The Application and Improvement of Temporally Ordered Routing Algorithm in Swarm Network with Unmanned Aerial Vehicle Nodes

Zhongqiang Zhai, Jun Du, Yong Ren
Department of Electronic Engineering
Tsinghua University
Beijing, China
elezzq@gmail.com, du-j11@mails.tsinghua.edu.cn, reny@tsinghua.edu.cn

***Abstract*—In recent years, the research and application of Unmanned Aerial Vehicle (UAV) network has become a significant topic. The mobile ad hoc network established by UAV nodes can be more efficient to complete various tasks in a harsh environment. Plenty of research focuses on the routing protocol, which is an important factor to play group advantage of UAVs. In the swarm network with UAV nodes, nodes failure or mobility may cause routing failure, which results in communication failure or longer delay. The existing routing-repair mechanisms are accompanied by a great deal of control overhead, which cannot solve the problem mentioned above effectively. This article analyses the advantages and disadvantages of Temporally Ordered Routing Algorithm (TORA), and proposes a routing protocol named Rapid-reestablish Temporally Ordered Routing Algorithm (RTORA). RTORA adopts reduced-overhead mechanism to overcome adverse effects caused by link reversal failure in TORA. The simulation results using OPNET demonstrate that RTORA has less control overhead and smaller delay than TORA.**

Keywords-UAV; swarm; routing failure; RTORA; OPNET.

I. INTRODUCTION

With the development of Unmanned Aerial Vehicle (UAV) and its application in various fields, some deficiencies using single UAV to perform tasks are exposed, such as limited scope of target search and monitoring, single task load and low task timeliness. In the past few years, establishing a mobile ad hoc network by multiple UAVs became a method to solve the problems above. In such a network, UAVs can sense environmental information in a wide range, and complete a number of different tasks at the same time through information exchange and dynamic task allocation. Furthermore, the remaining UAVs can continue to perform the task when several UAVs are damaged, which can improve the task timeliness. As an important factor to play groups advantage of UAVs, the routing protocol has been one of the key points in the UAV network. Swarm network with UAV nodes is a network that high-density UAVs implement a saturated search, detection or attack as a swarm through mutual cooperation. Such high-density networks are typically deployed in harsh environments. The probability of transmission link failure will greatly increase, which is caused by damaged relay nodes or neighbor nodes moving beyond the transmission range. Rediscovering and reestablishing new routes will bring longer delay. Therefore, a strategy to solve the problem of routing failure is needed.

One way to alleviate the issue above is to prevent link failure. Mobility Aware Ad hoc On-demand Distance Vector Routing (MA-AODV) is proposed to deal with link failure caused by mobility in [1]. MA-AODV periodically calculates mobility, and chooses the transmission route with smaller-mobility nodes. But this method cannot avoid link failure completely. Additionally, the period of calculation also needs to be considered. Too big value cannot guarantee the accuracy of mobility, and too small value will greatly increase the control overhead.

Another approach is to look for a new route after the current route is damaged. Some classic on-demand routing protocols use this method, e.g., Dynamic Source Routing (DSR), Ad hoc On-demand Distance Vector Routing (AODV), Temporally-Ordered Routing Algorithm (TORA), etc. The node detecting link failure sends a Route Error (RERR) message to the source node in DSR [2] and AODV [3]. Then, the source node discovers another route to destination by broadcasting a Route Request (RREQ) packet. TORA [4] repairs the transmission route in the local area where the link is interrupted. Some previous studies indicate that TORA is adapted to dense ad hoc networks [5][6], which will better meet the demand of the swarm network.

According to the above situation, we propose Rapid-reestablish TORA (RTORA) routing protocol based on TORA to solve routing failure in the swarm network with UAV nodes. The simulation results show that RTORA has smaller delay and lower control overhead than TORA.

The paper is organized as follows: Related research is presented in Section II. Section III analyzes the TORA protocol. In Section IV, we describe the mechanisms of RTORA. Section V presents the simulation results of TORA and RTORA. The conclusion and future work is given in Section VI.

II. RELATED WORK

With the focus on Quality of Service (QoS), many improved routing protocols about routing failure in the Mobile Ad hoc Network (MANET) are proposed. Z. Che-Aron et al. [7] design the Enhancement of Fault-Tolerant AODV (ENFAT-AODV) routing protocol, which uses the backup route to solve the problem of current routing failure in Wireless Sensor Networks (WSN). In [8], the AODV with

Reliable Delivery (AODV-RD) protocol reestablishes the route by the mechanisms of link failure prediction and alternate nodes selection. Multiple routes are created to solve the problem of link failure in [9]. In those three protocols, nodes periodically broadcast HELLO messages to acquire the link-status and topology changes, which is the same as AODV whose control overhead is huge due to periodic HELLO packets. Furthermore, the backup routing establishment and maintenance, as well as reasonable alternative nodes selection, will add to the broadcast of control packets. In [10], the researcher uses weight hop based packet scheduling for AODV routing protocol to reduce the queue length caused by link failure in the network.

The cost of these routing protocols is additional control packets, which is advantageous in a sparse network yet brings some shortcomings in dense swarm network. Because each node has many neighbor nodes in high-density network, there will be a large number of control packets in the entire network when a node broadcasts a routing update packet, which may cause congestion and increase delay. So, the control overhead of routing update must be as small as possible.

Researchers improved TORA considering the network life, bandwidth demand and load balance respectively in [11][12]. These protocols utilize the advantage of link reversal mechanism in TORA. The link reversal can be defined as follows. At the beginning, the link from node X to node Y is allowed to transmit data packets, which is known as a downlink. But the link from node Y to node X for transmission is prohibited. After the change of node status, the link from node Y to node X becomes the downlink. The allowable transmission direction of data packets is reversed. The link failure is the condition that may cause the change of node status. These protocols based on TORA can get the anomalies of routes and establish a new transmission path quickly. The overhead of updating is controlled in the local area, which reduces the overhead and delay. But all of the protocols assume that link reversal is successful. In fact, link reversal may fail due to the harsh environment, which will result in a lot of useless control overhead and increase the time to reestablish the transmission.

The proposed routing protocol in this paper not only keeps the advantage in TORA, but also reduces the control packets caused by routing reestablishment.

III. TORA PROTOCOL

As an on-demand routing protocol, TORA responds to link failure in the network quickly by link reversal. The mechanism limits the overhead at a local scale and avoids the control message flooding. Link reversal can increase bandwidth utilization and reduce the delay of routing reestablishment, which is suitable for high-dynamic mobile networks. Moreover, multiple paths from the source to the destination are created in TORA, which supports link reversal and multipath transmission.

A. Height Mechanism and Routing Establishment

A Directed Acyclic Graph (DAG) from a source to the destination is established by the "height" of nodes in TORA. Data packets are only allowed to be transmitted from a higher node to a lower node, which is called downlink. The height is a 5-tuple (t, oid, r, v, id), of which the first three values (t, oid, r) is called "reference level". The meanings of the various parameters are as follows:

1) Time t; the time of creating the reference level;

2) Identification oid; the identity of the node creating the reference level;

3) Reflection r; the value of the reflection bit;

4) Arab values v; the hop-count information relative to the destination node;

5) Identification id; the identity of a node itself.

The reflection bit is a binary value: "r=0" means the reference level has not been reflected; "r=1" means that the reference level created is reflected back.

The "height" of a node is very important for routing establishment and link reversal. The value of the "height" is the basis to determine the downlink. The strategy to compare the "height" of h_i (t_i,oid_i,r_i,v_i,i) and h_j (t_j,oid_j,r_j,v_j,j) is shown in Fig. 1.

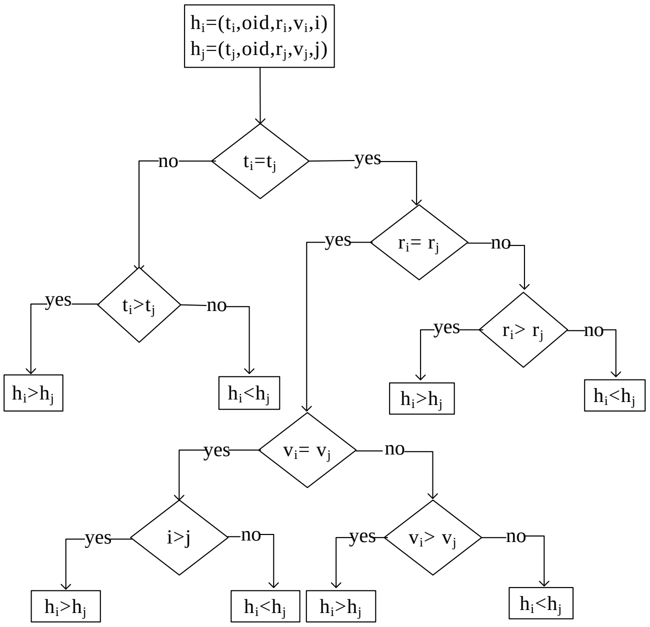

Figure 1. The comparison of height in TORA

Fig. 2 shows a simple network topology. If the source node S prepares to send data to the destination node D, it will broadcast the routing Query packet (QRY) to its neighbors. Each node that receives a QRY while not being the destination node will relay the control packet. When the destination node D receives the QRY from the source S at T_0, node D creates the height (T_0, D, 0, 0, D), then broadcasts an Update packet (UPD). Each node receiving UPD defines a height relative to the destination node D, such as node C and E in Fig. 2. After node C and E define their heights, they also send a UPD to indicate their heights. As a result, their neighbors can define the heights too. Finally, all nodes will define a height relative to the destination and get the height of its neighbors. Each node will also know the downlinks. In the storage of a node, its own height, the height of its neighbor nodes and the link-status information will be saved. The DAG is formed as shown in Fig. 2. The source node S can find two different shorter routes to transmission: S-A-B-C-D and S-A-B-E-D.

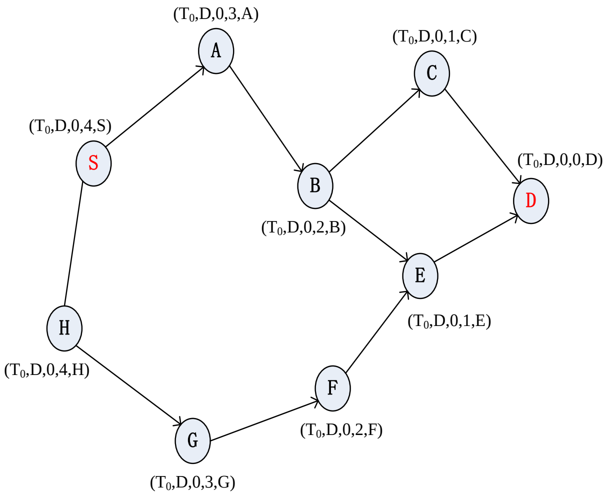

Figure 2. DAG of TORA

B. *Strength and Weakness of Link Reversal in TORA*

The nodes losing the last downlink will perform link reversal to update the route. We assume that the current transmission path is S-A-B-C-D in Fig. 2. If the link from node C to node D is interrupted at T_1, node C will lose the downlink to node D, which results in the change of the topology. Firstly, node C replaces previous height with new height (T_1, C, 0, 0, C), and then sends a UPD with the new height. The downlink from node B to node C reverses. Secondly, node B has another downlink from node B to node E, so it neither changes the height nor generates a UPD. The new DAG is shown in Fig. 3.

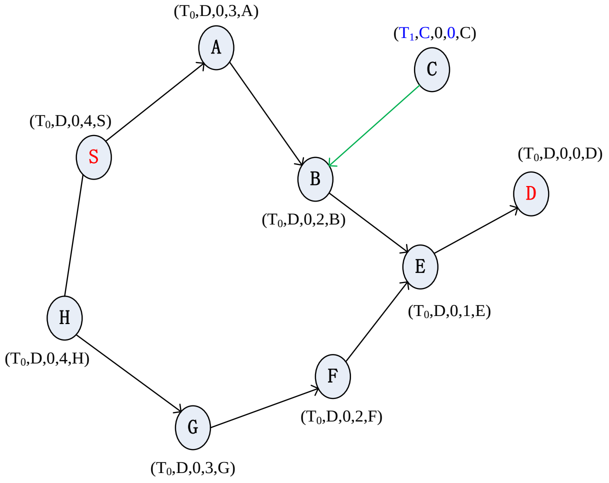

Figure 3. DAG of TORA with new height of node C

In the above case, the link reversal greatly reduces control overhead, and quickly finds another transmission path (S-A-B-E-D). Although the multipath in TORA supports the link reversal, link reversal failure will still occur under some conditions. In Fig. 3, for example, the downlink from node E to node D is interrupted at T_2, and the route will be updated as follows:

- Node E changes its height: (T_2, E, 0, 0, E), and then sends a UPD.
- Node B and F lose the last downlink, and update the height: B (T_2, E, 0,-1, B), F (T_2, E, 0, -1, F), and broadcast a UPD severally.
- Node C, A, G, H perform the same operation: C (T_2,E,0,0,C), A (T_2,E,0,-2,A), G (T_2,E,0,-2,G), H (T_2,E,0,-3,H).
- Node S changes the reflection bit of the reference level and updates the height (T_2, E, 1, 0, S), and becomes the highest node in the local area. All related nodes change the height successively: H(T_2,E,1,-1,H), A(T_2,E,1,-1,A), G(T_2,E,1,-2,G), B(T_2,E,1,-2,B), F(T_2,E,1,-3,F), C(T_2,E,1,-1,C).
- When receiving a UPD from node B and node F, node E realizes that the reference level created by itself is reflected back. Then node E changes the height into NULL (-,-,-,-,E), and broadcasts a cleared packet (CLR). Other nodes that receive a CLR delete the relational routes and set their heights NULL.

As we see，the link reversal is invalid. A large number of control packets are flooding the network, which results in more control overhead and greater delay of routing reestablishment. Hence, it has a significant impact on network transmission.

IV. RTORA PROTOCOL

In order to solve the problem resulting from the link reversal failure, we must prevent useless control packets from flooding. The RTORA protocol adopting reduced-overhead mechanism can ease this problem effectively.

Compared with TORA, RTORA also applies the height mechanism and the link reversal. Each node stores the information including the height list of neighbors and the link-status list. RTORA has some differences from TORA: The height of a node is defined as a 4-tuple (t, oid, v, id), which deletes the reflected bit. Once a node that is not the source node performs the link reversal, its height will be changed into NULL. The nodes with the height of NULL cannot participate in the routing updating until a new QRY arrives. Furthermore, the nodes receiving a CLR decide what to do according to various situations instead of direct deletion in TORA.

The main principle of routing maintenance is shown in Fig. 4. We call it reduced-overhead mechanism. All nodes receiving a UPD or CLR update the link-status list and the height list of their neighbors, and then check the link-status list. If another downlink exists, the nodes do nothing. Otherwise, the link reversal will be operated. If the node preparing to perform the link reversal is not the source node, it will change the height into NULL and send a CLR. On the other hand, the node having other neighbors without NULL will update its height to become the highest in the local area and send a UPD; the node having no other neighbors will create and send a new QRY.

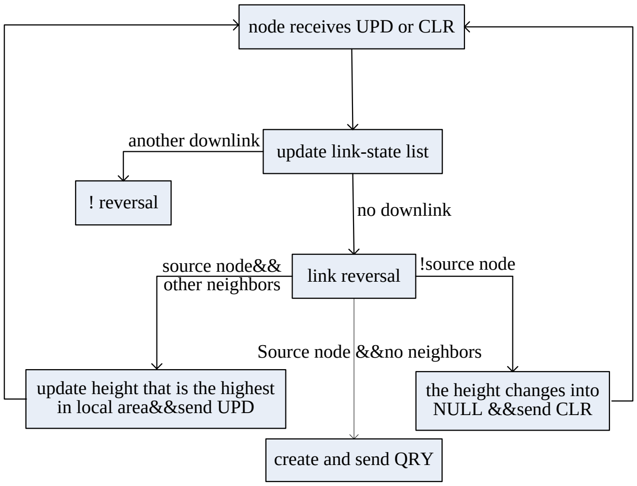

Figure 4. The reduced-overhead mechanism of RTORA

We still consider the example in Section III. The downlink from node C to node D is interrupted in Fig. 2. Node C changes the height into NULL and broadcasts a CLR. Because node B losing the downlink to node C has another downlink to node E, it deletes the information concerning node C in the link-status list without changing its own height or sending a CLR. The new topology is shown in Fig. 5.

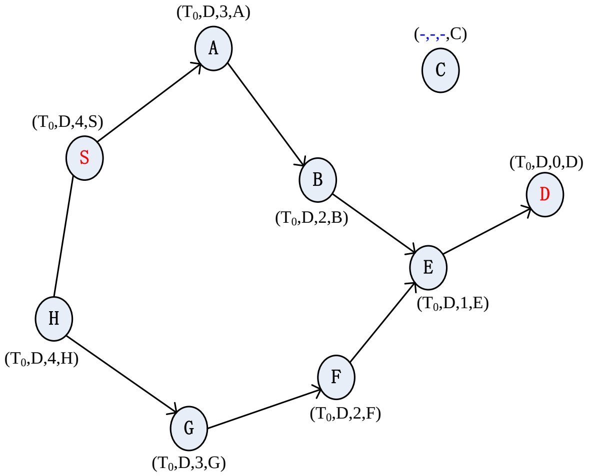

Figure 5. DAG of RTORA with new height of node C

If the downlink from node E to node D fails later, the sequence of events will happen as follows:

- Node E will replace the height by NULL, and send a CLR.
- Node B, F, C, A, G, H will change their heights into NULL.
- The source node S has no neighbors whose heights are not NULL, so it will delete routing information and broadcast a QRY to establish a new DAG.

The source node becomes a special node due to the change of the routing maintenance strategy. If we do not pay attention to this situation, a bad influence will appear. As shown in Fig. 5, we assume the downlink from S to A fails. Node S will change the previous height into NULL and send QRY to establish a route. But, in fact, node S only changes the height into S (T_0, D, 5, S), which is the highest in the local area. Then, a new transmission path (S-H-G-F-E-D) will be found quickly.

V. SIMULATION AND ANALYSIS

The network model is built and simulated by OPNET [13][14]. We assume that 30 UAV nodes are randomly deployed in an area of 4 square kilometers. In order to build a dense network, the communication radius of UAV is configured with the value of 400 meters. This will ensure that there are enough neighbors for every UAV node. The main parameters of TORA and RTORA routing protocols are given in Table I. These values are most often adopted in TORA simulation research.

TABLE I. MAIN PARAMETERS OF TORA AND RTORA

parameters	value
Mode of Operation	On demand
Beacon Period	3 second
Max Beacon Timer	30 second
Max Retries	3

A. *Traffic Configuration and Mobility Model*

Low-resolution video conferencing service is configured in the simulation. The source node generates a frame (128×120 pixels) at a rate of 10 frames per second. The values of main parameters are shown in Table II. The start-time is allowed for routing initialization. The random waypoint (RWP) mobility model is used where nodes move randomly in an area of 100 meters radius around its current position at the speed of 20 meters per second. The value of pause time is set to 0 second.

TABLE II. MAIN PARAMETERS OF TRAFFIC

parameters	value
Frame Interarrival Time Information	10 frames per second
Frame Size Information	128×120 pixels
Start Time	100 second
Duration	End of Simulation

B. *Performance Metrics*

In the swarm network with UAV nodes, node mobility will cause link failure. The routing reestablishment necessarily increases control overhead and delay. Furthermore, the congestion caused by the broadcasting of dense nodes will increase delay too. So we choose control overhead and average end-to-end delay as the global statistics to consider.

1) Control overhead; the number of bytes generated by routing discovery, routing establishment and routing maintenance in one second.

2) Average end-to-end delay; the delay caused by data transmitted from source nodes to destination nodes, including the waiting time of routing establishment, transmission and propagation delay.

C. Simulation Results

In order to guarantee the accuracy of the experimental results, five experiments with different simulation seed (100, 256, 512, 800, 1000) are run. The simulation time is set to 600 seconds. The results are shown in Fig. 6 and in Fig. 7, whose simulation seed is set to 512 (similar to other results with different simulation seed).

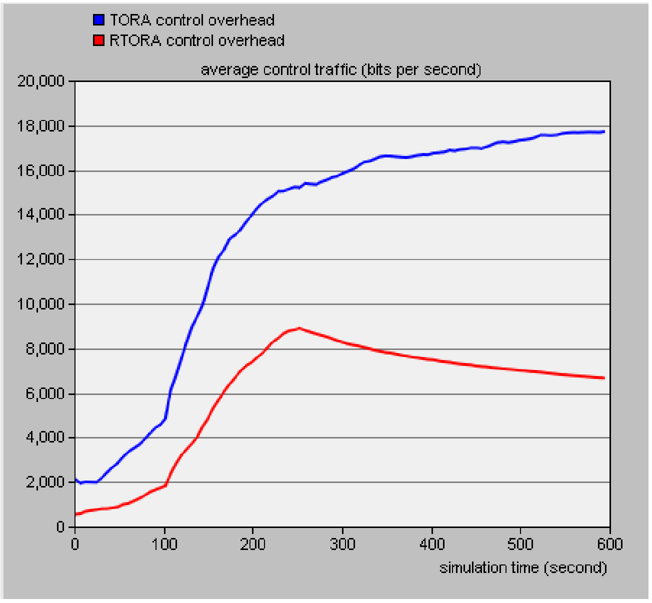

Figure 6. The control overhead of TORA and RTORA

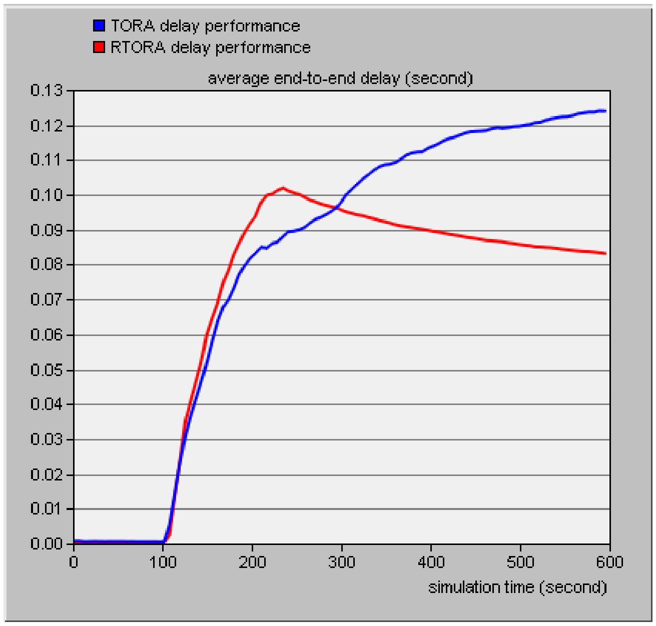

Figure 7. The average delay of TORA and RTORA

Fig. 6 shows that the control overhead of RTORA is reduced by about 56% compared with TORA, which can effectively improve network bandwidth utilization and reduce the probability of congestion caused by the communication overload. In Fig. 7, the delays of two protocols are close in the beginning, because the link reversal is successful when there are multiple paths. But with more link failures, the probability of link-reversal failure increases. In this situation, RTORA can quickly inform to the source to reestablish route and effectively reduce the control overhead. So the average delay is reduced by about 25% compared with TORA.

According to the above results, the routing maintenance strategy in RTORA plays the advantages of link reversal better. Regardless of success or failure of the link reversal, the protocol can quickly reestablish a new transmission path. Especially in the highly-dynamic networks, the probability of link failure and link-reversal failure greatly increases. If link reversal fails, the reduced-overhead mechanism in RTORA shortens the time of routing reestablishment and minimizes the control overhead. The routing update strategy in RTORA can avoid the flooding of control packets, so the probability of transmission congestion will be lower. Thus, RTORA further improves the delay performance of the network.

VI. CONCLUSION AND FUTURE WORK

In this paper, we analyze the characteristic of swarm network with UAV nodes, and discuss the shortcomings of current routing protocols. Based on the link reversal in TORA, we propose the RTORA protocol that adopts the so-called reduced-overhead mechanism and thus solves the problem resulting from the link-reversal failure in TORA. The simulation results show that RTORA has lower control overhead and better end-to-end delay performance in the harsh environment assumed. We will consider RTORA protocol using location-based information in the future work.

REFERENCES

[1] Y. Khamayseh, O. M. Darwish, and S. A. Wedian, “Ma-aodv: Mobility aware routing protocols for mobile ad hoc networks,” in Systems and Networks Communications, 2009. ICSNC’09. Fourth International Conference on, 2009, pp. 25–29, doi: 10.1109/ICSNC.2009.80.

[2] D. B. Johnson and D. A. Maltz, “Scalable support for transparent mobile host internetworking,” Wireless Networks, 1995, vol. 1, pp. 311–321, doi: 10.1007/BF01200849.

[3] C. E. Perkins and E. M. Royer, “Ad-hoc on-demand distance vector routing,” in Mobile Computing Systems and Applications. Proceedings. WMCSA’99. Second IEEE Workshop on, 1999, pp. 90–100, doi: 10.1109/MCSA.1999.749281.

[4] V. D. Park and M. S. Corson, “A highly adaptive distributed routing algorithm for mobile wireless networks,” in INFOCOM’97. Sixteenth Annual Joint Conference of the IEEE Computer and Communications Societies. Proceedings IEEE, 1997, vol.3, pp. 1405–1413, doi: 10.1109/INFCOM.1997.631180.

[5] M. Kassim, R. Ab Rahman, and R. Mustapha, “Mobile ad hoc network (MANET) routing protocols comparison for wireless sensor network,” in System Engineering and Technology (ICSET), 2011 IEEE International Conference on, 2011, pp. 148–152, doi: 10.1109/ICSEngT.2011.5993439.

[6] P. Kuppusamy, K. Thirunavukkarasu, and B. Kalaavathi, “A study and comparison of OLSR, AODV and TORA routing

protocols in ad hoc networks," in Electronics Computer Technology, 2011 3rd International Conference on, 2011, vol. 5, pp. 143–147, doi: 10.1109/ICECTECH.2011.5941974.

[7] Z. Che-Aron, W. F. M. Al-Khateeb, and F. Anwar, "ENFAT-AODV: The fault-tolerant routing protocol for high failure rate Wireless Sensor Networks," in Future Computer and Communication (ICFCC), 2010 2nd International Conference on,2010,vol.1,pp.V1–467,doi:10.1109/ICFCC.2010.5497747.

[8] J. Liu and F. Li, "An improvement of AODV protocol based on reliable delivery in mobile ad hoc networks," in Information Assurance and Security, 2009. IAS'09. Fifth International Conference on, 2009, vol. 1, pp. 507–510, doi: 10.1109/IAS.2009.78.

[9] V. Ramesh and P. Subbaiah, "Preemptive AOMDV routing for mobile Ad-hoc networks," in Sustainable Energy and Intelligent Systems (SEISCON 2011), International Conference on, 2011, pp.622–625, doi: 10.1049/cp.2011.0436.

[10] D. K. Sharma, C. Kumar, S. Jain, and N. Tyagi, "An enhancement of AODV routing protocol for wireless ad hoc networks," in Recent Advances in Information Technology (RAIT), 2012 1st International Conference on, 2012, pp. 290–294, doi: 10.1109/RAIT.2012.6194522.

[11] D. Dharmaraju, A. Roy-Chowdhury, P. Hovareshti, and J. S. Baras, "INORA-a unified signaling and routing mechanism for QoS support in mobile ad hoc networks," in Parallel Processing Workshops. Proceedings. International Conference on, 2002, pp. 86–93, doi: 10.1109/ICPPW.2002.1039716.

[12] F. Yu, Y. Li, F. Fang, and Q. Chen, "A new TORA-based energy aware routing protocol in mobile ad hoc networks," in Internet, 2007. ICI 2007. 3rd IEEE/IFIP International Conference in Central Asia on, 2007, pp.1–4, doi: 10.1109/CANET.2007.4401666.

[13] M. Rajput, P. Khatri, A. Shastri, and K. Solanki, "Comparison of Ad-hoc reactive routing protocols using OPNET modeler," in Computer Information Systems and Industrial Management Applications (CISIM), 2010 International Conference on, 2010, pp. 530–534, doi: 10.1109/CISIM.2010.5643454.

[14] X. Chang, "Network simulations with OPNET," in Simulation Conference Proceedings, 1999 Winter, 1999, vol. 1, pp. 307–314, doi: 10.1109/WSC.1999.823089.