PAPER

Energy and Link-State Based Routing Protocol for MANET*

Shi ZHENG[†a)], ***Member***, **Weiqiang WU**[†], ***Nonmember***, ***and*** **Qinyu ZHANG**[†], ***Member***

SUMMARY Energy conservation is an important issue in mobile ad hoc networks (MANET), where the terminals are always supplied with limited energy. A new routing protocol is presented according to the study on the influence of low-energy nodes in ad hoc networks. The novel routing protocol (energy sensing routing protocol, ESRP) is based on the energy sensing strategy. Multiple strategy routing and substitute routing are both adopted in this paper. Referring to the level of the residual energy and the situation of energy consumption, different routes are chosen for packets transmission. The local maintenance is adopted, which can reduce packets retransmission effectively when the link breaks. We focus on the network lifetime most in all performances. The evaluation is done in comparison with other routing protocols on NS2 platform, and the simulation results show that this routing protocol can prolong the network lifetime and balance energy consumption effectively.
key words: *ad hoc, energy conservation, routing discovery, local maintenance*

1. Introduction

Mobile ad hoc network (MANET), which has no existing infrastructure, consists of a group of mobile nodes. The nodes in the network can transmit packets among each other through one hop or multiple hops. In view of transmission, these nodes can be source nodes and destination nodes, also they can play a role in forwarding nodes for retransmitting packets. To fulfill their rapid autonomy and flexible mobility in MANET, the terminals should adopt battery with limited energy capacity. Furthermore, energy of some nodes in especial positions exhausts rapidly because they are overused as forwarding nodes for retransmitting packets. Once the energy of some nodes is exhausted, these nodes are then considered separated from the whole network, and they are called dead nodes. A set of dead nodes will cause a series of problems, such as the network segmentation and the link interruption. Therefore, the energy resource should be considered as an important protected issue in MANET. Most of the traditional routing protocols (e.g. AODV and DSR) in MANET only focus on the transmitting efficiency. In conventional schemes, the minimum hop routing is often chosen as the strategy, in which the nodes in central position may be used as the forwarding nodes by several links simultaneously. And congestion maybe arise in these positions, leading to frequently packets loss and retransmission. Therefore, simple routing protocols which ignore the situation of nodes' energy will cause several considerably serious transmitting problems in MANET.

In order to solve problems mentioned above, we make a trade-off between energy consumption of nodes and other performances. There are two main ideas to solve this trade-off problem. In [1] and [2], authors investigated the trade-off problem by exploring the power control mechanism to adjust transmit power or by exploring sleep mechanism in MAC layer, then the goal of saving energy and improving energy efficiency can be achieved. The other idea to solve this trade-off problem can be concluded as follows: the status information of energy in the network is transmitted to other nodes via a part of the control message, meanwhile, the cost function of energy is presented, which can be used as the chosen routing criterion [3].

Routing protocols based on energy consumption strategy for MANET attracts more and more attentions recently. The previous results are based on the simple routing mechanism (such as the AODV and the OLSR routing protocols) [4]–[8], i.e., the power control and the energy sensing are introduced into these simple routing protocols. With these proposed protocols, the energy efficiency and the balance of energy consumption are improved or the network lifetime is prolonged. Based on the estimation of the current average energy in the links, [4] discusses the routing protocol to protect the overused nodes in MANET. E-TORA [5] can select the routing according to the hop count and the residual energy of nodes, which shows that the nodes with more energy can be chosen at higher probability. In [6] and [7], the authors present the energy efficiency in OLSR where the routing decision is based on a load balancing approach. Once a routing decision is made, power adjustment per packet transmitted link by link is done based on the transmitting power control approach. The idea of multipoint relays (MPR) mentioned above is widely used in many routing protocols based on the energy conservation. In the minimum total transmission power routing (MTPR) [8], the total energy consumption in the link is chosen as the cost function for selecting the right routes. This routing protocol tends to transmit across short-distance nodes rather than long-distance nodes. In other words, more hops are used in the links instead of relatively less hops. Although this strategy reduces transmitting energy consumption theoretically and improves spatial multiplexing rate, introducing considerably quantity of forwarding nodes would cause network

Manuscript received September 30, 2010.
Manuscript revised December 29, 2010.
[†]The authors are with the Harbin Institute of Technology, ShenZhen Graduate School, China.
[*]This paper is supported by the national basic research program of China. (2009CB320400)
a) E-mail: zqy@hit.edu.cn
DOI: 10.1587/transinf.E94.D.1026

congestion or rapid energy exhaustion of key nodes, since some nodes are overused to retransmit packets. Based on the researches mentioned above, the minimum battery cost routing (MBCR) is presented. As for the MBCR protocol, the residual energy in MANET is considered, and the summation of the residual energy is used as routing cost which could partly avoid the problem of imbalance energy consumption. MBCR prolongs the network lifetime, but it only concerns about the whole cost of links and ignores a series of problems caused by the single node [9], [10]. For nodes in the network, their initial energy and energy consumption are different so that the residual energy value of some nodes is much lower than that of others. The min-max battery cost routing (MMBCR) protocol focuses on the residual energy of bottleneck nodes and it is considered as the routing cost. The targets of protocols discussed above aim to improve the network lifetime as much as possible; however, the protocols which adopt the same strategy can not ensure optimization of performance in different energy levels for MANET. Multiple strategies of routing protocol fulfill the performance optimization through choosing the right strategy according to the parameter changing [9]–[12]. The conditional max-min battery capacity routing (CMMBCR) combines MBCR and MMBCR, and it chooses the routing by setting the threshold. In [13] and [14], the performance comparison and evaluation are done to analyze the routing protocols mentioned above. However, these protocols do not achieve satisfying performance in energy consumption balance and protecting low-energy nodes. Especially when there is no appropriate link maintenance strategy, a large number of interruptions and retransmissions would happen on the late stage of the network.

Aiming at the above problems, a new routing protocol based on energy sensing is presented in this paper. It is based on the idea of multiple strategies. In this paper, in order to obtain better performance of the network lifetime, we divide the residual energy of the nodes into three levels by two thresholds. In the different level of the residual energy of the nodes, different routing strategy is applied. Therefore, the network lifetime can be prolonged. Meanwhile, to avoid the influence of singular nodes, we introduce the conception of relative residual energy, which means the better fairness of energy consumption in the whole network.

As is shown in Fig. 1, subfigure (*a*) and (*b*) show two links with four nodes, *A*, *B*, *C* and *D*. The total energy for these two links are the same while the energy of individual nodes are different. The network fairness and load balance affect the energy consumption rate of nodes, and these will result in different residual energy values of nodes in a certain link or region. By using the routing protocol which takes the total residual energy of nodes as the link cost, link (*a*) has a better performance of network lifetime than link (*b*). Since node *A* with large energy covers node *D* with low-energy in link (*b*), it may cause the problem of single node mentioned above. We define the node with considerable large or low residual energy as singular node. These nodes are one of unstable factors in the link. If each node with different residual energy has the same impact on the link cost of routing, i.e., they have the same weight value, then the singular nodes can influence the choice of the optimal routing. Therefore, we need to find a routing strategy, which makes these singular nodes not ignored by increasing their weights, to further prolong the network lifetime.

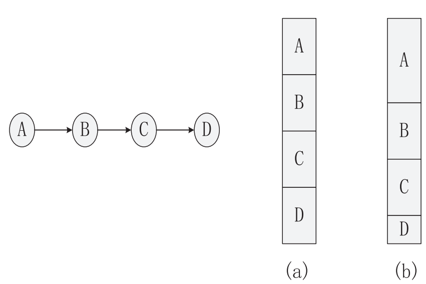

Fig. 1 Diagram of node energy in the link.

Since several strategies are introduced for improving the network lifetime in the routing discovery, the other performances (e.g. end to end delay) are degraded to a certain extent. To get a trade-off in performance, local maintenance mechanism is necessary. In this paper, the local nodes can utilize the messages of residual energy to estimate connection of link in the course of routing maintenance, which can decrease the number of link interruption and retransmission.

2. System Model

The routing discovery strategy can balance and protect the routes through collecting the information of the nodes' energy. First, we should build a model for residual energy and energy consumption. Second, the network lifetime is chosen as the most important criterion in this paper. A lifetime model is needed to analyze the performance of these protocols.

2.1 Energy Consumption and Residual Energy Model

Suppose that the distance between one pair of transmitter and receiver is d. In the free space, if the minimum value of the received energy needed by the receiver is E_{min}, then the transmitting energy $E_{amp}(d)$ can be obtained as follows:

$$E_{amp}(d) = kd^n \times E_{min} \tag{1}$$

Where n is an integer between 2 and 4 and k is a constant. In this paper, $n = 2$, $k = 1$. $E_{amp}(d)$ denotes the energy consumption when the inter-amplifier transmits a unit. While transmitting a m-bit packet the energy consumption $E_{tx}(m,d)$ is defined in (2), and that of receiving is in (3). E_{elec} presents energy consumption of node's inter-circuit in the course of transmission and receiving. This means energy consumption occurs in both courses of transmitting and receiving.

$$E_{tx}(m,d) = m \times (E_{elec} + E_{min} \times d^2) \tag{2}$$

$$E_{rx}(m) = m \times E_{elec} \tag{3}$$

Refer to a pair of communication ends, the whole cost of energy for transmission m-bit packet is as follows.

$$E_{tw}(m,d) = 2m \times E_{elec} + md^2 \times E_{min} \tag{4}$$

We adopt normalization for the residual energy of nodes according to the different initial energy of nodes. E_i^i is initial energy of node i. E_i^r is the residual energy of node i. E_i^c is energy consumption of node i. E_i^p is the residual energy ratio of node i. We define herein the residual energy ratio of node i as

$$E_i^p = E_i^r / E_i^i \tag{5}$$

The residual energy E_i^r of node i above is given as:

$$E_i^r = E_i^i - E_i^c \tag{6}$$

When a path is chosen from source to destination, it contains the source node, forwarding nodes and destination node. The whole cost of the nodes belonging to the path is given as follows:

$$E_{cw} = \prod_{i \in N} E_i^p \tag{7}$$

Where, N is the total number of nodes in the path.

In this paper, we adopt the residual energy ratio E_i^p as the available value of the nodes instead of absolute value used in CMMBCR and other energy routing protocols. Initial energy of nodes are different from each other. If the residual energy of some nodes in the network is much higher than others, sum of the residual energy is mainly related to the nodes with higher energy, and lower ones are ignored. To avoid the impact of singular nodes, the status of residual energy of nodes is equalized by getting the result of E_i^p, namely doing normalization to remain energy of the nodes in the path (excluding weights of the nodes). In addition, percentage of residual energy E_i^p, rather than E_i^r, can show the state of the traffic load in a period. If some nodes in the path have lower E_i^p, the path containing these nodes should not be chosen in priority. This condition has little effect on the sum of E_i^p, but has more effect on the product of E_i^p, because the product will become very small. Therefore, this kind of path will have lower priority in the candidate paths and protect lower residual energy nodes to a certain extent. The link cost C_R is as follows:

$$C_R = 1/E_{cw} \tag{8}$$

To the whole network, the forwarding nodes with heavy traffic load consume more energy. Therefore, the quantity of residual energy means the frequency of using this node. The probability of congestion is reduced greatly on account of using the nodes with more residual energy as the forwarding nodes.

2.2 Network Lifetime Model

Consider a directed graph $G(N, L)$, where $N = n_1, n_2, \ldots, n_k$ is the set of all nodes and $L = l_1, l_2, \ldots, l_m$ is the set of all directed links (i, j). l_i is side, m is the number of side. Let $S_i (j \in S_i)$ be the set of nodes that can be reached by node i with certain power level in its dynamic range. We suppose that the course of transmitting packets is reversible. Let E_i^i be the initial energy of node i and E_i^r be the remained energy of node i. The transmission energy required by node i to transmit one bit data to its neighbor nodes is denoted by $E_{tx}(1, d)$ and the received energy required by node i is $E_{rx}(1)$. Energy consumption of node i with transmission k-bit packet and receiving m-bit packet is shown as follows:

$$E_w^i = E_{tx}(k,d) + E_{rx}(m) \tag{9}$$

The time when E_w^i equals E_i^i is defined as the lifetime of node i denoted by T_i. Thus the network lifetime is denoted by:

$$T_{nek} = \min_{i \in N} T_i \tag{10}$$

We define the minimum lifetime of the node as the above network lifetime. Because the presence of singular node with low-energy will make its lifetime much lower than that of other nodes, it will be instability if using the network lifetime defined in Eq. (10). To reduce the probability of the instability, the definition of the network lifetime should be further improved. According to the different scales of network, we can take the mean value of some of the nodes with short lifetime as the network lifetime. This method can reduce the probability of the instability of the network lifetime, as is shown in Fig. 2.

In Fig. 2, simulation results show that the variance of average network lifetime decreases with the number of sample nodes increasing. It indicates that the stability of the average network lifetime is prolonged when we set more node lifetime as samples. From the figure we can see that different numbers of network corresponding to different variance in the same percentage of sample nodes. When the network scale is relatively small, we should get more sample nodes to acquire stability network lifetime, while in the large scale,

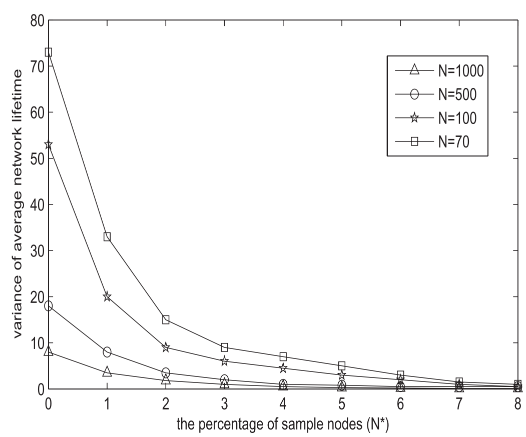

Fig. 2 Variance of average network lifetime with different number of sample nodes (N is the number of the nodes in the network).

the small percentage of sample nodes can meet the requirement of stability. Thus according to the results, we can see that the instability of the network lifetime can be eliminated, when the number of sample nodes is more than one-tenth of total number of nodes under the scenario in Sect. 4. In this paper, we define the improved network lifetime as the arithmetic mean node lifetime of the first ten nodes. The node lifetime is $T_i = T_1, T_2, \ldots, T_N$, $(T_1 < T_2 < \ldots < T_N)$. Thus, the network lifetime T_{nek} is as follows.

$$T_{nek} = 1/10 \sum_{j=1}^{10} T_j \qquad (N > 10) \tag{11}$$

3. Energy Sensing Routing Protocol

3.1 Routing Discovery

For the network with enough residual energy, more attention should be paid to the whole cost of a link, which indicates the state of traffic load and energy balance. So it is chosen as the routing discovery strategy. After a period of working, energy consumption of the nodes is becoming more, and residual energy decreases. The energy of nodes becomes different. At this time, we should focus on unit cost to protect nodes with lower residual energy. As a result, the lifetime of the node is prolonged and network partitioning is avoided. When a node has low residual energy, warning to other nodes is necessary; at the same time, we should not let it be the forwarding node as possible as we can. According to the analysis above, two thresholds r_1 and r_2 are set, which divide the energy into three levels, and have corresponding routing metric respectively.

r_1 is the normalized residual energy of the nodes. Since we introduce the protecting value r_2 for danger node, we set the range of r_1 from 10% to 100%. When r_1 is approaching 100%, the routing protocol tends to protect the single node, even though most nodes have sufficient energy at the beginning of network transmission. The advantage is that the single node is given more attention in the course of routing discovery, which makes it possible to reduce the presence of low residual energy. The performance of network lifetime is optimal with $r_1 = 100\%$. Meanwhile the defect is obvious. The protection mechanism for single node at early stage makes the average hops number increase, which causes the end to end delay increasing. It is important when we prolong the network lifetime by taking the end to end delay performance into account. When r_1 is 10%, routing protocols are more concerned about the integrity of nodes energy in the link. The routing protocol takes the energy of all nodes in the link as metric most of the time, rather than the residual energy of the single node. This will largely reduce the end to end delay. The performance of network lifetime is worse than that of $r_1 = 100\%$ due to the residual energy of the single node to be protected at late stage. Thus, different r_1 will lead to different network lifetime and end to end delay. We tend to get trade-off between network lifetime and end to end delay. We choose the product of the network lifetime and the inverse of end to end delay as the criteria of r_1 selection. The larger the product is, the better the trade-off performance is.

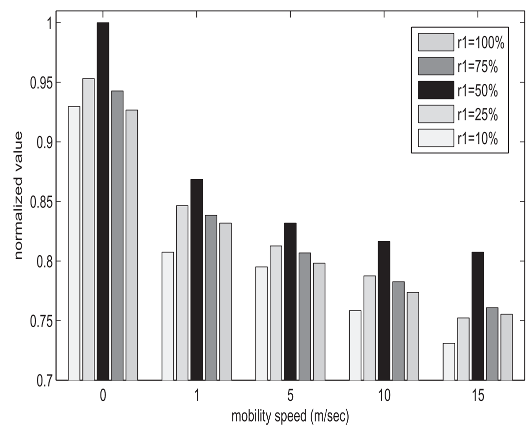

Fig. 3 The normalized value of C in different mobile mobility.

$$C = T_{nek} \times 1/t_{delay} \tag{12}$$

Where C is value of trade-off performance, t_{delay} is end to end delay.

In this paper, we set r_1 as five typical experiment values: 10%, 25%, 50%, 75%, 100%. Different values of C at different r_1 are normalized according to the value when $r_1 = 50\%$ and mobility speed 0 m/sec. The result is shown in Fig. 3.

From Fig. 3, we can see that $r_1 = 50\%$ corresponds to the optimal performance when taking network lifetime and end to end delay into consideration. In this paper, r_1 is set to 50%.

r_2 should be set between 0 and r_1, and adjusted according to the network environment. If r_2 is too large, danger node will be protected too early. As the protected node cannot be forwarding node, too early protection of danger node will lead to large areas of danger nodes in the later period of network transmission. These will cause the number of forwarding nodes reducing, which may lead to network partitioning and reachability reducing. Too low r_2 will decrease the effect of energy conservation and local maintenance.

From Fig. 4, we can see that the packet loss rate decreases with r_2 increasing. When r_2 is more than 10%, the packet loss rate increases sharply, and the packet loss rate is intolerable because of too many danger nodes. When r_2 is less than 10%, the value changes so slowly that we can ignore the difference. Furthermore, under the guarantee of the packet loss rate, for protecting the key nodes and danger nodes better, we set r_2 as big as possible. Therefore in this article, we set the value of r_2 10%.

r_1 is set to be 50% and r_2 is 10% in this paper. Therefore, based on energy sensing routing cost, R_c should satisfy the following formula.

$$R_{c1} = \max\{E_{cw}\} \qquad (E_p > r_1) \tag{13}$$

$$R_{c2} = \max\{E_p\} \qquad (r_1 > E_p > r_2) \tag{14}$$

$$R_{c3} = Protection \qquad (r_2 > E_p) \tag{15}$$

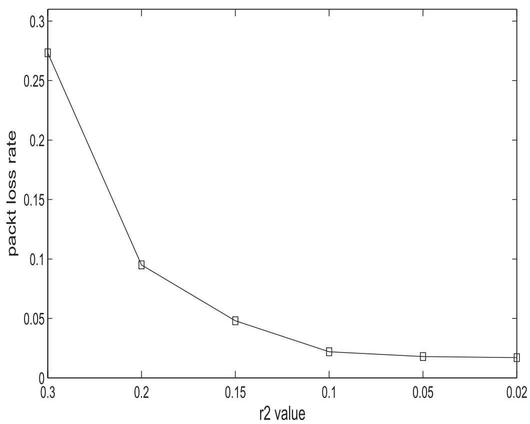

Fig. 4 The packet loss rate with different r2 value.

Table 1 Format of RREQ.

Source ID	Destination ID	Sequence ID	E_{cw}	E_p

E_p is the residual energy of the node. If $E_p > r_1$, i.e., energy of each node is abundant, the path with the maximum E_{cw} is preferred as the rule. If $r_1 > E_p > r_2$, i.e., there are some nodes that consume much energy, and the path with the maximum residual energy is chosen as the optimization. If $r_2 > E_p$, the path is protected for use.

3.1.1 Course of Routing Request

When a node is required to retransmit packets, its routing table will be checked for the available path to the destination. If there is not any available routing in the table, the routing discovery course will be started up. The RREQ is sent to the neighbors from the source. The RREQ will carry the Source ID, which means source sequence number, Destination ID, Sequence number, E_{cw}, and E_p, as is shown in Table 1.

When the forwarding node receives the RREQ, its routing table will be checked for the available path to the destination. If there is an available path, it will give a RREP with the right path to the source along the RREQ path. If not, E_p and E_{cw} value in the RREQ will be calculated and updated by the forwarding node i as follows. The new RREQ is transmitted until they reach the destination. Before this, the sequence number will be checked to avoid the loop path. The information of energy updates as follow.

$$\begin{cases} E_p(new) = E_p(i) & E_p(i) < E_p(old) \\ E_p(new) = E_p(old) & E_p(i) > E_p(old) \end{cases} \tag{16}$$

$$E_{cw}(new) = E_{cw}(old) \times E_p(i) \tag{17}$$

3.1.2 Course of Routing Reply

Routing reply packet RREP is sent by the intermediate node which has valid routing to the destination on receiving the RREQ, or by the destination node. When the destination node receives the RREQ, it will start a timer for collecting the corresponding routing in time 0 to T. Among the valid routing, the rest energy E_p is compared with threshold r_1 and r_2, and then, the right routing according to (12)–(14) is chosen and sent to the source in the RREP.

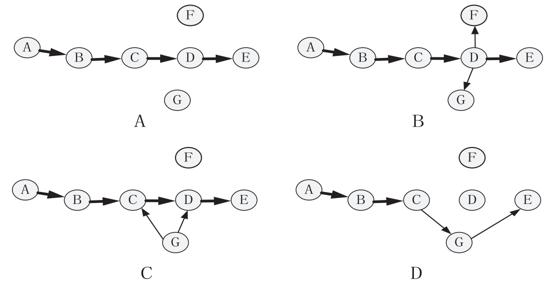

Fig. 5 The course of warning node's link maintenance.

3.2 Local Routing Maintenance

Because the movement of the nodes or exhaustion of the node energy may cause link broken, the routing maintenance is necessary. When a node detects link broken, it will inform the upper node through the routing error (RERR) packet. With the strategy of energy awareness and protecting of low-energy nodes in the routing discovery, we can get the information of the node's residual energy. According to this, we can inform other nodes in this link and discover other right routing ahead. The course in Fig. 5 shows how a danger node warns the situation to the neighbor, and a new path is built up quickly with the local maintenance. It is not necessary to inform the source to perform a new routing discovery in this course.

It is a normal link ABCDE to transmit packets from A to E, as is shown in Fig. 5 (A). The residual energy of node D is lower than the threshold r_2, so it starts the local maintenance strategy to inform other nodes. It includes the ID of node C and E. The nodes F and G receive this message, and check their own residual energy to see whether there is valid routing to get both of them. The node G meets the requirement. So it will inform the nodes C and D that it could be the forwarding node. If the link is built up successfully, the packets will be transmitted along the new link $ABCGE$.

4. Results and Discussions

In this section, the new routing protocol ESRP is simulated based on the analysis above. The simulation is done on NS2 platform. Simultaneously compared with AODV, MTPR and CMMBCR in the same environment, the results are analyzed. The simulation parameter setting is shown in Table 2.

As for the new routing protocol, network lifetime is considered as the most important measure introduced for comparing with other algorithms. Thus, we focus on the improvement of the new protocol in the aspect of network lifetime. The performances such as end to end delay and energy efficiency are also considered in the followings as assistants. In addition, different traffic load and mobility speed are referred to the simulation.

Table 2 Simulation model parameter.

Simulator	NS-2 version 2.29	
	network size	$1500\,m \times 700\,m$
	node numbers	70
PHY	Signal propagation model	Two ray ground
	Maximal transmission range	280 m
	Antenna model	Omnitenna
MAC	Link bandwidth	2 Mbps
	MAC protocol	802.11
	Queue	DropTail/ PriqueueSize/100
Network layer	AODV, MTPR, CMMBCR, ESRP	
Mobility model	Random-way point model	
	Maximum node speed (m/s)	0, 1, 2, 5, 10
	Minimum node speed (m/s)	0
	Pause time (sec)	0
Traffic model	Traffic type	CBR, UDP
	Data packet size	512 bytes
	Packet sending rate (p/s)	2, 5, 7, 10, 15, 20
	Maximum source/ destination number	30/50
Energy consumption parameters	Initial node energy	500 J
	Transmitting energy	1.35 J
	Receiving energy	0.95 J
	Idle energy	0.85 J
	Promiscuous listening	No

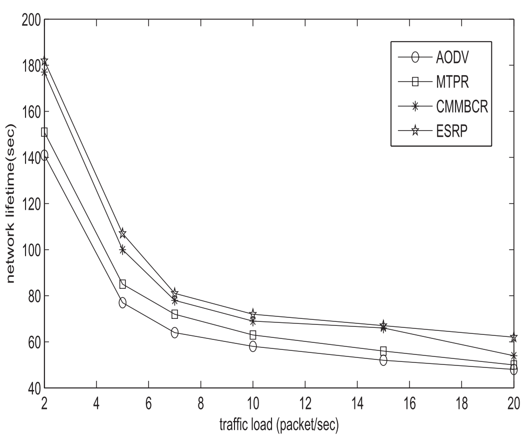

Fig. 6 Lifetime in different traffic load (lifetime defined in Formula (10)).

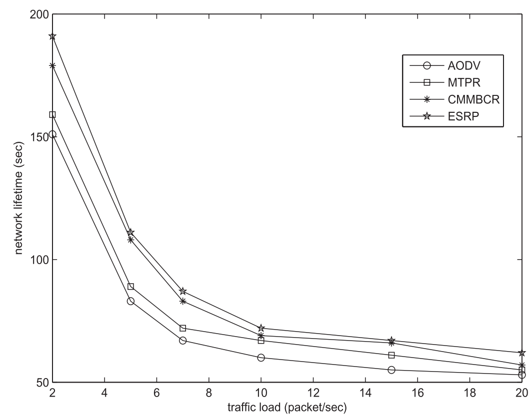

Fig. 7 Lifetime in different traffic load (lifetime defined in Formula (11)).

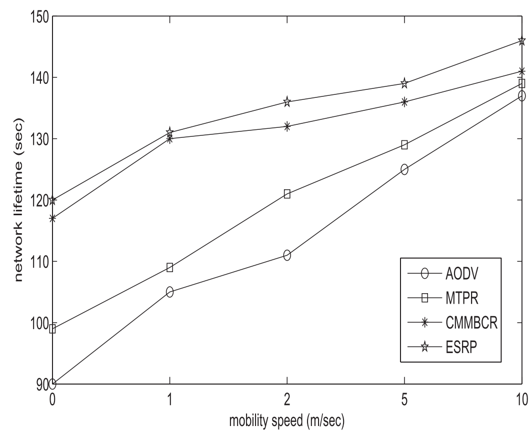

Fig. 8 Lifetime in different mobility speed.

According to the lifetime model defined in Sect. 2.2, the performances of four routing protocols are compared in Fig. 6 and Fig. 7. The same mobility speed and different traffic load are adopted in the scenario. In Fig. 6 and Fig. 7, the mobility speed is set to $2\,m/s$. As is shown in them, the network lifetime reduces gradually while traffic load increases. AODV performs worst because energy factor is not considered in it. Other protocols improve the network lifetime in different degree because they introduce different energy mechanism. In particular, when the forwarding nodes have a certain period of heavy load conditions, using the strategy of protecting the low residual energy nodes significantly has better performance. Because there is no such mechanism in AODV protocol, AODV protocol defects become more pronounced using Eq. (10) as a criterion. This is because the probability of becoming a singular node is relatively small in the low-energy protection mechanisms. Figure 6 and Fig. 7 show that the simulation results have the same trend and no distortion with the network lifetime setting in small-scale and large-scale.

In Fig. 8 and Fig. 9, the traffic load is set to $5\,p/s$. The description of the lifetime in all protocols with nodes in different mobility speed is shown in Fig. 8. The Formula (11) is adopted as the definition of network lifetime. As the mobility of nodes increases, the network lifetime also has a slight increase. The nodes' movement will lead to some link broken and packets retransmission. But simulation results show that when the mobility speed of nodes is not fast, the mobility of nodes balances the traffic load. In this simulation, the network lifetime of AODV protocol compared with ESRP and CMMBCR is improved from stillness to the mobility speed $10\,m/s$. The difference cuts down from 30%, 33% to only 3%, 6.6%. With the increasing of mobility speed, we can see that the difference of network lifetime performance between these protocols gradually becomes smaller. When the mobile speed is greater than $10\,m/s$, the difference is

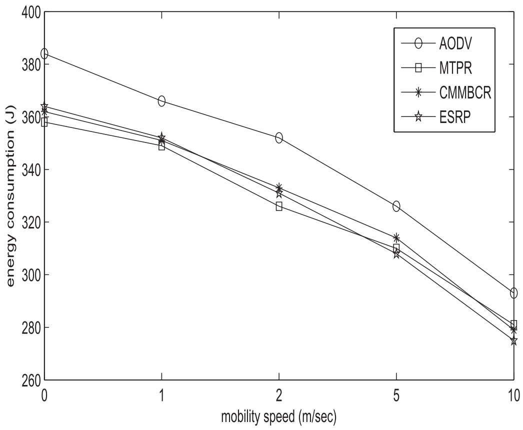

Fig. 9 Average energy consumption of packets in different mobility speed.

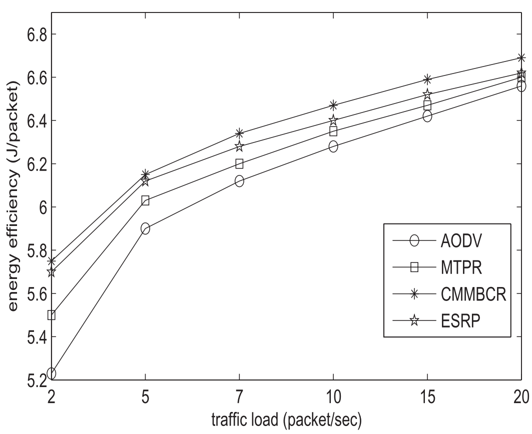

Fig. 10 Energy efficiency of packets in different traffic load.

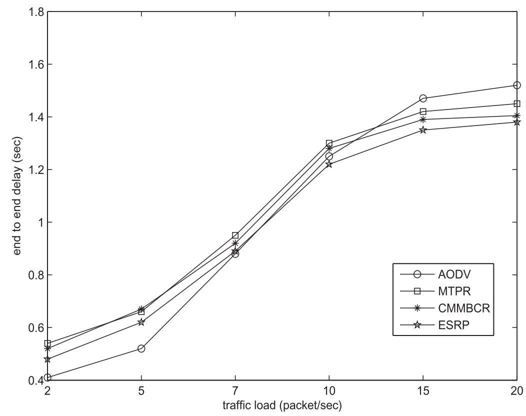

Fig. 11 Delay in different traffic load.

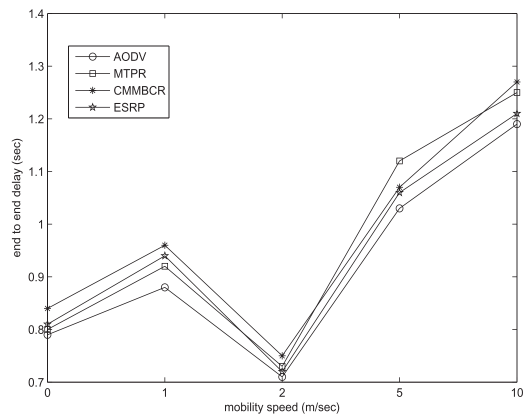

Fig. 12 Delay in different mobility speed.

further reduced. The trend remains unchanged, i.e., ESRP protocol is still better than the other protocols.

In energy consumption, as is shown in Fig. 9, ESRP and CMMBCR are slightly better than the AODV protocol with the same traffic load. The value of four protocols becomes closer with the mobility speed increasing. CMMBCR and ESRP protocols take the residual energy of nodes into account, and protection to the low-energy nodes in the latter network is done. Therefore, the energy consumption is much better than that of the other two protocols. Nodes' energy consumption is more balanced in the two protocols. When the nodes' mobility rate reaches $10\,m/s$, energy consumption of the nodes in CMMBCR and ESRP protocols becomes lower than MTPR.

The energy efficiency means the ratio of energy consumption and throughput, which is shown in Fig. 10. CMMBCR has worse performance than other protocols. The performance of energy efficiency in ESRP is better than CMMBCR because of the introduction of local maintenance strategy. And while traffic load is increasing, the superiority becomes more and more obvious. Simple routing protocols such as AODV often have better performance of throughput. The superiority reduces in heavy traffic load conditions as is shown in Fig. 10.

Figure 11 and Fig. 12 show the end to end delay in different traffic load mobility speed. In Fig. 11, the mobility speed is set to $2\,m/s$. With the traffic load increasing, the end to end delay of all protocols increases. When the pairs of sending and receiving data are fewer, the delay increases slowly, and as traffic load increasing, the congestion in the network will cause a significant increase in end to end delay. The MTPR and CMMBCR have worse performance in end to end delay. Despite increasing in the complexity of routing discovery, by adopting load balance strategy and local maintenance strategy, ESRP reduces link congestion and rebuilding. Therefore it is less decreased than other protocols. The end to end delay of AODV protocol is smaller when the traffic load is lighter. While the traffic load increases, the end to end delay of AODV protocol rises quickly. This is because AODV adopts single route strategy and no load balance strategy, and heavy traffic load may causes congestion at some forwarding nodes and increase the retransmission times. Thus, in heavy traffic load condition, the performance is not good as ESRP. Figure 12 shows that at low mobility speed of nodes, the end to end delay in these protocols is basically the same. In Fig. 12, the traffic load is set to $5\,p/s$. As the node mobility increases, the performance of routing protocols with more hops degenerates faster. The end to end delay of MTPR and CMMBCR increases more, while that of ESRP protocol has not a large increase because of the strategy of local maintenance, which is little closer to AODV protocol. We can see the influence of mobility to the end to end delay from three stages. When the node is stable or with low mobility speed, due to the insufficiency of alternative routes, the transmission for the source-destination does not have diverse routes. Thus many packets focus on some forwarding nodes. This may result in the long receiving and waiting time in the packet transmission. If the buffer of the node is not large enough, it will lead to the overflow of the packets. These above-mentioned issues may make the end to end delay increasing. With the mobility of the nodes increasing, the mobility of nodes can play a role in load balance in the network, thus the waiting time will decrease. At the same time, the situation of packets loss and retransmission will be improved because buffer overflow decreases, and the end to end delay will decrease, too. When the mobility speed is high, the rapid mobility causes the link broken, which makes the situation of packets retransmission and routing rediscovery increasing. These can cause the end to end delay increasing, while the transmission efficiency will be lower with mobility speed increasing due to the energy consumption of the retransmission. Therefore, we can see that the node mobility for the network plays a different role between the low and high speed. It can be seen, when the mobility speed is around $2\,m/s$, the traffic load and processing ability of the nodes can match with each other, therefore, the end to end delay achieves the optimal value, and the efficiency of the nodes are also relatively high.

5. Conclusion

In this paper, the energy consumption model and the network lifetime model are studied, and an efficient routing protocol based on energy sensing (ESRP) is proposed. By dividing residual energy of nodes into three levels with corresponding routing strategy, ESRP protocol achieves energy consumption balancing and low-energy nodes protecting. On the other hand, by adopting local maintenance strategy, link broken and routing rebuilt times decrease visibly. The performance of ESRP, AODV, MTPR and CMMBCR protocols are simulated in this paper. Comparing with other protocols, ESRP can prolong the lifetime more than others in the whole network, especially for static network and nodes with slower mobility. Because strategy of energy consumption balance is adopted, ESRP has much superior performance than AODV in load balance. In the high speed of mobility, the end to end delay in ESRP is shortened more effectively than in CMMBCR because of the strategy of local maintenance. Thus we declare that ESRP is an effective protocol to prolong network lifetime. In future work, we will consider the cross-layer design between MAC layer and network layer. Meanwhile, the sleep and power control mechanism will be considered, too.

References

[1] A. Muqattash and M. Krunz, "Powmac: A single-channel power-control protocol for throughput enhancement in wireless ad hoc networks," IEEE Trans. Wirel. Commun., vol.23, no.5, pp.1067–1084, 2005.

[2] R. Oda, T. Ohta, and Y. Kakuda, "An adaptive transmission power control for hierarchical routing in mobile ad hoc networks," Proc. 29th Distributed Computing Systems Workshops Conf. on June, pp.312–317, June 2009.

[3] J. Li and J.Y. Zhang, "Power-aware routing protocols in ad hoc wireless networks," Wirel. Commun., vol.12, no.6, pp.69–81, 2005.

[4] P.Y. Ren, J. Feng, and P. Hu, "Energy saving ad-hoc on-demand distance vector routing for mobile ad-hoc networks," Proc. Communications IEEE International Conf. on, pp.1–5, June 2009.

[5] F. Yu, Y. Li, and F. Fang, "A new tora-based energy awared routing protocol in ad hoc networks," Proc. Internet 3rd IEEE/IFIP International Conf., pp.1–4, Sept. 2007.

[6] S. Mahfoudh and P. Minet, "An energy efficient routing based on OLSR in wireless ad hoc and sensor networks," Proc. 22nd Advanced Information Networking and Applications Conf., pp.1253–1259, March 2008.

[7] C. Taddia, A. Giovanardi, and G. Mazzini, "Energy efficiency in OLSR protocol," Proc. 3rd Sensor and Ad Hoc Communications and Networks Annual IEEE Communications Society Conf., pp.792–796, Sept. 2006.

[8] S. Singh, M. Woo, and C. Raghavendra, "Power-aware routing in mobile ad hoc networks," Proc. 4th Annual ACM/IEEE Conf. on Mobile Computing and Networking, pp.181–190, 1998.

[9] S.P. Terdal, V.D. Mytri, and A. Damodaram, "Multiple metrics based load balancing routing protocol for mobile ad hoc networks," Proc. 1st Asian Himalayas International Conf., pp.1–5, Nov. 2009.

[10] L.J. Cao, K. Sharif, and Y. Wang, "Adaptive multiple metrics routing protocols for heterogeneous multi-hop wireless networks," Proc. 5th IEEE Consumer Communications and Networking Conf., pp.446–451, Jan. 2008.

[11] J.W. Liu, J. Chen, and Y.H. Kuo, "Multipath routing protocol for networks lifetime maximization in ad-hoc networks," Proc. Wireless Communications, Networking and Mobile Computing Conf., pp.1–4, Sept. 2009.

[12] S.P. Terdal, V.D. Mytri, and A. Damodaram, "Multiple metrics based load balancing routing protocol for mobile ad hoc networks," Proc. 1st Asian himalayas International Conf., pp.1–5, Nov. 2009.

[13] J.C. Cano and D.K. Kim, "Investigating performance of power-aware routing protocols for mobile ad hoc networks," Proc. Mobility and Wireless Access Workshop Conf., pp.80–86, Oct. 2002.

[14] L.J. Cao, T. Dahlberg, and Y. Wang, "Performance evaluation of energy efficient ad hoc routing protocols," Proc. Performance, Computing, and Communicationgs Conf., pp.306–313, April 2007.

Shi Zheng is a Ph.D. candidate of Communication Engineering Research Center, Shenzhen graduate school, Harbin Institute of Technology, China. He received B.S. and M.S. degrees from Harbin Institute of Technology in 2004 and 2006. His research interest includes wireless communications network and applications.

Weiqiang Wu is a Ph.D. candidate of Communication Engineering Research Center, Shenzhen graduate school, Harbin Institute of Technology, China. He received B.S. and M.S. degrees from Harbin Institute of Technology in 2005 and 2007. His research interest includes mobile communications network and applications.

Qinyu Zhang is a professor of Communication Engineering Research Center, Shenzhen graduate school, Harbin Institute of Technology, China. He received B.S. degree in 1994 from Harbin Institute of Technology, China. And he received Ph.D. degree in 2003 from Tokushima University, Tokushima, Japan. His research interest includes wireless communication, space communication and NGN.