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An Energy Entropy-Based Minimum Power Cost Multipath Routing in MANET

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Abstract

Mobile Ad hoc Networks (MANETs) are non-infrastructure networks consisting of mobile nodes. Since the mobile nodes have limited battery power, they are very important to using energy efficiently in MANETs. In order to maximize the lifetime of MANET, traffic should be sent via a route that can avoid nodes with low energy while minimizing the total transmission power. This paper proposes an Energy Entropy-based minimum Power cost Multipath routing algorithm in MANET (EEPMM). It is typically proposed to increase the reliability of data transmission or to provide load balancing. In simulation experiments, we compare EEPMM routing protocol with SHM and MEA-DSR routing protocol, in terms of the network lifetime, and the energy consumption when a packet is transmitted. The performance results indicate that the proposed scheme is quite adaptive for energy-efficient communication in MANETs.

Keywords: *MANET; multipath routing; energy entropy; energy efficient*

1. Introduction

A mobile ad hoc network (MANET) is a collection of hundreds and thousands of low cost and low power mobile nodes connected by wireless links. No static infrastructure such as communications base stations exists, besides, if there are two nodes out of the radio range, messages would have to pass through one or more intermediary nodes. As the nodes are free to move in an either orderly or random fashion, there will be a dynamical change in network topology [1-13]. Building such networks usually meets enormous technical challenges because of the constraints imposed by the characteristics of the MANETs. One of these constraints is the scarce power resource under the condition that the nodes are operated by batteries [14-18].

Multipath routing techniques have been discussed in the literature for several years. There are three different approaches including node-disjoint, link-disjoint, or non-disjoint routes [5-12]. Node-disjoint routes have no nodes or links in common. In contrast to node-disjoint routes, link-disjoint routes do not have links in common, but may have nodes in common. And non-disjoint routes have nodes and links in common. The multipath routing is more effective than the single path routing because the former can provide load balancing, fault-tolerance, and higher aggregated bandwidth [5-12].

In MANETs, since energy efficiency directly affects the network life time, it is as important as general performance measures such as delay, remaining energy, and packet delivery ratio. The network under investigation is a set of wireless energy-limited transceiver-processors. Each transceiver-processor is energy-limited in the node where its battery operated and unattended; once its battery energy has been depleted, the

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transceiver-processor can no longer support packet transport [14-18]. Similarly, energy entropy was defined [19] to optimize clusterhead power using in electing cluster members. Although no central authority exists for MANETs, some protocols entrust certain nodes with greater authority. Relative energy entropy can be used to characterize node energy consumption predictability, which can then be used to build connectivity tables based on projected node positions [14-18]. These uses are categorized as providing a measure of predictability and using in optimization.

In this paper, an effective way for energy efficient consumption has been proposed through the introduction of the Energy Entropy-based minimum Power cost Multipath routing algorithm in MANET (EEPMM), which in turn causes an increase in the networks lifetime, one of the most important parameters in this type of network. The goal of this paper is to develop a protocol to find out energy entropy-based multipath routing provisioning for load balancing, to reduce power consumption for packet transmission, and to prolong network lifetime in MANETs.

The rest of the paper is organized as follows: In section 2, we introduce multipath routing in MANETs. In section 3 we present energy entropy model in MANET. The proposed methodology for EEPMM is discussed in section 4. Section 5 explains simulation and results. Finally, the paper concludes in section 6.

2. Related Works

Multipath routing which maintains multiple paths for packet transmission between the source and destination nodes can address the limitation of single path routing and improve the network performance. The overall evaluation and classifications of multipath routing protocols for MANETs is in [5, 6]. The main objectives of multipath routing protocols are to provide reliable communication, to ensure load balancing and to improve quality of service (QoS) of ad hoc and mobile networks. Marina *et al*. [7] proposed an ad hoc on-demand multipath distance vector (AOMDV), AOMDV based on a prominent and well-studied on-demand single path protocol known as ad hoc on-demand distance vector (AODV) [8]. AOMDV has three novel aspects compared to other on-demand multipath protocols. First, it does not have high inter-nodal coordination overheads like some other protocols. Second, it ensures disjointness of alternate routes via distributed computation without the use of source routing. Finally, AOMDV computes alternate paths with minimal additional overhead over AODV; it does this by exploiting already available alternate path routing information as much as possible. The advantages of AOMDV are reduced routing overhead, increased throughput and reduced end-to-end data packet delay. Yilmaz *et al*. [9] proposes a novel distributed shortest hop multipath algorithm (SHM) for wireless sensor networks in order to generate energy efficient paths for data dissemination or routing. The SHM algorithm generates shortest hop braided multipath to be used for fault-tolerance or load-balancing, guarantees the distributed Bellman–Ford tree, and generates near optimal paths in $O(V\cdot D+V)$ message complexity and $O(D^2)$ time complexity regarding the communication costs towards the sink after termination of algorithm. The advantage of multipath routing protocol is a higher throughput in comparison with the standard IEEE 802.11 MAC and the reduction of the contention interference are the results of slot reservation mechanism for high-data traffic. Other goals of multipath routing protocols are to improve delay, to reduce overhead and to maximize network life time. As such, any approach utilizing multipath and multiflow communication could have the potential for tolerating faults, if these concepts are exploited for reliability [5, 6].

On the other hand, in order to support node mobility, scalable routing strategies have been designed and these protocols try to consider the path duration in order to respect some QoS constraints and to reduce the route discovery procedures. It is very difficult to satisfy energy saving and path duration and stability because they are two contrast efforts more often than not. In order to verify the correctness of the proposed solution a bi-objective optimization formulation which has been designed and a novel routing protocol called LAER (Link-stability and Energy aware Routing protocols) is proposed in [10]. The LAER algorithm requires each node i to advertise its location (x_i, y_i, z_i), rate of energy consumption (MDR_i) and link stability index for each link outgoing by node *i*. We will insert the information mentioned above in LAER HELLO packet. Each node broadcasts HELLO packets to all its neighbors that are in its communication range; each node in LAER maintains the table of its direct neighbors. When a node receives the HELLO packet, it updates the information of the neighbor, if neighbor ID is already present in table or adds neighbor information and if a node is a new neighbor.

Chanak *et al*. [11] presents energy efficient node fault diagnosis and recovery for wireless sensor networks referred as energy efficient fault tolerant multipath routing scheme for wireless sensor network. The scheme is based on multipath data routing. One shortest path is used for main data routing in our scheme and other two backup paths are used as alternative path for faulty network to handle the overloaded traffic on main channel. In [12], the authors propose the Multipath Energy Aware DSR (MEA-DSR). The MEA-DSR is an extension to the DSR (Dynamic Source Routing protocol) [13] protocol for computing multiple node-disjoint paths, where the “best” path is the most energy-efficient.

Energy efficiency is a prime metric in MANET performance analysis. Kunz *et al*. [14] proposes two techniques to reduce energy level inaccuracies, Prediction and Smart Prediction. In the Prediction technique, a node energy level is adjusted based on its past behavior (its own consumption rate). Smart Prediction is a modified version of the Prediction technique such that, if no consumption rate can be determined for a node, its energy level is adjusted based on the average of all known consumption rates for other nodes. Jeba *et al*. [16] proposes an energy efficient multipath data transfer scheme to address the troubles caused by false data injection attack. This can be done by early detection and filtering of injected false data. Moreover, the multipath data transfer technique prevents the direct access of event information by a compromised en-route node. Feng *et al*. [17] considers the realistic two dimensional (2D) scenario where nodes are distributed in rectangular space and derive an optimal transmission range in rectangular MANETs. Furthermore, grid-lifetime is considered in order to evaluate the network lifetime. Zhang *et al*. [18] proposes a novel recursive method to solve the optimization problem of power control, which operates as easily as the steepest descent method but converges much faster and does not require parameter training. The fast convergence and no need for training make the proposed method suitable for different wireless networks that come with vastly different characteristics and whose topology and link quality vary frequently over time. Metrics describing node energy consumption such as relative energy entropy have been proposed by generalizing Shannon’s information entropy [19] and have been used to assess node energy consumption predictability.

3. Energy Entropy Model

3.1. Path Entropy Calculation

Entropy [4, 19, 20] presents the uncertainty and a measure of the disorder in a system. There are some common characteristics among self-organization, entropy, and the location uncertainty in mobile ad hoc wireless networks. The corresponding methodology, results and observations can be used by the routing protocols to select the most stable route between a source and a destination, in an environment where multiple paths are available, and to create a convenient performance measure to be used for the evaluation of the stability and connectivity in mobile MANETs.

The main idea behind the proposed formulation is to explore a broad variety of legitimate routes by quantifying the uncertainty that is naturally involved in routing of communication networks. Let h denote the maximum number of links of possible routes from the source node s to the destination node d. If n is the total number of nodes in the network, then $h \leq n$-1. $p^i_j \in [0,1]$ represents the probability that the jth node occupies the ith position of the route. The connection probabilities

$$\sum_{j \in N} p^i_j = 1, \quad 2 \leq i \leq h \tag{1}$$

The set of connection probabilities $\{p^i_j\}$ can be used to quantify the uncertainty that is naturally involved in the search for the best route.

The entropy was proposed by Shannon [19] as a measure of uncertainty for statistical models. We consider the probability distribution (p_1, p_2, …, p_n) in the experiment. Assuming that the probability distribution is complete, *i.e.*, $\sum_{i=1}^{n} p_i = 1$, the Shannon entropy is defined as

$$H(p_1, p_2, \cdots, p_n) = -\sum_{i=1}^{n} p_i \log_\theta p_i \tag{2}$$

Using the definition of the connection entropy, it can be shown that $0 \leq H(P) \leq \ln n$. The connection entropy is minimized if and only if the entries p^i_j of P take on values from the set {0, 1}. In such a case, $H(P)=H_{\min}=0$ and $\{p^i_j\}$ define the least uncertain route. The connection entropy attains its maximum value if and only if p^i_j=1/n, $\forall i, j$. In such a case, $H(P) = H_{\max} = \ln n$ and $\{p^i_j\}$ define the most uncertain route.

3.2. Energy Consumption Model

We use the same radio model as Heinzelmen *et al*. [14] assuming a simple model where the radio dissipates (E_{elec})=50nJ/bit to run the transmitter or receive circuit and (E_{amp}) =100pJ/bit/m^2 for transmitting amplifier. The electronics energy (E_{elec}) depends on many factors such as the digital coding, the modulation, the filtering, and the spreading of the signal, whereas the amplifier energy, $(E_{amp}) \times d^{-\alpha}$, depends on the distance to the receiver and the acceptable bit-error rate. It assumes that the attenuation in the signal strength is inversely proportional to the square of the distance *i.e*., if P_t and P_r are transmitted and receiver powers respectively, transmitting a k-bit message a distance d using the above model radio expends:

$$P_t = E_{elec} \times k + E_{amp} \times k \tag{3}$$

It assumes that the attenuation in the signal strength is inversely proportional to the square of the distance *i.e*., if P_t and P_r are the transmit and receiver powers respectively,

$$P_r = P_t \times d^{-\alpha} \tag{4}$$

Where is the path loss exponent and usually lies between 2 and 6, α =2 for short distance and =6 for longer distance. d is the transmission distance.

3.3. Energy Required

A generic expression to calculate the energy required to transmit a packet p is: $P_t = i \times v \times t_p$ Joules, where: i is the current consumption, v is the voltage used, and t_p the time required to transmit the packet [12]. It is supposed that all mobile devices are equipped with IEEE 802.11b network interface cards. The values of energy consumption were obtained by comparing commercial products with the experimental data reported in [14].

In order to conserve energy, senders dynamically adjust the transmission power proportional to the transmission distance [15]. The transmission power cost function is defined as:

$$C_R = \sum_{i=0}^{k-1} P_t(i) \tag{5}$$

where $P_t(i)$ is transmission power of node i, k is the number of hops from source node s to destination node d. To more accurately represent the energy cost and constraint hop count, the power cost $P_r(i+1)$, for the transceiver at node i+1 to receive a packet, is also added to the above cost function:

$$C_R = \sum_{i=0}^{k-1} (P_t(i) + P_r)i+1)) \tag{6}$$

where, $P_r(i+1)$ can help reduce hop count.

$P_s(i)$ is proportional to $\|i, i+1\|^n$, while $\|i, i+1\|$ is the distance between node i and i+1. The calculating transmission power is defined as:

$$P_t(i) = \frac{\varepsilon \| i, i+1 \|^n}{S_{i,i+1}} \tag{7}$$

where, ε is a constant, and $S_{i,i+1}$ characterizes the current channel conditions and interference on link (i, i+1). $S_{i,i+1}$ is a dynamic factor and is estimated based on the historical data. Clearly, this energy calculation is dependent on the number of hops required to get from source node s to destination node d, but NOT the actual links used.

3.4. Remaining Energy Capacity

The network lifetime is defined as the duration from the beginning of the network setup to the first depletion of a node in the network. If some nodes work on multiple minimum cost paths, the nodes will get depleted fast. Therefore, the network lifetime is not ensured. To maximize the network lifetime, a number of power aware routing protocols which use the remaining energy capacity as the cost metric [14, 15] have been proposed. The remaining energy capacity cost function is defined as:

$$C_R = \sum_{i=1}^{k-1} (1 / E_r^i(t)) \tag{8}$$

where $E^i_r(t)$ is remaining energy capacity of node i at time t. Thus, routes containing nodes with little energy capacity can still be chosen.

3.5. Energy Entropy

Now let us calculate the uncertainty in the relative distance between a transmitter and a receiver. Since the nodes are randomly scattered, the receiver will lie anywhere in the circle with radius $R_{\max}$ in equal probability, with the transmitter node being at the center of the circle. In polar co-ordinates, the radial distance is assumed to be uniformly distributed from 0 and $R_{\max}$, and the angle is uniformly distributed direction from 0 and 2π. The definition of entropy of the literature [19, 20] gives more details.

The position of the receiver is characterized by $f_R(r)$ and $f_\theta(\theta)$, which denote respectively the distance probability density function (*pdf*) and the directional *pdf*. The two *pdf*s are defined as follows:

$$f_R(r)=\begin{cases}\dfrac{2r}{R_{\max}^2}, & 0\le r\le R_{\max}\\ 0, & \text{elsewhere}\end{cases} \tag{9}$$

$$f_\theta(\theta)=\begin{cases}\dfrac{1}{2\pi}, & 0\le \theta\le 2\pi\\ 0, & \text{elsewhere}\end{cases} \tag{10}$$

The joint *pdf* is given by

$$f_{R\theta}(r,\theta)=\begin{cases}\dfrac{r}{\pi R_{\max}^2}, 0\le r\le R_{\max}, 0\le \theta\le 2\pi\\ 0, \quad \text{elsewhere}\end{cases} \tag{11}$$

Since, according to our assumption that transmission power is directly proportional to the energy consumed, the transmission power *pdf* to calculate the energy entropy. Shannon's entropy for a random variable with *Y* with *pdf* $f_Y(y)$ is

$$H_S(Y)=\int_{-\infty}^{+\infty} f_Y(y)\log f_Y(y)dy \tag{13}$$

Thus, the energy entropy is given by

$$H(f_P)=\int_0^{R_{\max}} (f_{R\theta}(P_t^{-\alpha})\log f_{R\theta}(P_t^{-\alpha})dP_t \tag{14}$$

Let it present the route stability (RS) between two nodes s and d during some interval Δ_t as RS. We define and evaluate two different measures to estimate and quantify end to end route stability, which denoted by $F'(s, d)$ and $F(s, d)$ and defined as follows respectively:

$$F(s,d)=\prod_{p=1}^{k} H(f_p) \tag{15}$$

where k denotes the number of intermediate mobile nodes over a route between the two end nodes (s, d).

$$F(s,d)=-\ln F'(s,d)=-\sum_{p=1}^{N_r}\ln H(f_p) \tag{16}$$

4. Route Discovery Process

The EEPMM routing protocol is used to find multiple paths between a pair of source node and destination node. It has three phases, the initialization phase, the paths search phase, and the data transmission and maintenance phase.

The initialization phase: The route request message (RREQ) message is one of the control messages exchanged between nodes in the initialization phase. Table 1 shows different fields within a RREQ message.

Table 1. The Format of Extended a RREQ Message

Message seq	Message type	Node ID	Hop count	Forward ID	Forward node energy entropy

The paths search phase: After multiple paths are discovered, the regular nodes and the source can communicate with each other effectively through them. The EEMRA protocol provides the mechanism of paths adjustment to avoid insignificant paths transmissions which require more time to the source or merely consume energy. Table 2 shows the format of a route reply message (RREP) message.

Table 2. The Format of a RREP Message

Message seq	Message type	Source ID	Destination ID
Route ID	Path Cost	Forward ID	Forward node energy entropy

Data transmission and paths maintenance phase: After multiple paths are discovered, the source node begins to transmit data packets with the assigned rates on each path. The DATA message carries the event data and has the fields as shown in Table 3.

Table 3. The Format of a DATA Message

Message seq	Message type	Source ID	Destination ID	Route ID
Data Count	Path Cost	Data Load	Forward ID	Forward node energy entropy

In route discovery procedure, the EEPMM builds a route between source to destination using a route request and route reply query cycle. When a source node wants to send a packet to destination for which it does not already have a route, it broadcasts a route request (RREQ) packet to all the neighbors across the network, each node will update its neighboring node table with the forward node ID, mark the node n id as its parent and forward node energy information. Next, the node verifies if the node type is set to be source node. In such case, the sender ID is compared with the source list of the node. A new entry is created in the source table if necessary, with the hop distance updated only when it is smaller than the value recorded. When RREQ receives at the destination node, it forwards a RREP packet back to the source. In EEPMM the route is selected on the basis of energy entropy.

In order to detect the path failure, the destination node also monitors the inter-arrival delay of data packets on each path. When the delay is above a pre-determined threshold, the destination node presumes that the path is broken. If the number of current working paths is equal to or lower than two, the destination node will send a RREP message to the source through the optimal path to re-initiate the paths search phase. Otherwise, the destination node re-adjusts the data rate allocation over other functional routes. This mechanism can avoid having the path search phase being invoked frequently.

5. Simulation Experiments

5.1. Simulation Model

In this section, we present the result obtained from simulating different scenarios under different network sizes, different node's mobility speed. To conduct the simulation studies, we have used randomly generated networks on which the algorithms were executed in [21]. This ensures that the simulation results are independent of the characteristics of any particular network topology. The results of the simulation are positive with respect to performance. We use the NS-2 simulator [22] to evaluate the EEPMM protocol.

In order to evaluate our algorithm, we compare EEPMM with other famous routing protocols such as SHM [9] and MEA-DSR [12] in terms of the network lifetime and the energy consumption. We assume that 50 mobile nodes are randomly and uniformly distributed in a 1000 m × 1000 m unit area. Each node has a pause time of 2 seconds to simulate a high mobility environment. Radio propagation range for each node is 250 meters and the channel capacity of 2 Mbps is chosen. The node's mobile speed is set up to 0-20 m/s. And there were no network partitions throughout the simulation. Each simulation is executed for 600 seconds of simulation time. Multiple runs with different seed values are conducted for each scenario and the collected data are averaged over those runs. A free space propagation model is used in our experiments. A traffic generator is developed into simulating CBR sources. The size of data payload is 512 bytes. Data sessions with randomly selected sources and destinations are simulated. Each source transmits data packets at a minimum rate of 4 packets/sec, and at a maximum rate of 10 packets/sec. Table 4 lists the simulation parameters which are used as default values unless otherwise specified.

Table 4. Simulation Parameters

Number of nodes	50	Node's mobility speed	0-20 m/s
Terrain range	1000m ×1000 m	Node pause time	2 seconds
Transmission range	250 m	Electronics energy Eelec	50nJ/bit
Simulation time	600 seconds	Amplifier energy Eamp	100pJ/bit/m2
Mobility model	Random way point	Examined routing protocol	SHM [9], MEA-DSR [12]

Energy consumption only counts receiving and transmission. Thus, idle nodes do not consume energy. The values used for the voltage and the packet transmission time are v = 5V and $t_p = (p_h/6\times10^6 + p_d/54\times10^6)$ s, where p_h and p_d are packet header and payload size in bits, respectively. The powers for transmission and receiving are fixed values, 0.66 Watt and 0.365 Watt, respectively. We assume a packet p with time length $t(p)$, and when a node transmits p, the node's energy capacity will be decreased by $E_{tx}(p)$, where $E_{tx}(p)$ = 0.66×$t(p)$, when a node' receives p, the node's energy capacity will be decreased by $E_{rx}(p)$, where $E_{rx}(p)$ = 0.395×$t(p)$.

5.2. Metrics for Evaluations

We will compare the performance of three multipath routing methods under the same movement models and communication models. We evaluate the performance according to the following metrics:

Network lifetime: One of the most important performances for protocol designing with energy considered is defined as the time from the very beginning to the first node failure due to exhaustion of battery power.

Average energy consumption: This parameter allows us to considerate about energy wastage associated with the route maintenance and route discovery and accounts for energy consumption during transmission and reception of control and data packets.

5.3. Simulation Results

In EEPMM technique, energy loss rate of node in different network size with different node's mobility speed is shown in Figure 1 and Figure 4. The number of delivered data packets is the total number of delivered data packets of each node.

In this simulation, we use most of nodes in the network to transmit data packets repeatedly. For every different number of nodes, we are getting average network life of the network. Experiments' results are shown in Figure 1. In SHM and MEA-DSR, same nodes are used for transmissions, so some selected nodes get overused rapidly and decrease network life. In EEPMM, the main reason is that we take into account the power saving and power saving to design the routing protocol. Average network life in EEPMM is better than that in SHM and MEA-DSR.

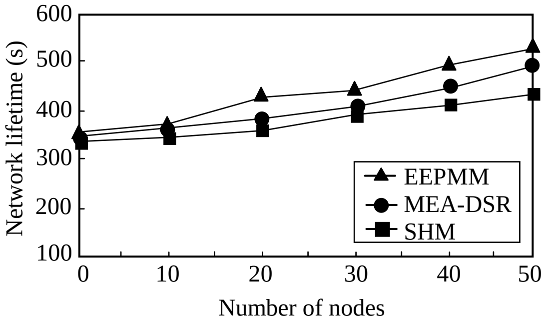

Figure 1. Comparison of Network Lifetime

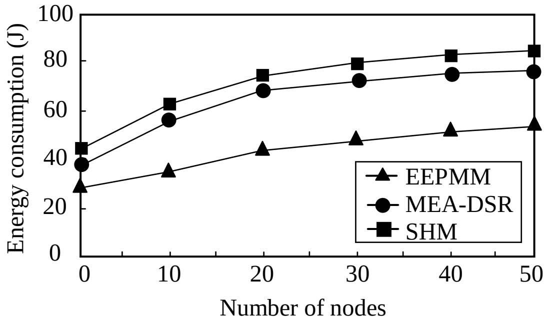

Figure 2. Comparison of Energy Consumed

For other routing schemes, a larger network requires more exchange of control messages to discover and construct the routes; therefore, more energy is consumed in the set-up phase. To see the energy balance, Figure 2 shows the energy consumption of all 50 nodes drawn in an increasing order of energy consumption. Figure 2 shows the simulation results of EEPMM routing protocol, SHM and MEA-DSR. From the simulation results in Figure 2, the energy consumption in our proposed routing protocol is less than that in SHM and MEA-DSR. The main reason is that the paths found by the SHM and the MEA-DSR has lower bandwidth than EEPMM routing protocol has, so the SHM and the MEA-DSR take more time to transmit the same amount of data than EEPMM routing protocol does. EEPMM works well even for larger number of nodes. It can be seen from the plot in Figure 2 that the energy consumed in EEPMM is lesser compared with SHM and the MEA-DSR. The energy is saved, as the number of hops increases. On the other hand, EEPMM keeps on changing the path with the increase in the time and maintains the energy load balance. Such experimental results demonstrate that the energy efficiency of multipath routing is stable and has little impact by the increase of the network size, while the performance of other schemes degrades with larger network size.

Figure 3 and Figure 4 show a comparison of network lifetime and energy consumption performance of the three routing protocols by taking the mobility speed. It is interesting to observe how EEPMM, SHM and MEA-DSR consume lower energy: due to the energy entropy topology management and the absence of route discovery procedures that are energy consuming. Under all the max speeds, EEPMM gives much longer network lifetime than SHM and MEA-DSR approach does. EEPMM get nearly network lifetime 10-20% higher than lifetime of SHM and of MEA-DSR. This justifies that EEPMM can balance the traffic load among different nodes and prolong the individual node's lifetime and even the entire system lifetime. We can also observe that the network lifetime with multipath routing degrades more gracefully than other routing protocols do when the nodes' mobility speed increases. Figure 4 shows that the energy consumption of EEPMM is less than the consumption of both SHM and MEA-DSR. And from the curve of Figure 4, we can also find that the improvement of energy consumption decreased with the increasing of mobility speed. With the rising of maximal node mobility speed, the network dynamics will increase and the network routes will be changed frequently for fast moving of nodes, which will distribute the network traffic and extend the network lifetime of EEPMM, SHM and MEA-DSR, the advantages of EEPMM will not be palpable in this high dynamics network, so the percent of improvement will be decreased.

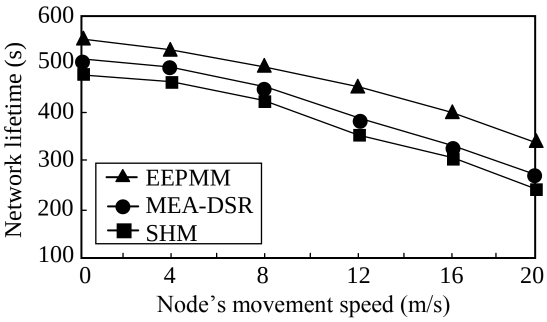

Figure 3. Comparison of Network Lifetime

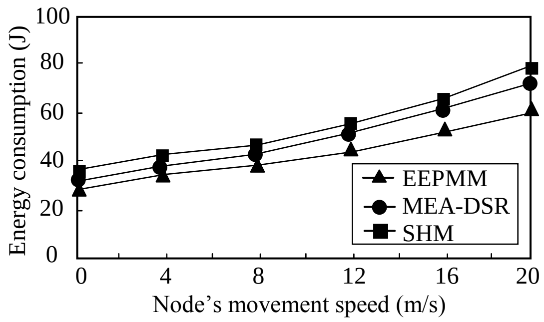

Figure 4. Comparison of Energy Consumed

5. Conclusion

This paper discusses multipath routing problem, which may deal with the energy entropy model for researching the MANET multipath routing problem. It presents an Energy Entropy-based minimum Power cost Multipath routing algorithm in MANET (EEPMM). The key idea of EEPMM algorithm is to construct the new metric-entropy and to select the stability multipath with the help of entropy metric to reduce the number of route reconstruction so as to provide load balancing in the MANET whose topology changes continuously. As a result, by taking network lifetime, and energy consumed into account, the EEPMM routing algorithm efficient reduces power consumption of packet transmission and prolongs network lifetime. The results of the performance indicate that the proposed scheme is quite adaptive for energy-efficient communication in MANETs.

The following are the thoughts for future work: (1) Introducing the above-mentioned features in our approach; (2) Updating different parameters used in EEPMM according to the workload and the node requirements in the network; (3) Applying EEPMM for other purposes such as load balancing is another issue for future work.

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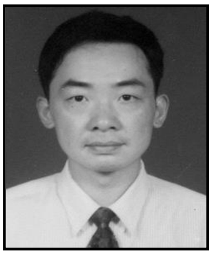

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