A Maximum Network Lifetime QoS Routing Algorithm in MANETs

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ABSTRACT

A MANET is composed of a group of mobile wireless nodes that form a network independently of any centralized administration, while forwarding packets to each other in a multi-hop manner. The application and connection with the Internet demand MANETs to support Quality of Service (QoS). Since the mobile nodes are battery-powered and each mobile node in a MANET performs the routing functions for establishing communication among different nodes, the "death" of even a few nodes, due to energy exhaustion, might cause the disruption of service in the entire network. So for obtaining QoS on a MANET, it is not sufficient to provide traditional QoS routing functionality. Power consumption should also be taken into consideration. And how to prolong the network lifetime has become a very important objective for guaranteeing QoS in a MANET. In this paper, a formulation is given to describe the problem of maximizing the network lifetime with QoS routing which has also been proved as a maximum flow problem later. Referring to the idea of solving the maximum flow problem, a distributed maximum network lifetime QoS routing algorithm (DMNLQRA) is proposed. The performance of the protocol is evaluated by simulation. The results show that DMNLQRA can prolong network lifetime, improve data packets delivery rate and lessen delay.

Categories and Subject Descriptors

C.2.2 [**Computer Systems Organization**]: Network Protocols – *Routing protocols.*

General Terms

Algorithms

Keywords

MANET; network lifetime; distributed; QoS routing

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1. INTRODUCTION

The research of QoS gurantee problem in ad hoc network begins in the 1990s, and has gradually become a hot issue of research in ad hoc network. However, dynamic features of ad hoc networks make it very difficult to support QoS. Currently QoS routing protocols proposed for ad hoc networks generally use the bandwidth or delay as its metric parameters, less consideration of the impact of energy consumption of routing to real-time QoS traffic. As ad hoc networks are energy-constrained system, in order to meet the QoS requirements of the traffic, only to use bandwidth and delay constraints is not enough, the energy constraint must therefore be considered.

The current energy optimization routing protocols mainly considered two types of metrics, that is minimizing transmission energy consumption and maximizing the network lifetime. The routing protocols of minimizing transmission energy consumption are to find a path between the source node and destination node with the least the transmission energy consumption so as to achieve the purpose of saving energy. In [1-3], several typical minimum transmission energy routing protocols are proposed. The routing algorithms of the minimum transmission energy are simple and easy to the work with existing on-demand routing or table-driven routing strategies. However, due to a number of key nodes frequently are often lied in different paths and will make these nodes run out of their energy prematurely, which will result the whole network division. In addition, as a result of choice of the multi-hop path as a packet transmission path, it will lead to a large number of retransmissions, and the energy consumption caused by retransmission may even more than its saved energy. The energy-efficient routing protocol of maximizing the network lifetime is to research how to distribute loads between the various nodes and balance energy consumption between the various nodes of the network, so that the entire network can maximize the lifetime. A lot of the current maximum network lifetime routing algorithms and protocols are proposed. [4] proposed MBCR strategy, that is, to select the path with the largest remaining battery power in all possible paths. MBCR tries to get the largest average battery power path in the network, but still cannot avoid premature routing failure caused by energy exhausting of some nodes with lower residual energy. [5] marks the nodes with minimum remaining energy in the paths as symbol nodes, and then select a path with the symbol node of largest remaining battery energy to transmit data in all possible paths. [6] defines a cost metrics, which not only consider the node battery energy, but also considering the packet transmission energy consumption in the link. The algorithm select a path which can transmit the most data packets so as to achieve the extension of survival time of the network and avoid the premature network partitions caused by the excessive use of certain key nodes.

In this paper, a distributed maximum network lifetime QoS routing algorithm (DMNLQRA) is proposed. Considering energy optimization of routing and QoS guarantee, a mathematic model of the problem of maximizing the network lifetime with QoS routing is given. The problem of maximizing the network lifetime with QoS routing has also been proved as a maximum flow problem. And then a solution to the problem is proposed. The rest of this paper is organized as follow: In section 2, The description of the problem of maximizing the network lifetime with QoS routing is given. In section 3, the routing protocol is described. In section 4, the simulation results are given. Section 5 discusses the conclusions.

2. DEFINITION AND SYSTEM MODEL

2.1 Related Definition

Ad hoc network can be expressed as $G=(V,E)$, in which V for the collection of network nodes, E is the link between the collection of nodes. |V| and |E| respectively represents the number of nodes and the number of links of the network. Here s represents the source node, and d represents the destination node:

Definition 1: Set $n=|V|$, $m=|E|$, edge $e_{ij}\in E$, $e_{ij}=(v_i,v_j)$, it represents a link between node v_i and node v_j, $v_i,v_j\in V$, $i,j=1,...,n$.

Definition 2: For any node v, $N(v)$ is the Neighbor node set of node v, $E(v)$ is link set of connecting node v and its neighbor nodes.

Definition 3: h_F is the forward hops of node v, that is the hops from v to s.

Definition 4: v_i is neighbour nodes of node v, $v_i\in N(v)$, if $h_F<h_{iF}$,then v_i is the downlink node of node v; if $h_F>h_{iF}$, then v_i is its uplink node, and when $h_F=h_{iF}$, v_i is its parallel nodes.

Definition 5: when nodes v and v_i meet $v\in V-\{s,d\}, v_i\in N(v)-N_d(v)$, and v is uplink node of v_i, then $c_v(t)$ can is defined as link capacity of (v,v_i).

Definition 6: $c_{p(s,d)}(t)$ is defined as capacity of a path from s to d, and $c_{p(s,d)}(t)=\min\limits_{v\in p(s,d)}\{c_v\}$.

Definition 7: if there is a path $p(s,d)$, then the path of the remaining energy can be defined as: $Energy\big(p(v_1,v_k)\big)=\min\limits_{i\in p(v_1,v_k)}\big(E_r^{v_i}\big)$, where $E_r^{v_i}$ is the node remaining energy.

This paper assumes that all of the mobile network nodes share channel, and the network does not exist in a one-way links, all the mobile nodes are aware of their status, including the adjacent link available bandwidth, link delay, node capacity, etc.

2.2 Description of The Maximum Network Lifetime QoS Routing Problem

Assume that node v_i use the same power level, $e_{tran}^{v_i}$, to transmit packets, then the maximum amount of data $c_{v_i}(t)$ that node v_i can send can be defined as follows:

$$c_{v_i}(t)=\frac{E_r^{v_i}(t)}{e_{tran}^{v_i}}$$

In [6], the maximum network lifetime routing problem is transformed into to find a path which can send the largest data and its description is as follows:

$$p_{candidate}=\arg\max\left\{\min_{v_i\in P}\left\{c_{v_i}(t)\right\}\middle|P\in all\ possible\ route\right\} \quad (1)$$

However, a nodea in a path may forward a number of traffics, so the maximum network lifetime routing problem defined by (1) is not suitable for this situation. A reviced definition is given as follows:

Definition 8: assuming that there are m traffics forwarded by node v_i, if $l_{v_i}^k$ is forwarded data of the traffic k in node v_i, the utility function of node v_i to forward traffic k is defined as follows:

$$profit_{v_i}^k(t)=\frac{c_{v_i}(t)}{l_{v_i}^k} \quad (2)$$

And the maximum network lifetime routing problem can be described as:

$$p_{candidate}=\arg\max\left\{\min_{v_i\in P}\left\{profit_{v_i}^k(t)\right\}\middle|P\in all\ possible\ route\right\} \quad (3)$$

Accouting the QoS requirements of traffic, the maximum network lifetime QoS routing problem can be defined as:

Definition 9: if s refers the source node, d refers the destination node, the maximum network lifetime QoS routing problem can be described as follows.

$$\begin{aligned}&P(s,d)=\arg\max\left\{\min_{v_i\in P}\left\{profit_{v_i}^k(t)\right\}\middle|P\in all\ possible\ route\right\}\\&s.t.:\ f_i\le\delta_i, i=1,2,\cdots,6\end{aligned} \quad (4)$$

where δ_i refers traffic constraint, $\delta=\left\{D,H,J,L,\frac{1}{B},\frac{1}{E_r}\right\}$, D refers delay constraint, H refers hop constraint, B refers bandwidth constraint, J refers delay jitter bound, L refers packet loss constraint, E_r refers node energy constraint.

Lemma 1: the maximum network lifetime QoS routing problem in ad hoc networks can be equivalent to the maximum flow problem [7].

Proof: If $c_{v_i}(t)$ is the value of link, s and d are the meeting point. $p(v_1, v_k)$ is a path to meet the QoS requirements, traffic k's distribution flow in $p(v_1, v_k)$ refers the flow of the path, then:

$$\sum_{p(i,j)\in P(v_1,v_k)} l^k_{p(i,j)} - \sum_{p(j,i)\in P(v_1,v_k)} l^k_{p(j,i)} = \begin{cases} L_k, i = v_1 \\ 0, i, j \in V - \{v_1, v_k\} \\ -L_k, i = v_k \end{cases} \quad (5)$$

$$L_k = \sum_{p(i,j)\in P(v_1,v_k)} l^k_{p(i,j)}, 0 \le l^k_{p(i,j)} \le \min_{v_i \in p(i,j)} \{c_{v_i}(t)\}$$
$$s.t.: f_i \le \delta_i, i = 1, 2, \cdots, 6 \quad (6)$$

where δ_i refers traffic constraint, and $\delta = \left\{D, H, J, L, \frac{1}{B}, \frac{1}{E_r}\right\}$.

By the definition of Maximum flow problem and the definition 9, it can get that the maximum network lifetime QoS routing problem in ad hoc networks can be equivalent to the maximum flow problem.

3. DISTRIBUTED MAXIMUM NETWORK LIFETIME QOS ROUTING ALGORITHM

Distributed Maximum Network Lifetime QoS Routing Algorithm (DMNLQRA) uses RREQ and RREP packet to build up all the inter-network connections between the source node and destination node as much detail as possible, and then select one or more appropriate path to send data. DMNLQRP is composed of several parts, the local information management, message data structure and routing algorithm.

3.1 Local Information Management

In order to achieve DMNLQRP, Each node need to maintain two tables, that is, routing information table and the neighbour node status information table. Routing information table used for routing maintenance and management. The content is the same as that in AODV protocol. Neighbor node status information table shows in table 1.

Table 1. Status information of adjacent node of node v

Node	Forward Hops	Residue Energy	height	Link State	Attribute	Life time
v	h_F	E_r	height	—	I	T
v_1	h_{1F}	E_{r1}	$height_1$	B_1, D_{1F}	F	T_1
…	…	…	…	…	…	…
v_i	h_{iF}	E_{ri}	$height_3$	B_i, D_{iF}	F	T_i

in which:

Forward Hops: the hops from the source node to its neighbour nodes;

Residue Energy: node's residue energy;

Height: defined as follows, make $height(v)$ refers the node's height function, if $E^r_v \ge E_r$, E_r refers node energy constraint, and $height(v)$ meets:

$$height(v) \le height(v_i) + 1, v_i \in N(v)$$

Link State: Record the link available bandwidth (B)between node and its neighbor nodes and the accumulated delay from the node to the source node, D_{iF} is the cumulative node delay from node to the source node and D_{iB} is the accumulated delay from node to the destination node;

Attribute: is used to describe whether the node to forward traffic or not. Attribute can be divided into three states, the initial state (I), forwarding state (F) and blocked state (B);

Lifetime: is the TTL time.

3.2 Packet Data Structure

The packets used in protocol are defined as following:

(1) RREQ packet

RREQ packet is defined as a 9-tuple, $\left\{\begin{matrix} SrcAddr, DestAddr, Seq, Hops, ReqBand, \\ ReqDelay, ReqHops, E_r, CurNdTime \end{matrix}\right\}$, of which, $SrcAddr$ is the source node address, $DestAddr$ is the destination node address, Seq is the serial number of routing request packet, $Hops$ is the hops to the source node, $ReqBand$ is path bandwidth required by the traffic, $ReqDelay$ is the delay required by the traffic, $ReqHops$ is the hops required by the traffic, E_r is remaining energy value of the node, $CurNdTime$ is the accumulated delay time for the current node to receive RREQ packet from the source node.

(2) RREP packet

RREP packet is defined as $\left\{\begin{matrix} SrcAddr, DestAddr, Seq, CurNdTime, \\ Hops, Addr[1,,n], c_p, l_p, B_p \end{matrix}\right\}$. Where $SrcAddr$, $DestAddr$, Seq, $CurNdTime$ and $Hops$ have the same meaning as RREQ packet, $Addr[1,,n]$: $Addr[i]$ is the i-th node address in RREP packet return path, c_p is path capacity, l_p is path traffic flow, B_p is path bandwidth.

(3) RRER Packet

RRER packet is the same with AODV protocol.

(4) DATA Packet

DATA packet is defined as $\{SrcAddr, DestAddr, Seq, c_p, Data\}$, where $SrcAddr$, $DestAddr$, Seq and c_p have the same meaning in RREP message, $Data$ is the data to be sent.

3.3 Distributed Maximum Network Lifetime QoS Routing Algorithm

Ordinary distributed routing protocols, such as DSR, AODV, often use RREQ and RREP packet to build up all network connections information between the source node and destination node as much detail as possible, and then one or more available paths will be set up based on these information. In this paper, referring to [8], a new RREQ and RREP packet forwarding rules are designed as follows.

RREQ packet forwarding rule:

When intermediate node received the first RREQ packet, it will set its delay time according to traffic QoS requirements and determine whether to transmit it or not. At the same time it will update its local information table according to the received packets. The delay time is determined by the following formula:

$$\Delta delay = \begin{cases} \mathrm{Re}\,qDelay - CurNdTime, \mathrm{Re}\,qDelay \geq CurNdTime \\ 0, \mathrm{Re}\,qDelay < CurNdTime \end{cases} \quad (7)$$

When destination node received the first RREQ packet, it will set the delay time in accordance with (7) and set the value of path capacity in RREP packet as L_k which is gotten from RREQ packet. When the delay time is up, it will send RREP packet to its neighbor. When intermediate node v receives RREP message from its neighbors v_i, it will determine whether to transmit the packet or not according to RREP packet forwarding rules and update its local information. In order to prevent broadcast storm caused by forwarding RREP packets, RREP message must be forwarded only in the nodes that have received RREQ packet before and forwarding nodes must be met:

$$D_{iF} + CurNdTime \leq \mathrm{Re}\,qDelay \wedge h_F + hops \leq \mathrm{Re}\,qHops \quad (8)$$

In the formula, *CurNdTime* is the cumulative delay from the destination node to current node, *hops* is the hops of RREP packet from the destination node to current node.

Taking into account the QoS requirements of traffic, the delay, hops, link bandwidth and the lifetime are used in this paper, so after the intermediate node v receives the RREP packet from its neighbour nodes v_i, to decide whether to the forward RREP packet or not, node v also need to meet the following formula:

$$B_{vv_i} \geq B \wedge e_r^{v_i} \geq E_r, \forall v_i \in N(v) - v_j \quad (9)$$

In order to find an optimal path, the push and lift operation in relabel-to-front method to solve the maximum flow problem is referred to determining whether node to forward RREP packet or not. The RREP packet forwarding rules are defined as follows.

RREP packet forwarding rule:

When v received RREP packet from its neighbor v_j at time t,

if v satisfies formula （8） and (9),

and $l_{p(d,v_j)}(t) > l_{p(d,v)}(t-1)$

($l_{p(d,v)}(t-1)$ is the path capacity value of the node transmitting RREQ message at last time)

do

if $height(v) < \max\{height(v_i) : B_{vv_i} \geq B \wedge e_r^{v_i} \geq E_r, v_i \in N(v) - v_j\} + 1$

then $height(v) \leftarrow \max\{height(v_i)\} + 1$

do

if $height(v) = \max\{height(v_i) : B_{vv_i} \geq B \wedge e_r^{v_i} \geq E_r, v_i \in N(v) - v_j\} + 1$

then v forward RREQ packet

else

discard RREP packet

A path can be obtained by reversing node ID which the source node gets from its received RREP packet. As there may be several available paths, the source node will wait to receive more RREP packets in order to get adequate path information before sending data packets. Waiting time determined by the following formula.

$$T_{delay} = \mathrm{Re}\,qDelay - CurNbTime_{firstRREQ} \quad (10)$$

In the formula, $CurNbTime_{firstRREQ}$ is the cumulative delay of having received the first RREP message from the source node.

After the end of the waiting time, the source node will chose a path or multi-path to send data packets from all avialable paths. The selection strategy can be distinguished as single path selection strategy and multi-path selection strategy.

4. THE SIMULATION RESULTS

In order to evaluate the performance of the algorithm, we have adopted a simulation approach. The OMNET + + simulation platform[9] is used as a tool. The CSMA/CA is used as the MAC layer in our experiments. The channel capacity is 2Mbit/s. The network possesses 50 nodes uniformly distributed in a 500×500 meter square. The transmitting radius of each node is 230 meters. Channel delay of is 10μs and transmission error rate for channel is 10^{-6}. In the simulation, we choose constant bit rate (CBR) traffic flow to simulate real-time services, which the QoS bandwidth constraints of each CBR traffic is $250Kbps$ and the delay bound is random distributed in $[20ms, 200ms]$. The nodal transmit power and receive power is 1.33 watts and 0.97 watt, the initial node energy is 20 joules. The length of each data packet and each control packet is 512 bytes and 64 bytes. There are 10 real-time CBR traffics generated randomly. The mobility speed of a node is set from 0 m/s to 15 m/s and nodes in the simulation move according to the Random-Waypoint mobility model[10]. Three kinds of routing protocols are carried out in simulation experiments, they are AODV protocol, a single-path DMNLQRP-S protocol and multi-path DMNLQRP-M protocol. For each scenario, 100 connected network topologies are randomly generated to compute the average performance of each protocol to compute the average network performance of each protocol. The performance measures of interest are:

In order to evaluate the performance of each routing protocols, the following performance parameters are studied:

(1) Average network lifetime: duration of the simulation when the first node to run out of energy[11].
(2) Average delivery rate: the ratio of the number of data packets received by the destination node to the number of data packets transmitted by the source node during the network lifetime;
(3) Average delay: the time required by transmitting a data packet from the source node to destination node. It defined as the ratio of the sum of delays in data transmission to the total number of packets received in the network during the network lifetime;

Average control message overhead: defined as the ratio of the control packets number to the number of successful received data packets in the network during the network lifetime.

Figure 1 show the average network lifetime of the three protocols. AODV, as a result of the use of the shortest path and no strategy for the use of resource reservation, will lead to a number of traffics forwarding through the same node, which will result in rapid depletion of energy of the node and reduce the average network lifetime. As using the largest network lifetime transmission path and resource reservation, the average network lifetime of DMNLQRP-S and DMNLQRP-M is greater than that of AODV. Because DMNLQRP-M adopts multi-path strategy, which make energy consumption more balanced among nodes, so the network lifetime is the greatest among the three protocols.

Figure 2 and Figure 3 show the average delivery rate and the average end-to-end delay of three protocols. When node moves slow, the average delivery rate of the three protocols is very high. However, with the increase of node speed, the network topology changes frequently and the probability of link disconnect becomes large, the delivery rate of three protocols both has a downward trend. As a result of using of the resource reservation strategy which can reduce end-to-end network congestions, DMNLQRP-S and DMNLQRP-M protocols have a higher delivery rates and less end-to-end delay than AODV. And as a result of the use of the multi-path strategy which can better adapt to the dynamic changes of network environment, the average end-to-end delivery rate and the delay of the DMNLQRP-M is the better than that of the DMNLQRP-S.

Figure 4 shows the average routing overhead of three protocols. As the routing discovery mechanism of DMNLQRP-S and DMNLQRP-M are different from the AODV, when nodes move slow, their routing overhead are higher than AODV protocol. As node speed increases, the overhead caused by the failure of the path and routing maintenance in AODV increases fast, whereas, the path caching mechanisms in DMNLQRP-S and DMNLQRP-M makes the overhead of routing maintenance is smaller than AODV protocol. Overall, the average routing overhead of three protocols is almost as the same.

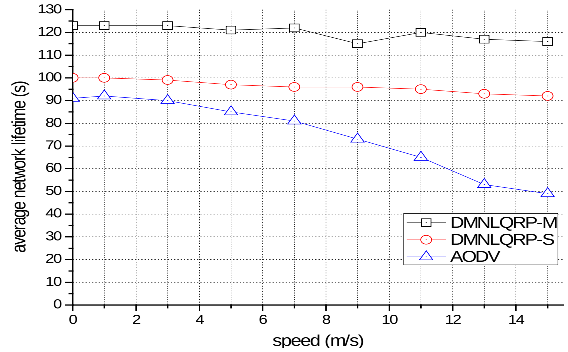

Figure 1. Average network lifetime

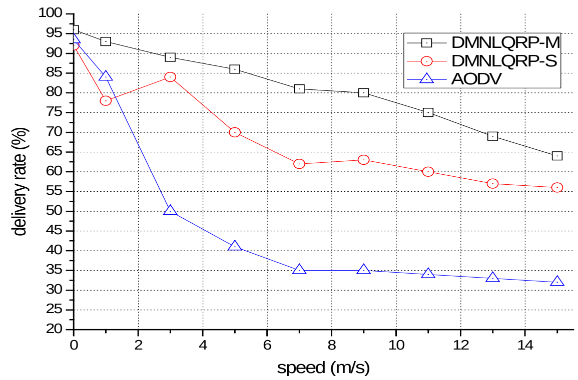

Figure 2. Average delivery rate

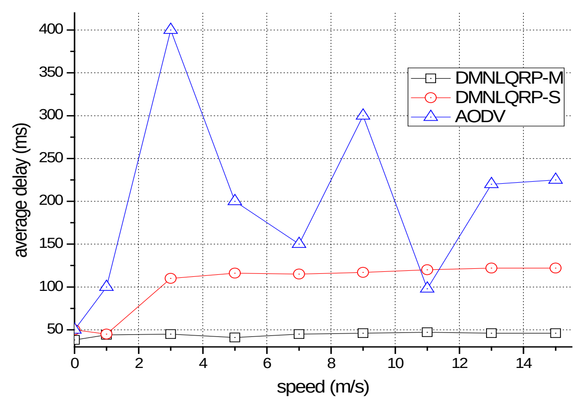

Figure 3. Average delay

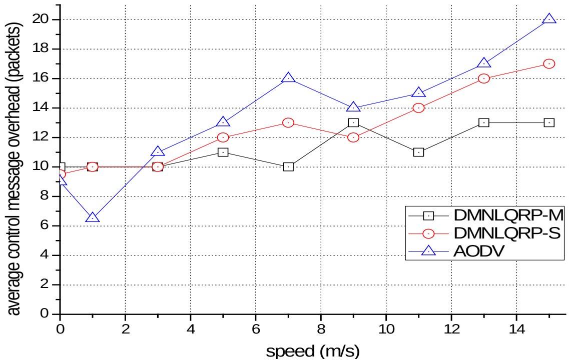

Figure 4. Average control message overhead

5. CONCLUSIONS

In this paper, aimed at energy-constrained characteristics in Ad hoc networks and taking into account the different QoS requirements of traffics, by transforming the problem of maximizing the network lifetime into a maximum flow problem, a distributed maximum network lifetime QoS routing algorithm (DMNLQRA) is proposed. The routing recovery of the protocol is based on the QoS requirements of traffics, through the introduction of a high degree of function and referring to the push and lift operations in relabel-to-front algorithm, the routing construction can be done. According to the simulation results, DMNLQRA can prolong network lifetime, improve data packets delivery rate and lessen delay.

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