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Research paper

Mathematical formulation of energy efficient routing with constraint in mobile ad hoc network

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Abstract

Energy consumption of nodes during the transmission is an important factor for the efficiency and lifetime of a mobile ad hoc network. The reduction in consumption of energy can be achieved, only when its consumption at each step is known. The purpose of this paper is to formulate the mathematical model of energy consumption of network on the basis on links and available nodes in order to formulate the energy optimization function. The probability of link failure in route and innetwork have been taken into consideration as constraints while formulating the objective function of estimated energy consumption, as the low connectivity is one of the challenges due to mobility in ad hoc network.

Keywords:*Ad Hoc Network; Dynamic Topology; Energy Aware; Link Failure; Routing Protocol.*

1. Introduction

Energy efficient routing is an effective technique for reducing the energy consumption during the transmission in Mobile Ad hoc Network (MANET). In general, link failure in the network leads to unsuccessful transmission and causes retransmission of packet from one node to another. This amounts to the wastage of energy of the nodes in the path.Hence, energy efficient routing in ad hoc networks is neither complete nor efficient without the consideration of link assessment prior to the transmission. Transmission on healthy linked path enhances the reliability and quality of the service. It is desirable for a routing protocol to cope up with undesirable situation like link failure and link breakdown situation. This paper estimates energy requirement for the successful transmission of packet in the network. It considers possible consumption of energy of all three kinds of node in the network.

2. Literature survey

In order to reduce the energy consumption in transmission, the vital role is being played by the routing mechanism employed in the network. There are several scientists and researcher contributed in this area but it still demands the focus to reduce power consumption. In [1] author applied technique to reduce the number of transmission and decreases the energy consumption by using the network coding for head of the cluster and furthermore improve the coding opportunities while employing the queue management process. The work in paper [2], expresses the power saving protocol based on MAC in mobile ad hoc network. The protocol is used a technique which allows the host to sleep for a given interval of time and wake up as soon as its assigned time is over in order to minimize the power consumption. The work by author [3] on energy efficiency based on combination of node's lifetime and distance-based power metrics and investigates some properties of power adjusted transmissions and demonstrates the power is the function of linear equation. The transmission decision is made as per the location of neighbors and the destination nodes in the network and optimizes the power between two nodes. In paper [4] discussed the power requirement of nodes in the network by using the two techniques namely carrier-sense multiple-access/collision-avoidance (CSMA/CS) and request-to-send (RTS)/clear-to-send (CTS). The work proposed in paper [5], focuses to minimize the energy by utilizing the combination of two concepts that are multipath routing and energy reservation mechanism. In paper [6] focuses on reducing the energy consumption while avoiding the packet loss of wireless sensor network. The paper [7] aimed the energy consumption optimization in mobile ad hoc network for ad hoc on demand multipath distance vector (AOMDV) by employing the fitness function technique in routing protocol. On the basis of this fitness function it obtained the multipath which reduces the energy consumption in the transmission. The work in paper [8] discussed the cluster based scheme which improves the scalability and stability of the given network. The articulated algorithm treated the cluster of nodes the bird's flock with dynamic formation. Furthermore a mechanism based dynamic topology is proposed to reduce the congestion in the network in order to enhance the performance of the network. In work [9], the author proposes a routing protocol, which is based on dynamic connectivity without the any intervention and maintain connectivity metric and reduces the overhead of RREQ and RREP messages in the network. The work [10] illustrates a protocol which optimizes the transmission overhead while utilizing prediction of node mobility in combination with cluster formation. The paper [11] uses the greedy algorithm for the formation of cluster of nodes. The paper is based on the theoretical analysis of decision making problem based on cooperative game analysis theory. The research work expressed [12] is simulate the urban scenario for the large network for the quality of services along with the scalability. The protocol uses a technique which utilizes node clustering along with the virtual backbone. The author proposed an algorithm [13] which uses the genetic algorithm and cellular automata that exploits the procedure to reduce the energy and delay in the network. The author has projected [14] an algorithm that supports the self organized transmission mechanism based on node clustering in order to reduce the routing overhead. The article [15], is aimed to reduce the energy optimization of wireless sensor networks based on clustering phase and routing phase using harmony search method. The author projected a work [16] which dealt with single path and multipath routing and articulated the set of reliability for the different packets at different time of transmission. The author in the work [17], describe the research based challenges available in wireless mobile network and systems that provides logical connectivity to huge numbers of mobile network nodes co-located within a limited volume. The article [18] used an algorithm describes the generation of cluster that maintains a metric for the potential cluster members and a node is elected as cluster head that has maximum number of potential cluster members. In order to minimize the nodes in backbone network, an associated node is assigned the responsibility to communicates between two cluster heads. The work [19] is proposed to reduce the size of search space, and a new decoding scheme to generate high-quality solutions effectively. The author has introduced a technique [20] for large scale Wireless Sensor Networks (WSNs). The algorithm is used to evaluate the node which has energy supply and optimize Greedy perimeter stateless routing for wireless networks. The author proposes a routing [21] protocol which is based on position, it takes the decision of packet transmission after looking the position of router and the destination node. The decision is made as per information available about the immediate neighbors of router in the network.

3. Proposed approach

3.1. Energy consumption in message transmission (based on node link)

Let energy consumption in message transmission of length x (bit) from node a to node b through physical link (a, b) is represented by $\delta_{a,b}(x)$, energy consumption in message receiving of length x (bit) at node b from node a is expressed by $\emptyset_{a,b}(x)$, I_a represents the necessary energy to run the processing unit of node a, $P_{a,b}$ be the transmission power between nodes a and node b, y_a be the energy efficiency of energy amplifier of node a; $0 < y_a \leq$, $J_{b,}$, J_b represents the necessary energy to run the processing unit of receiving node b, rrepresents the rate of data transmission of physical link between node a and node b.
Hence energy consumption in message (of length x bit) transmission from node a to node b

$$\delta_{a,b}(x) = \left(I_a + \frac{P_{a,b}}{y_a}\right)\frac{x}{r}\ ;\ \forall\, x \geq 0\ \&\ \forall\,(a,b) \in \mathbb{E} \tag{1}$$

And required energy to receive message of length x, at node b

$$\emptyset_{a,b}(x) = J_b\frac{x}{r}\ ;\ \forall\, x \geq 0\ \&\ \forall\,(a,b) \in \mathbb{E} \tag{2}$$

The retransmission of message is not taken into consideration here.

3.2. Transmission count (expected) in message transmission

Assume T_a be the number of transmissions of a message is allowed for node a (including the first transmission), that is T_a-1 retransmissions are possible for node a. ACK message is sent to node a on the arrival of data packet to node b. If ACK is lost, a new ACK will be transmitted to node a after the arrival of same data packet at node b correctly. Hence the maximum T_a times ACK can be transmitted to the sender node as the acknowledgement of data packet at receiver node. But no ACK will be transmitted to node if ACK is lost T_a times for a data packet. Assuming the length of ACK message y (bit) and let $E[n_{a,b}(x)]$ be the number of predictabletransmissions that is needed in order to successful delivery of packet of sizex (bit) from node a to node b, where $1 \leq n_{a,b}(x) \leq T_a$. $E[m_{a,b}(y)]$ represents the expected number of times ACK message (length y (bit)) is sent to node a by node b, where $0 \leq m_{a,b}(y) \leq T_a$. The values $E[n_{a,b}(x)]$ and $E[m_{a,b}(y)]$ is depended on the link quality and signal strength between the two nodes that a to b and b to a, the value decreases with the quality of link.

$$E[m_{a,b}(y)] = \sum_{i=0}^{T_a} i P_r\{m_{a,b}(y) = i\} \tag{3}$$

If $Q_a \rightarrow \infty$ the equation will be

$$E[n_{a,b}(x)] \rightarrow \frac{1}{P_{a,b}(x)\, P_{a,b}(y)} \tag{4}$$

$$E[n_{a,b}(y)] \rightarrow \frac{1}{P_{a,b}(y)} \tag{5}$$

Where $P_{a,b}(x)$, represents the probability of successful receiving of message of size x bit from node a to node b. The $P_{a,b}(y)$ represents the probability of successful receiving of ACK of size y bit by node a (sent by node b).

3.3. Energy consumption at each link

Assume $\alpha_{a,b}(x)$ represents the power consumed by node a, in transmission, $\beta_{a,b}(x)$stands for the power consumed by node b in receiving the message of size x bit from node a. The hop by hop retransmission is taking into consideration the, the value can be computed as

$$\alpha_{a,b}(x) = E[n_{a,b}(x)]\delta_{a,b}(x) + E[m_{a,b}(y)]\emptyset_{a,b}(y) \tag{6}$$

And across node b, the energy total energy consumption is also computed as

$$\beta_{a,b}(x) = E[n_{a,b}(x)]\emptyset_{a,b}(x) + E[m_{a,b}(y)]\delta_{a,b}(y) \tag{7}$$

Where
$\delta_{a,b}(x)$ be the power required by node a to transmit a message to node b of length x (bit), $\emptyset_{a,b}(x)$represents the power required by node b in receiving a message of length x (bit),$\delta_{a,b}(y)$ be the power required by node b to transmit an ACK message to node a of length y (bit) and $\emptyset_{a,b}(y)$ be the power required by node a in receiving a ACK message of length y (bit).

3.4. Mathematical formulation of objective function

In route, as per transmission in path, there exists three types of nodes, source node transmits the packet and receives the ACK message, called source node. Second type of node is destination node in the route, receives the data packet and transmits the ACK message. Third type of nodes are intermediate nodes, involve in transmitting and receiving the packet and ACK message.

Let be

$$E[n_{a,b}(x)] = E[n\ \ (x)],\ E[m_{a,b}(y)] = E[m\ \ (y)]\ ,\ \emptyset_{a,b}(x) = \emptyset\ \ (x)$$

And

$$\delta_{a,b}(y) = \delta\ \ (y)$$

Hence the source node consumes the energy as under

$$E[n(x)]\delta(x) + E[m(y)]\emptyset(y) \tag{8}$$

Energy consumption across the destination node

$$E[n(x)]\emptyset(x) + E[m(y)]\delta(y) \quad (9)$$

Energy consumption by intermediate nodes

$$E[n(x)]\emptyset(x) + E[m(x)]\delta(x) + E[m(y)]\emptyset(y) + E[m(y)]\delta(y) \quad (10)$$

Let be the (n-1) nodes in the path and intermediate nodes can be express by (n-3).
The energy consumed in entire route can be obtained by using equation 8, 9 and 10.

$$\rho = E[n(x)]\delta(x) + E[m(y)]\emptyset(y) + E[n(x)]\emptyset(x) + E[m(y)]\delta(y) + (n-3)\{ E[n(x)]\emptyset(x) + E[m(x)]\delta(x) + E[m(y)]\emptyset(y) + E[m(y)]\delta(y)\}$$

$$\rho=(n-2)\{E[n(x)]\delta(x) + E[m(y)]\delta(y) + E[n(x)]\emptyset(x) + E[m(y)]\emptyset(y)\} \quad (11)$$

The objective is to find out the optimal path which required the minimum energy subjected to constraints on link failure and node failure in network. There are three decision variables: $N(=x_1)$, $n(=x_2)$ and $f_a (= x_3)$ have been proposed, where N represents total number node links in the network, n represents the number of node links in the route from source to destination and f_a signifies the number faulty links in network.
The objective is to minimize the value of ρ that is the minimization of energy required in entire path from source node to destination node. Replacing with the corresponding decision variable

$$\rho=(x_2-2)\{E[n(x)]\delta(x) + E[m(y)]\delta(y) + E[n(x)]\emptyset(x) + E[m(y)]\emptyset(y)\}$$

The value $E[n(x)]$ and $E[m(y)]$ are constant let these are Δ_1 and Δ_2 respectively.
Hence

$$\rho(x) = (x_2-2)[\Delta_1\delta(x) + \Delta_2\,\delta(y) + \Delta_1\,\emptyset(x) +$$

$$\Delta_2\,\emptyset(y)\,]\rho(x) = (x_2-2)[\Delta_1\{\,\delta(x) + \emptyset(x)\}\Delta_2\{\delta(y)\emptyset(y)\}] \quad (12)$$

The equation (12) is called equation of objective function, which needs to be optimized under the certain constraints as follows:

3.4.1. Constraints

a) Constraint I: Link failure at network level
Let be total number of link failure should not be greater than 10 % of links existing in network.Hence

$$\frac{10\,f_a}{N} \le 1$$

$$\frac{10\,f_a}{N} - 1 \le 0$$

$$10f_a - N \le 0$$

In terms of decision variables

$$g_1(x) = 10x_3 - x_1 \le 0 \quad (13)$$

b) Constraint II: Link failure at route level
Let f_a be the number of link failure in network, for the network survivability and stability of network for the successful transmission of packets through a route, the maximum number of link failures in a route should not be more than 5% of the nodes in the possible routes. Hence this can be represented [22] by the following equation

$$nf_a + 3\sqrt{nf_a(1-f_a)} \le \frac{5n}{100}$$

$$20f_a + 60\,\frac{\sqrt{f_a(1-f_a)}}{\sqrt{n}} - 1 \le 0$$

Replacing with the corresponding decision variables (x_1, x_2 and x_3)

$$20x_3 + 60\,\frac{\sqrt{x_3(1-x_3)}}{\sqrt{x_2}} - 1 \le 0$$

$$g_2(x) = 20x_3\sqrt{x_2} + 60\sqrt{x_3(1-x_3)} - \sqrt{x_2} \le 0 \quad (14)$$

c) Constraint III: Minimum link in network
In network there must be at least one link, hence

$$g_3(x) = x_1 \ge 1$$
$$g_3(x) = 1 - x_1 \le 0 \quad (15)$$

d) Constraint IV: Minimum link in route
In route there must be at least one link, thus

$$g_4(x) = 1 - x_2 \le 0 \quad (16)$$

The optimization problem is formulated in previous steps, which is (Eq. 12)

$$\text{Minimize}\,\rho(x) = (x_2-2)[\Delta_1\{\,\delta(x) + \emptyset(x)\}\Delta_2\,\{\delta(y) + \emptyset(y)\}]\,]$$

Subjected to (Eq. 13, 14, 15 and 16)

$$g_1(x) = 10x_3 - x_1 \le 0$$

$$g_2(x) = 20x_3\sqrt{x_2} + 60\sqrt{x_3(1-x_3)} - \sqrt{x_2} \le 0$$

$$g_3(x) = 1 - x_1 \le 0$$

$$g_4(x) = 1 - x_2 \le 0$$

4. Conclusion

The purpose of this paper is to formulate the energy function and its optimization viz. ρ(x). The mathematical formulation of energy has been estimated theoretically subjected to some constraints like percentage of link breakdown in network and in the routes namely g_1, g_2, g_3 and g_4. The decision variables for the number node links at network level, at route level and failure links in the route have been taken into consideration to realize the formulation. The advantage of this formulation would be in the minimization of retransmission of packet, improvement of network lifetime, minimizing the packet drop, enhancement in throughput etc.

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