Journal of Theoretical and Applied Information Technology
31st August 2018. Vol.96. No 16
© 2005 – ongoing JATIT & LLS
ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

ROUTING PROTOCOL FOR SDN-CLUSTER BASED MANET

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ABSTRACT

Mobile Ad hoc NETwork (MANET) is a network of mobile nodes that connect with each other through the wireless interfaces without infrastructures. These nodes have limited energy and move freely from one location to another. Software Defined Networking (SDN) is a new architecture consists of data and control parts. It was discovered to increase the possibilities of traditional network architecture. Moreover, it plays a big role in saving the energy by selecting the optimal path with minimum energy consumption or the path included intermediates node with highest remaining energy. The mobility of MANET nodes makes the routing process very difficult and needs in sometimes that all nodes participate in this process, which leads to high overhead and energy consumption. Therefore, there is need to a special routing protocol to resolve the above troubles. The aim of this work is to design a routing protocol called SDN-Cluster Based Routing Protocol (S-CBRP) to enhance the route building/rebuilding process and increase the lifetime of MANET by selecting the optimal path to the target node with minimum energy consumption and takes into account the node's remaining energy and delay constraints. The proposed architecture depends on implementing SDN agent in each cluster head node to work as a local SDN controller for managing one or more clusters. All the local controllers connect to the central SDN controller that manages the entire network. Also, the full dump and incremental transmission approaches are used to decrease the energy consumption and overhead of sending the cluster information to the central SDN controller. The results demonstrated that S-CBRP is better than FF-AOMDV in terms of energy consumption, network overhead, average source-to-destination delay and packet delivery ratio.

Keywords: *Cluster-Based-MANET, SDN, Local Controller, SDN Agent, Network Lifetime*

1. INTRODUCTION

MANET is a special kind of the wireless networks composes of nodes (devices) with limited energy and move in different speeds without limitations from one location to another which increases the topology dynamic [1]. In order to perform the connection session in MANET, the devices can be achieved the duties of the host and router. Therefore, they can play a role of the sender and receiver as well they can be as intermediate nodes [2]. MANET has become widely used in several applications like civilian and military [3]. The routing process, constrained energy and security are the most important aspects of MANET [4].

In some times, MANET can be partitioned into smaller networks (i.e. clusters) to avoid the overhead and the scalability problems through different clustering approaches depending on several effected metrics. Each one of these smaller networks has three types of nodes that play different roles. First, the cluster head node that control and manage the cluster and all the nodes in the cluster connect to it in one or multi hops. Second, the gateway nodes that used to exchange the information between the related clusters. The final type of nodes is the normal nodes [5].

The Cluster Based Routing Protocol (CBRP) is the common example of routing protocols used in cluster based MANET. The route process by using CBRP causes high delay. This delay represents the summation of the transmission delay (i.e. links delay) and processing delay (i.e. node delay). The former represents the time spent to send a route request (RREQ) packet from the source to the target node or target's neighbour node and the time required to deliver the route reply (RREP) packet back to the source node while the latter represents the time spent in the cluster head nodes to check whether the destination IP address found in its routing table or not. If so, it will create RREP packet and send it along the reverse path to the source node, else it will add its IP address in the

RREQ packet and forward it. This delay increases with increasing the number of hops and effects on the performance especially in large scale MANET. Moreover, this process accompanied with high energy consumption, bandwidth consumption and overhead. For more details about CBRP, please see [6], [7].

The traditional architecture of networks is static and new computing trends like changing traffic patterns, rise of cloud services and big data demand a new paradigm to handle them. The limitations of the traditional networks include vender dependence, inability to scale and complexity. This is the rationale behind the need for SDN which is the paradigm shift in controlling networks and underlying services and applications [8]. SDN is one of the new innovated approaches to improve performance in real time applications. It is an emerging architecture that separates network control and forwarding functions, thus it enables network control to be a programmable for a large number of services and applications [9]. It is cost-effective, adaptable, manageable and dynamic in nature besides its suitability for today's high-bandwidth applications [10]. Moreover, SDN can provide many benefits and services as well as enhancing the routing process in the ad hoc networks [11].

The integration of SDN with MANET has very useful utility in communication networks because it may be provides the centralization for MANET. Towards this end, in [12] software defined networking was explored as an upcoming possibility that can help in having flexible, reliable and programmable controller. Most of the decision making can be separated from the actual forwarding functions of the network by decoupling controller from the rest of the network. This is the motivation behind this research work which aims to build a new architecture for MANET and routing protocol to improve routing process in order to increase the overall performance of the MANET specially the lifetime.

This paper continues with the following sections: Section 2 discusses related works, section 3 describes the proposed architecture, section 4 illustrates the proposed routing protocol, section 5 explains the case study, section 6 shows the simulation and results, section 7 explains the limitations of proposed work, and the conclusions and future works are presented in section 8.

2. RELATED WORKS

Many studies have proposed various routing protocols to improve performance and lifetime of the MANET. This section focuses on the most recent and efficient studies in this field. S. Cheng et al. [13] employed power-saving strategy, clustering approach and position information to produce a routing protocol for MANETs to overcome the problems of ILAR routing protocol and increase the lifetime of the network and nodes. Moreover, their proposed routing protocol can decrease the network overhead. Preetha K G et al. [14] produced a routing strategy depending on selecting a group of nodes as domination nodes and used to make connection with all other nodes in MANET. They demonstrated that the proposed routing strategy can reduce the network loading and the delay of the route correction process (i.e. route maintenance) of the broken routes. J. Huang at al. [15] proposed a hierarchical routing mechanism and cost-based-clustering strategy to increase the total performance and avoid the high broken of cluster (i.e. increases the stability of each cluster) in MANET with large-scale respectively. M. Uddin et al. [16] modified the widely used MANET's multipath routing protocol (AOMDV) by employing the Fitness Function strategy called FF-AOMDV to compute an efficient path to the target node to provide a reduction in the power consumption of the multipath routing mechanism. They demonstrated depending on the simulation results of several scenarios with varying the packet size, simulation time and node speed that their proposed protocol is better than AOMDV in increasing packet delivery ratio, network lifetime and throughput. Moreover, it can reduce the delay of sending data to the destination. D.R. Cañasant et al. [17] combined the reactive and proactive concepts and presented ant colony optimization based hybrid routing mechanism for MANET. This mechanism takes into account many factors in the selection process of an optimal path to the target node such as disjoint-node, hops number and disjoint-link. Also, they added the parallelized concept to their proposed mechanism to improve broadcasting operation of the message, new route computation and route correction. C. Mafirabadza et al. [18] modified the common routing protocol AODV to decrease the total delay and energy consumption in MANET by pointing the shortest route to the target node including intermediate nodes which have more energy as an optimal path. M. Zhang et al. [19] merged physarum autonomic optimization, trust assessment and ant colony optimization to produce a bio-inspired routing

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

strategy for MANET. The authors partitioned the network into several zones. The routing table of each zone can be obtained proactively by using the perceptive ants while the available routes from source to destination among different zones can be computed reactively. Finally, the optimal path is selected by using the physarum autonomic optimization. Pawan et al. [20] designed a routing mechanism for MANETs depending on the common artificial intelligence technique Genetic Algorithm. The proposed mechanism selects the route that included minimum energy consumption from the available routes to the destination as an optimal one to transfer the data.

The authors in [21]-[23] merged SDN with MANET. M. Mendonca et al. [21] focused on adapting SDN for heterogeneous networks. They considered two MANET networks connected through Internet: one MANET is based on a traditional scenario while the other one is based on SDN scenario. In the traditional scenario Bob's device can act as a gateway. However, the service provider of mobile network is not aware of the existence of Alice. Internet Service Provider (ISP) can't apply Quality of Service (QoS) rules and cannot control the bandwidth of devices in MANET. Only Bob is made responsible for the traffic of Alice as Bob acts as a gateway. In SDN scenario, there is controller who can take care of runtime requirements of the MANET devices. For instance, it is aware of Alice as well. The separation of the network controlling from forwarding hardware makes it flexible to take care of QoS requirements and improve performance as the controller is programmable. As there is Internet connecting two MANETs, it makes it a networking environment that appears in the real world and fully connected world. From this network, it can be understood how the SDN helps to separate network controlling activities to leverage the performance. A similar kind of research was done by M. Mendonca et al. [22]. M. Albanese et al. [23] presented moving target defence mechanism in MANET. They employed the concept of SDN for flexible and reliable outcomes as intended by such application in the real world. Their proposed mechanism was robust against Sybil attack.

The authors in [24]-[29] applied SDN with vehicular ad hoc network (VANET). M. Zhu et al. [24] employed SDN in VANET to produce a routing strategy to send the messages to the target vehicle with minimum delay and overhead. In their proposed architecture, the controller contains a routing server application. Moreover, there is a routing client application applied in the vehicles to transmit the packets. The routing requests and replies are exchanged between routing client and routing server. Y. Liu et al. [25] designed a suitable GeoBroadcast protocol for the VANET's safety application based on SDN to transmit safety messages in the emergency cases to neighbour vehicles that are found in a limited geographical area. The SDN controller in their proposed architecture uses two components: first one used to collect information about the location of the RSU named RSU Location Management Component while the second one named GeoBraodcast Component used to build the routing paths to broadcast safety messages. X. He et al. [26] used the SDN capabilities and fog computing environment to provide mobility support and location awareness in the Internet of Vehicle network. Also, they produced a modification for the particle swarm optimization algorithm to enhance the total network performance based on SDN. Z. He et al. [27] produced a SDN-based architecture for enhancing the communications in the vehicular network. In this paper, the network bandwidth can be assigned by the logical centralized control plane, which provides good capability of network configuration. X. Ji et al. [28] proposed SDN-based geographic routing protocol for SDN-based VANET depends on node location, vehicles density and digital map. Their proposed protocol uses two algorithms: first one used to find the shortest forwarding path named optimal forwarding path algorithm while the second one used to determine the next hop in a packet forwarding process named packet forwarding algorithm. B. Dong et al. [29] exploited the SDN concept to provide on demand routing protocol for VANET. They used two levels: global and local. The first one is used to find the position of the vehicle and calculates the global route based on the vehicles information while the second one is used to compute the route for every vehicle.

The contributions of this article can be summarized as follows:

- Producing SDN architecture for cluster based MANET to simplify the routing process.
- Running SDN agent on each cluster head node to establish the connections among the mobile nodes that are found in its own cluster.
- Producing a clustering approach to select the cluster head node based on LTE and Wi-Fi connections support, remaining energy and speed.

- Producing a routing protocol by exploiting the SDN capabilities to enhance the route building (i.e. route discovery) and route rebuilding (i.e. route maintenance) in cluster based MANET. This protocol considers the path with minimum energy consumption as an optimal path and takes the node's remaining energy and delay constraints into account.
- Using the full dump and incremental techniques in each cluster head node to send the cluster information to the central SDN controller. These techniques can increase the lifetime of the cluster head nodes and decrease the network overhead.

3. THE PROPSED ARCHITECTURE

In this paper, we want to improve route building process by producing a new and efficient routing protocol for cluster based MANET by exploiting the capabilities of the SDN controller. Therefore, first we propose SDN architecture for cluster based MANET in order to add the centralization to this type of networks that can help in increasing the speed of the route building and route rebuilding processes depending on the global view of the controller and as a result of which the delay, energy consumption, bandwidth occupies and network overhead will be decreased.

The proposed architecture consists of three layers: infrastructure layer (MANET nodes), control layer (static central SDN controller) and application layer as shown in Figure 1. The MANET nodes layer consists of clusters of the mobile nodes. In each cluster, the cluster head has SDN agent and works as a local SDN controller to manage the cluster, establish the connections among the nodes in the cluster and generates the flow tables. In this paper, we assume that there are two types of the mobile nodes: first type represents the nodes that have both Wi-Fi and LTE interfaces while the other type supports only the Wi-Fi connection. Only the first type nodes can work as a cluster head (i.e. local controller). The cluster head is mobile and changeable and can be changed depending on some features such as its battery life, location, etc.

For every group of mobile nodes in a geographical area, the cluster head is selected based on LTE and Wi-Fi connections support, remaining energy and speed. Therefore, each node must broadcast to its neighbour nodes some packets with information about the energy, speed and is it support the LTE and Wi-Fi connections or not. If there is only one node supports both the LTE and Wi-Fi connections, it will be selected as a cluster head. Otherwise, the cluster head will be selected based on a trade-off between the speed and remaining energy of the nodes that support the LTE and Wi-Fi connections. If there is no any device with both these connection interfaces, then this group of nodes will be controlled by the cluster head of the neighbour cluster through multi hops connection. The cluster head uses Wi-Fi interface to connect to the nodes in its own cluster while connects with the central SDN controller by using LTE interface.

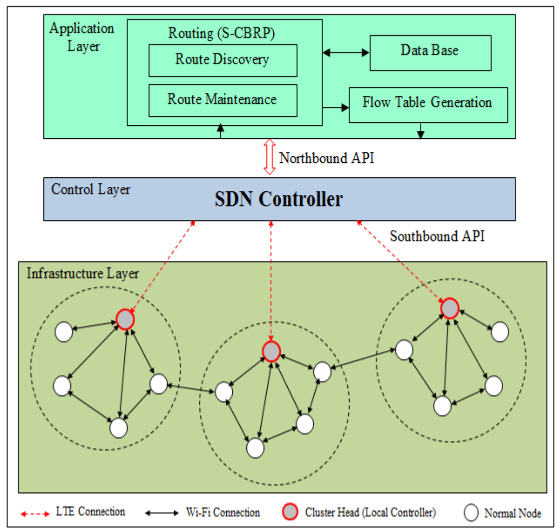

Figure 1: The proposed architecture of SDN-cluster based MANET.

Each cluster head saves complete information about its own cluster such as the normal and gateway nodes, node's remaining energy and connection between the nodes in its database. It sends this information to the central SDN controller by using full dump and incremental strategies. The full dump is used only one time after each construction operation of a new cluster to send all cluster information while the incremental method is used only when there is a change in the cluster to send only the changed information. The changed information may be about shutdown of a particular node, the exit of a node from the cluster, entering of a new node to the cluster, moving a node to another location inside the cluster and changing the connection links, etc. These techniques can decrease the number of sending times and amount of the cluster information that is sent to the central SDN controller and as a result of which decrease the energy consumption in the cluster heads and network overhead. Therefore, the central SDN controller always has a global view of

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

the MANET. In the application layer, the proposed routing protocol is applied based on the SDN database.

4. THE PROPSED ROUTING PROTOCOL

The main goal of the proposed routing protocol (S-CBRP) is to increase the lifetime of the nodes in MANET by exploiting the clustering concept and SDN capabilities to select the optimal path to the target node that has minimum energy consumption. Also, in the route building/rebuilding, SCBRP takes the delay and node's remaining energy into consideration. It works based on demand and the routing process contains two strategies as follows:

4.1 Route Building

When a node (i.e. source node) wants to send information to another node (i.e. target node), it sends a RREQ packet to the cluster head (local controller). This RREQ packet contains IP addresses of the source and destination nodes as well as the delay constraint to send the data. The cluster head checks whether the target node found in its own cluster or not. If so, it will use the SDN agent to compute the optimal path and send a flow table as a reply to the source node to start the sending process of information. Otherwise, it will forward the RREQ packet to the central SDN controller, which computes the optimal path based on its global acknowledge of the MANET.

In this paper, the optimal path is a path from the source to the destination with minimum energy consumption and meets the delay and node's remaining energy constraints. To compute the optimal path, the MANET is modelled as a weighted graph G = (V, L) where V and L refer to the set of MANET nodes and the set of links respectively. Let e_{ij} is the required energy to send the data from node i to node j, l_{ij} is the link between node i and node j, $delay_{ij}$ is the required time to send the data from node i to node j, μ is the delay constraint, e_i is the remaining energy in the node i, and Ω is the node's remaining energy constraint. The objective function is to compute the optimal path and can be defined as follows:

$$\text{Objective: Min} \sum_{i \in V} \sum_{j \in V} e_{ij} \, l_{ij}, \quad (1)$$

S.T.

$$l_{ij} \in \{0,1\}, \quad \forall\, i, j \in V, \quad (2)$$

$$\sum_{i,j \in V} delay_{ij} \leq \mu, \quad (3)$$

$$e_i \geq \Omega, \ \forall\, i \in V, \quad (4)$$

According to the first constraint, the value of l_{ij} will be 1 if it is part of the optimal path, otherwise it will be 0. The second constraint explains that the total time that are spent in the optimal path must be less than or equal to delay constraint. The third constraint shows that the SDN controller must select intermediate nodes with good remaining energy to participate in the forwarding process of the data. Therefore, the energy of each one of the intermediate nodes must be more than or equal to the predefined threshold Ω.

After the computation of the optimal path, the SDN controller sends flow tables to source node and intermediate nodes that belong to that path. The flow table represents routing table and contains only the required entries to send certain data packets (i.e. it is not contain the routes to all nodes). Therefore, the sending process of these flow tables from the SDN controller to the source and intermediate nodes do not consume a lot of the communication bandwidth. For more details about the flow table, please see [30, 31]. At this point, the source node sends the data according to the action field of the flow table. Also, the intermediate nodes use this field to forward the data to the target node.

In some situations, the source node moves to another location before arriving of the response from the central SDN controller. Therefore, if the source node exited from a cluster (let cluster 1) and go to another cluster (let cluster 2), then the cluster head of cluster 2 sends notification to the central SDN controller to inform it that this node became a member of its own cluster. At this point, the central SDN controller will compute the optimal path from the new source node location to the destination. After that, it will send the flow tables to the intermediate nodes and do not send anything to the cluster 1 if their nodes do not belong to the computed optimal path.

4.2 Route Rebuilding

In some situations, the link between two mobile nodes is broken and leads to stopping of the sending process of data. To solve this problem with minimum overhead, delay, energy and bandwidth consumption, the affected node sends a route error (RERR) packet to the nearest cluster head. If the cluster head knows another available link, it will solve this problem locally and creates an updated flow table by using the SDN agent. Else, it will forward the RERR packet to the central SDN controller, which used its information about the entire MANET to correct the broken links or compute a new optimal path based on links availability, delay and node's remaining energy constraints. Finally, it creates the updated flow tables.

5. CASE STUDY

The aim of this section is to explain how the SDN can help in the route building process in the cluster based MANET that is achieved by S-CBRP and compare it with the route building process in traditional cluster based MANET that is done by using CBRP. The route building delay, number of nodes and energy consumption are considered as metrics in this comparison. Therefore, at the beginning, we must explain how these metrics can be calculated in the traditional cluster and SDN-cluster based MANET. The calculation of these metrics is as follows:

- **Traditional Cluster Based MANET**

Let V_1 represents the set of MANET nodes. In the route building process, ($s, t \in V_1$) represent the source and target nodes respectively, $N \subseteq V_1$ represents the set of nodes that belong to the path that must be spent by the RREQ packet to reach target node, $\acute{I}$ represents the set of links that belong to the RREQ path, $\hat{I}$ represents the set of links that belong to the RREP path and $RB_{(s,t)}$ represents the Route Building process from s to t.

- **The Number of hops**: The number of hops of the route building process in traditional cluster based MANET can be calculated as follows:

$$hops(\mathrm{RB}_{(s,t)}) = \sum_{i=1}^{N*2} \mathrm{H}\,, \quad (5)$$

Where H represents the total number of hops that belongs to the route building process and N*2 represents the number of nodes that belong to RREQ path and RREP path.

- **The Delay of the Route Building Process**: The delay between every two nodes along the RREQ path may be differ from the delay between the same two nodes along the RREP path due to the mobility, transmitted data size and available bandwidth. The delay function associated with the route building process in traditional cluster based MANET is as follows:

$$Delay(\mathrm{RB}_{(s,t)}) = \sum_{i\in\acute{I}} \mathrm{D}_i + \sum_{j\in\hat{I}} \mathrm{D}_j + \sum_{c\in \mathrm{C}} \mathrm{D}_c\,, \quad (6)$$

Where D_i represents the link delay between every two nodes along the RREQ path, D_j denotes to the link delay between every two nodes along the RREP path, D_c represents the processing delay inside each cluster head c along the RREQ path and RREP path where C represents the set of the cluster head nodes.

- **Energy Consumption in the Route Building Process**: In the traditional cluster based MANET, there are many nodes may participate in the route building process by forwarding the RREQ packet, whether they have a route to the target node or not. The energy consumption function associated with the route building process represents the summation of consuming energy for sending, receiving and processing and can be defined as follows:

$$Energy(\mathrm{RB}_{(s,t)}) = \sum_{v\in V1} (TE_v + RE_v) + \sum_{c\in C} PE_c\,, \quad (7)$$

Where TE_v represents the consumed energy to transmit the RREQ/RREP packet(s) from node v to one or many node(s), RE_v represents the consumed energy by the node v to receive the RREQ/RREP packet(s), and PE_c represents the consumed energy by the cluster head node c to search in the routing table about the IP destination address and the consumed energy to update the header of the RREQ/RREP packet.

- **SND-Cluster Based MANET**

Let V_2 represents the set of MANET nodes and the central SDN controller and ($s, t \in V_2$) represent the source and target nodes respectively.

- **The Number of Hops**: In SDN-cluster based MANET, the number of hops in the route building process is always as follows:

$$2 \le \text{Number of Hops} \le 4, \quad (8)$$

  - When the source and target nodes are in the same cluster, then the local controller computes the route. Therefore, the number of hops is only 2 hops as follows:
    - One hop from the source node to the closest cluster head.
    - One hop from the closest cluster head to the source node.

- When the source and target nodes are in different clusters, then the central SDN controller computes the route. Therefore, the number of hops is only 4 hops as follows:
  - One hop from the source node to the closest cluster head.
  - One hop from the closest cluster head to the central SDN controller.
  - One hop from the central SDN controller to the closest cluster head.
  - One hop from the closest cluster head to the source node.

o **The Delay of Route Building Process**: This delay can be computed based on the locations of the source and target nodes as follows:

- When the source and target nodes are in the same cluster, then there are three delays as follows:
  - D_1 is the transmission delay of the RREQ packet from the source node to the closest cluster head.
  - D_2 is the processing delay spent in the closest cluster head to compute the optimal path.
  - D_3 is the transmission delay of the table flow from the closest cluster head to the source node.

Therefore, the total delay of the route building process can be computed as follows:

$$Delay(\mathrm{RB}_{(s,t)}) = D_1 + D_2 + D_3 , \quad (9)$$

- When the source and target nodes are in different clusters, there are six delays as follows:
  - D_1 is the transmission delay of the RREQ packet from the source node to the closest cluster head.
  - D_2 is the processing delay spent in the closest cluster head to check are the source and target nodes found in its own cluster or not.
  - D_3 is the transmission delay of the RREQ packet from the closest cluster head node to the central SDN controller.
  - D_4 is the processing delay spent in the central SDN controller to compute the optimal path.
  - D_5 is the transmission delay of the flow table from the central SDN controller to the closest cluster head.
  - D_6 is the transmission delay of the flow table from the closest cluster head to the source node.

Therefore, the total delay of the route building process can be computed as follows:

$$Delay(\mathrm{RB}_{(s,t)}) = \sum_{i=1}^{6} D_i , \quad (10)$$

o **Energy Consumption in Route Building Process:** In the SDN-cluster based MANET, the energy is consumed only in the nodes that belong to the optimal path. The energy consumption of the route building process represents the summation of consuming energy for sending, receiving, processing in the closest cluster head and central SDN controller and can be defined as follows:

$$Energy(\mathrm{RB}_{(s,t)}) = \sum_{v \in V2} (TE_v + RE_v) + PE_{cc} + PE_{sdn} \quad (11)$$

Where TE_v represents the consumed energy to transmit the RREQ packet or flow tables from node v to one or many node(s), RE_v represents the consumed energy by the node v to receive the RREQ packet or flow tables, PE_{cc} represents the processing energy consumed in the closest cluster head, and PE_{SDN} represents processing energy consumed in the central SDN controller to compute the optimal path.

In this section, a test example of network consists of 20 mobile nodes is used to compare S-CBRP with CBRP in terms of number of hops, delay and energy consumption in the route building process to prove the efficiency of the proposed work.

To apply CBRP in this test example, we assume for simplicity, but not for generality that each link has some delay as shown in Figure 2. Moreover, the processing delay in each cluster head node along the RREQ and RREP paths is 1ms. Also, we assume that the required energy to send or receive the RREQ/RREP packet is 1unit and the processing energy in each cluster head node is 1 unit.

Also, to apply S-CBRP in the test example, we assume for simplicity, but not for generality that the delays of the links are as shown in Figure 3. Moreover, the processing delay in the nearest cluster head node is 1ms while the

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

processing delay in the central SDN controller is 2ms. In the same method, we assume that the required energy to send the RREQ packet from the source node to the nearest cluster head is 1 unit, the required energy to receive and process the RREQ packet in the nearest cluster head is 2 units, and the consumed energy to forward the RREQ packet to the central SDN controller is 2 units. After computing the optimal path by the SDN controller, it will send flow tables as a reply to all cluster heads along that path. Therefore, we assume that the consumed energy to receive the flow tables by each one of the cluster heads along that path is 2 units and the required energy to send the flow table from cluster heads to the source node and each one of the gateway nodes is 1 unit while consumed energy to receive the flow table by the source node and gateway nodes is 1 unit.

The cases that used in this study are as follows:

5.1 Case 1

Let the nodes 1 and 11 are source and target nodes respectively. Figure 2 and figure 3 show the route building process by using CBRP and S-CBRP respectively. The optimal path is 1→2→3→6→9→11 and the other information about this case study is shown in Table 1.

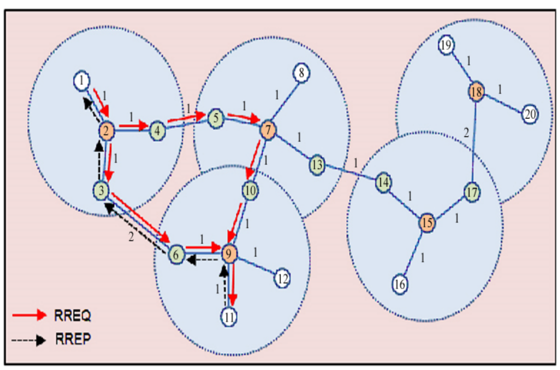

Figure 2: route building process of case 1 using CBRP.

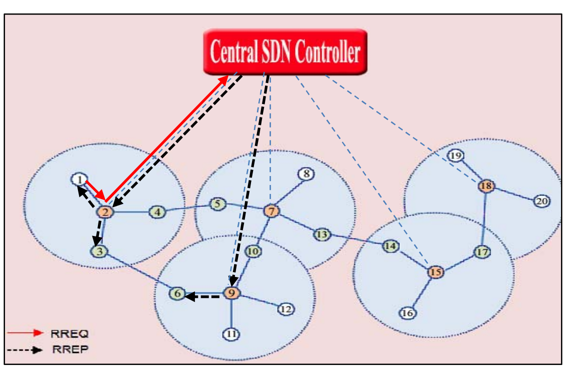

Figure 3: The route building of case 1 using S-CBRP.

5.2 Case 2

Suppose that the nodes 1 and 17 are source and target nodes respectively. Figure 4 and figure 5 explain the different of the route building process by using CBRP and S-CBRP respectively. The optimal path to the target node is 1→2→4→5→7→13→14→15→17 and the other details are described in Table 1.

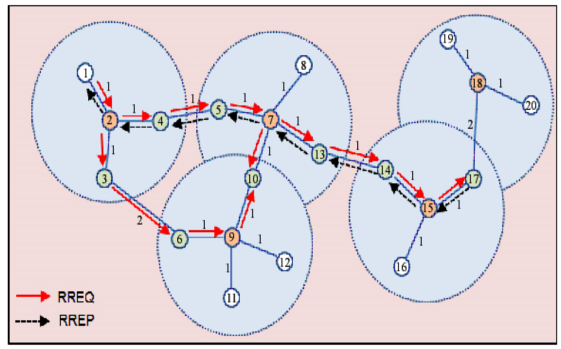

Figure 4: The route building of case 2 using CBRP.

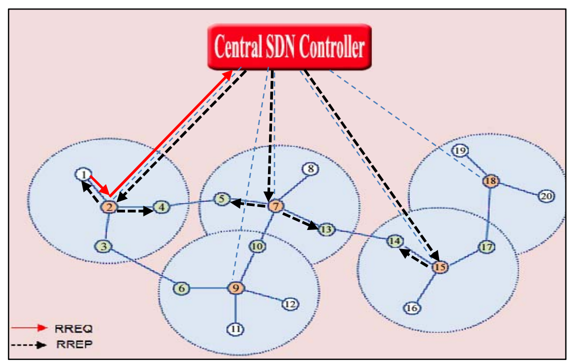

Figure 5: The route building of case 2 using S-CBRP.

5.3 Case 3

Let nodes 1 and 19 are the source and target nodes respectively. Figure 6 and figure 7 show how the route can be built by using CBRP and S-CBRP respectively. The optimal path is 1→2→4→5→7→13→14→15→17→18→19. More details about this case study are illustrated in Table 1.

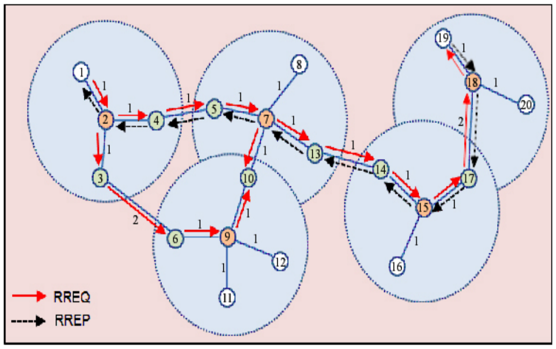

Figure 6: The route building of case 3 using CBRP.

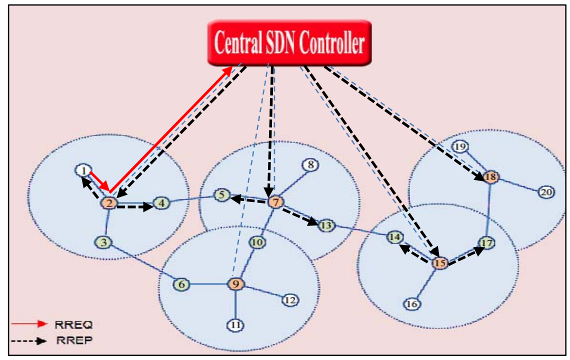

Figure 7: The route building of case 3 using S-CBRP.

Table 1: The details of the route building process by using CBRP and S-CBRP.

Parameter	Case 1		Case 2		Case 3	
	CBRP	S-CBRP	CBRP	S-CBRP	CBRP	S-CBRP
The number of participating cluster heads in RREQ forwarding.	**3** (node 2, 7 and 9)	**1** (node 2)	**4** (node 2, 7, 9 and 15)	**1** (node 2)	**5** (node 2, 7, 9, 15 and 18)	**1** (node 2)
The number of participating cluster heads in RREP forwarding.	**2** (node 2 and 9)	**2** (node 2 and 9)	**3** (node 2, 7 and 15)	**3** (node 2, 7 and 15)	**4** (node 2, 7, 15 and 18)	**4** (node 2, 7, 15 and 18)
The number of participating gateway nodes in RREQ forwarding.	**5** (node 3, 4, 5, 6 and 10)	**0**	**7** (node 3, 4, 5, 6, 10, 13 and 14)	**0**	**8** (node 3, 4, 5, 6, 10, 13, 14 and 17)	**0**
The number of participating gateway nodes in RREP forwarding.	**2** (node 3 and 6). They receive and forward the RREP.	2 (node 3 and 6). They **only** receive the RREP.	**4** (node 4, 5, 13 and 14). They receive and forward the RREP.	**4** (node 4, 5, 13 and 14). They **only** receive the RREP.	**5** (node 4, 5, 13, 14 and 17). They receive and forward the RREP.	**5** (node 4, 5, 13, 14 and 17). They **only** receive the RREP.

According to (5), (6), (7), (8), (10) and (11), the number of hops, total delay, total energy consumption of the route building process by using CBRP and S-CBRP for all above cases are shown in Table 2.

Table 2: The results of case 1, 2 and 3.

a s	No. of hops		Delay(second)		Energy(unit)	
	CBRP	S-CBRP	CBRP	S-CBRP	CBRP	S-CBRP
1	10	4	14	11	46	15
2	16	4	19	11	58	21
3	20	4	26	11	68	25

From the above cases, can be seen that the number of participating nodes, processing operations and hops decreased in the route building process by using S-CBRP and as a result the overhead, delay, energy consumption and bandwidth usage are also decreased.

6. SIMULATION AND RESULTS

In this paper, the simulator OMNeT++ version 4.6 running on the windows 7 was used to create the simulation environment. The general simulation parameters are in Table 3.

Table 3: The general simulation parameters.

Parameter	Description
SDN Controller	POX
Simulation Area	1500m*1500m
Pause Time	5 s
Moving Pattern	Random waypoint mobility model
MAC	802.11
Traffic Type	FTP
Transmission Rate	5 packets/second
Packet Size	512 bytes/packet
Simulation Time	600 s
Simulation Iterations	10

The evaluation criteria are as follows:

- **Average Source to Destination Delay**: it is often called End to End delay and represents the average time to send the data packet from the source to the destination and can be computed by dividing the total time required to send all packets by the number of that packets [32].
- **Packet Delivery Ratio (PDR):** it represents the ratio between the total number of packets that received by the destinations and the total number of packets that sent by the sources [33].
- **Network Overhead:** it is called in sometime the normalized overhead load and represents the ratio between the number of routing packets and number of received data packets [32].
- **Energy Consumption:** This metric represents the amount of energy that consumed in the operations of route building, route rebuilding and receiving and transmission of data [34].
- **The Percentage of Messages that Meet the Deadline:** it is called successfully transmission ratio and represents the percentage of messages that reach to the destinations within the deadline [35].
- **The Dead Nodes:** it represents the number of nodes that lose their energy and shutdown during the simulation**.**

In this study, several simulation scenarios are used to prove the efficiency of the proposed work as follows:

6.1 Scenario 1

The first scenario focuses on studying the effect of the node speed on the performance of S-CBRP and FF-AOMDV [16] in MANET with 100 nodes and different mobility speeds range from 2 to 15 m/s in terms of average source-to-destination delay, packet delivery ratio (PDR), overhead, energy consumption and percentage of messages that meet the delay constraint.

Figure 8 shows that S-CBRP produces little average source-to-destination delay than FF-AOMDV for many reasons. First, the intermediate nodes in SDN architecture use the flow tables to forward the data packets without any need to search in their routing tables to find the optimal path. Second, if a link is failed, S-CBRP can repair it by using the local controller (depending on the link availability). Third, the SDN helps in avoiding the delay in the rebuilding processes of the paths in the failed cases. Fourth, S-CBRP takes into account the remaining energy in the computation of the optimal path. Therefore, the selected path is less prone to failure due to the shutdown of the nodes. However, the average source-to-destination delay increases with increasing the mobility speed due to the link failure and continuous cluster reconstruction.

Figure 9 describes that increasing the mobility speed effects on the link and cluster stabilities and as a result decreases the PDR. Also, S-CBRP is better than FF-AOMDV in term of PDR because it computes the optimal path and repairs the broken links quickly and efficiently depending on the capabilities of SDN by using the local controller or central SDN controller.

Figure 10 shows that the overhead of S-CBRP is less than FF-AOMDV because the number of participating nodes in the route building and route rebuilding processes are few and as a result decreases the number of control packets that exchange among the nodes. High mobility speed means high overhead because the continuous link failure cases and cluster reconstruction need to high control packet exchanging.

Figure 11 explains that S-CBRP is better than FF-AOMDV in term of energy consumption because it always selects the optimal path with minimum energy consumption. Moreover, it decreases the number of hops, processing operations and participating nodes in the route building/rebuilding process. Also, the intermediate nodes do not consume any energy to check the routing table to find the optimal path because they use the flow tables to forward the data packets.

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However, with increasing the speed, the energy consumption will increase due to the continuous route rebuilding and cluster reconstruction processes that need to exchange additional control packets which consume the nodes energy.

Figure 12 illustrates that the percentage of messages that meet the delay constraint decreases with increasing the speed. However, S-CBRP produces better results than FF-AOMDV in meeting the delay constraint because it takes into account this factor in the route building/rebuilding process.

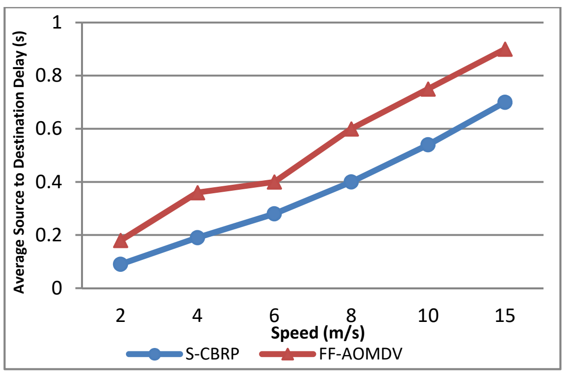

Figure 8: The average source to destination delay with different speeds.

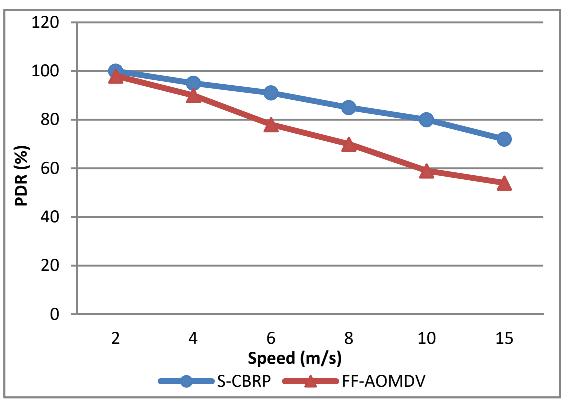

Figure 9: The PDR with different speeds.

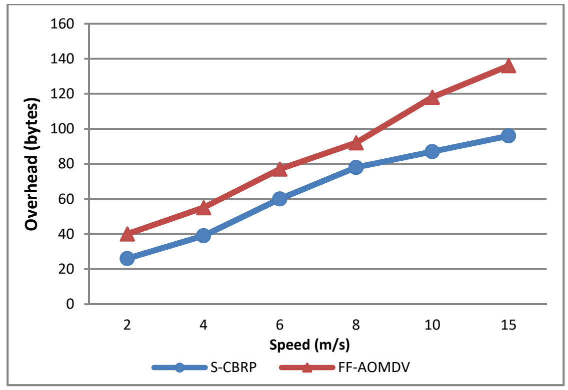

Figure 10: The overhead with different speeds.

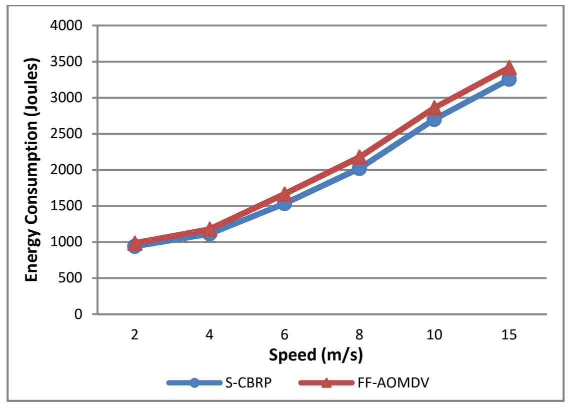

Figure 11: The energy consumption with different speeds.

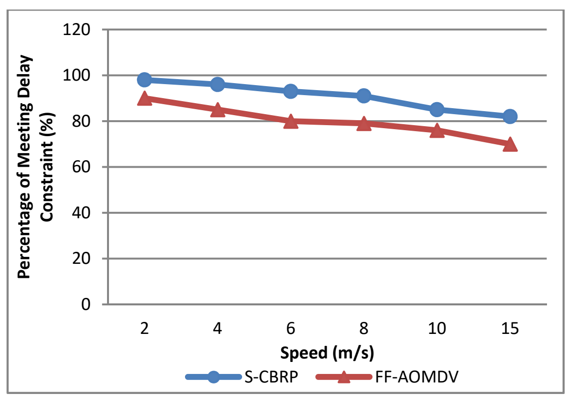

Figure 12: The percentage of messages that meet the delay constraint with different speeds.

6.2 Scenario 2

This scenario investigates the behaviour of S-CBRP and FF-AOMDV in MANET with different nodes numbers (25, 50, 75, 100, 150 and 200 nodes) moving at the speed 8m/s in terms of average source-to-destination delay, PDR, overhead, energy consumption and percentage of messages that meet the delay constraint.

Figure 13 shows that the average source-to-destination delay decreases with increasing the number of nodes due to the increasing of available

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links. Therefore, the central SDN controller in S-CBRP can select the optimal path efficiently from the several available links. Moreover, the local route building process by the local controller will be very useful with increasing the available links which leads to a reduction in the delay. Also, when a data packet reaches an intermediate node, it does not take any time to calculate the optimal path because it will forward this packet directly by using the flow table.

Figure 14 explains that the available links increases with increasing the number of nodes. Therefore, S-CBRP exploits the advantages of this feature in the route building/rebuilding process and provides better results than FF-AOMDV in term of PDR.

Figure 15 illustrates that the overhead increases with increasing the number of nodes. It is normal because the high node number means high exchanging of control packets among the nodes and high number routing requests that need to exchange RREQ, RREP and RERR packets. However, S-CBRP decreases the number of nodes that participate in the route building/rebuilding process and redundant control packets by using the clustering and SDN concepts that decrease the total overhead in the network.

Figure 16 explains that the energy consumption increases with increasing the number of nodes due to the high number of control packets that exchange among these nodes. However, S-CBRP consumes little energy as compared with FF-AOMDV because it decreases the number of processing operations in each node, exchanging control packets and hops. Also, it always selects the optimal path with minimum energy consumption.

Figure 17 shows that the percentage of messages that meet the delay constraint increases with increasing the number of nodes due to the high link availability. S-CBRP is better than FF-AOMDV in this performance metric.

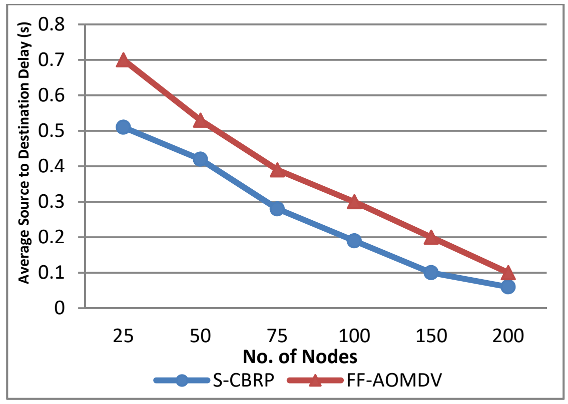

Figure 13: The average source to destination delay with different node numbers.

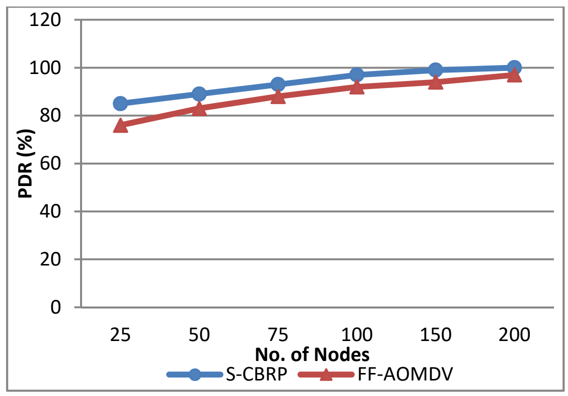

Figure 14: The PDR with different node numbers.

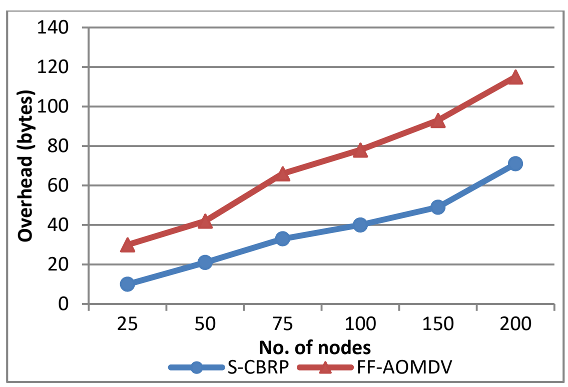

Figure 15: The overhead with different node numbers.

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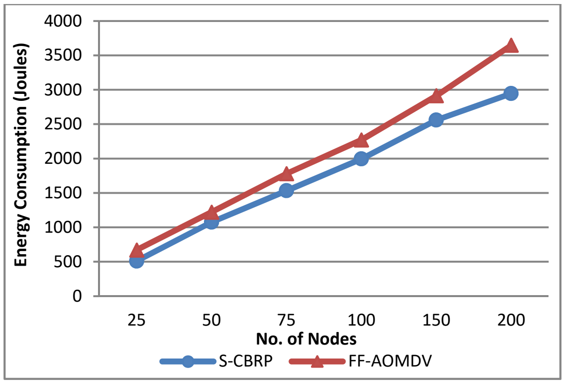

Figure 16: The energy consumption with different node numbers.

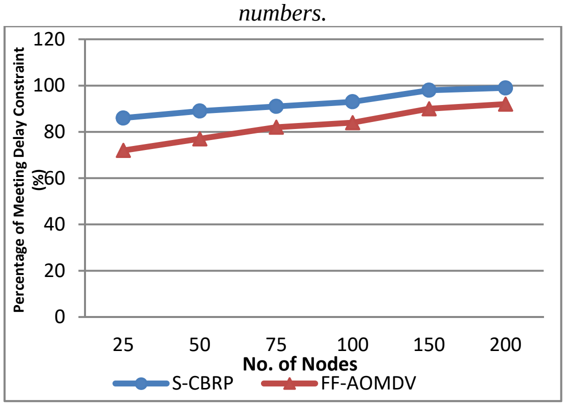

Figure 17: The percentage of messages that meet the delay constraint with different node numbers.

6.3 Scenario 3

In this scenario, the number of dead nodes by using S-CBRP and FF-AOMDV was investigated. The number of nodes used in this scenario is 200 nodes moving at the speed 20m/s. Figure 18 shows that S-CBRP increases the lifetime of the nodes and network more than FF-AOMDV because it decreases the number of nodes that participate in the processes of route building/rebuilding. Therefore, it decreases the energy required to transmission and receiving of redundant RREQ, RREP and RERR packets. In the traditional cluster based MANET, the nodes need to search in routing tables to find the optimal path. But, in SDN architecture there is no need to these search operations because the nodes use the flow tables. Therefore, the energy consumption and number of dead nodes will be decreased.

7. THE LIMITATIONS

The proposed work enhances the routing process in MANET, but it has some limitations as follows:

- It is always need to static central SDN controller.
- It needs to support of both LTE and Wi-Fi connections by some of the mobile nodes to be work as cluster head nodes.
- Each cluster head node must contain SDN agent to be work as a local mobile SDN controller.
- The mobility of nodes decreases the stability of cluster head nodes. Therefore, the procedure of cluster head selection must be executed frequently. This problem can be solved by selecting an associate cluster head node for each essential cluster head.

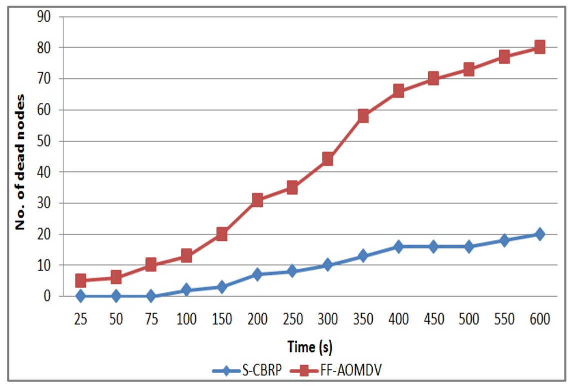

Figure 18: The number of dead nodes at different times.

8. CONCLUSIONS AND FUTURE WORKS

In this paper, we presented SDN architecture and routing protocol for cluster based MANET that focus on minimizing the route building and route rebuilding delay and energy consumption by minimizing the number of hops, participating nodes, and processing operations. Moreover, the proposed routing protocol considers the path from the source to the target node with minimum energy consumption as an optimal path and takes into consideration the node's remaining energy and delay constraints. The continuous sending of the cluster information by the cluster heads to the central SDN controller leads to increase the network overhead and consume the energy. Therefore, the full dump and incremental techniques were applied to decrease the energy consumption in the cluster head node and network overhead by decreasing the amount and number of sending times of the cluster information. From the case study, we found that S-CBRP produces better results than CBRP in terms of number of hops and energy consumption as well as it can reduce the delay of the route building/rebuilding process and increase the lifetime of the network by minimizing the number of gateway nodes that participate in these processes. The results of the simulation demonstrated that S-CBRP is better than FF-

AOMDV in terms of average source-to-destination delay, PDR, overhead, energy consumption, percentage of messages that meet the delay constraint and number of the dead nodes with different mobility speeds and node numbers. **In the future**, we will produce a power-aware multicast routing protocol for SDN-cluster based MANET to build the optimal multicast route from the source node to a set of destination nodes with minimum energy consumption and takes into consideration the mobility speed. Therefore, the stopped nodes or that move slowly are more suitable than those move at high speed to increase the link stability.

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