transmission, and MBCR considers only the residual battery energy of nodes, RMECR considers both of them. On the other hand, while MRPC, which also considers these two factors, uses a max-min scheme that can increase the total energy consumption in the network, RMECR finds the minimum cost path.

However, RMECR scheme is based on the theoretical assumption that if the distance between the nodes decreases, then the power consumption also decreases. That is, the distance between the corresponding nodes is inversely proportional to that of the power consumed by the respective nodes (energy ∞ 1/distance). Hence if the distance between the source and destination increases, then it will require high energy. This is the drawback of the existing RMECR algorithm.

4. Proposed Solution

Thus there are several theoretical studies on the modeling of power aware reliable routing algorithms. Out of those, the use of max-min route selection scheme in energy-aware routing algorithms such as MMBCR and MRPC increases the hop count of the routes as in (3) and (4). This increases the latency of end-to-end packet transfer as well as the total energy consumption in the network. On the other hand, energy-aware routing algorithms such as MBCR and MER which find the minimum cost routes can achieve a lower hop count (2) and (1) respectively. RMECR is also a minimum cost routing scheme, which considers both remaining battery energy of nodes and the reliability of links in route selection. This does not provide an efficient power saving and hence it could be improved through A-RMECR.

Hence we propose a new energy-aware routing algorithm for wireless ad hoc networks called Advanced Reliable Minimum Energy Cost Routing (A-RMECR), which is an extension to the existing RMECR scheme. The proposed algorithm is able to increase the network lifetime [9] and find reliable and energy-efficient routes simultaneously. A-RMECR finds minimum energy cost routes, where the energy cost of packet forwarding from a node is a function of the Power Saving Mode (PSM) of the nodes. We show that A-RMECR can reduce the overall energy consumption in the network by finding minimum energy cost routes. It can also find reliable routes in which constituent links require less number of retransmissions due to packet loss[3]. Furthermore, A- RMECR can balance the traffic load in the network and increase the network lifetime by facilitating Online Delivery Policy [9].

A-RMECR assumes nodes deploy automatic repeat request (ARQ) for reliable packet transmission in each hop. The receiving node in each hop acknowledges the correct reception of the packet. If the packet or its acknowledgment is lost, the sender will retransmit the packet. This continues until the packet is delivered successfully to the receiver, or the maximum number of transmission trials is reached. Many wireless standards such as IEEE 802.11 and IEEE 802.15.4 support such a feature [8].

To formulate A-RMECR, assume *Ei,j* is the expected energy consumed by the node *i* to transmit a packet to node *j* over the link (*i, j*) including the energy consumed for retransmissions. The link weight of (*i, j*), *wi,j*, in A-RMECR is defined as the fraction of the residual battery energy that node *i* consumes to transmit a packet reliably over (*i, j*). That is,

$$w_{i,j} = \frac{E_{i,j}}{B_i}, \qquad (5)$$

where B_i is the residual battery energy of node *i*. The path weight is then defined as,

$$Warmecr(P) = \sum_{i=1}^{h} \frac{E_{i,i+1}}{B_i}, \qquad (6)$$

and the path with the minimum weight is selected.

In a distributed implementation, this can be done using Constraint Based Routing (CBR) algorithm by defining constraints that should be satisfied by the data transfer. The motivation behind this definition of constraints is to make the network more efficient and also to capture the effect of reliability of a link and the residual battery energy of nodes together. Higher energy consumption and lower battery energy both increases the link weight.

While MER only considers the required power for packet transmission, and MBCR considers only the residual battery energy of nodes, RMECR considers both of them. On the other hand, while MRPC, which also considers these two factors, uses a max-min scheme that can increase the total energy consumption in the network, RMECR finds the minimum cost path based on the factor that as the distance increases the battery energy decreases. But A-RMECR overcomes this drawback by assigning an analytical model for power saving. As we will show in the next section, ARMECR can increase the lifetime of the network compared to MRPC, CMRPC and RMECR.

4.1 Reliable Packet Transmission

In order to calculate *Ei,j*, we first use a model which has been verified using the empirical measurements, to compute the energy consumed for a single transmission of a packet. In this model the consumed energy by a node during packet transmission consists of two elements.

The first element is the energy consumed by the processing part of the transceiver circuit, and the second element is the energy consumed by the transmitter amplifier to generate the required power for signal transmission. If we denote the data rate of the wireless interface as *r*, then the energy consumed for a single transmission of a packet of length *L* bits over (*i, j*) link is computed as

$$\varepsilon_{i,j}(L) = \frac{P_0 L}{r} + \frac{P_{t_{i,j}} L}{r}, \qquad (7)$$

where P_0 is the power consumed by the processing part of the transceiver circuit, and $P_{ti,j}$ is the power consumed by the transmitter amplifier.

In ad hoc networks, nodes might be able to adjust their transmit power to the link distance such that packets are transmitted with minimum power required for decoding the packet at neighboring nodes with certain error rate. If such a transmission power control (TPC) scheme is supported, $P_{ti,j}$ will be proportional to $d^{\eta}_{i,j}$. That is,

$$P_{t_{i,j}} = Ad^{\eta}_{i,j}, \quad (8)$$

where A is a constant. If nodes cannot adjust their transmission power per link distance, $P_{ti,j}$ will be the same for all links going out from them, which could be their maximum transmission power. In other words, with no TPC,

$$P_{t_{i,j}} = P_{max} \ \forall \ (i,j). \quad (9)$$

As mentioned before, each node in the network may retransmit a packet several times to deliver it reliably to the next hop. If we define $n_{i,j}$ as the expected number of transmissions (including the first transmission) to deliver a data packet over (i, j) link, then the expected energy consumed to deliver a data packet over a link, $E_{i,j}$, is

$$E_{i,j} = \bar{n}_{i,j}\varepsilon_{i,j}(L) = \bar{n}_{i,j}\left(\frac{P_0 L}{r} + \frac{P_{t_{i,j}} L}{r}\right), \quad (10)$$

Since $E_{i,j}$ depends on the packet length L, the link weights in will also depend on L. However, we can eliminate L, which is a constant term in all link weights without changing the ranking of path weights. If we replace $E_{i,j}$ from (10) into (5) and neglect L in the resulted expression, we can compute the link weight in A-RMECR as,

$$w_{i,j} = \frac{\bar{n}_{i,j}}{rB_i}\left(P_0 + P_{t_{i,j}}\right). \quad (11)$$

In order to calculate $n_{i,j}$, we remember that a packet is retransmitted, if the packet or its acknowledgment is lost. If $p_{i,j}$ represents data packets delivery ratio over (i, j), and $q_{j,i}$ represents acknowledgment packets delivery ratio over (j, i), then the probability that a packet is transmitted k times is as follows:

$$\Pr\{n_{i,j} = k\} = \begin{cases} (1 - p_{i,j}q_{j,i})^{k-1} p_{i,j}q_{j,i}, & k = 1..Q-1 \\ (1 - p_{i,j}q_{j,i})^{Q-1}, & k = Q, \end{cases} \quad (12)$$

where Q is the maximum number of transmission tries. For any values of Q, we can find the exact value of $n_{i,j}$ given the probability density function in (12). However, we can easily show that for sufficiently large Q, $n_{i,j}$ could be approximated as

$$\bar{n}_{i,j} = \frac{1}{p_{i,j}q_{j,i}}, \quad (13)$$

where $n_{i,j}$ is referred to as the expected transmission count (ETX) of the link. After replacing $n_{i,j}$ from (13) into(11), an alternative expression for the link weight in RMECR is resulted as follows:

$$w_{i,j} = \frac{1}{rB_i p_{i,j} q_{j,i}}\left(P_0 + P_{t_{i,j}}\right). \quad (14)$$

The overview of the proposed A-RMECR algorithm is as follows:

Algorithm 1 Operation of each node i in A-RMECR.

Require: P_0, B_i, P_{max}, r,

Estimate $p_{i,j}$ and $q_{j,I}$ $\forall$ j in *Neighbors*(i)

if TPC is used then

Estimate $P_{ti,j}$ $\forall$ j in *Neighbors*(i)

else

$P_{ti,j} \leftarrow P_{max}$ $\forall$ j in *Neighbors*(i)

end if

$w_{i,j}$ $\leftarrow$ $1/r$ B_i $p_{i,j}q_{j,i}$ $\forall$ j in *Neighbors*(i).

Construct network topology $G(V,E)$

Determine min. cost path to each node using Constraint Based Routing Alg. & Markov Chain Model

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4.2. Cost Minimization

Thus using the Constraint Based Routing algorithm the shortest fulfilling the constraints such as reliability, minimum bandwidth required per link (also known as bandwidth guaranteed constraint), end-to-end delay, maximum number of links traversed, include/exclude nodes, etc are selected and other links which violate the given constraints are pruned for active data transfer.

4.3. Markov Chain Model

The Markov Chain based analytical model [5] is used for addressing the power consumption issues, wherein RMECR it is based on the theoretical concept that distance is inversely proportional to that of the power consumed. In this framework, the delivery procedure of a single frame is treated as an atomic operation, lasting for a fixed period. All PS (Power Saving) data are delivered periodically in each DP (delivery period).

At the beginning of a DP, the neighboring nodes broadcasts a notification message (may be a beacon for 802.11 PSM-Power Saving Mode) to the network. The message contains traffic information for data delivery, such as whether there are pending data at the node. An intermediate node receiving this message determines whether there are PS data for it in this DP by parsing the information element in the message. If so, the node remains awake until a received frame has explicitly indicated the end of the data delivery for the current period by a cleared MoreData field or set EOSP bit in the frame header; otherwise, the node can enter into sleep state immediately until the next DP.

In 802.11 PSM, the data arrived before the conclusion of data delivery procedure in a listen interval will be delivered immediately within the same interval, and only those data that arrived after the conclusion of delivery procedure will be buffered until the next listen interval. This delivery policy is called the online delivery Policy. Therefore, most PS protocols in 802.11 wireless LANs employ the online delivery policy to reduce network delays [5]. Thus the energy is saved as the nodes that are not involved in an active data transfer are put to sleep state.

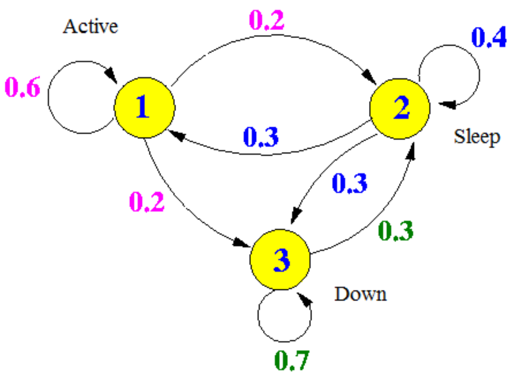


Figure 1. Example of a Markov chain model on the modes of nodes

A- RMECR algorithm can be implemented with the existing routing protocols for ad hoc networks. To this aim, nodes must be aware of the power consumption of their wireless interface, P_0, their residual battery energy, B_i, and their data rate, r, which are implementation issues. They must also know their transmit power per link, $P_{ti,j}$ (or alternatively their link distance $d_{i,j}$), if TPC is utilized, or their maximum transmit power P_{max}, when TPC is not supported. Furthermore, they must know the packet delivery ratio of their links [3], which could be estimated using the proposed mechanism in [3]. In this mechanism, node i broadcasts hello messages with sequence numbers. The neighboring node j counts the number of received hello messages from i to calculate the packet delivery ratio of the link (i, j). Similarly, i can calculate the packet delivery ratio of the link (j, i) using the hello messages it receives from j.

Nodes could also estimate their distance to each other using the signal strength indicator of the received hello messages (see [10] for more details). Each node broadcasts the measured values in hello messages that it propagates. In this way, each node obtains the packet delivery ratio of all the links between itself and its neighbors as well as all the links between its neighbors and itself. These values can approximate the delivery ratio of data packets, $p_{j,i}$, as well as the delivery ratio of acknowledgment packets, $q_{j,i}$. The accuracy of this approximation, however, depends on the hello message size. Acknowledgments are usually small packets, and their loss probability is lower than that of large data packets.

5. Performance Comparison

Fig.2 shows the total number of survived nodes during the network lifetime. Here, we assumed that nodes do not adjust their transmission power per link distance, and use their maximum transmission power. With this assumption, MER will actually find the shortest hop routes. Fig. 2 clearly shows that A-RMECR can significantly delay the first node failure compared to the other algorithms, while it also achieves a high network lifetime. We also observe that in MER the first node failure happens before all other algorithms, because it does not consider the residual battery energy of nodes in route selection. Hence, nodes are overused and fail fast. MRPC and CMRPC consider both the residual battery energy of nodes and the link reliability. They are able to delay the first node failure compared to MER and Min-ETX, but their network lifetime is lower than that of MER and Min-ETX.

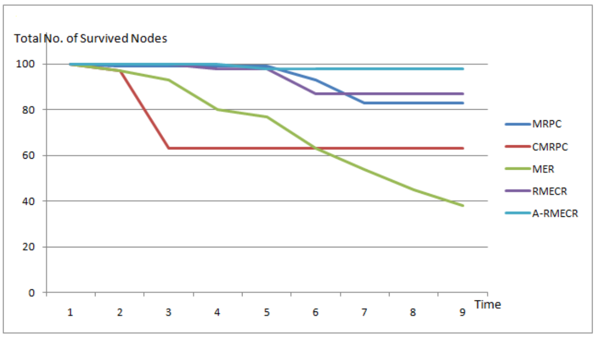


Figure 2. Total number of survived nodes during the network operational lifetime for

various routing algorithms for p_{min} = 0.5. The horizontal axis is the elapsed time of the simulation. Here, nodes do not adjust their transmission power per link, and results are for a single simulation link.

We can find the reason of this phenomenon in Fig. 3(a) and Fig.3(b). The max-min nature of route selection in MRPC increases the hop-count (see Fig. 3(a)). This in turn increases the overall energy consumption in the network as well (see Fig. 3(b)).CMRPC can improve the performance of MRPC, but its hop-count and its energy consumption is still much higher than that or MER, RMECR, and Min-ETX algorithms.

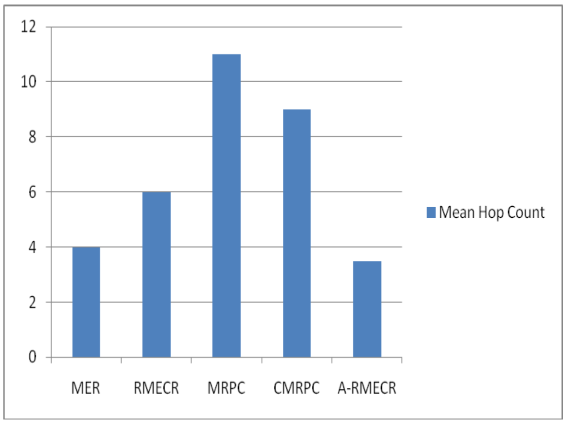


Figure 3(a). The mean hop count of the selected routes and the average energy consumed to deliver a packet from its source node to its destination node

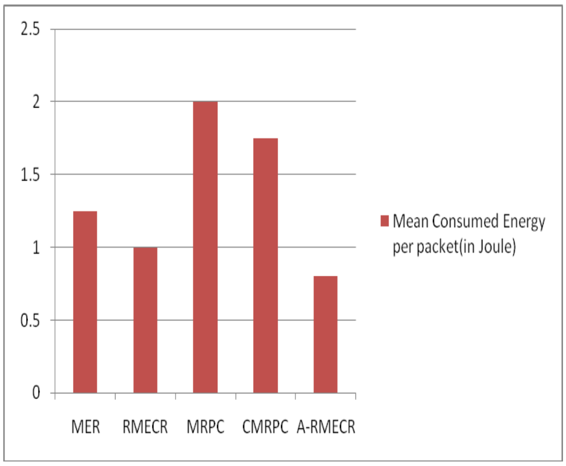


Figure 3(b). The mean ETX of the selected routes

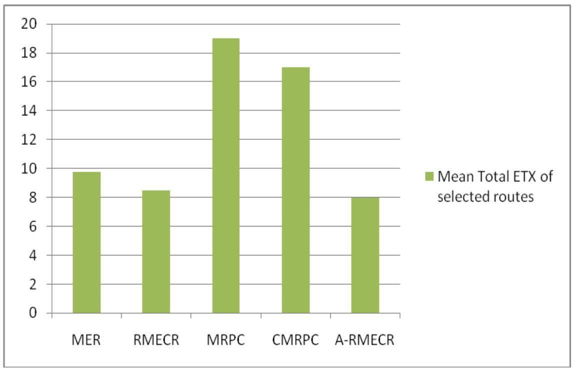
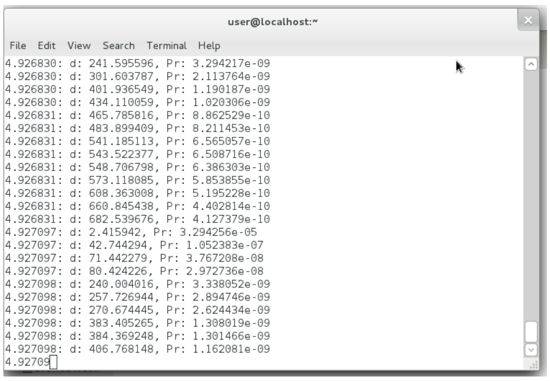
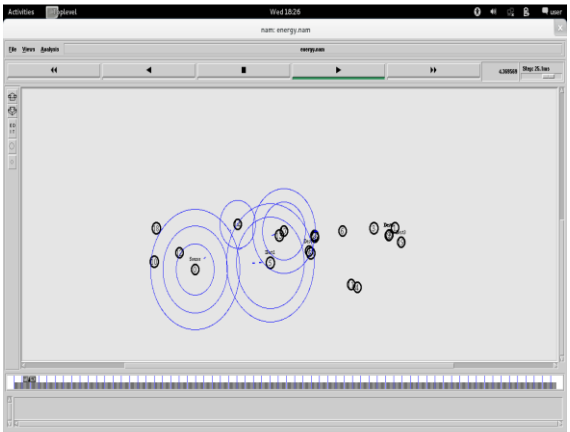


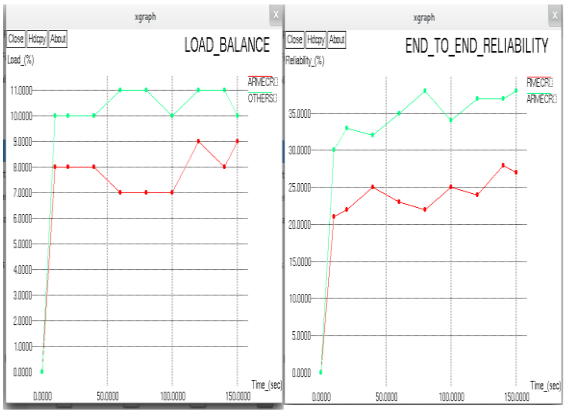
Figure 3(c)) For various routing algorithms for p_{min} = 0.5. Here, nodes do not adjust their transmission power per link, and results are for 50 simulation runs.).

Ultimately, we observe that A-RMECR, not only delays the first node failure, but also achieves a high network lifetime. Since A-RMECR finds the minimum cost routes, its hop count is very close to the hop count of MER (i.e., the minimum hop count). Hence, it can reduce the total energy consumption in the network, and achieve a high network lifetime. Furthermore, since A-RMECR considers the actual energy for reliable packet transmission as well as the residual battery energy of nodes, it prolongs the lifetime of nodes by delaying the first node failure compared to the other algorithms [6]. We can also observe in Fig. 2 that the time at which the first node dies, and the time at which the network reaches its lifetime after failure of 25%, or as matter of fact even 100% of nodes are very close in A-RMECR, which means A-RMECR can balance the load in the network better than the other algorithms.

From the results we are able to find more reliable paths compared to the other algorithms. We could also observe that the transmission power control (TPC) can increase the network throughput for various algorithms [4]. The following are the simulation results obtained using the ns-2 simulator.







6. Conclusion

In this paper, we proposed an extension to the RMECR algorithm for wireless ad hoc networks. A-RMECR finds minimum energy routes for reliable packet transmission from a source node to a destination node. Through extensive simulation results, we showed that A-RMECR can significantly increase the operational lifetime of ad hoc networks compared to the similar best known algorithms. It also reduces the energy consumption per packet delivery in the entire network, which increases the energy-efficiency. Furthermore, it can find highly reliable routes. Our results showed that a minimum cost formulation for route selection can balance the load more effectively than a max-min formulation used in other algorithms.

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