ANALYTICAL MODELLING OF COMMUNICATION OVERHEARING FOR ROUTE FAILURE RECOVERY IN MOBILE AD HOC NETWORKS

MOHAMMAD M. KADHUM

National Advanced IPv6 Center (NAv6), Universiti Sains Malaysia (USM), 11800 Pulau Pinang, Malaysia
Telecommunication Research Laboratory, School of Computing, Queen's University, K7L 3N6 Kingston, ON, Canada
E-mail: kadhum@usm.my, kadhum@cs.queensu.ca

Abstract- MANETs have been utilized for data acquisition in many critical domains including emergency search-and-rescue, policing, and military operations. The characteristics of MANETs pose some issues such as high error rate and arbitrary power consumption. Random mobility nature of nodes in MANETs causes frequent irregular changes in the network topology resulting in communication disruption. Several routing protocols have been developed to cope with such problems, where the backup routes are created primarily during initial routes discoveries. However, those routes do not reflect the topology changes appropriately; hence, there is a very low chance of using them. The availability of information about a link on an active route before the breakage happens would help in restoring the active route before it becomes unobtainable. This can reduce packet loss and improve the network performance. This paper shows the benefit of utilizing the overhearing of communications for such purpose.

Keywords- Wireless Mobile Ad Hoc Network, Link Failure, Route Maintenance, Routing in Wireless Networks

I. INTRODUCTION

The simple deployment capabilities of Mobile Ad Hoc Mobile Networks (MANETs) have paved the way for new solutions for infrastructureless environments. However, MANETs have several characteristics such dynamic topologies, variable throughput, limited bandwidth, limited transmission range, energy constraint, limited physical security that pose some issues for instance high error rate and arbitrary power consumption. A MANET is formed of self-configuring, mobile, wireless nodes that communicate to relay data exchanged between nodes that are out of the radio transmission range of each other. Thus, mobile nodes can act as sender, receiver, or relay (forwarder). Multi-hop communication drives mobile nodes that act as relays to discover and maintain routes to certain destinations whenever required. The random mobility nature of nodes in MANETs causes frequent irregular changes in the network topology resulting in communication disruption. To cope with such problems, several peer-to-peer routing solutions have been developed for MANETs using multi-hop communications. These solutions are generally classified into three classes:

- Proactive routing (table-driven) protocols such as Destination-Sequenced Distance-Vector Routing protocol (DSDV) [1], Optimized Link State Routing (OLSR) [2], and Dynamically Self-adjustable Proactive Routing [3]. Protocols in this class attempt to maintain routing to every node in the network. So as to maintain a global view of the network when topology change takes place, routing information updates are propagated throughout the whole network. Thus, the network becomes vulnerable due to high usage of the capacity for maintaining up-to-date routing information that might never be used.
- Reactive routing (on-demand) protocols, such as Signal Stability based Adaptive routing (SSA) [4], Ad Hoc On Demand Distance Vector (AODV) [5], Dynamic Source Routing (DSR) [6], Temporally Ordered Routing Algorithm (TORA) [7], are source-initiated on-demand protocols that produce routing information only when it is needed. When a route to a certain destination is required, route discovery operation will be initiated by the demanding node. Once a route is found, it will be maintained by the route maintenance mechanism. Although reactive protocols are better suited for MANETs, as require less overhead and power consumption than proactive ones, but they suffer from high latency in finding routes and their excessive flooding can lead to considerable overhead.
- Hybrid routing protocols, such as Zone Routing Protocol (ZRP) [8], initially establish routing with some proactively searched routes and then serves the demand from additionally activated nodes through reactive flooding. The choice of one or the other method requires predetermination for typical cases. The disadvantages of these protocols include that advantage depends on number of other nodes activated; and reaction to traffic demand depends on rate of change in traffic volume [9].

II. LINK FAILURE RECOVERY

In MANETs, mobility of nodes can cause link failure on the active route established for transferring data between a sender-receiver pair. Thus, the active route would be broken and the routing protocol should take action to recover the broken route, or discover another one where interested nodes should be aware of such topology change. Usually, routing protocols react to route failure differently according to their design objectives. For instance, in DSR, a complete ordered list of nodes that a packet goes through should be included in the packet header. Once a link on the active route broken, the upstream node sends a route error (RERR) message all the way back to the packet sender. Upon the receiving of RERR, the sender would remove all routes that include the causing node (the downstream node of the broken link) from its cache. The sender then would start a new route discovery or uses another route to that specific receiver from the cache [10]. Conversely, AODV requires that the upstream node tries to restore the broken route by initiating Route Request (RREQ) to its neighboring nodes. However, more data packets would be lost if the route recovery fails.

To put it briefly, the common routing protocols (AODV and DSR) do not react to link failure phenomenon timely and when they do, they flood the whole network with RREQs resulted of new route discoveries. Several research works [11-16] were proposed to improve those protocols to overcome the aforementioned limitations; typically by caching additional backup routes, found during route discoveries, to be used later when link failure occurs. However, as the reserved routes are found mostly through earlier routes discoveries, they not reflect the topology changes appropriately; hence, there is a very low chance of using them. Having information about a link before it actually fails, would be useful in predicting the near future condition of the link; and thus, avoiding active route breakage, taking into account the assistance from overhearing nodes. Overhearing communication can be of benefit in recovering the active route or building a new route before the current active route becomes unavailable and packet loss takes place. The goal of this paper is to model the utilization of overhearing communications in the recovery of an active route and show how this concept could enhance the routing process in MANETs and overcome the shortcomings related to the route maintenance in source routing protocols. It would make source routing protocols more effective, and hence, improve the network performance to a great extent. The rest of the paper is organized as follows; Section 3 presents an innovative route failure recovery approach that is based on overhearing communications. Section 4 illustrates the analytical modeling that shows the effectiveness of the route recovery process. The experimental evaluation including simulation setup and results discussion is demonstrated in Section 5. Finally, conclusions and some potential future work are presented in Section 6.

III. OVERHEARING-BASED ROUTE RECOVERY APPROACH

This section presents the proposed approach for source routing in MNAETs. The technical objective of the overhearing-based route recovery approach is to predict the route breakage and try to maintain the current active route by utilizing links from neighbouring nodes who overhear the established communications on that route. A prediction mechanism is used to estimate the link status and when a failure might happen. According to the output of this mechanism, if there is a high potential that a link failure will occur soon, a route recovery procedure will be triggered to maintain the route.

3.1 Link Failure Estimation

The link failure estimation mechanism uses the signal strength of two communicating nodes on the path to predict whether they are going to be disconnected soon. The function of signal strength (s), operated by an intermediate node (denoted n), collects information about the condition of a link between two nodes (node n and n-1) on the way towards the receiver using the beacon received from node n-1. The transmission range of any node in the network is divided in zones; Zone 1, Zone 2, and Zone 3, as shown in Figure 1. Based on the Received Signal Strength Indicator (RSSI), s value is compared to two predefined thresholds (R/2 and 3R/4) and categorized into strong, normal, and weak signal; and then mapped the corresponding zone [11]. Thus, for node n, the downstream node n-1 is believed to be located in Zone1 if $s \leq R/2$, or in Zone 2 if $R/2 < s < 3R/4$, or in Zone 3 if $s \geq 3R/4$. Similarly, node n-1 implements that process to estimate its location with respect to the node n (the upstream node).

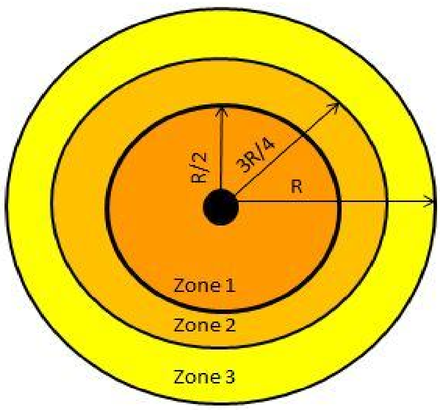

Figure 1. Transmission range zones (adapted from [11])

For link failure prediction, when a node n_i -1is about to go out of the range of the upstream node, it sends beacons to node n_i (the upstream node that receives packets from). Based on the signal strength s, node n_i checks the connectivity to node n_i -1. If there is a probability that node n_i -1is moving out of the transmission range soon, n_i tries to maintain the active route or sends a notification to the sender if maintaining the route seems impossible. Node n_i is uses two thresholds to make its decisions:

- R/2 (called $inst_{thr}$) is the value after which node n_i needs to compute its instantaneous velocity with respect to its downstream node n_i -1 in order to obtain the movement information (speed and direction) of node n_i -1.
- 3R/4 (called $beacon_{thr}$) is the value at which node n_i starts router recovery process.

3.1 Route Recovery

The broadcast nature of communications in MANETs allows nodes to overhear the communication between neighbouring nodes that are within the transmission range. Mobile nodes that are close to an active route may overhear the data packet transmission on that route. Thus, they can collect some information of the travelling packets, which can be used for route recovery. This information also helps in deciding whether overhearing nodes are appropriate for the route recovering. An overhearing node checks the packet header for information about the nodes involved in the active route toward the receiver. It compares the IDs of the nodes, from where it overheard and onward, to nodes in its catch. If there is a common node, it stores an association of common_node-receiver in its cache to be used later for forwarding data packets to toward the receiver when link failure about to happen. Hence, the control overhead resulted from flooding RREQs for discovering new routes can be reduced significantly. .

When node n_i predicts that there is a possibility that a link failure is going to take place soon, it triggers the recovery process by sending RREQ packets to neighbouring nodes. Every neighbour M receives the RREQ checks its association information on whether it has a path to the receiver. If it does, its sends a Route Reply (RREP) packet back to n_i, which in turn, notifies the sender in order to include M in the header of the next generated packets and exclude the node causing the failure. Else, node M will forward the RREQ to its neighbours and so on, until a node that is close to the receiver is found. If useful information is received, n_i sends a RERR packet to the sender after the link failure is actually happened, so that the sender would initiate a new route discovery to the receiver.

IV. ANALYTICAL MODELLING OF COMMUNICATION OVERHEARING

In order to measure the efficiency of the route recovery process, analytical modeling is used to capture the dynamics of route recovery procedure and to gain further insight into the behavior of the protocol implementing this approach. Therefore, in this section, a theoretical analysis that is derived from a Random Geometric Graph (RGG) is presented to characterize a MANET.

Let a geometric graph G(n,r) represents a MANET with n mobile nodes deployed in 2-dimension space R^2 (each mobile node is located at some random position in $[0,1]^2$ selected uniformly at random.), where r denotes the transmitting distance. We assume that the distribution of mobile nodes follows a Poisson distribution; as in Poisson process, the number of nodes can only be a random number, which satisfies the nature of MANETs where nodes mobility drives them to be part of routes or away from communication range. An edge $E_{u,v}$ connecting every two mobile nodes (vertices) u and v at distance $d(u,v) \leq r$, where d(.,.) denotes the Euclidean distance between node u and node v . Let $V_k = \{v_1, v_2, \ldots, v_k\}$ be the random variable representing the number of independently and identically distributed (i.i.d.) mobile nodes in a specific zone z of the network area (that is, $v_1, v_2, \ldots, v_k \in [0,1]^2$ i.d.d.). Let $w(V_k,r,z)$ denotes the RGG used to model a MANET of k nodes on V_n with transmission range r and deployed in a rectangle zone area z . Each vertex in $w(V_k,r,z)$ represents a mobile node and each edge connecting every two mobile nodes (vertices u and v $(u \neq v)$) represents the communication link between them when they are within the radio communication range of each other if $\|u-v\| \leq r$. Figure 2 illustrates a MANET (formed of seven nodes with transmission range of r deployed in a rectangle zone z) and its corresponding RGG. If the transmission ranges of any pair u and v (modeled by a circle in Figure 2) are equal, then when they are within the transmission range of each other, they are called properly connected. As the communication between the nodes exists, the sender node can send data to the receiver node through multi-hops.

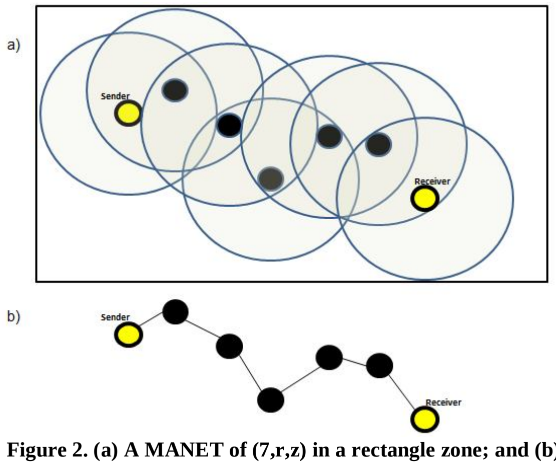

Figure 2. (a) A MANET of (7,r,z) in a rectangle zone; and (b) its associated RGG $w(V_7,r,z)$

In other words, if the circle of node u (transmission range) includes the center of any other node v, then they are properly intersected.

Definition1. The overlapping area A (lens) of the properly intersected circles of nodes u and v with the same radius r can be expressed by:

$$A = \begin{cases} 2r^2 cos^{-1}\left(\frac{d}{2r}\right) - \frac{d}{2}\sqrt{4r^2 - d^2} & \text{for } 0 \leq d \leq 2r \\ \text{or} \\ \pi - (3\sqrt{3}/4)\, r^2 \end{cases} \quad (1)$$

The estimation of the number of neighbor nodes overhearing the communication of any pair nodes u and v is as follows:

Proposition 1. For any edge (communication link) between any pair nodes u and v in a $w(V_k,r,z)$, the number of neighbor nodes N_{nbr} fall inside the overlapping area A of u and v is $N_{nbr} = V_k \times A / |z|$, where V_k is the number of mobile nodes and z is the zone area where nodes are deployed randomly.

Proof. Given two mobile nodes u and v with the same transmission range r (represented by circles) in a $w(V_k,r,z)$, the area formed by the intersection of overlapping circles whose centers are within the others is A (given by Equation 1). For the three distinct edges $E_{u,v}$, $E_{u,w}$, $E_{v,w}$ in $w(V_k,r,z)$, where $u \neq v \neq w$, if C(C') is the circle that its center is v(w) with radius r , then, by Definition 1, the probability of that u falls in A of the two circles C and C' is.

$$\Pr(E_{u,v}, E_{u,w} \mid E_{v,w}) = A / |z| \tag{2}$$

Thus, we have the number of neighbor nodes N_{nbr} fall inside the overlapping area A of u and v is $N_{nbr} = V_k \times A / |z|$, where V_k is the number of randomly deployed mobile nodes and z is the deployed area.

As nodes in MANETs move randomly and unpredictably, every link on a route has the same probability of failure due to mobility. Let P_{bs} denote the probability of that a link on an active route will be broken soon; and P_{rc} denote the probability of that a route is successfully recovered (maintained) upon the link prediction. The following proposition presents a bound of the probability of a successful route recovery in the proposed approach.

Proposition 2. There is $P_{rc} \geq 1 - (P_{bs} \times (2 - P_{bs}))^{Nnbr}$ in a $w(V_k,r,z)$, where $N_{nbr} = V_k \times A / |z|$ and V_k is the number of randomly deployed mobile nodes, A is the overlapping area of the transmission range of nodes, and z is the deploying area.

Proof. In general, G'(V',E') is a subgraph G(V,E) if all of its vertices $V' \subseteq V$ and edges $E' \subseteq E$. A graph G' is called an induced subgraph of G if every edge of G connecting vertices of G' is an edge of G'. Thus, each of the nodes of the induced subgraph G' together with nodes u and v form an induced cycle on three vertices (of length 3). These nodes create M disjoint routes of length 2 as a potential alternative routes, as shown in Figure 3. If the communication link between u and v ($E_{u,v}$) on the active route about to be broken soon in a $w(V_k,r,z)$, there is high possibility to use the neighbouring nodes N_{nbr} of both nodes u and v to maintain the active route. By Proposition 1, the number of neighbor nodes N_{nbr} in the overlapping area A of u and v is $N_{nbr} = V_k \times A / |z|$. Therefore, the probability of recovering P_{rc} the active route is:

$$P_{bs} + (1- P_{bs}) \times P_{bs} = P_{bs} \times (2- P_{bs}) \tag{3}$$

It is because of that route recovery is related to the successful prediction process of the failure of any link on the active route. Thus, as there are M potential alternative disjoint routes, the failure of maintaining the active route at the link $u \rightarrow v$ ($E_{u,v}$) occurs when all M potential disjoint routes fail. Hence, we have the result $P_{rc} \geq 1 - (P_{bs} \times (2- P_{bs}))^{Nnbr}$.

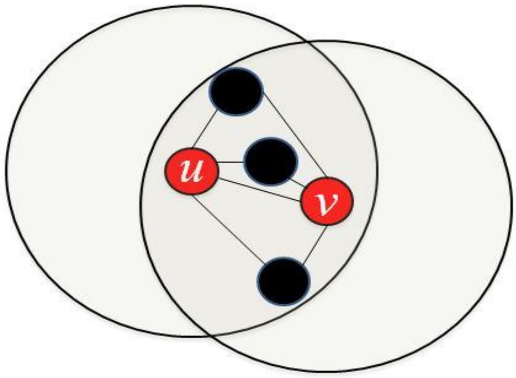

Figure 3. A communication link between nodes u and v with common neighbours who can overhear the communications

V. EXPERIMENTAL EVALUATION

To validate the theoretical analysis of the proposed route recovery approach and to observe how the routing protocol operates under a given situation, a MANET of 400 nodes was simulated using Network Simulator 2 (ns2.35). The number of nodes is chosen to mimic different scenarios such as airport, shopping malls, conferences, and emergency situations where MANETs are used. Nodes move randomly in an area of 850m∗ 2300m with speed accelerating from 1m/sec to maximum speed of 18m/sec with random pause time from 0 to 40sec; and the transmission range of the node is 130m. Random Way Point (RWP) algorithm [12] was used for generating random movement of nodes. In order to properly estimate packet loss, delay, and throughput, simulation experiments were run for 800 seconds. However, the first and last 100 seconds of the simulation time were not considered in the result analysis as it is assumed that the system was in the steady state. 60 to 70 nodes were randomly selected to establish connections for sending CBR data packets to their corresponding receivers, with a transmission rate of 0.2Mbps and packet size of 512bytes. Each of the simulation experiments was repeatedly run for 20 times to confirm that packet loss occurs because of the delay of delivering the notification of the alternative path and not due to the unavailability of alternative routes to the receivers.

The evaluation results been analysed in terms of accomplished route recovery ratio, packet delivery ratio, and control packet overhead with respect to the nodes mobility and link failure events that were occurred during the simulation. As the proposed approach is designed based on source routing, the evaluation results were compared to that of DSR routing protocol.

4.1. Route Recovery Ratio

During the simulation run, it was perceived that the probability of predicting a link failure on an active route is 0.8. That is, (P_{bs} = 0.5) is the probability of that a link failure is going to happen soon, Given V_k = 400, r = 130, and z = 850m × 2300m, we have $N_{nbr} = V_k \times A / |z| = 400 \times 31138.25 / (850 \times 2300) \approx 6.37$. This shows that for each link on an active route, there are around six backup routes. Thus, by Proposition 2, the probability P_{rc} of recovering an active route is $P_{rc} \geq 1 - (P_{bs} \times (2 - P_{bs}))^{Nnbr} = 1- (0.5 \times (2 -0.5))^{6.37} \approx 0.84$. This confirms that more than 80% of the possibly broken routes can be recovered using the proposed approach, eliminating the flood of RREQs initiated by the sender and the loss of data packets resulted from the link failure. Figure 4 shows the rate of effective route recoveries with respect to pause time.

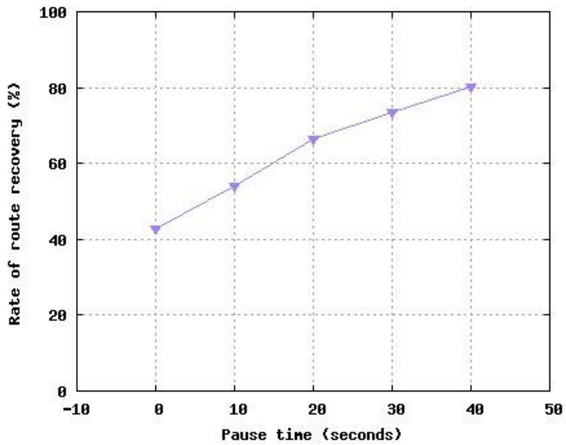

Figure 4. Route recovery rate with respect to pause time

The results proved that active routes can be recovered in average of 63% of all experiments of the simulation scenarios. From the figure, it is obvious that the rate of successful route recovery increases as the pause time increases. The reason is that, for longer pause time, the network is stable and topology changes are no likely to take place.

4.2. Packet Delivery Ratio

The results of PDR observed for both of the proposed approach and DSR are shown in Figure 5. It is clear that the proposed approach presents better PDR compared to that of DSR. For high node mobility (low pause time), PDR of DSR is degraded significantly. It is because of the rapid topology changes and the process that DSR follows when a link failure occurs. DSR is supposed to offer better PDR as it can detect the link failures by utilizing the feedback provided by the link layer, which helps in reducing packet loss. However, DSR link failure detection procedure is initiated only after the link failure is already happened. This justifies the poor performance of DSR in regard to PDR. On the other, operating the link failure prediction in the proposed approach provides early detection that can enable the concerning node to take a prompt action early enough to avoid route breakage. When it is perceived that a link failure is going to happen soon, the concerning node would utilize the overhearing neighbouring nodes to recover the current active route.

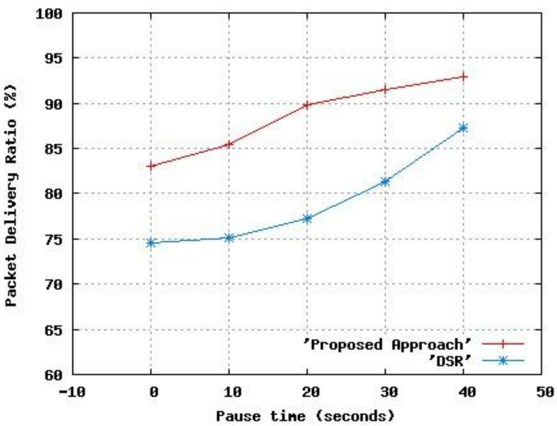

Figure 5. PDR gained by the proposed approach and DSR

4.3. Control Packet Overhead

Figure 6 presents the control packets produced by the proposed approach and DSR. From the figure, it is clear that the routing overhead is reduced considerably when using the proposed approach as it performs much lesser route discoveries compared to that of DSR. This is because of the route recovery technique and link failure prediction mechanism it uses which confirms the assumption that early prediction of potential link failure helps in avoiding unnecessary packet drops and overflowing the entire network with routing packets to find other new routes. The principles of failure detection theory require that communication systems must promptly respond to unexpected changes in the connectivity. The results in Figure 6 show that DSR presents slow reaction under frequent topology changes situation. Whenever link failures happen, DSR operates route switching which include route breakage detection, new route discovery, and sending data through the new route to the corresponding receiver. That is why a high control overhead is produced by DSR compared with the proposed approach.

.

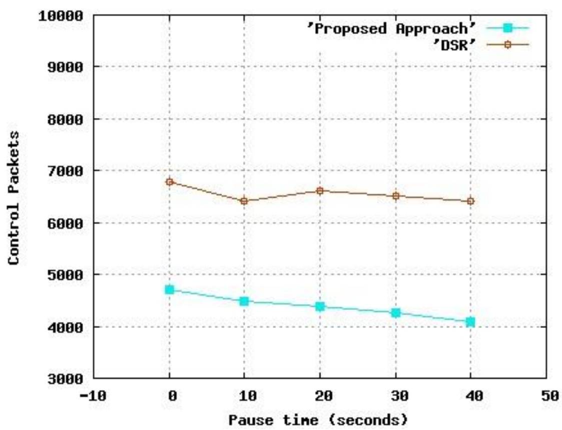

Figure 6. Number of control packets produced by the proposed approach and DSR

CONCLUSIONS

In this paper, we have presented the analytical modelling of how communication overhearing can be of great benefits for route failure recovery in mobile ad hoc networks. Based on the theoretical modelling, a source routing overhearing-based route recovery approach was presented. It aims at predicting the link failure and maintaining the active route. It was demonstrated how link failure prediction can enhance the connection stability in MANETs. We have validated the theoretical modelling through simulations. The experimental results showed that the proposed approach outperforms DSR in medium-sized highly dynamic network. It was proved that the proposed approach is capable of timely recovering routes with much less control packets requirement. It was revealed that the proposed approach presents better PDR and lower control overhead compared to DSR. Result analysis was done with respect to the rate of link failures events due to nodes mobility. In future work, we are going to develop an enhanced source routing discovery mechanism to be integrated with the proposed approach and evaluate the combination in large scale MANETs.

ACKNOWLEDGEMENTS

The author would like to thank Univeristi Sains Malaysia for supporting the publication of this work under grant no.1001/PNAV/814233.

REFERENCES

[1] Perkins, C. E., & Bhagwat, P. (1994, October). Highly dynamic destination-sequenced distance-vector routing (DSDV) for mobile computers. In ACM SIGCOMM computer communication review (Vol. 24, No. 4, pp. 234-244). ACM.

[2] Clausen, T., Jacquet, P., Adjih, C., Laouiti, A., Minet, P., Muhlethaler, P., & Viennot, L. (2003). Optimized link state routing protocol (OLSR).

[3] Belghith, A., & Abid, M. A. (2009, October). Dynamically self adjustable proactive routing protocols for mobile ad hoc networks. In 34th Conference on Local Computer Networks, 2009. LCN 2009. IEEE (pp. 506-513).

[4] Dube, R., Rais, C. D., Wang, K. Y., & Tripathi, S. K. (1997). Signal stability-based adaptive routing (SSA) for ad hoc mobile networks. Personal communications, IEEE, 4(1), 36-45.

[5] Perkins, C., Belding-Royer, E., & Das, S. (2003). Ad hoc on-demand distance vector (AODV) routing (No. RFC 3561).

[6] Johnson, D., Hu, Y., & Maltz, D. (2007). The dynamic source routing protocol (DSR) for mobile ad hoc networks for IPv4 (No. RFC 4728).

[7] Park, V., & Corson, M. S. (1997). Temporally-ordered routing algorithm (TORA) version 1 functional specification (pp. 2-6). Internet-Draft, draft-ietf-manet-tora-spec-00. txt.

[8] Haas, Z. J., Pearlman, M. R., & Samar, P. (2002). The zone routing protocol (ZRP) for ad hoc networks.

[9] Haas, Z. J., & Pearlman, M. R. (2001). The performance of query control schemes for the zone routing protocol. IEEE/ACM Transactions on Networking (TON), 9(4), 427-438.

[10] Goyal, D., & Tripathy, M. R. (2012, January). Routing protocols in wireless sensor networks: a survey. In Second International Conference on Advanced Computing & Communication Technologies (ACCT), 2012 (pp. 474-480). IEEE.

[11] Khudayer, B. H., Kadhum, M. M., & Chee, W. T. (2015). Topology-aware mechanism to improve routing in mobile ad-hoc networks. In the 2015 International Conference on Machine learning and Signal Processing (MALSIP), 15 to 17 December, 2015 in Melaka, Malaysia, 2015. ACCEPTED.

[12] Kumar, P. N. (2013, July). A novel method to avoid stale route cache problem of dynamic source routing protocol for mobile ad hoc network. In International Conference on Current Trends in Engineering and Technology (ICCTET), 2013, (pp. 167-170). IEEE.

[13] Kumar, R., & Arya, K. V. (2011, October). A Modified approach for route maintenance using Alternate Path in AODV. In International Conference on Computational Intelligence and Communication Networks (CICN), 2011, (pp. 37-41). IEEE.

[14] Jeon, J., Lee, K., & Kim, C. (2011, January). Fast route recovery scheme for mobile ad hoc networks. In International Conference on Information Networking (ICOIN), 2011, (pp. 419-423). IEEE.

[15] Jaisankar, N., & Saravanan, R. (2010). An extended AODV protocol for multipath routing in MANETs. International Journal of Engineering and Technology, 2(4), 394.

[16] Ngo, H. P., & Kim, M. K. (2012). MRFR-Multipath-based routing protocol with fast-recovery of failures on MANETs. KSII Transactions on Internet and Information Systems (TIIS), 6(12), 3081-3099.

[11] Kadhum, M. M. (2015, November). Innovative route maintenance based on link failure prediction for Mobile Ad Hoc Networks. In Telecommunication Networks and Applications Conference (ITNAC), 2015 International (pp. 59-64). IEEE.

[12] Bettstetter, C., Resta, G., & Santi, P. (2003). The node distribution of the random waypoint mobility model for wireless ad hoc networks. IEEE Transactions on Mobile Computing, 2(3), 257-269.

★★★