Design of an Energy Efficient Routing Protocol for MANETs based on AODV

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Abstract

Mobile Ad Hoc Networks (MANETs) also called mesh networks are self-configuring networks of mobile devices connected by wireless links. MANETs are deployed in situations where there is no e xisting infrastructure, such as emergency search and rescue, military, etc. Each application has a different set of requirements. In this paper we concentrate on emergency search and rescue operations which rely heavily on the availability of the network. The availability is a direct cost of the overall network lifetime, i.e., energy of the nodes.

The first objective of our work is to select two existing energy efficient routing protocols based on AODV, each of which is based on a d ifferent energy cost metric. We then propose the design of a protocol that is a combination of two energy cost metrics in a single protocol. The second objective is to evaluate the performance of the proposed protocol against the two protocols chosen for combination and against the traditional AODV. The performance metrics used for evaluation are packet delivery ratio, throughput, network lifetime and average energy consumed. The simulation will be done using NS2 network simulator.

Keywords: *MANETs, emergency search and rescue, network lifetime, energy efficiency, AODV, NS2.*

1. Introduction

Mobile ad hoc networks (MANETs) are composed of a collection of mobile nodes which can move freely and communicate with each other using a wireless physical medium..Therefore, dynamic topology, unstable links, limited energy capacity and absence of fixed infrastructure are special features for MANET when compared to wired networks. MANET do not have centralized controllers, which makes it different from traditional wireless networks (cellular networks and wireless LAN) [1].

MANETs, find applications in several areas. Some of them are: military applications, collaborative and distributed computing, emergency operations, wireless mesh networks, wireless sensor network, and hybrid wireless network architectures [2].

The characteristics of MANETs have led to the design of MANET specific routing protocols. These protocols are mainly classified as proactive and reactive [2]. Proactive protocols are table driven i.e., nodes maintain information regarding the routes. Reactive routing protocol find the routes only when they are needed i.e., on-demand. Reactive protocols have gained more importance as they reduce routing overhead and consume less energy [4].

Energy is a scarce resource in ad hoc wireless networks [3]. Each node has the functionality of acting as a router along with being a source or destination. Thus the failure of some nodes operation can greatly impede performance of the network and even affect the basic availability of the network, i.e., routing, availability, etc. Thus it is of paramount importance to use energy efficiently when establishing communication patterns. Energy management is classified into battery power management, transmission power management, system power management [2]. There are four energy cost metrics based on which we can decide the energy efficiency of a r outing protocol. They are transmission power, remaining energy capacity, estimated node lifetime and combined energy metrics.

In recent years, a n umber of studies have been done on the different layers of the OSI model, such as MAC layer and application layer, to achieve energy conservation. Our work focuses only on the routing/network layer. Routing protocols without considerations of energy consumption tend to use the same paths for the given traffic demands. This results in a quick exhaustion of the energy of the nodes along the paths if the traffic demands are long-lasting and concentrated. The reactive routing protocol Ad hoc On-demand Distance Vector (AODV) is found to be the most energy efficient. Our work is mainly concentrated towards improving the existing AODV algorithm, using two energy cost metrics, to obtain an energy efficient AODV algorithm.

The paper is organized as follows: In section II, we briefly discuss the literature survey relevant to our paper. Section III, discusses the related works carried out in the area. Section IV, provides a detail description of the proposed work. In section V a conclusion to our work is listed.

2. Literature Survey

The design of an energy efficient routing protocol for MANETs requires a detailed insight into routing and energy management strategies for MANETs.

The characteristics of MANETs have led to the development of MANET specific routing protocols. A routing protocol is the mechanism by which user traffic is directed and transported through the network from a source node to a destination node [18]. Based on this definition the classification of routing protocols is given as follows.

2.1 Classification of Routing Protocols in MANETs

MANET routing protocols could be broadly classified into two major categories based on the routing information update mechanism [5]:

1. *Proactive Routing Protocols:* Proactive protocols continuously learn the topology of the network by exchanging topological information among the network nodes. Thus, when there is a need for a route to a destination, such route information is available immediately. If the network topology changes too frequently, the cost of maintaining the network might be very high. If the network activity is low, the information about actual topology might even not be used. Ex: DSDV, WRP, CGSR, etc.

2. *Reactive Routing Protocols:* The reactive routing protocols are based on some sort of query-reply dialog. Reactive protocols proceed for establishing route(s) to the destination only when the need arises. They do not need periodic transmission of topological information of the network. Ex: DSR, AODV, TORA, etc.

3. *Hybrid Routing Protocols:* Often reactive or proactive feature of a particular routing protocol might not be enough; instead a mixture might yield better solution. Hence, in the recent days, several hybrid protocols are also proposed.

Proactive approaches introduce more overhead compared to reactive ones. This is because even when there are no changes in network topology, control messages are flooded in order to maintain a full knowledge of the network in each node [11]. In proactive routing protocols first packet latency is less when compared with on-demand protocols [11].Proactive (Table-driven) protocols are inherently more energy consuming compared to Reactive (On-demand) ones, hence most of the proposals involve modifications to reactive protocols [5]. In Reactive protocols, AODV is found to be the most energy efficient routing protocol. Hence many researchers have their studies concentrated on making AODV routing protocol more energy efficient.

2.2 Ad hoc On-demand Distance Vector

AODV [5] is a reactive routing protocol instead of proactive. It minimizes the number of broadcasts by creating routes based on demand, which is not the case for DSDV. When any source node wants to send a packet to a destination, it broadcasts a route request (RREQ) packet. The neighbouring nodes in turn broadcast the packet to their neighbours and the process continues until the packet reaches the destination. During the process of forwarding the route request, intermediate nodes record the address of the neighbour from which the first copy of the broadcast packet is received. This record is stored in their route tables, which helps for establishing a reverse path. If additional copies of the same RREQ are later received, these packets are discarded. The reply is sent using the reverse path. For route maintenance, when a source node moves, it can reinitiate a route discovery process. If any intermediate node moves within a particular route, the neighbour of the drifted node can detect the link failure and sends a link failure notification to its upstream neighbour. This process continues until the failure notification reaches the source node. Based on the received information, the source might decide to re-initiate the route discovery phase.

Energy management in MANETs is the basis on which routing protocols are improved to attain energy efficiency. The choice of the routing protocol affects each of the dimensions along which energy is consumed, such as transmission, battery, device and processor energy. These dimensions are discussed in detail in the remainder of the section. Along with these schemes there is also a description of the energy cost metrics which measure the amount of energy saved by using different path selection schemes.

2.3 Energy Management in MANETs

Energy is a scarce resource in ad hoc wireless networks and it is of paramount importance to use it efficiently when establishing communication patterns [3].

Energy Management is defined as the process of managing the sources and consumers of energy in a node or in a network as a whole for enhancing the lifetime of the network [2].

Energy Management can be classified into the following categories:

1. *Transmission Power Management:* The power consumed by the radio frequency (RF) module of a mobile node is determined by several factors such as the state of operation. The transmission power, and the technology used for the RF circuitry. The state of operation refers to the transmit, receive,

and sleep modes of operation. The transmission power is determined by the reachability requirement of the network, the routing protocol and the MAC protocol employed. The RF hardware design must ensure minimum power consumption in all the three stages of operation.

2. *Battery Energy Management:* The battery management is aimed at extending the battery life of a n ode by taking advantage of its chemical properties, discharge patterns, and by the selection of a battery from a set of batteries that is available for redundancy.

3. *Processor Power Management:* The clock speed and the number of instructions executed per unit time are some of the processor parameters that affect power consumption. The CPU can be put into different power saving modes during low processing load conditions. The CPU power can be completely turned off if the machine is idle for a l ong time. In such cases, interrupts can be used to turn on the CPU upon detection of user interaction or other events.

4. *Devices Power Management:* Intelligent device management can reduce power consumption of a mobile node significantly. This can be done by the operating system (OS) by selectively powering down interface devices that are not used or by putting devices into different power-saving modes depending on their usage[2].

2.4 Energy Efficiency Metrics

A survey of the recent research in energy efficient routing protocols for ad hoc networks allows classifying the power efficient routing protocols into four categories based on their path selection scheme.

The first set of protocols use the energy cost for transmission as the cost metric and aim to save energy consumption per packet. However, such protocols do not take the nodes' energy capacity into account. Thus, the energy consumption is not fair among nodes in the network. Minimum Total Transmission Power Routing (MTPR) [1] is an example protocol for this category.

The second set of protocols use the remaining energy capacity as the cost metric, which means that the fairness of energy consumption becomes the main focus. But, these protocols cannot guarantee the energy consumption is minimized.

The third set of protocols is similar to the second set, but use estimated node lifetime instead of node energy capacity as the route selection criteria. Therefore, these protocols still aim to fairly distribute energy consumption.

In order to both conserve energy consumption and achieve consumption fairness, *Conditional Max-Min Battery Capacity Routing* (CMMBCR) [1] has been proposed to combine these two metrics. CMMBCR is an example of the fourth category of protocols, which use combined metrics to represent energy cost.

Table 1 list some of the energy related cost metrics in literature [1].

Metrics Classifications	**Objective**	**Drawbacks**
Total transmission power	Minimize energy consumption	May cause node depletion
Remaining energy capacity	Evenly distribute energy depletion	Does not ensure least energy cost path
Estimated node lifetime	Evenly distributes depletion	Does not ensure least energy cost path
Combination	Tradeoff between power consumption and fairness	Hard to find perfect tradeoff

Table1: Energy Related Cost Metrics

3. Related Work

The proposed work is aimed at developing energy efficient AODV routing protocol. This section documents some of the many energy efficient schemes based on AODV developed by researchers in the field.

In [6], Jin-Man Kim and Jong-Wook Jang proposes an enhanced AODV (Ad-hoc On-demand Distance Vector) routing protocol which is modified to improve the networks lifetime in MANET (Mobile Ad-hoc Network). One improvement for the AODV protocol is to maximize the networks lifetime by applying an Energy Mean Value algorithm which considerate node energy-aware. Increase in the number of applications which use Ad hoc network has led to an increase in the development of algorithms which consider energy efficiency as the cost metric.

In [7], Yumei Liu, Lili Guo, Huizhu Ma and Tao Jiang propose a multipath routing protocol for mobile ad hoc networks, called MMRE-AOMDV, which extends the Ad Hoc On-demand Multipath Distance Vector (AOMDV) routing protocol. The key idea of the protocol is to find the minimal nodal residual energy of each route in the process of selecting path and sort multi-route by descending nodal residual energy. Once a new route with greater nodal residual energy is emerging, it is reselected to forward rest of the data packets. It can balance individual node's battery power utilization and hence prolong the entire network's lifetime.

In [8], Zhang Zhaoxiao, Pei Tingrui and Zeng Wenli propose a new mechanism of energy-aware routing named EAODV, which is based on the classical AODV protocol. Here a backup routing mechanism is adopted. In EAODV, the route which spends less energy and owns larger capacity is selected by synthetic analysis.

3.1 Some algorithms with specific characteristics are:

1. Local routing

In on-demand ad hoc algorithms, all nodes participate in the phase of path searching, while the final decision is made in the source or destination node. The Woo et al. [9] algorithm grants each node in the network permission to decide whether to participate in route searching, which thus spreads the decision- making process among all nodes. The Local Energy-Aware Routing (LEAR) algorithm has as a main criterion the energy profile of the nodes. The residual energy defines the reluctance or willingness of intermediate nodes to respond to route requests and forward data traffic. When energy Ei in a node i is lower than a predefined threshold level Th:

$$E_i < Th,$$

the node does not forward the route request control message, but simply drops it. Thus, it does not participate in the selection and forwarding phase. The technique of shifting the responsibility for reacting to changes in the energy budget of the nodes from the source-destination nodes to the intermediate nodes avoids the need for the periodic exchange of control information.

2. Expected energy consumption

The Conditional MMBC algorithm in [10] is proposed to maximize the lifetime of the nodes. It also uses transmission energy as a metric but the route is chosen on the minimum transmission energy basis until the residual energy of the constituent nodes in a network is above a predefined threshold. If there are any nodes on the discovered routes whose energy is below the threshold, the MMBC is applied.

The work done in [11] accounts not only for residual energy and transmission power but also for possible retransmissions. It brings an important aspect to light in the design of energy- efficient routing algorithms: the estimation of future energy consumption. The authors estimate the energy that is expected to be used in order to successfully send a packet across a given link. The cost metric as in Eq. (1) thus comprises a node-specific parameter (battery power Bi of node i) and a link-specific parameter (packet transmission energy Ei,j) for reliable communication across the link (between nodes i and j):

$$C_{i,j} = \frac{B_i}{E_{i,j}} \tag{1}$$

Where as the expected transmission energy as in Eq. (2) is defined by the power to transmit a packet over the link between nodes i and j (Ti,j) and the link's packet error probability (pi,j):

$$E_{i,j} = \frac{T_{i,j}}{(1 - p_{i,j})^L} \tag{2}$$

The main reason for adopting the above is that link characteristics can significantly affect energy consumption and can lead to excessive retransmissions of packets. The maximum lifetime of a given path is determined by the weakest intermediate node, which is that with the lowest cost.

3. Battery-sensitive routing

The approach is presented in [12] by Chiasserini and Rao, and subsequently by Ma and Yang [13]. Their solutions make use of the available battery capacity by means of battery-sensitive routing. Both works [12 and 13] study the lifetime of the battery and the algorithms proposed by their authors are based on two processes, namely, recovery (reimbursement) and discharging loss (over-consumed power). These processes are experienced when either no traffic or new traffic is transmitted. This line of study led to the design of a cost function that penalizes the discharging loss event and prioritizes routes with "well recovered" [13] nodes. Thus, battery recovery can take place and a node's maximum battery capacity can be attained. The selection function in [12] is a minimum function over the cost functions of all routes.

4. Energy drain rate

The authors [14] introduce an energy drain rate metric, which represents the speed of energy consumption. It estimates the lifetime of a node; therefore, if the estimated value is below a threshold, the traffic passing through it can be diverted in order to avoid node failure due to battery outage. The cost functions of a node i is defined as the ratio between the Residual Battery Power (RBC) and the Drain Rate (DR):

$$C = \frac{RBP}{DR} \tag{3}$$

The drain rate is computed by the exponential weighted moving average method and gives the estimated energy dissipation per second as in Eq. 4:

$$DR_i = \alpha DR_{old} + (1-\alpha) DR_{sample} \quad (4)$$

5. *Least hops and minimum remaining energy*

The routing algorithm used in this method is based on AODV. In AODVEA [5], routing is based on the metric of minimum remaining energy. The node with minimum remaining energy in the route is identified and the route having maximum of minimum remaining energy is selected.

The protocol performs a route discovery process similar to the AODV protocol. The difference is to determine an optimum route by considering the network lifetime and performance; that is, considering residual energy of nodes on the path and hop count. In order to implement such functions, a new field, called Min-RE field, is added to the RREQ message as described above. The Min-RE field is set to a default value of -1 when a source node broadcasts a new RREQ message for a route discovery process.

Eq.(5) gives the calculation of Routing metric for modified AODV:

$$\alpha = \frac{(MinRE)}{HopCount} \quad (5)$$

The optimum route is determined by using the value of α described above. The destination node calculates the values of α for received all route information and choose a route that has the largest value of α. Here Min- RE is the minimum residual energy on the route and HopCount is the hop count of the route between source and destination.

4. Proposed Work

The algorithm which we propose combines two of the energy metrics and integrates these metrics into AODV in an efficient way so that the Ad hoc network has a greater life time and the energy consumption across the nodes is reduced. The two energy metrics which we try to combine are:

A. Transmission Power
B. Remaining Energy Capacity

Here, for each metric used by certain routing protocols, we always consider a *k*-hop route $R = v0, v1, \ldots, vk$ from the source $v0$ to destination vk. We also use the following notations listed in Table 2.

Table 2: Explanation of the notations

Notations	Meaning
C_R	Cost of route R
P_T (i)	Transmission power of node v_i
P_R (i)	Receiving power of node v_i
E_r^i (t)	Remaining energy capacity of node v_i at time t
E_o^i	Initial energy capacity of node v_i

A. Transmission Power

The received signal power attenuates as d^{-n} where *d* is the transmission distance, and usually, $n = 2$ for short distance and $n = 4$ for longer distance. In order to conserve energy, senders dynamically adjust the transmission power proportional to the transmission distance.

The cost function of transmission is defined as:

$$C_R = \sum_{i=0}^{k-1} P_T(i)$$

This selects the route with the minimum cost value. Thus, it can ensure that energy consumption per packet is the minimum. P_T(i) is proportional to ||vi, vi+1||n, while ||vi, vi+1|| is the distance between node vi and vi+1. Thus, this scheme tends to select routes with more hops, which results in more nodes along the route and longer end-to-end delay. To more accurately represent the energy cost and constrain hop count, the power cost P_R(i + 1), for the transceiver at node vi+1 to receive a packet, is also added to the above cost function:

$$C_R = \sum_{i=0}^{k-1} ([(P]_T(i) + P_R(i+1)) \quad (6)$$

Here, P_R(i + 1) can help reduce hop count compared to the original scheme.

B. Remaining Energy Capacity

This cost metric makes the fairness of energy consumption the main focus. Using remaining energy capacity as an energy metric the energy along the route is calculated as follows:

$$C_R = \sum_{i=1}^{k-1} f\left(E_r^i(t)\right)$$

where

$$f\left(E_r^i(t)\right) = \frac{1}{E_r^i(t)} \quad (7)$$

Operation:

During route discovery from the source to the destination the energy values along the route are accumulated in the RREQ packets. At the destination or intermediate node (which has a fresh enough route to the destination) these values are copied into the RREP packet which is transmitted back to the source. The source alternates between the maximum remaining energy capacity route and minimum transmission route every time it performs route discovery.

Once the algorithm has been designed we intend to implement it in ns2 .Then the performance of the protocol will be evaluated using packet delivery ratio, throughput, network lifetime and average energy consumed as the parameters. We intend to compare the above proposed algorithm with traditional AODV and the energy efficient algorithms based on the individual cost metrics.

5. Conclusion

This paper provides an overview of MANETs and discusses how energy is one of the most important constraints for these type of networks. A detailed study of the energy management strategies, energy cost metrics and energy efficient routing algorithms is provided. From the study it is seen that focusing on two energy cost metrics for routing in order to achieve energy efficiency is better than the use of a single metric.
A combined strategy is then proposed by using the above concept. The objective of the proposed work is to develop an energy efficient AODV routing algorithm in a way which allows researchers to choose the most appropriate routing algorithm.

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