An Advanced Energy Efficient and High Performance Routing Protocol for MANET in 5G

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Abstract —Nowadays, mobile ad-hoc networks (MANETs) are applied in various aspects such as rescue, military, medical applications and smart cities. Also, they are expected to be so popular in 5G as they possess intrinsic and advanced features of the future communication technology. A MANET in 5G will be a radio system aimed at extremely high data rate, low latency, lower energy and cost. To support this, routing protocols in the MANET must be flexible, energy-efficient and highly performance achievable. In addition, increasing the network lifetime has recently become a mandatory requirement in design of any routing protocol for MANETs. In this paper, we propose a new energy-efficient and high performance routing protocol extended from AODV to meet the above requirements. We equip the new protocol with a novel powerful costing function that is able to select high throughput, lower energy-consumed and longer lasting routes for data transmission. The simulation results will prove this assertion.

Index Terms—Routing protocol, energy saving, AODV, MANET, 5G

I. Introduction

Energy savings are now a mandatory demand of most aspects of information and communications. This requirement has a significant impact on the design of new wireless communication systems. It also requires improvement in existing ones [1], [2]. Mobile Ad-hoc Networks (MANETs) was born in the 1970s as a type of wireless networks to exchange data very conveniently. Indeed, MANETs have advanced features such as, self-organization and self-configuration that support low cost network connection without using predefined infrastructure [3].

In recent years, MANETs has a number of real applications for people in areas such as healthcare [4], rescue, disaster recovery [5], entertainment [6], military [7], smart traffic [8], [9]. In addition, MANETs can also be used in the many other areas, as indicated in [10]. Therefore, it promises an important contribution to the development of future Internet.

The next generation (5G) of mobile ad-hoc networks is shaping up and is expected to become a main communication technology of the Internet. In [11], different from previous generations, 5G will be the unified technology system that supports a much larger and more diverse set of devices. Moreover, 5G will need to be able to increase data transfer rate, reduce latency and energy efficiency.

MANETs in 5G can reach unprecedented levels of flexibility and intelligence than ever. Fig. 1 illustrates an example of a complicated and powerful MANETs with rich multimedia applications.

Fortunately, important results established for traditional MANETs can be extended to MANETs in 5G [12]. In this work, we extend a well-known routing protocol, named ad-hoc on-demand distance vector (AODV for short), to obtain a new energy-efficient and high performance routing protocol for MANETs in 5G.

Our new routing protocol has two stages: route discovery and route maintenance. We modify the route discovery procedure so that nodes' energy-related information can be collected in this stage. There are two kinds of information that each node has to provide, those are: the total remaining energy and the estimated energy-consumed rate. We form routing metrics to represent the information, and then use these metrics as an input to define a cost function for a given route. The cost function knows about the total energy consumed by all nodes in a route. It can also know about the number of hops (i.e. hop-count) and the node with the lowest remaining energy. As a result, the cost function can select appropriate routes among candidates. The selected routes will be high throughput, lower energy-consumed and longer lasting routes for data transmission.

II. Related Work

In the last few years, the field of energy efficiency and performance improvement in MANETs has been studied and achieved several positive results. We may summarize main approaches to this area as follows:

Approach towards the use of mobile agents [13], the authors proposed a load distribution algorithm, namely MAR-AODV (Mobile Agent – AODV), as a modified Ad-hoc on demand Distance Vector (AODV) protocol which uses mobile agents to improve the performance of MANETs. The focus of this study is a method to select the route that can ensure the load balancing traffic in a network.

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The simulation results show that the probability congestion of MAR-AODV is lower than that one of AODV protocol. Particular, in [14] the authors proposed an on-demand routing protocol for 5G MANETs, named A_WCETT (Advance Weighted Cumulative Expected Transmission Time), improved from AODV. This protocol works on multi-channel radio environments and is based on the mobile agent technology. The results of simulation shows that, the A_WCETT protocol with the improvement of parameter ∝ and routing method (based on mobile agent) is better performance than the traditional protocols.

A very recent approach to improving MANETs performance is to use multi-parameter cost functions to calculate and make the decision to choose the route is currently of special interest to researchers for data transmission. In [15], authors propose a multi-metric routing protocol with a cost function based on a set of three parameters: the length of queue, the link quality and hop count. Depending on the actual working condition of the network, one or more parameters may be involved in calculating the route cost. The simulation results show that routing protocol with the new cost function outperforms the conventional AODV protocol as it gains a better achievable performance.

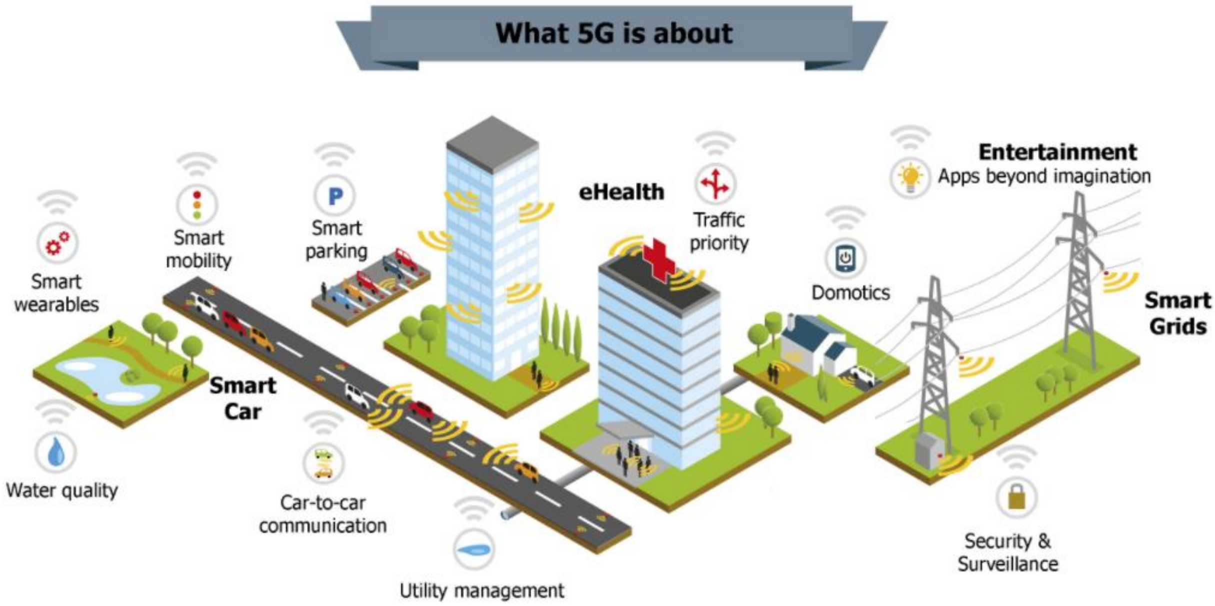

Fig. 1. An example of Mobile Ad-hoc Network applied in 5G.

III. TRADITIONAL ROUTING PROTOCOL

The AODV routing protocol (Ad-hoc On-Demand Distance Vector) [16] and DSR (Dynamic Source Routing) [17] has been standardized by the IETF (The Internet Engineering Task Force) for the MANETs. This 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.

The route discovery process begins with the source node sending broadcast the path finder packets, RREQ (Route Request). Then, these packets will be forwarded through the intermediate nodes to finally reach the destination node (Fig. 2, red line). The destination node or intermediate node (the node knows about the route to the destination) will respond by sending unicast RREP (Route Reply) packet back to source node (Fig. 2, green line).

When the source node receives the RREP packet, the route is established and it can start transmitting data. Beside the route discovery function, AODV also has route maintenance procedures that use error packets, RRER (Route Error) (Fig. 2, yellow line).

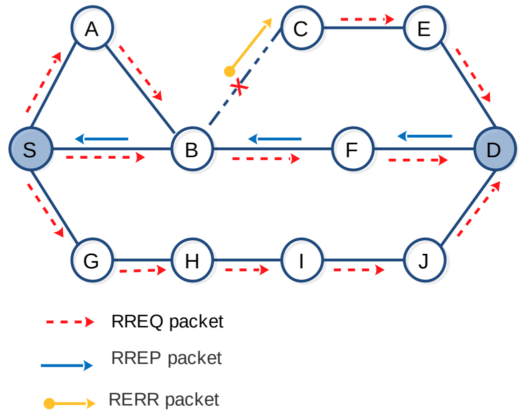

Fig. 2. Three stage of reactive protocols.

The reactive protocols don't pre-build a route to transfer data from source to destination. The route will be determined by each the node when the data arrives, based on the system state information that the node receives. At the same time, it uses a sequence number of destination or source to identify new routes as well as avoid repeat routing. It does not have a mechanism for storing routing information.

Although the reactive protocols use less resources, energy savings and better support for the features of Ad-hoc network architecture/organization such as: self-organizing, self-configuring and mobile. However, using AODV for the MANETs in 5G will require many improvements to optimize network performance as well as energy consumption.

IV. Proposed Routing Protocol

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 in the next subsections.

A. Protocol Description

Like AODV routing protocol, which has been standardized by the IETF (Internet Engineering Task Force) for the MANETs. AERP 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.

The route discovery process begins with the source node sending broadcast the pathfinder packets RREQ (Route Request) with header modified (*MinEnergy, TotalEnergy, AODV RREQ Header*). Then, these packets will be forwarded to the intermediate nodes to finally reach the destination node.

A different point from the traditional packet forwarding method is that, at each intermediate node, when receiving the RREQ packet, the intermediate node performs a procedure, named *Energy-check*, and is described by the schema as shown in Fig. 4.

This schema has two main tasks, as follows:

(1) Determine the lowest remaining energy in the route

(2) Determine the total energy remaining in the route

Finally, the destination node sends the RREP (Route Reply) packet identifier with the modified header (*MinEnergy*, *TotalEnergy*, *AODV RREP Header*) to the source node. In this way, the source node receives all candidate routes as shown in Fig. 5. The detail about routing mechanism of the protocol proposed is described in Fig. 3

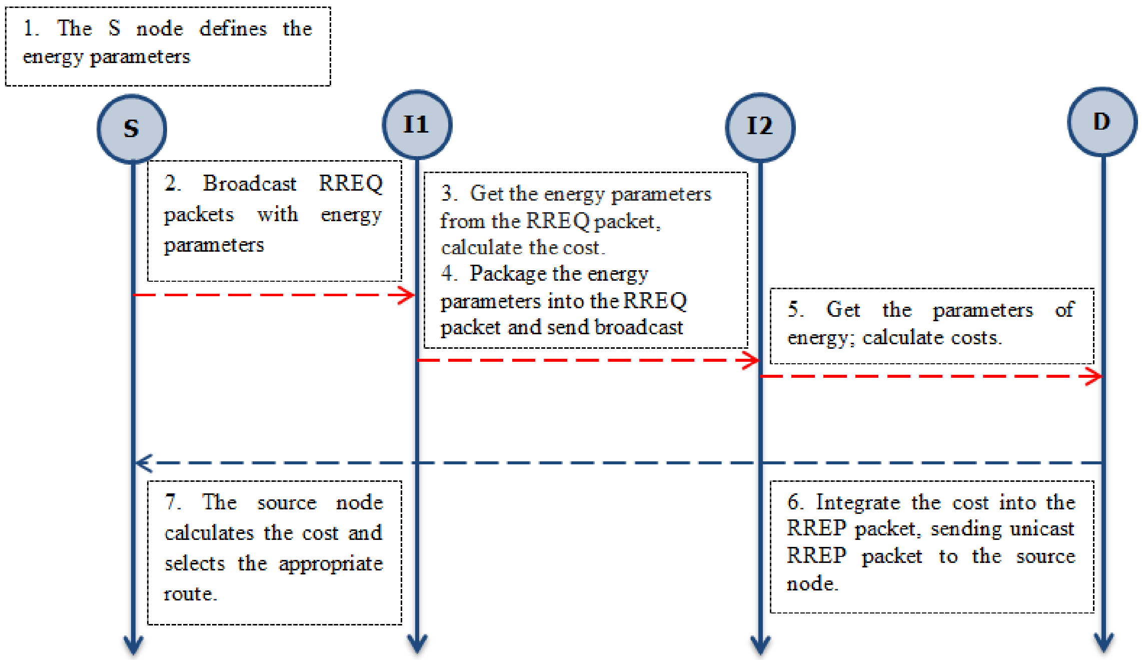

Fig. 3. Describe the calculation mechanism and route selection of the proposed routing protocol.

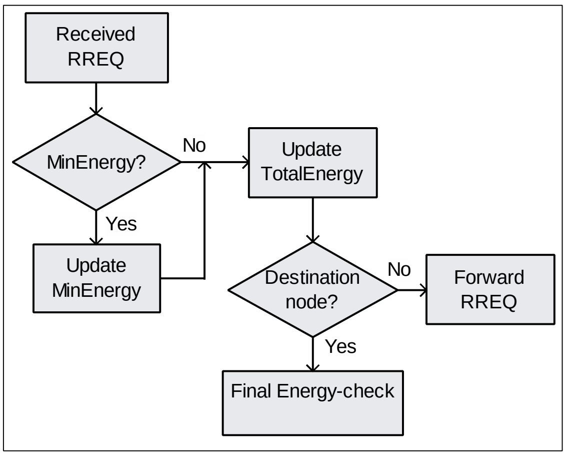

Fig. 4. Energy-check procedure

B. Routing Metrics

The first, we consider the main reason for energy consumption. The energy consumed at a node due to the following activities:

- Transmit/receive packets: the node consumes a certain amount of energy when each packet is transmitted or received;
- Overhearing from the neighbor nodes: due to the nature of radio waves, when a node transmits information, it sends broadcasts to all nodes in the communication area. Receiving and processing unneeded packets will consume the energy of the node.

Our routing protocol uses two main parameters to calculate the cost of a route as follows:

- Remaining battery capacity of the node: the selected routes will be ones that evolve richer energy nodes;
- Hop count: choosing the route with the least hop number and the most energy-efficient is the best way to save energy and to improve throughput.

Therefore, we propose the cost function to determine a route in a given MANET as follows:

$$\text{AERP} = \sum_{i=1}^{P+1} \left(1 - \frac{E_i}{E_{max}}\right) \tag{1}$$

where:

E_i, is the remaining energy of node i;

$E_{\max}$, is the initial energy of each node;

P, is the hop number that the packet needs to pass from the source node to the destination node.

At a time T_0, $E_i \approx E_{max}$, therefore: $(1 - \frac{E_i}{E_{max}}) \approx 0$, AERP ≈ 0; until T_t, after a period of time operate, the mobile node consumes energy, therefore, $E_i \ll E_{max}$, $\frac{E_i}{E_{max}} \approx 0$, AERP $\approx$ P. Thus, the value of AERP is in the range, AERP $\in [0, P]$. The variation of AERP depends on the remaining battery capacity of the node in the route.

As the remaining battery capacity of the nodes decreased, the value of the AERP function increases. As a result, the route with the highest total remaining battery capacity will be selected. However, the Equation (1) is limited: it can't be eliminated the route with the highest total remaining battery capacity but contains the node has energy is lowest (the node has the remaining battery capacity near the threshold).

To solve this issue: the total remaining battery capacity of the entire route and the node has energy is lowest in the route. We propose to extend the equation 1 by adding the lowest remaining battery capacity parameter, as follows:

$$AERP = \underbrace{\left(\frac{\sum_{i=1}^{P+1}\left(1-\frac{E_i}{E_{max}}\right)}{P+1}\right)}_{(Average\ Total\ Energy)} + \underbrace{\left(1 - \min_{1\le j\le P}\left(\frac{E_j}{E_{\max}}\right)\right)}_{(Min\ Energy)} \tag{2}$$

There are two ways to explain the Equation (2). First, we can see that the balance between the total energy of the route and the lowest remaining battery capacity in the route. Second, it shows the relationship between the most influential node with the nodes in the route. Put parameter the lowest remaining battery capacity into the equation can be seen as an attempt to balance these two problems. Specific examples of how to calculate AERP values with different values are shown in Fig. 5 and Table I.

Assume, 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. 5. The emaining battery capacity of S and D nodes have value is 5/10.

With the information about the cost of the route obtained, using the costing function (Equation 2), the AERP routing protocol will select route 3 with cost value AERP = 0.86, as shown in Table I.

TABLE I. THE CALCULATE AND DETERMINE AERP METRICS

Route	*P+1*	*Average Total Energy*	*Min Energy*	*AERP*
1	4	0.65	0.80	1.45
2	5	0.38	0.50	0.88
3	5	0.36	0.50	0.86
4	5	0.56	0.60	1.16

C. Modified the RREQ Packet Structure

According to our proposal, in the process of calculating the routing cost, the node must to obtained the total remaining battery capacity of the route and the lowest remaining battery capacity in the route. An effective way is to insert this information into the header of the RREQ packet. This technique has been proposed in many recent studies [3], [7], [14], [15], which has the advantage of not significantly increasing the packet size and affecting the overall performance of the entire network. We extend the RREQ packet as shown in Fig. 6.

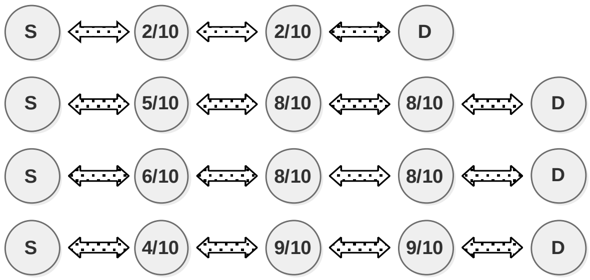

Fig. 5. An Illustrated candidate route after the discovery phase

Type	Reversed	Last hop	Hop count	E_{total}	E_{min}
RREQ ID					
Destination IP Address					
Destination Sequence Number					
Originator IP Address					
Originator Sequence Number					
Residual Energy Field					

Fig. 6. RREQ structure when adding fields to store energy information

V. EXPERIMENTAL RESULTS AND ANALYSIS

In this section, we set up a simulation on the NS2 software to evaluate the performance of the MANET according to the criteria presented in subsection 5.1. The protocols tested are: AODV, DSR and the protocol we proposed in Section IV, called AERP.

A. Criteria for Performance Evaluation

We consider the performance of the protocol based on the following criteria:

1) **Packet Dilivery Ratio (PDR)**: defined as the ratio percentage of packets received by the destination node on the total number of packets sent from the source node. We use the average packet delivery ratio, denoted is PDR, which is the ratio percentage of the total number of packets received per total packet sent during the entire process of performing a simulation and determined by the follows equation:

$$\mathrm{PDR} = \frac{\mathrm{P_s}}{\mathrm{P_r}} \times 100\% \tag{3}$$

2) **Average residual energy of node**: defined by the total energy in the system/the total number of nodes at that time. Unit is Joules (J), as follows equation:

$$\text{Average residual energy}_{(t)} = \frac{\sum_{i=1}^{n} E_i^t}{n} \tag{4}$$

3) **Network lifetime**: the period of time from the network operate until one of the first network nodes is out of energy or more exactly, the node's energy level decreases to the threshold. Unit is seconds (s).

where:

$\mathrm{P_r}$, is the total number of packets received by the destination nodes in the entire simulation process

$\mathrm{P_s}$, is the total number of packets sent by the source node in the entire simulation process

E_i^t, is the energy of node i at time t

n, is the number of mobile node of system

B. Setup Simulation

Our simulation system consists of 300 mobile nodes, arranged randomly in an area of 2000 × 2000(m). We use the IEEE 802.11 standard and the UDP traffic type. Simulations performed in 350(s). The number of end-to-end connections is: 5, 10, 15, 20, 25, 30, 35 and 40. The simulation parameters are summarized in Table II.

TABLE II. SIMULATION PARAMETERS

Parameter	Value
Simulation Time	350 s
Simulation Area	2000 m × 2000 m
Number of Nodes	300
MAC Layer	802.11
Traffic Type	CBR
Bandwidth	2 Mbit/s
Size of Packets	512 byte
Transport Layer	UDP
Mobility Model	Random Way Point
Mobile Node Speed	2 m/s
Transmission Range	250 m
Initialization energy	7 J
Transmission Power	1.2 W
Receive Power	0.25 W
Overhearing Power	0.01 W

C. Simulation Results

Fig. 6 shows the simulation result by the criterion: Average residual energy of the node with the case has 30 end-to-end connections. The results show that the average residual energy of node in the AERP protocol is always higher than the AODV and DSR protocols and increases at the end of the simulation. This is perfectly consistent with theoretical calculations. Due improved, the AERP is not only based on the number of hop as AODV, but also integrated the energy of the node is in the cost function. As a result, higher-energy total routes will be selected and lifetime of nodes is longer. Therefore, the performance of the network is significantly improved at the end of the simulation and will be analyzed in detail in the next section.

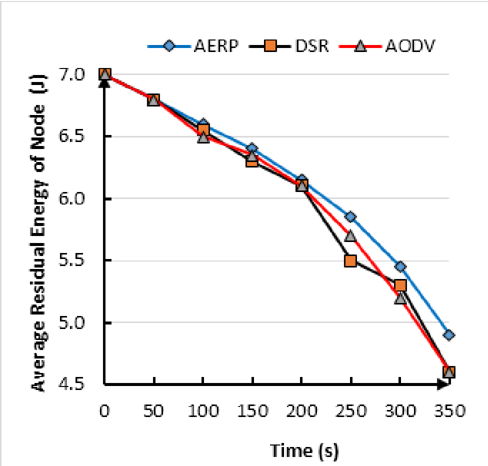

Fig. 6. The average residual energy of node with the case of 30 end-to-end connections

Initially, when nodes are full of energy, the route selection mechanism of AODV and AERP are basically the same. When the node has about 20% of the original energy level, the AERP can switch to another route, unless it is the only route to reach the destination. Simulation with cases different the number of end-to-end connections have similar results. Due, in this study, we present only a simulation result graph for the case of 30 end-to-end connections as Fig. 6.

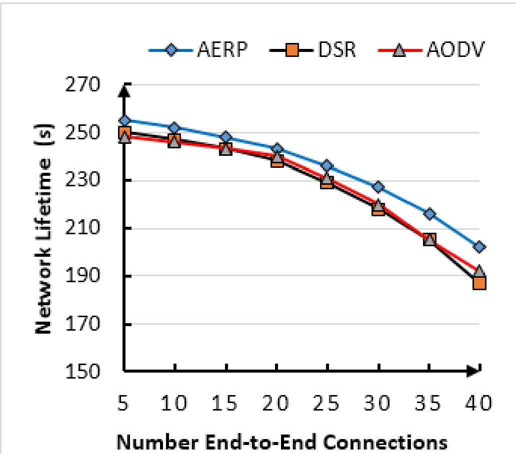

Fig. 7. Evaluation performance on metric: Network Lifetime

Fig. 7 shows the performance of the network based on metric: network lifetime and Fig. 8 shows network performance based on metric: average packet delivery ratio. Observing the results, we find that the network lifetime and average packet delivery ratio of both protocols are decreasing as the number of end-to-end connections increases. However, the AERP protocol always shows better performance than the AODV and DSR protocols in both of case. Because, as the number of connections increases, network traffic will increase, which causes congestion. This is the main reason that the average packet delivery rate and the lifetime of both protocols are the downtrends.

In Fig. 7, the lifetime of AERP is always higher than AODV. Due, AERP not only chooses route has the smallest hop count, but also it is certainly the most energy-efficient route. This mechanism always helps AERP to increase the lifetime of the network higher than the AODV protocol.

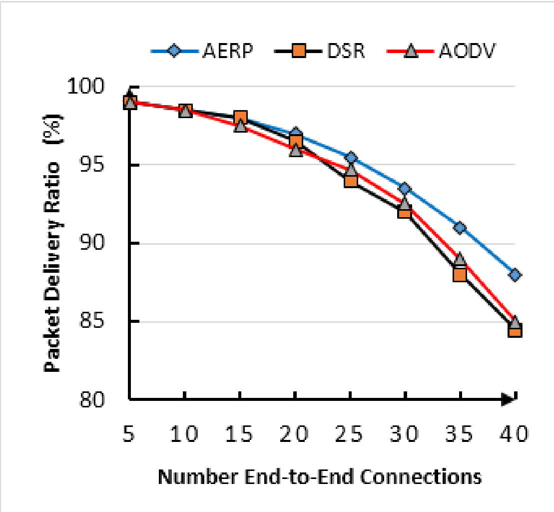

Fig 8. Evaluation performance on metric: Average Packet Delivery Ratio

In Fig. 8, the average packet delivery ratio of the protocols is decreased when the number of end-to-end connections increases. However, the average packet delivery ratio of AERP protocol is always higher than AODV and DSR protocols.

Because, as the number of connections is increased, due to, the traffic network is increased. The AODV and DSR protocols use the hop-number route mechanism, so, a lot of nodes is overloaded and rapidly energy exhausted. This leads to congestion, collision, and re-transmission. As result, packet delivery ratios decreased. In when the AERP protocol limited the number of nodes energy exhausted, therefore, the network structure is stable than the traditional protocols, due to, packet delivery ratios of AERP is significantly improved.

VI. Conclusion and Future Research

In this study, we have proposed an on-demand routing protocol, extended from AODV for MANETs, which we called AERP. The AERP protocol uses a routing cost function that forces the shortest route selection mechanism and the highest total residual energy of the entire route for the purpose of restricting the use of the route containing the node, which the remaining battery capacity is too low. The proposed routing protocol can restrict the nodes out of energy, the simulation result show, the AERP protocol improves the average resident battery remaining of nodes, network lifetime as well as average packet delivery rates better than the AODV protocol. However, routing information security has not yet been considered. In the future, we will focus on the design of high-performance routing protocols in the MANETs.

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