Multi objective problem formulation for routing protocol in Mobile Ad hoc Network (MANET)

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Abstract. Mobile ad hoc network (MANET) is a dynamic network, easily deployed in an environment with minimum infrastructure. These networks are most widely used in military surveillance, terrain surveillance, natural disaster recovery and much more. The topology changes caused by mobile nodes may lead to link failure affecting the quality of service of the network. To improve the performance of MANET, multiple criteria such as link stability, residual energy of the nodes need to be optimized. This paper addresses the address the optimal path selection for energy efficient routing protocol and to improve the quality of service, a mathematical model is formulated for optimizing multiple constraints. The optimization will improves the efficiency of the routing protocol.

Keywords: Residual energy, hop count, delay, energy, bandwidth.

1 Introduction

Ad hoc network is collection of wireless nodes, that are frequently changing locations and they configure itself on the fly. Each node operates not only as a host but also as a router, forwarding packets to other nodes that may or may not be within the transmission range. These networks are feasible for situations where temporary network created for specific purpose and in places where infrastructural set up cannot be made. Mobile ad hoc networks are widely used in emergency search and rescue operations, data acquisition in health care, conventions that wish to share information and in various military applications. In ad hoc network developing a routing protocol satisfying various parameter is a challenging task and is very critical for the basic network operations. Normally nodes move in random direction in an ad hoc network in an uncontrolled manner. This random motion of nodes results in topological changes in a dynamic network. Frequent route failures occur resulting in overhead. A routing protocol for this network environment has to adapt dynamically to the changing network topology. Minimum bandwidth per node is assigned when wireless channel is a shared. So routing protocols should be bandwidth-efficient by expending a minimal overhead for computing routes so that the remaining bandwidth is available for the actual data communication. Normally nodes are battery operated which have limited energy supply. For mobile nodes to stay alive and actively participate during communication over longer periods, that a routing protocol is desired to be energy-efficient as well. This is one of the reasons to reduce the overheads occurring in the network. Considering the above scenario, the routing protocols designed must meet the conflicting goals of dynamic adaptation, minimum energy consumption and delay; reduce the overhead to deliver packets efficiently.

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A mathematical model is formulated for optimizing the critical resources like bandwidth, energy, delay and link stability. This optimization will help in designing an efficient routing protocol for MANET.

2 Related Work

Tickoo et al. [1] proposed a fragility based route metric named Route Fragility Coefficient (RFC) which estimates the rate at which a given route expands or contracts. Route discovery phase will yield the route that last longer. In dynamic environment, to calculate the speed of the neighbors with respect to nodes, a distributed algorithm is executed.A best stable route is selected by the destination that depends on Cumulative Expansion Metrics (CEM) and Cumulative Contraction Metrics (CCM). But this method does not consider the mobility of the node. The preliminary design of a proactive stable path routing protocol [2] that makes use of the look-ahead window concept and an efficient strategy to dissipate location-update broadcasts is proposed. A tradeoff between energy and delay was analyzed by Meganathan [3]. A Bi-objective Integer Programming (BIP) [4] model was modeled to consider the energy consumption and link stability of mobile nodes. The fundamental contradiction between the link stability and minimum hop count during the route selection process is analyzed. A basic framework model [5] to minimize the overall energy consumption during data transmission is designed.

Sofra and Leung [6] developed methods that will estimate the wireless link quality and residual lifetime of the link for successful data transmission. A cross layer approach using signal strength is proposed. This approach predicts the active time of the link to compute the stability of the route. The link quality and residual time is measured using signal processing along with empirical decomposition and robust regression. Guerriero [7] proposed a bi-objective optimization model which considers energy consumption and link stability of nodes simultaneously.

Sivaganesan [8] proposed an efficient routing protocol for vehicular network to handle traffic in an intelligent manner and to avoid discomfort during the travel. Wang [9] proposed multiobjective optimization for power management in cognitive radio network. The algorithm proposed a methodology to reduce the power consumption by minimize the delay during transmission. Smys [10] et al analyzed various methods to optimize the performance by considering the energy level of the nodes to improve the network lifetime.

3 Problem formulation

A problem is formulated for choosing an optimal path for any given pair of nodes namely source and destination, accounting for energy consumption of nodes, stability of links, time delay of the path, bandwidth utilization. A mobile ad hoc network can be modeled as a connected directed network graph G = (N, L). N is the collection of nodes $\{n_1, n_2, \dots, n_k\}$ and L is the set of links such that $L = \{L_{12}, L_{21}, L_{13}, L_{31}, \dots, L_{ij}\}$. $L_{ij} \in L$ is an ordered pair (n_i, n_j) [11], link between nodes n_i, n_j. Let $N_i \subset N$ denote group of nodes reached by a node n_i with a constraint that $d(n_i, n_k) \leq R$ where $d(n_i, n_k)$ is the distance between n_i and n_k and R is the transmission range of node.

Due to the random properties of the wireless channel, connectivity of the link is not stable. To denote the stability of the link, consider a binary variable x_{ij} associated with a link L_{ij} such that

$$x_{ij} = \begin{cases} 0, \text{when link is not connected} \\ 1, \text{when link is connected} \end{cases}$$

Let t_{ij} be the binary variable associated with packet transmission from node n_i to node n_j at slot k such that

$$t_{ij} = \begin{cases} 1, \text{when packet transmission is at slot k} \\ 0, \text{when no packet transmission at slot k} \end{cases}$$

Let F_{ij} be a non-negative continuous variable representing the flow produced by initiator n_s going through the link L_{ij} and P_{ik} be the transmission power of node n_i at slot k.

The overall multi-objective of routing protocol is to select the best path linking source n_s and destination n_d accounting for energy, link stability, bandwidth utilization and delay. The model is given below.

Minimize $x_{ij} P_{ij}(t)$

Minimize $x_{ij} S_{L_{ij}}(t)$

Minimize $\sum_{L_i \in L} x_{ij} D_{L_{ij}}$

Maximize $x_{ij} B_{RP}$

Subject to

$$x_{ij} \times T_{ij} \times P_{ij}(t) \le E_{res} \forall L_i \in L$$

$$P_{ij} = P_{ji} \forall L_{ij} \in L$$

$$x_{ij} \in \{0,1\}, \forall L_{ij} \in L$$

$$B_p \ge B_{\min}$$

$$D_{L_{ij}} \le D_s$$

The proposed routing protocol chooses an optimal path satisfying multiple criteria such as energy consumption, link stability, delay and bandwidth. Each of these criteria are defined and discussed below.

4 Energy Consumption

In ad hoc network, each node consumes energy during communication, The energy consumedby the nodes is divided into three categories namely energy consumed for transmitting a message, energy consumed for receiving the message and energy consumed in idle state. In the energy model, an assumption is made in such a way that each node is able to transmit and receive packets to and from neighboring nodes. Each node can overhear the packets if it is within the transmission range. The energy consumed by a node to transmit a packet (E_{tx}) of D bytes is given by

$$E_{tx}(D, n_i) = I \times V \times T_D$$

where I is the current (in Amperes), V is the voltage (in Volts) and T_D the time taken to transmit the D bytes packet (in seconds) and E_{rx} is the energy needed to receive D bytes.

The total energy E(D, n_i)spent to transfer a packet from node n_i to node n_j is given by

$$E(D, n_i) = E_{tx}(D, n_i) + E_{rx}(D, n_j)$$

The energy consumed in idle state is negligible when compared to energy consumed during transmission and reception; hence in this model it is ignored. It is important that starting from node n_i, the generic non-destination neighbor node $n_j \in N_s$ can be chosen only if node n_j has energy greater than or equal to threshold energy (E_{th}) which is the minimum energy required by a node $n_i$to receive and forward a packet from a relay node.

In the proposed model, the transmitting or receiving power of a node is proportional to distance between two nodes n_i and n_j involved for communication and represented as

$$P_{ij}(t) \propto d_{ij}^{\eta}$$

Based on the above equation, the power dissipation during transmission can be modeled as

$$P_{ij}(t) = c.d_{ij}^{\eta}$$

where $P_{ij}(t)$ is the power required to transmit packet from n_i to n_j and d_{ij} is the distance from node n_i to n_j. η is the path loss index and the value ranges between 2 and 4 and c is a constant.

Let RP represent the routing path from source n_s to destination n_d. The total energy consumption during D bytes of packet transmission is given by the relation

$$E_{RP} = \sum_{L_{ij}} x_{ij} P_{ij}(t)$$

The objective function to minimize the energy consumption in the routing path P_{RP} is

Minimize $\sum_{L_i} x_{ij} P_{ij}(t)$

subject to

$$x_{ij} \times T_{ij} \times P_{ij}(t) \leq E_{res} \forall L_i \in L$$

$$P_{ij} = P_{ji} \forall L_{ij} \in L$$

Link Stability

A link L_{ij} between two nodes n_i and n_j is stable only when the distance between the two nodes n_i and n_j is less than the transmission range R. (i.e) $d_{ij}< R$. A link between the two nodes will be broken if distance between the two nodes is greater than transmission range R (ie) $d_{ij} > R$. A link is said to be established when two nodes n_i and n_j have reached each other's transmission range and declared broken when their distance exceeds the transmission radius. Due to the random properties of the wireless channel, the connectivity of the link L_{ij} is not stable. The age of the link is the time interval between the time at which the link is established and the time when the link is broken and it can be calculated using

$$T_a = T_{fin} - T_{ini}$$

A generic approach is used to formulate the link stability model. The expected lifetime of the link is calculated based on the previous statistical data. The residual lifetime (T_{resi}) of the link L_i of age T_a is given as

$$T_{resi} = \frac{\sum_{T_a}^{T_{max}} T \times arr[T_a]}{\sum_{T_a}^{T_{max}} arr[T_a]} - T_a \forall L_{ij} \in L$$

Where T_{max} represents the maximum observed age of links L_i and arr[] is an array of length $T_{max} + 1$ used to store the observed data. The arr[] is calculated through the sampling of link ages at frequent time interval and arr[T_a] represents the number of links with age T_a. The stability of the link L_i at time t is given by

$$S_{L_i}(t) = \frac{d_{ij}^{avg}}{T_{resi} \times k} \forall L_{ij} \in L$$

where k is the scaling factor and d_{ij}^{η} is the average distance travelled between the nodes n_i and n_j. From the above equation, it is found that when the residual lifetime of the link is higher, its stabilitywill be increased. The average distance travelled between two nodes is higher; there is a possibility of link failure. The objective function for link stability is given as

Minimize $x_{ij} S_{L_i}(t)$

subject to

$$x_{ij} \in \{0,1\}, \forall L_{ij} \in L$$

Delay

The delay is defined as the time of propagation of packets on a path. The delay D is caused during propagation of packet is due to link delay $D_{L_{ij}}$ and node delay D_{n_i}, due to computation time in the node. This is formulated as

$$D = D_{L_{ij}} + D_{n_i}$$

Node delay involves the protocol processing time at node n_i for link L_{ij} (i, j), and link delay is the latency consumed by the packet to travel from node i to node j, i.e., along L_{ij}. The end-to-end delay of a path represents the sum of delay incurred at each link along the path.

The objective function for delay for a link $L_{ij} \in L$ $L_{ij} \in$ L can be given as

Minimize $\sum_{L_{ij} \in L} x_{ij} D_{L_{ij}}$

Subject to

$$D \le D_s$$

where D_s is the maximum delay accepted during packet transmission.

The energy of node is consumed during propagation of packets. When there is a delay due to packet retransmission energy of node is consumed. This leads to minimizing the residual energy of that node. Whenever there is a more residual energy of node, less will be the delay.

Bandwidth

The bandwidth is the binary flow on the channel. It is calculated as number of bits transmitted in unit time. Let $B_{L_{ij}}$ be the available bandwidth on link L_{ij} and $B_{\min}$ be the required bandwidth for successful packet transmission. The objective function is to maximize the bandwidth for a given path RP.

Maximize $x_{ij} B_{RP}$

Subject to

$$B_{RP} \geq B_{\min}$$

where $B_{RP} = \min\left(B_{L_{ij}}\right) \forall L_{ij} \in L$

5 Conclusion

In this paper multi objective optimization model for the energy consumption, link stability, delay and bandwidth is proposed. The main focus is to optimize the parameter and implemented in designing the routing protocol will select a more stable path that will improve the performance of the routing protocol to greater extent. The stability of the link is calculated to improve the Quality of Service but at the cost of high response time and dead node formation at critical situations. This model checks for multiple constraints and hence results in a trade of link stability and energy usage. In future enhancement, the protocol can be designed and implemented to reduce the response time and improve the quality of service in terms of minimum response time.

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