A Trade-off between Energy Efficiency and High-Performance in Routing for Mobile Ad hoc Networks

Vu Khanh Quy[1] and Le Ngoc Hung[2]
[1] Faculty of Information Technology, Hung Yen University of Technology and Education, Hung-Yen, Vietnam
[2] Research and Development Center, VKX Company Limited, Ngoc Hoi Street, Ha-Noi, Vietnam
Email: quyvk@utehy.edu.vn; lnhung@vkx.com.vn

Abstract —Mobile Ad hoc Networks are currently being rapidly developed and are expected to become popular in the future Internet due to their simplicity and efficiency in solving real human problems. However, with the characteristics of mobile devices, saving energy is always a problem of study. In this study, we propose an energy-efficient routing protocol which uses a cost function integrating the hop count and the node's energy states as a metric for decision-making on route selection. Then, we evaluate the performance of the proposed protocol on NS2 simulation software version 2.34. Experimental results show that our proposed protocol increases the network lifetime, as well as the performance of the network, compare with known traditional routing protocols.

Index Terms—Energy-Efficient, routing protocol, MANET

I. INTRODUCTION

Mobile Ad-hoc Networks (MANETs) was first introduced in the 1970s, is a set of mobile devices capable of self-configuration, self-management and they can communicate with each other without using any fixed infrastructure or base station. Due to the flexibility of setting up and transmitting data, MANETs have a huge number of real applications for people in areas such as healthcare, rescue, disaster recovery, entertainment, military, smart traffic control and smart cities [1]-[2]. In addition, MANETs can also be used in special areas as indicated in Fig. 1. With the outstanding advantages in data communication, MANETs are expected to be very popular and is the future of the Internet [2]-[5].

However, when the scale expands, MANETs face problems such as energy efficiency, security, and bandwidth optimization. Due to the mobile and distributed nature of network nodes, routing becomes the most important issue to improve the performance of networks. Thus, designing a high-performance and energy-efficient routing protocol for MANETs is a major challenge. First of all, we need to understand that mobile network nodes operate based on battery energy. If a network node is out of energy, the links based on it will be disabled. At that point, the related nodes must reroute to transmit the packet to the destination. Consequently, the performance of the overall network is reduced. Moreover, MANETs also face the risk of fragmentation and the total operation time or network lifetime may be shortened. Therefore, designing energy-efficient routing protocols for MANETs is very interesting, besides other performance measures such as throughput and end-to-end delay.

In this paper, we proposed a new routing protocol, improving from AODV (Ad hoc On-demand Distance Vector), using the metrics hop-count and the remaining battery energy of the node purpose to improve energy-efficiency and performance for MANETs. The rest of the article is organized as follows: In Section 2, we present the related studies, Section 3 describes the proposed protocol, Section 4 is the evaluation performance of the proposed protocol and Section 5 is the Conclusion.

II. RELATED WORK

Based on energy-saving routing approach for MANETs [6]-[8], the survey results show that there are two main approaches to *power control* and *load distribution*. Accordingly, the power control approach determines the optimal routes so the total power consumption to transmit packets from the source node to the destination node is minimum [9], [10]. Another important approach is to load distribution. The main goal of load distribution is to balance the use of energy between nodes and maximize the network lifetime by avoiding selecting routes which contain low energy nodes [11]-[14].

The first and typical routing protocol proposed for MANETs based on the load distribution approach is Minimum Battery Cost Routing (MBCR) [12]. The main idea behind the design of this protocol is to use the remaining energy of each node as the routing metric. The route which has the highest remaining capacity energy will be selected as the candidate routes. However, MBCR has a limitation, that is, it includes routes with the highest total energy, but it also contains exhausted energy nodes. To overcome this limitation, the authors continue to propose and improve the MBCR protocol to obtain a better one, namely Max-Minimum Battery Cost Routing (MMBCR) protocol. This protocol will select the route with the maximum remaining energy in the set of minimum energy candidate routes.

Manuscript received May 7, 2019; revised February 10, 2020.
Corresponding author: quyvk@utehy.edu.vn.
doi: 10.12720/jcm.15.3.263-269

Recently, several studies have proposed the use of combined metrics between the remaining energy levels and the hops number. Accordingly, in [13], authors have proposed a routing protocol, called Hop Count based Energy Saving Dynamic Source Routing (HCESDSR) to improve the network lifetime for MANETs. The main idea presented here is to use a new parameter, called the expected minimum lifetime of the route. Basing on this parameter, the cost function will select the route with the highest average expected lifetime. The simulation results on NS2 showed that the proposed protocol helped to improve the network lifetime as well as delay compared to Dynamic Source Routing (DSR) and Energy Saving DSR (ESDSR) protocols. Also following this approach, the authors in [14] proposed a protocol, called BBU-AODV (Balanced Battery Usage Ad hoc On-demand Distance Vector) that used three routing metrics including the remaining energy, the number of hops, and the minimum energy thresholds of the node. The purpose is to avoid routes that contain exhausted nodes and to balance the total power consumption of all nodes in the network.

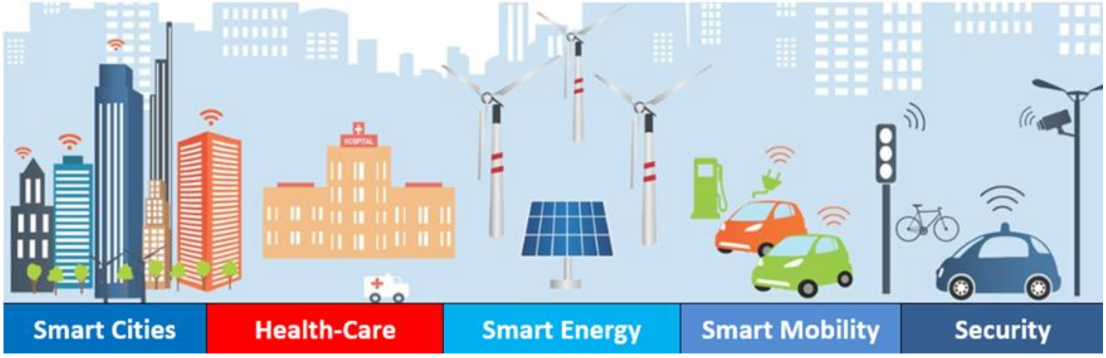

Fig. 1. An example of mobile Ad-hoc networks is applied in the internet of Things.

Based on improve the performance routing approach for MANETs, in [15], the authors proposed a new routing protocol, named Multimedia Multimetric Map-Aware Routing Protocol (3MRP), to send video messages over vehicular ad hoc networks (VANETs) in smart cities. 3MRP uses five routing metrics (i.e. distance, trajectory, density, available bandwidth and MAC layer losses) to select the optimal route. Simulation results based on NS-2 show that 3MRP improves latency and packet delivery ratios when compared with other routing protocols for VANETs. In [16], Lin et al. proposed a routing protocol called Moving Zone Based Routing Protocol (MoZo) for the purpose of data exchange between vehicles without relying on an infrastructure system. The main idea of this proposal is that each vehicle is equipped with a GPS module to obtain location information in real time, combined with clustering techniques to improve the performance of VANETs. Obtained experimental results show that MoZo improves the routing load and packet delivery ratios.

Also following this approach, in [17] we proposed a new routing protocol for MANETs, called AERP. This protocol selects routes based on information about the remaining energy levels of network nodes. However, in some special cases, the route selected by this protocol has not yet optimal results.

Although the protocols proposed above improved network lifetime or performance network but in general, in network applications, these factors influence each other. Thus, the issue of maximizing network lifetime should be balanced with other factors such as delay, throughput to ensure routing protocol is effective for MANETs.

III. Proposed Routing Protocol

In this section, we present our proposed protocol, named Efficient Energy and High-Performance Routing Protocol (EEMA). The main goal of the proposed routing protocol is to increase the network lifetime and improve the overall performance of MANETs. The details of our protocol design will be provided below.

A. System Model

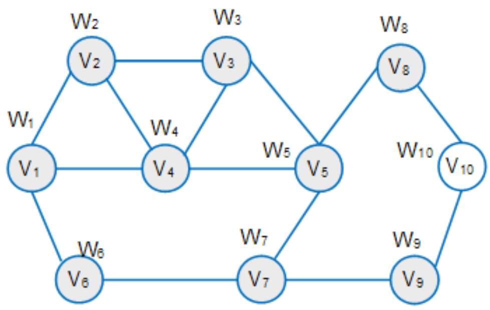

Fig. 2. The graph model of a MANETs.

To present the main principles and ideas of the protocol, we define a MANET network model as shown in Fig. 2. Each mobile node has a weight which is the remaining battery capacity. From the system model, we can achieve the interconnection network model. We define $G = (V, E)$ as the communication graph of the MANET, where $V = \{V_1, \ldots, V_n\}$ is the set of mobile nodes, E is the set of links, $L_{i,j} = (V_i, V_j)$ if they have direct links. To solve the high performance routing problems for MANETs, we model the interconnection network architecture by a node-weighted graph as follows.

Each mobile node V_i is translated into a pair (V_i, W_i), where W_i is the remaining energy battery of V_i. A mobile node can connect directly with other nodes or communicate indirectly with other nodes via intermediate nodes.

B. Protocol Description

Like AODV [18] routing protocol, which has been standardized by the IETF (Internet Engineering Task Force) for the MANETs. Our protocol is an on-demand routing protocol that operates on the principle that whenever a data transfer is required, the source node will discover and find a route to the destination node.

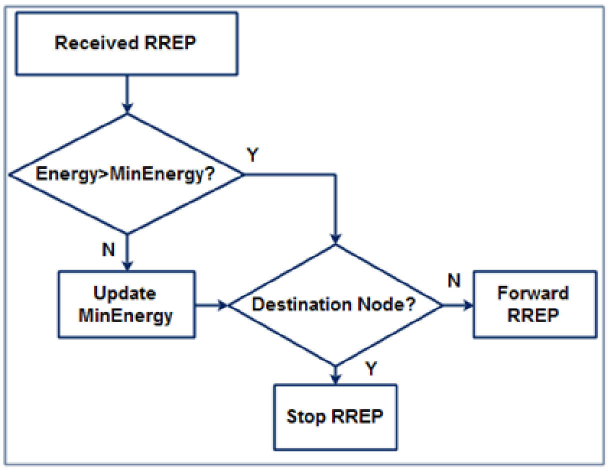

Fig. 3. Energy-check procedure.

The route discovery process starts with the source node sending the RREQ (Route Request) packets, with the header changed as follows {*MinEnergy, AODV RREQ Header*}. These packets are then forwarded through intermediate nodes to reach the destination node. A different point from traditional RREQ packet forwarding is that, at each intermediate node, when received an RREQ, the intermediate node performs a procedure named ***Energy-check***. This procedure is described by the scheme as shown in Fig. 3. This scheme has the main task of checking and updating the minimum remaining battery capacity of the route.

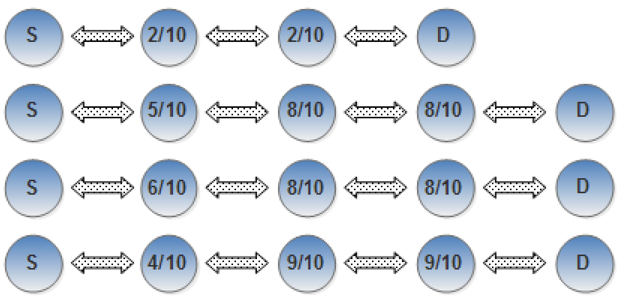

Fig. 4. The set of candidate routes between a pair of nodes after the discovery phase.

Finally, the destination node sends the RREP (Route Reply) unicast packet with the modified header {MinEnergy, AODV RREP Header} to the source node. Besides, similar to AODV, the protocol has route maintenance procedures using RRER (Route Error) messages. The source node receives all candidate routes (Fig. 4) if the process reaches a successful completion.

C. Route Selection Algorithm

After receiving a set of candidate routes by the route discovery procedure, we define two constraints as follows:

1) The hops number of the candidate routes must be within [Hopmin, Hopmax]. The route with the hops number exceeding this range will be discarded.

$$Hopcount = [Hopmin, Hopmax] \qquad (1)$$

where, $Hopmin$ is the hops-number of the shortest candidate route between a pair of the nodes (S, D). To limit the number of candidate routes to be considered, we define $Hopmax = Hopmin + k$ (k is a natural number). For the simulation purpose in this work, we set k=2.

2) To obtain richer energy candidate routes, we define the EEMA cost function as follows:

Let $MER_{(i)}$ be the minimum remaining energy of route i received via the $MinEnergy$ field of the RREP packet.

Let N and $MinEnergySet$ (MES), consequen be the total number of routes and sets of routing cost of the candidate routes satisfying above conditions, respectively. We have:

$$MinEnergySet = \begin{bmatrix} \mathrm{MER}_{(1)} \\ \mathrm{MER}_{(2)} \\ \vdots \\ \mathrm{MER}_{(n-1)} \\ \mathrm{MER}_{(n)} \end{bmatrix} \qquad (2)$$

$$Optimalroute = \mathrm{Max}\,(MinEnergySet) \qquad (3)$$

Accordingly, the best-effort route can be determined by Equation (3). The route selection algorithm of EEMA is summarized as follows:

Algorithm 1: EEMA Route Selection Algorithm

```
routeset=shortest-route(S,D)
minhop=min(shortest-route(S,D))
maxhop=minhop+2; cons1valid=Ø
// Equation (1)
for i=1 to maxsizeof(routeset) do
    if minhop ≤ numhop(routeset(i)) ≤ maxhop
        cons1valid <- route(i)
    endif
end for
// Equation (2)
Cost= ∞, weight=0
for i=1 to sizeof(cons1valid) do
    weight= MinEnergy(cons1valid(i))
    if Cost > weight then
        Cost=weight
        selectedroute=cons1valid(i)
```

Algorithm 1: EEMA Route Selection Algorithm
end if
end for
return(selectedroute, Cost)

TABLE I. METHOD OF CALCULATING THE COST OF THE ROUTE

Route	*P*	*Min Energy*	*EEMA*
1	3	0.20	0.2
2	4	0.50	0.5
3	4	0.60	0.6
4	4	0.40	0.4

Assuming that, there exist 4 routes between a pair of source nodes (S) and the destination node (D), each node has the remaining battery capacity as shown in Fig. 4. The remaining battery capacity of S and D nodes have the value of *5/10*, $Hopmin = 3$ and $Hopmax = 5$. With the information obtained, using the cost function, Eq. 3, the EEMA protocol will select route 3 with cost value EEMA = 0.6, as shown in Table I.

With the proposed dynamic load distribution approach, we believe that always find the approximate route between a pair of nodes that ensures the trade-off between the two criteria: network lifetime and performance.

D. Structure of the RREQ Packet

In the EEMA protocol, the process of discovering and determining the route between the source node and the destination node is based on RREQ and RREP packets as described in Section 3.2. To obtain information and determine the optimal route according to equation (3), we use the Reserved fields in the header of the RREQ packet to save the value of the energy (MinEnergy field). This method has been proposed in many recent studies [4, 6-8]. Using the Reserved fields in the header of the RREQ packet helps to determine the metric of the route without increase routing load and energy consumption. Therefore, we extend the RREQ packet as in Fig. 5.

Type	MinEnergy	Last hop	Hop count
RREQ ID			
Destination IP Address			
Destination Sequence Number			
Originator IP Address			
Originator Sequence Number			

Fig. 5. Structure of RREQ packet

IV. SIMULATION RESULTS AND EVALUATION

In this subsection, we set up a simulation to evaluate and compare the performance of EEMA with two typical routing protocols including AERP [17] and AODV [18], on NS2 software version 2.34.

A. Performance Metrics

We use the following metrics to evaluate the experimented routing protocols' performance.

1) *Packet Delivery Ratio (PDR)* (in %): the ratio of the number of packets delivered to the destination nodes P_r over the number of packets sent by the source nodes P_s:

$$PDR = \frac{P_r}{P_s} \times 100\% \qquad (4)$$

2) *Average End-to-End Delay (Delay)*: the time taken for a packet to be transmitted across a network from source to destination:

$$Delay_{avg} = \frac{\sum_{i=1}^{n}(t_r - t_s)}{P_r} \qquad (5)$$

3) *Throughput*: the throughput on a link is determined by multiplying the numbers of packets transmitted and the size of the packet per one second:

$$Throughput = \frac{P_r \times KT}{T} \qquad (6)$$

4) *Network Lifetime*: defined as the time interval that the network starts to operate until the first node is out of energy, or more exactly, the energy of the node is less than the threshold. The unit is seconds.

where:
P_r is the packet number received by the destination node
P_s is the packet number sent by the source node
t_r is the time the packet is received at the destination node
t_s is the time the packet is sent at the source node
T is the time of the measurement process
KT is the size of the packet.

B. Simulation Parameters

In all simulation, we use the CBR traffic type with 100 randomly assigned mobile nodes (using the Random Waypoint mobility model) in an area of 2000×2000 (m). The transmission range of the mobile node is set to 150 m. Velocities of mobile nodes are set at 2 (m/s). Simulations were set in 500 (s). The number of end-to-end connections measured is 10, 20, …, 90, 100. The simulation parameters are summarized in Table II.

TABLE II. SIMULATION PARAMETERS

Parameter	**Value**
Simulation Area	2000×2000 (m)
Simulation Time	500 (s)
Number Nodes	100
MAC Layer	802.11b
Transport Layer	UDP
Size of Packets	512 (byte)
Transmission Range	150 (m)
Mobile Node Speed	2 (m/s)
Initialization Energy of the Nodes	7 (J)

Parameter	Value
Transmission Power	1.0 (W)
Receive Power	0.2 (W)
Overhearing Power	0.01 (W)
Hopmax	$Hopmin + 2$
Mobility Model	Random Waypoint

C. Simulation Result

Fig. 6, shows the performance of the network by the criterion: Network Lifetime. Observing the results, we find that the network lifetime of AERP always improved better than EEMA and AODV protocol in all simulations. Because, traditional protocols (as AODV) use the routing method based on the hops-number, therefore, the network traffics is concentrated on the route with the lowest hops number. This is the main reason for nodes rapid consumption energy and out of energy. In contrast, AERP uses routing method based on the remaining energy of node, therefore, all nodes in the network can balance the consumption energy level. As a result, the network lifetime of AERP is always higher other protocols.

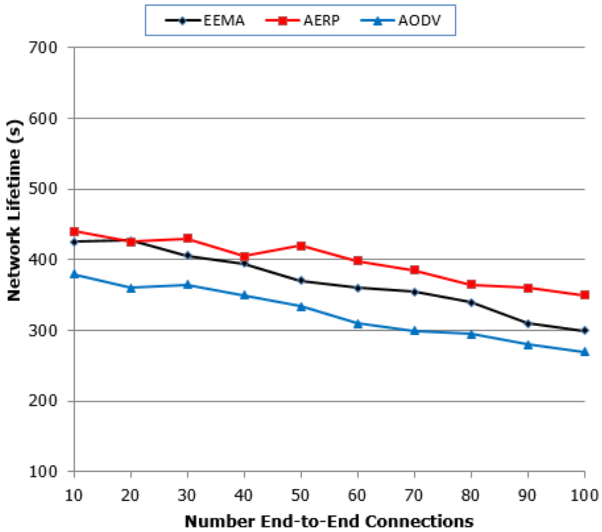

Fig. 6. Network lifetime.

With the purpose to improve network lifetime but must guarantee the performance, special is the end-to-end delay criterion, so, EEMA conducts load distribution on some of the routes can guarantee limit latency (routes have hops number in the range [*hop min, hopmax*]). In other words, EEMA not trading off the issue increases the network lifetime by all ways. As a result, the network lifetime of EEMA is improved over AODV but lower than AERP.

Fig. 7, shows the performance of the network by the criterion: Packet Delivery Ratio. The simulation result shows, when the network traffic is low (the number of end-to-end connection is low), the packet delivery ratio of three protocols is quite high and not much different. When the network traffic is increased (the number of end-to-end connection is high), the packet delivery ratio of three protocols is reduced.

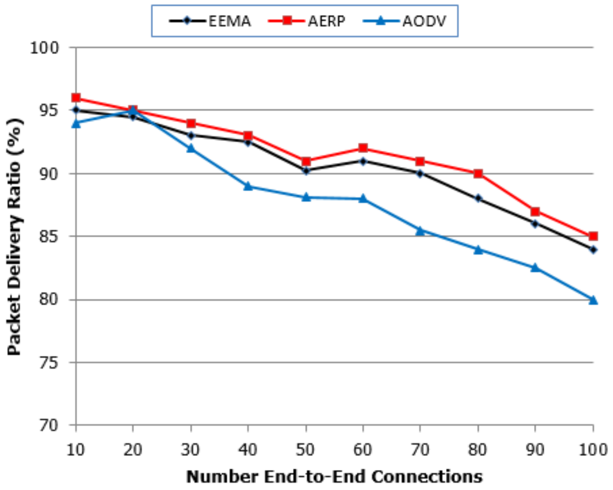

Fig. 7. Packet delivery ratio.

With routing method based on the hops-number of AODV, the shortest routes are selected to transmit data. Therefore, some network nodes can be overload. Moreover, the collision status between packets happens to more and more with time, thus the routes need re-establish and data packets re-transmission increase.

As a result, the packet delivery ratio of AODV is the lowest compared to other protocols. In contrast, with dynamic balancing routing method, the routes of EEMA and AERP will be selected based on the minimum remaining battery energy of route. Therefore, the collision status between packets is reduced. As a result, the packet delivery ratio of EEMA and AERP protocols is improved. However, due to using the limit hops number mechanism to improve network performance, packet delivery ratio of EEMA is slightly lower than AERP.

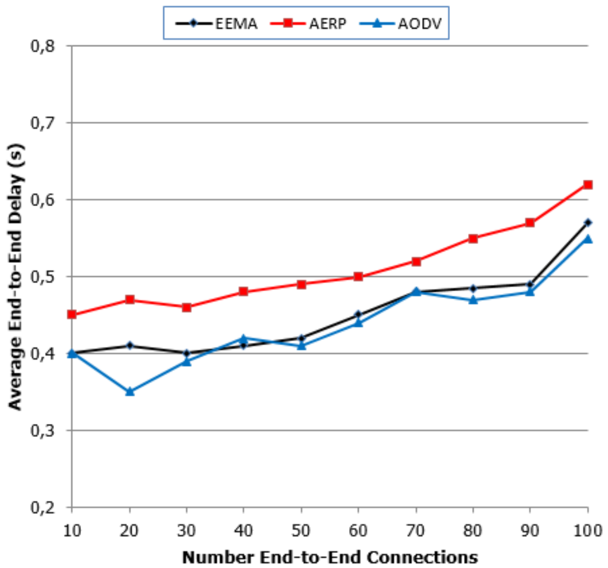

Fig. 8. The average End-to-End delay.

Fig. 8, shows the simulation results based on the average delay with the three protocols. The simulation results show that the average delay of the three protocols increase more and more when the number of end-to-end connections is increased however the average delay of AERP is the highest and the average delay of EEMA is approx. AODV. The explanation for this result consists of two reasons: (1) the average delay does not include re-transmission packets, and (2) AERP always select the route with maximum remaining energy, else AODV always select the shortest route. EEMA is proposed for balancing between two methods. As a result, EEMA improves the average end-to-end delay compared to AERP and approximates the delay of AODV.

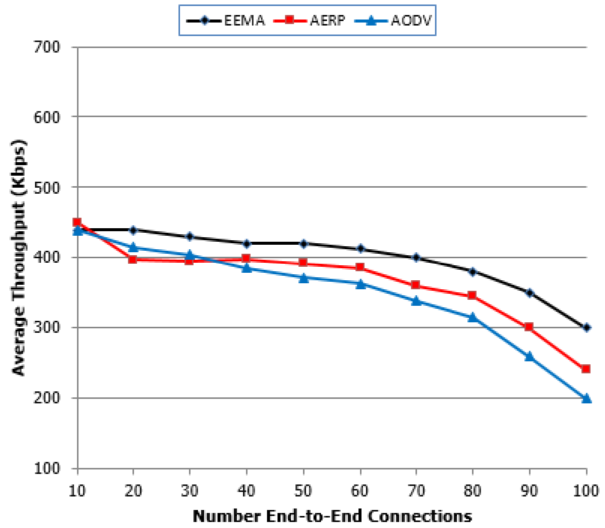

Fig. 9. Average throughput.

Fig. 9, shows that the simulation results are based on the throughput with the three protocols. The simulation results show that the average throughput of the three protocols are more and more decreased when the number of end-to-end connections is increased however the average throughput of EEMA is improved well rather than the other two protocols. This is suitable for our theoretical calculations. With routing method proposed, EEMA improves packets delivery ratio, network lifetime; limit the status congestion and re-transmission. As a result, the average throughput of EEMA is improved than other protocols.

V. Conclusion and Future Research

In this study, we proposed an on-demand routing protocol, extended from AODV for MANETs, called EEMA. The EEMA protocol uses a hybrid mechanism to select the optimal route based on the hops-number and cost function EEMA. In other words, this protocol will select the route which balances between the delay and the minimum remaining battery capacity to longer network lifetime and improve the performance of the MANETs. The simulation result shows that the EEMA protocol improves network lifetime, average packet delivery ratios better than the AODV and AERP protocols. In the future, we will focus on the performance evaluation of the protocol EEMA with varying levels of mobility.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

We have conducted the research, analyzed the data and performed simulations together. All authors had approved the final version.

Acknowledgment

The authors sincerely thank Ass Prof. Dr Nguyen Tien Ban and Ass Prof. Dr Nguyen Dinh Han for their constant support from starting to end of this research work.

References

[1] V. K. Quy, N. T. Ban, V. H. Nam, D. M. Tuan, and N. D. Han, "Survey of recent routing metrics and protocols for mobile ad-hoc networks," *Journal of Communications*, vol. 14, no. 2, pp. 110-120, 2019.

[2] S. Buzzi, I. C. Lin, T. E. Klein, *et al*., "A survey of energy-efficient techniques for 5G networks and challenges ahead," *IEEE Journal on Selected Areas in Comm. Mag.*, vol. 34, no. 4, pp. 697–709, 2016.

[3] V. K. Quy, L. N. Hung, and N. D. Han, "CEPRM: A cloud-assisted energy-saving and performance-improving routing mechanism for MANETs," *Journal of Communications*, vol. 14, no. 12, pp. 1211-1217, 2019.

[4] V. K. Quy, N. T. Ban, and N. D. Han, "A high-performance routing protocol for multimedia applications in MANETs," *Journal of Communications*, vol. 14, no. 4, pp. 267-274, 2019.

[5] A. Gharaibeh, M. A. Salahuddin, S. J. Hussini, *et al*., "Smart cities: A survey on data management, security and enabling technologies," *IEEE Communications Surveys & Tutorials*, vol. 19, no. 4, pp. 2456-2501, 2017.

[6] W. Sun, Z. Yang, X. Zhang, *et al*., "Energy-Efficient neighbor discovery in mobile ad hoc and wireless sensor networks: A survey," *IEEE Communications Surveys & Tutorials*, vol. 16, no. 3, pp. 1448-1459, 2014.

[7] V. K. Quy, N. D. Han, and N. T. Ban, "PRP: A high-performance routing protocol for mobile ad-hoc networks," in *Proc. International Conference on Advanced Technologies for Communications (ATC)*, 2018, pp. 226-231.

[8] A. Taha, R. Alsaqour, M. Uddin, *et al*., "Energy efficient multipath routing protocol for mobile ad-hoc network using the fitness function," *IEEE Access*, vol. 5, pp. 10369-10381, 2017.

[9] J. Liu, X. Jiang, H. Nishiyama, *et al.*, "Throughput capacity of MANETs with power control and packet redundancy," *IEEE Transactions on Wireless Communications*, vol. 12, no. 6, pp. 3035–3047, 2013.

[10] Shivashankar, *et al*., "Designing energy routing protocol with power consumption optimization in MANET," *IEEE Transactions on Emerging Topics in Computing*, vol. 2, no. 2, pp. 192-197, 2014.

[11] W. K. Kuo and S. H. Chu, "Energy efficiency optimization for mobile ad hoc networks," *IEEE Access*, vol. 4, pp. 928-940, 2016.

[12] C. K. Toh, "Maximum battery life routing to support ubiquitous mobile computing in wireless ad hoc networks," *IEEE Comm. Mag.*, vol. 39, no. 6, pp. 138-147, 2001.

[13] N. Geetha and A. Sankar, "Hop count based energy saving dynamic source routing protocol for ad hoc network," in *Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering*, Springer, Berlin, Heidelberg, 2012, vol. 108.

[14] E. Yitayal, J. M. Pierson, and D. Ejigu, "A balanced battery usage routing protocol to maximize network lifetime of MANET based on AODV," in *Proc. Conf. on Wireless Information Networks and Systems (WINSYS)*, Vienna, 2014, pp. 1-10.

[15] A. M. Mezher and M. A. Igartua, "Multimedia multimetric map-aware routing protocol to send video-reporting messages over VANETs in smart cities," *IEEE Transactions on Vehicular Technology*, vol. 66, no. 12, pp. 10611-10625, 2017.

[16] D. Lin, J. Kang, A. Squicciarini, Y. Wu, S. Gurung, and O. Tonguz, "MoZo: A moving zone based routing protocol using pure V2V communication in VANETs," *IEEE Transactions on Mobile Computing*, vol. 16, no. 5, pp. 1357-1370, 2017

[17] V. K. Quy, N. T. Ban, and N. D. Han, "An advanced energy efficient and high-performance routing protocol for MANET in 5G," *Journal of Communications*, vol. 13, no. 12, pp. 743-749, 2018.

[18] RFC3561. [Online]. Available: https://www.ietf.org

Vu Khanh Quy was born in Hai Duong Province, Vietnam, in 1982. He received his B.Sc. degree from Hung Yen University of Technology and Education (UTEHY) in 2007 and his M.Sc. degree from Posts and Telecommunications Institute of Technology (PTIT), in 2012. Currently, he is a PhD student at Faculty of Telecommunications 1, PTIT and a lecturer at Faculty of Information Technology, UTEHY. His research interests include Wireless Communications, Mobile Ad-hoc Computing and Next-Generation Networks.

Le Ngoc Hung was born in Thanh Hoa Province, Vietnam, in 1968. Graduated from Hanoi University of Science and Technology in 1992 and the Master degree from Hanoi National University, in 2001. Currently, he is a student at Post and Telecommunication Institute of Technology and general manager of VKX Company Limited. Research Areas: Decision Making, Mobility Management, Computational Modeling Methods.