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An Adaptive Mechanism to Optimise Routing Performance in Mobile Adhoc Networks

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ABSTRACT

The primary goal of a MANET routing protocol is to provide a stable and efficient route to exchange messages between source and destination in a timely manner. This paper proposes an adaptive mechanism, namely Optimised Border node based Most Forward within Radius (OBMFR) mechanism to improve the method of choosing forwarding nodes towards the destination. The routing constraints such as region, mobility speed, residual energy and queue length are utilised by fuzzy logic controller to elect the potential forwarding node to improve the stability of routing paths. The performance metrics such as delay, routing overhead and energy consumption are significantly reduced as inferred from NS2 simulation.

Keywords: Fuzzy logic, MANET, NS2, overhead, routing protocol

INTRODUCTION

Mobile Adhoc NETwork (MANET) belongs to the family of wireless adhoc networks which finds application in a wide range of hostile environments, where human access is limited or unfeasible (Conti et al., 2014). A rising interest in MANETs research has been observed mainly due to its issues in routing, broadcasting, QoS, connectivity, safety and security (Boukerche et al., 2011 and Swain et al., 2017). In the routing protocols design, the issues such as dynamic network topology, recurrent network partition, irregular demography and density are to be considered. Due to these issues, MANET routing protocols are incapable of adopting conventional routing techniques in adhoc-networks (Guptha et al., 2011).

Topology and Position based routing are the two broad categories of routing protocols in MANET (Husain et al., 2011). The topology-based approach utilises information about communication path to transmit data from source to destination. It is further divided into

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three types: (i) Proactive (Table Driven) (ii) Reactive (On Demand) and (iii) Hybrid routing protocol. Proactive routing protocol makes routing decision with the help of routing tables which has network connectivity information in the form of tables. Since the routing table is frequently updated, it contains up-to-date connectivity information thus minimizing route discovery time. However, the overhead due to upgrading and maintenance of the routing tables is inevitable, especially in highly dynamic network (Taha et al., 2017).

To minimise such difficulties, the reactive routing protocols trigger the route discovery process when it is required, thereby minimising traffic on the network. Since the route discovery process needs to be started before data can be exchanged between source and destination pairs, it imposes a delay for the first packet to be transmitted. Moreover, if the network topology is frequently changed, then significant amount of routing control packets is to be exchanged (Hong et al., 2002).

Hybrid routing protocols have emerged to address the efficiency and scalability of routing protocols (Royer & Toh, 1999). Proactive routing component is used locally and reactive component is used globally to achieve benefits of both the protocols. Limitation of hybrid protocols is that they are not recommendable for highly mobile nodes, dynamically changing topology and large network size. Position-based routing protocols use periodic beacons to generate position information for routing. As routing is based on the position of the forwarding node and the destination node, unlike other routing protocols, it does not require establishment of the route or maintenance of the route (Mauve et al., 2001).

In this paper, an adaptive position-based routing is proposed to enhance selection of the best forwarding nodes. As multiple routing constraints such as region, mobility speed, residual energy and buffer size, are considered in this proposed work, a fuzzy logic controller is used to facilitate the selection process. The rest of the paper is structured as follows: Section 2 gives the overview of the related protocols found in the literature. In Section 3, the proposed methodology is elaborated by emphasising the next hop selection procedure. Section 4 analyses the performance of the proposed algorithm using NS2 simulation results. Finally, the paper is concluded in Section 5.

RELATED WORK

In this section, some of the existing position-based routing algorithms are discussed. Location Aided Routing (LAR) (De Rango et al., 1998), uses Global Positioning System (GPS) to gather local information to facilitate route discovery process. It uses partial flooding of control packets to enhance the route discovery phase. Three variants of LAR are proposed (Ko & Vaidya, 2000). The aim of the work is to enlarge the size of *request zone* when route discovery fails rather than using flooding. Modified LAR retains the advantages of original LAR with respect to delay and packet loss. In addition, it decreases control overhead.

Probabilistic rebroadcasting scheme in QoS-Aware node Selection Algorithm (QASA) (Mostafaa et al., 2014) utilises node density, distance and transmission range to elect the preferred next hop node. Among these factors, transmission range may be changed based on the application requirement. Similar to QASA, the factors, density and distance between previous hop and current receiving node are used (Bae et al., 2013) as the fuzzy inputs to calculate rebroadcast degree.

A cross layer approach along with Position based forwarding technique is used (Patil et al., 2009) to improve the performance of Adhoc On-demand Distance Vector (AODV) Routing. Medium Access Control (MAC) layer estimates the signal strength of received packets. If the received packets have lesser signal strength than the threshold value, then MAC layer reports the network layer of the node. The network layer removes such nodes from the routing table. It excels than AODV in terms of latency, throughput and control overheads. The limitations include routing table overhead and the layer message overhead due to cross layer design.

Fuzzy logic approach is suggested (Babu et al., 2012) with fuzzy inputs, such as remaining energy, trust level and distance to determine the priority level. The node which has higher priority level is selected as forwarding node among many worthy nodes. From the simulation results, it has been shown that the lifetime of nodes and hence network lifetime is increased by electing appropriate forwarding node. Energy-Efficient Opportunistic Routing (EEOR) (Mao et al., 2011) selects a forwarder set. The nodes in forwarder set are prioritised using energy saving optimization technique. It mainly focuses on energy efficiency of individual node and did not consider the residual energy of other relaying nodes in the network. To overcome this problem, ENergy Saving via Opportunistic Routing (ENS-OR) algorithm is proposed (Luo et al., 2015). Using optimal energy strategy, the set of forwarding nodes are prioritised to protect the nodes with low residual energy. Based on the distance to the destination and residual energy, the optimal relay node is chosen among the potential forwarding nodes. From the simulation results, it has been shown that ENS-OR reduces energy consumption, thus, maximising network lifetime.

Position Based Multicast Routing Protocol for Ad-hoc Network Using Backpressure Restoration (PBMRP-BR) (Daniel et al., 2010) works for multimedia specific applications in Ad-hoc network. Here, routing is priority based in terms of route length, traffic and bandwidth, hence this information about each node is maintained for routing decisions. Among these parameters, route length has the highest priority whereas traffic load has the lowest priority. If there is more than one optimum path, then the tie is broken based on priority. Backpressure technique is used to deal with deteriorating QoS due to link failure. The PBMRP-BR protocol is better than DSR scheme as it provides higher reliability and lower overhead through Backpressure Restoration. It offers higher bandwidth utilisation and reduces congestion. The PBMRP is suitable for one-to many multicast scenarios.

Beacon-less Routing Algorithm for Vehicular Environments (BRAVE) is developed (Ruiz et al., 2010) based on beacon-less geographic routing. BRAVE executes hop-by-hop data forwarding after opportunistically selecting the next hop node using beaconless geographic routing. It makes use of a reactive scheme in which instead of performing periodic beacons, forwarding decisions are based on the position of the neighbors. Once the current node has forwarded the data packet, the next forwarding node is selected among the nodes which have received the packet correctly. The node which responds first is selected as the next hop node.

Reactive Virtual Cord Protocol (RVCP) (Awad et al., 2011) is a virtual location-based routing protocol that is reactive and uses Distributed Hash Table (DHT) like services for joining nodes and its selection as forwarding nodes. Forwarding packets are sent through a route and flooding is not employed for route discovery. Adaptive methods are used to offer lower end-to-end delay and minimum power consumption. All the aforementioned protocols demand tedious time-consuming operations which in turn increases energy consumption thereby curtailing network lifetime. The necessary remedial measures are incorporated into the proposed mechanism. In the next subsection, the successors of the proposed mechanism are elaborated along their drawbacks.

PROPOSED OPTIMISED BORDER NODE BASED MOST FORWARD WITHIN RADIUS (OBMFR) MECHANISM

This section discusses about Most Forward within Radius (MFR) protocol, and Border-node based Most Forward within Radius (BMFR) and proposes an Optimised Border node based Most Forward within Radius (OBMFR) mechanism.

Most Forward within Radius (MFR)

Most Forward within Radius (MFR) (Omer et al., 2010), establishes a route in a network by calculating the distance of a neighbour node from the sender node. The next hop chosen for sending the packets further is the one whose progress on the straight line is maximum. Hence, the node chosen to forward the packet is near to the destination compared with the others. It helps in minimising the number of hops between sender and destination (Takagi & Kleinrock, 1984). In order to decide the next hop, unicast forwarding is used by making use of the position of the sender, its neighbour and the destination. Since the node closest to the destination is chosen as next hop, MFR reduces end-to-end delay. But the mobility of node may disturb the network connectivity.

Border-node based Most Forward within Radius (BMFR)

Border-node based Most Forward within Radius (BMFR) (Shringar Raw & Lobiyal, 2010) is an improvement over MFR. It selects the border node as the next hop to forward the packets to the destination. In this method, nodes are classified into three categories: border node, outer node and interior node. Nodes which are in the transmission range of sender are classified as interior nodes, those which are exactly at the maximum transmission range of the sender are classified as border nodes and the nodes lying outside the transmission range of the sender are outer nodes. Neglecting the interior nodes, BMFR selects the border node as the next hop by utilising the position of the nodes. BMFR minimises the number of hops to a maximum extent to reduce end to end delay as compared to MFR.

But, it fails to decide the next hop in the case of conflicting nodes. Moreover, it considered distance as the only parameter to consider the next hop. Before receiving data from the sender, the selected node may go out of the transmission range of the sender. Until the source detects this movement of the selected border node, it keeps sending the data. Hence, the packets are not delivered to the destination, thereby leading to underutilisation of the available resources.

Proposed OBMFR

To mitigate the above-mentioned drawbacks, the proposed OBMFR utilises four significant factors, Radius, Residual Energy, Mobility speed and Queue length, to facilitate next hop election. It yields better performance as shown in Section 4 in terms of throughput, delay, routing overhead, routing reconstruction and energy consumption.

Fuzzy logic approach is applied in control system to improve performance, especially when the input data is insufficient to form the crisp output (Wong & Wong, 2002). The block diagram of the proposed fuzzy logic controller in OBMFR is shown in Figure 1. Fuzzy inference engine applies fuzzy logic rules on the fuzzified variables to grade the node which is then used for forwarding data from source to the destination. The subsequent section discusses the function performed by various blocks in the fuzzy controller.

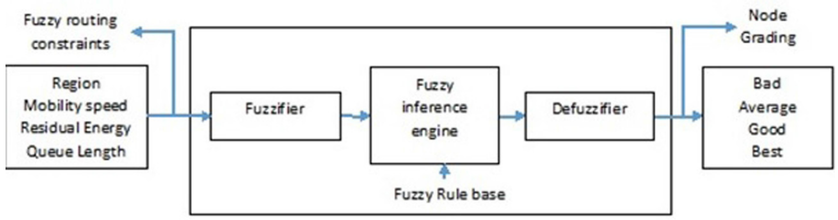

Figure 1. Fuzzy controller in OBMFR

Routing Constraints

The fuzzy system uses the following routing constraints to elect the best candidate node to be used in the routing process.

Region (R_i). The node's region helps to select the node from the appropriate region, which is neither too far nor too close from the sender node. The proposed OBMFR divides the sensing range of a node into four regions, namely R1, R2, R3 and R4 as shown in Figure 2. The snapshot in Figure 3 shows one of the scenarios in the simulation to grade node 1's neighbors. Node 1 is assumed as a source node where the position of all the nodes is generated randomly. All the nodes which are in the sensing range of node 1 are connected via a line with node 1 at the centre. Nodes which are not connected are outside the sensing range of node 1. On applying the fuzzy rules based on the four input parameters, neighbour nodes of node 1 are classified into various grading, i.e., bad, average, good and best. Nodes connected with red, cyan, blue and green colours are bad, average, good and best candidates respectively. The node connected with green is considered as the best candidate and is considered as the next hop for routing and the process continues till the destination is reached.

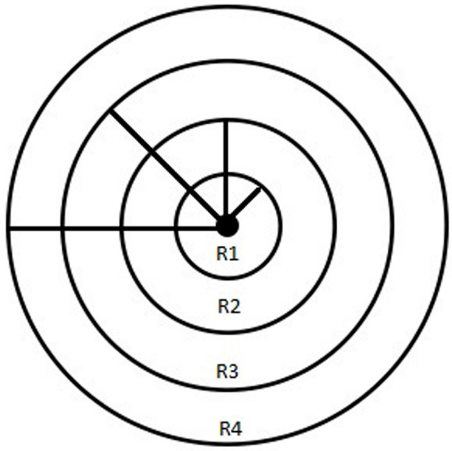

Figure 2. Node with four regions

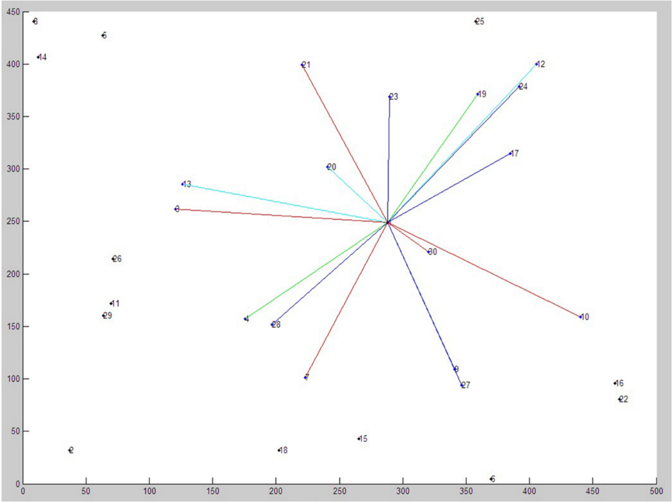

Figure 3. Grading of node 1's neighbours

Mobility Speed (S_i). Mobility speed is an important factor as it indirectly affects connectivity of nodes in the network. Since, the nodes with high speed motion leads to frequent link breakages, it is not considered for further routing process. Nodes with medium and slow speed can lead to better lifetime of a link.

Residual Energy (E_i). As every node is battery powered in a wireless network, residual energy must be used in next hop selection. Only the nodes with adequate energy are selected to avoid node failure resulting from exhausted energy.

Queue Length (Q_i)

The node's queue length can select the optimum node so as to avoid the problem of buffer overflow. Thus, the overloaded node will not be further considered by repeatedly selecting an intermediate node. Instead, alternate nodes with sufficient queue length are elected by the proposed OBMFR.

The membership functions of these fuzzy inputs are shown in Figure 4 (a)-(d) and Figure 5 shows the membership function of output. The minimum and maximum values of inputs and outputs for Fuzzy Logic Controller are shown in Table 1. The input and output domain of fuzzy variables are given in Table 2. Once the membership function is defined, the crisp inputs (R_i, S_i, E_i and Q_i) are fuzzified to map the inputs to the range [0,1]. Based on the fuzzy inputs, fuzzy inference engine determines the grading of node by evaluating the fuzzy rules in the fuzzy rule base. In fuzzy rule base, the set of IF THEN rules are constructed on the basis of human expert's knowledge. Using the fuzzy variable of four parameters, 108 rules can be formed. These rules will then help in deciding the category of the node. A snapshot of fuzzy rules is shown in Figure 6. For example:

Rule 1. From Table 2, if a node lies in the far region with high speed, high energy, and fair queue length, then the node will be considered as a Best candidate.

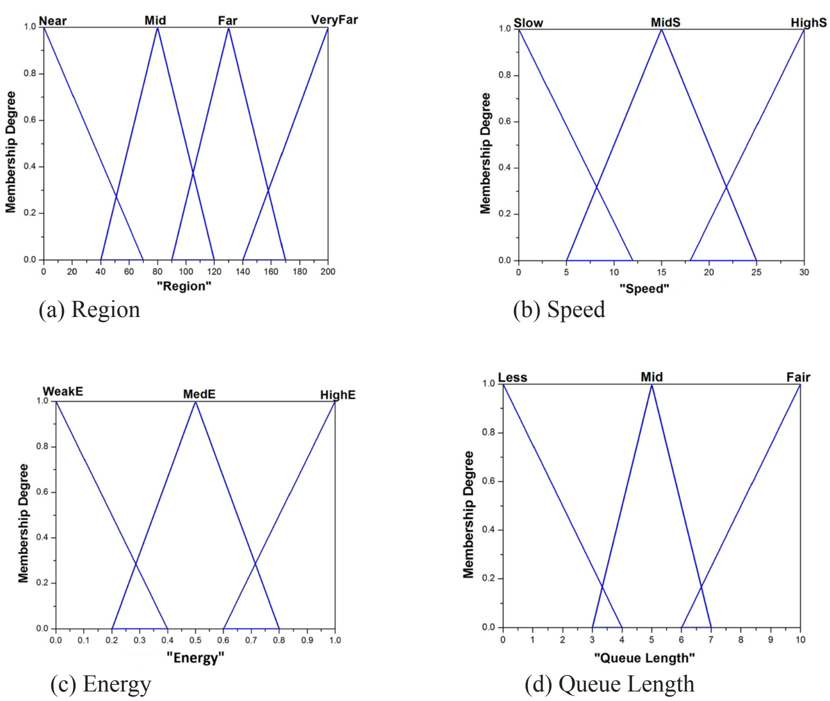

Figure 4(a)-(d). Fuzzy membership function for different Input Parameters

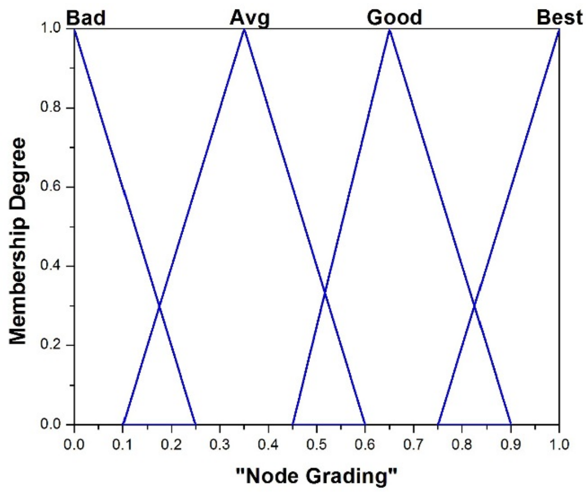

Figure 5. Fuzzy membership function for Output Parameters

Table 1
Universe of Discourse for different input and output parameters

Name	Input /Output	Min. value	Max. Value
Node's Region (Ri)	I	0	200
Node's Energy (E_i)	I	0	1
Node's Speed (S_i)	I	0	30
Node's Queue Len (Q_i)	I	0	10
Node's Grading (G_i)	O	0	1

Table 2
Fuzzy variable for different input parameters with their domain

I. Node's Region		IV. Queue Length	
Input Domain	Fuzzy Variable	Input Domain	Fuzzy Variable
0-80	Near / R1	0-4	Less
40-120	Mid / R2	3-7	Med
90-170	Far / R3	6-10	Fair
140-200	Very Far / R4		
II. Energy Level		Node Grading:	
Input Domain	Fuzzy Variable	Input Domain	Fuzzy Variable
0-.4	Weak	0-.25	Bad
.2-.8	MedE	-1-.6	Avg
.6-1	HighE	.45-.9	Goog
III.Speed		.75-1	Best
Input Domain	Fuzzy Variable		
0-12	Slow		
5-25	MedS		
18-30	HighS		

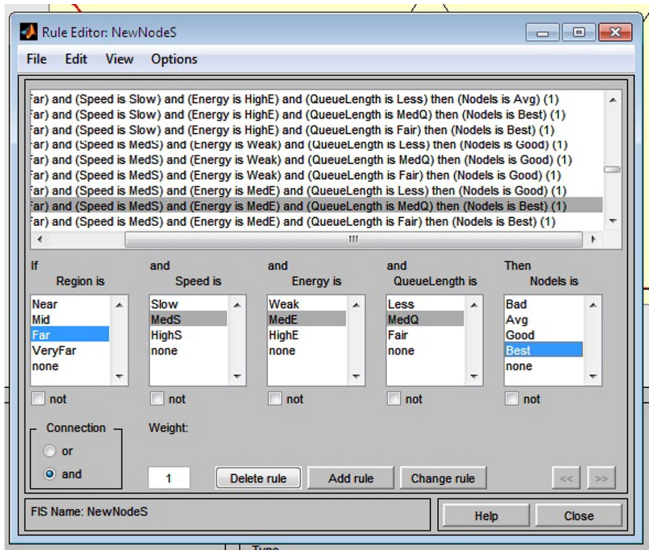

Figure 6. Proposed fuzzy rule base

Rule 2. Similarly, from Table 2, if a node lies in the very far region with high speed, low energy and less queue length, then the node will be considered as bad node, not suited for the routing data to destination. Due to high speed and distance, the node may go out of range before a sender node can send the packet to the underlying node. The surface graphs shown in Figure 7-9 depict the significant impact of fuzzy inputs on node grading. The output of fuzzy inference engine is then aggregated. These aggregated outputs fuzzy set is defuzzified to get a single output that gives the grade level of nodes. With the help of this grading, only the potential nodes are used in the routing to exchange data between source and destination. The efficiency of the proposed algorithm is tested using NS2 simulation and results are discussed in Section 4. Also, its time complexity is analysed and compared with MFR and BMFR in the next subsection.

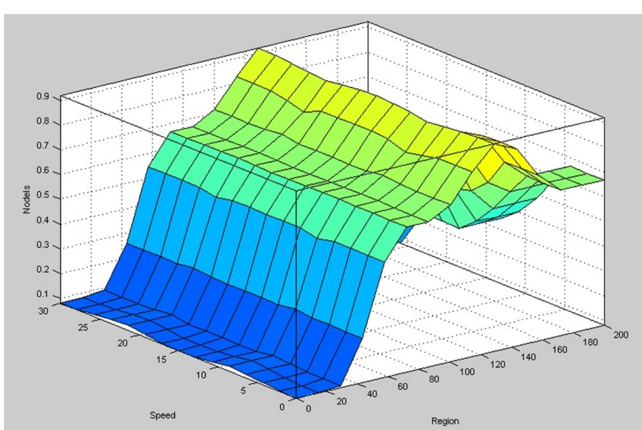

Figure 7. Region and speed vs grading

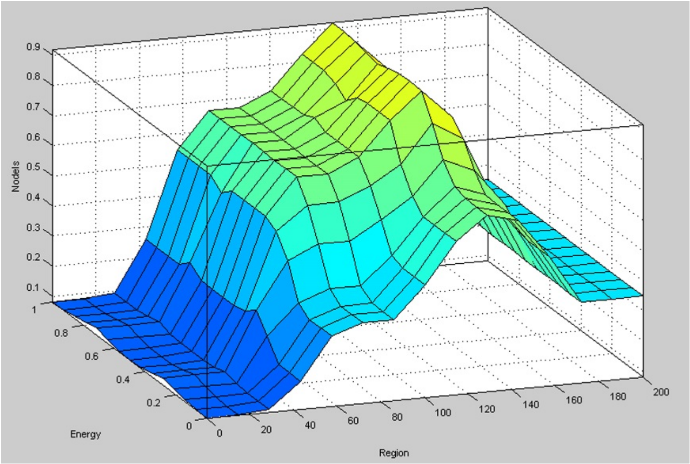

Figure 8. Region and energy vs node grading

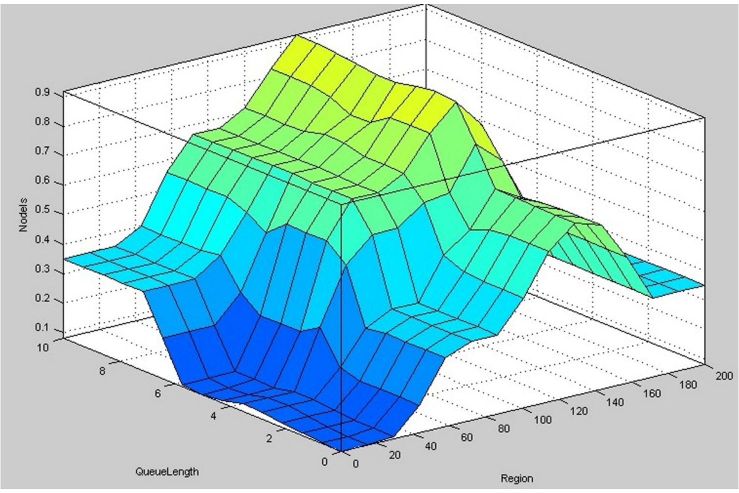

Figure 9. Region and queue length vs node grading

Time Complexity

In this section, the time complexity of MFR, BMFR and the proposed OBMFR are analysed. In MFR, the node which has the greatest projection on the source-destination line is selected as next hop from the source node and this is repeated until the destination node is reached. With n nodes and for one source destination pair, this method takes a worst-case time complexity of $O(n^3)$. When all n nodes become part of the communication, the worst-case time complexity is $O(n^4)$. In BMFR, the Euclidian distance from the source to all of its neighbour nodes are computed and for one node, this takes a worst-case time of O(n). So, for n nodes, it is $O(n^2)$. From this, after examining the neighbouring nodes, the border nodes are selected as candidate nodes and this process takes time of O(n). Hence, the total time taken by BMFR is $O(n^3)$.

The proposed OBMFR algorithm consists of two phases, namely Fuzzy logic-based node selection and data forwarding. In the first phase, the potential next hop neighbours are selected using fuzzy logic. Fuzzy logic computations do not necessarily increase the time complexity in asymptotic sense (Khan et al., 2004), it is calculated for the comparison purpose. As stated by Balázs et al., 2008, the time complexity of Mamdani base fuzzy inference technique is $O(r^*m)$, where r and m denote number of rules and number of input dimension respectively. In the proposed OBMFR, *r* is 108 and *m* is 04. In the second phase, forwarding of data from source to destination is done with the aid of selected nodes and worst-case time complexity of this phase is O(n). Hence, the overall time complexity of the proposed OBMFR is $O(r^*m) + O(n)$. Table 3 shows the comparison of time complexity of MFR, BMFR and the proposed OBMFR.

Table 3
Complexity analysis

Algorithm	Time complexity
MFR	$O(n^4)$
BMFR	$O(n^3)$
OBMFR	O(r*m)+O(n)

SIMULATION AND PERFORMANCE ANALYSIS

Simulation of the proposed Optimised Border node based Most Forward within Radius (OBMFR) is performed using NS2. The simulation results obtained from the simulation are compared with BMFR to emphasise the enhancements of OBMFR in terms of throughput, loss, routing overhead and energy consumption. To investigate the scalability of the proposed OBMFR, the number of nodes varies from 10 to 70. The radio propagation range of 250 meters with 2Mbps link capacity is assumed. A free space propagation model with Direct Sequence Spread Spectrum (DSSS) is considered for the simulation. A random way point mobility model is utilised to incorporate node mobility into random topology. The traffic generator that generates 512 bytes TCP data is used. IEEE 802.11 MAC protocol with RTS/CTS access method is used to control channel access. The following subsections analyse the performance of OBMFR, BMFR and MFR under throughput, delay, packet loss, route reconstruction and energy consumption.

Throughput

Figure 10 shows the throughput performance of the proposed OBMFR, BMFR and MFR for varying number of nodes. The proposed OBMFR minimises the frequent network partition thereby improving the connectivity of the network. This enhanced performance is obvious due to the role of the decision parameters in the next hop selection. The low energy node and overloaded node are restricted from the route construction process. OBMFR selects only quality nodes based on the mobility speed, residual energy and location with respect to source node. It leads to greater number of packets to be transmitted through the routing path which is more stable than in BMFR. Thus, the proposed algorithm enhances the success rate of transmission.

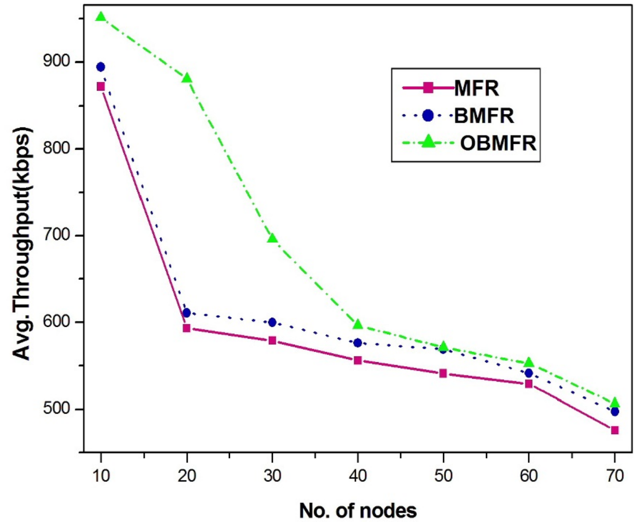

Figure 10. Throughput performance

End-to-End Delay

Figure 11 shows the end-to-end delay performance of proposed OBMFR, BMFR and MFR. Since the probability of selecting potential next hop towards the destination is improved by the proposed OBMFR, the lifetime of the established routing path is increased. The number of disconnected nodes due to the failure (as a result of exhausted energy and buffer overflow) and failures of link (due to mobility) are significantly reduced. Hence the tedious process of route discovery is minimised. By enhancing the connectivity between the nodes in the network, data is exchanged successfully with minimum end to end delay.

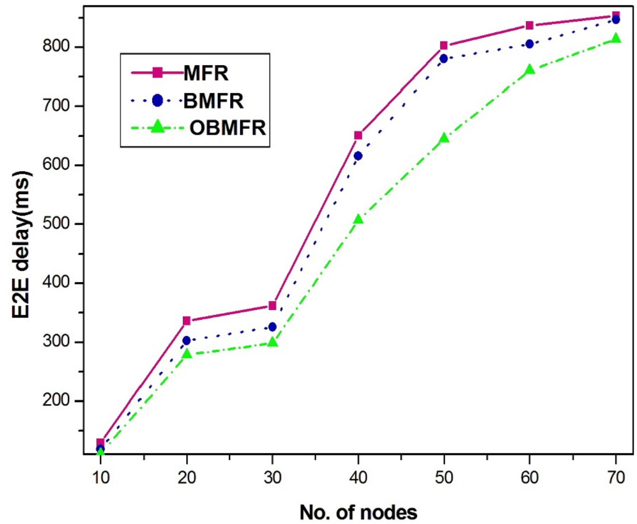

Figure 11. End-to-End delay performance

Packet Loss

Selection of an overloaded node as one of the nodes participating in routing may result in packet loss by frequently dropping the packets. To overcome this problem, queue length is considered as one of the parameters in deciding the next hop. The node with average or fair queue length is preferred to minimise the packet loss as caused by buffer overflow. Figure 12 shows the packet loss incurred by OBMFR, BMFR and MFR. Whereas in BMFR, distance is the only parameter to elect the border node that is closest to the destination. Even though the number of hops between the source and destination is reduced, the border node which lies exactly at the maximum transmission range may move out of the transmission range before receiving the packet from the source. This situation occurs frequently in highly dynamic network, thereby leading to more collision rate as depicted in Figure 13. As a result, more packet losses are inevitable in BMFR and MFR as compared to the proposed OBMFR.

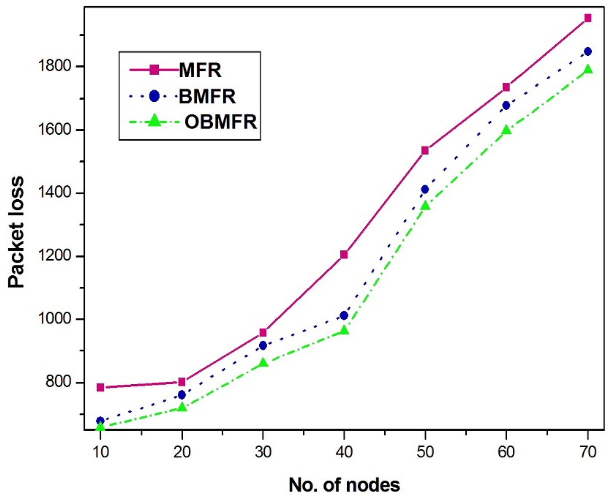

Figure 12. Packet loss performance

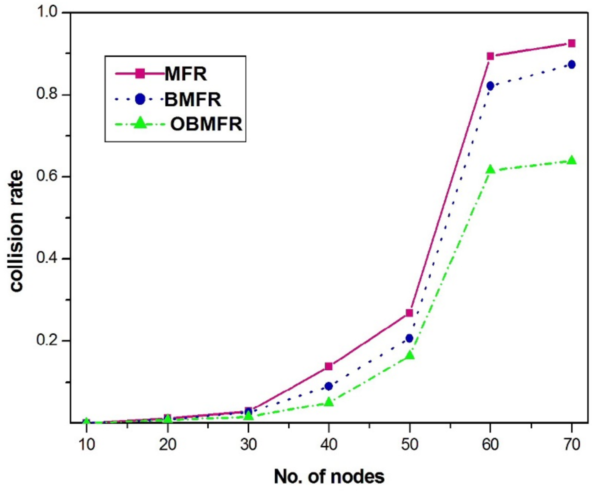

Figure 13. Collision rate performance

Route Reconstruction

Link disruption reinitiates the route discovery process causing too many routing control packets on the fly from source to the destination. In BMFR, communication between the source and the destination is facilitated by the border nodes. Based on the number of border nodes and their mobility, the availability and life time of routing paths may vary affecting the overall network performance. From Figure 14, it is inferred that the proposed OBMFR minimises the occurrences of route reconstruction process by effectively maintaining the connectivity among the nodes. With the aid of significant factors, namely region, residual energy, mobility speed and queue length in the next hop selection, the proposed algorithm improves the stability of routing path. Hence the frequency of route reconstruction is minimised.

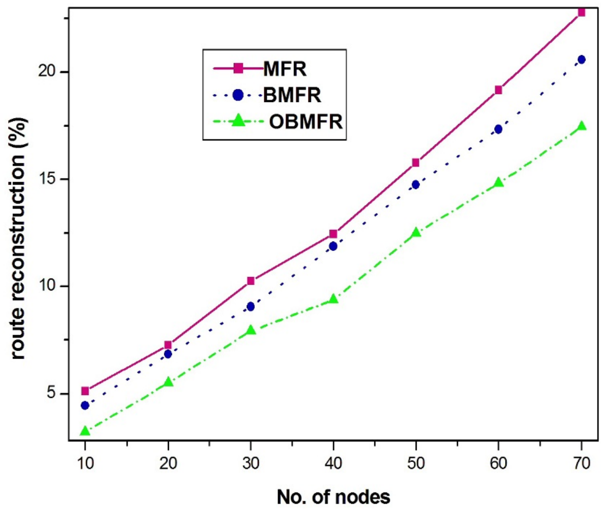

Figure 14. Percentage of route reconstruction performance

Energy Consumption

The lesser the node participates in communication, the lower will be its energy consumption resulting in increased network lifetime. Energy is another driving factor in wireless scenario. The residual energy is considered as one of the parameters in deciding the next hop in the proposed OBMFR. For this reason, a node with moderate or high energy is chosen as next hop using fuzzy rules. The fact is taken into consideration to avoid reselection of a particular node again and again, failing to do so will sooner make the victim node to be dead soon. The proposed OBMFR shows significant decrease in energy consumption as compared to the traditional BFMR as shown in Figure 15. As mentioned in the previous section, the proposed OBMFR significantly reduces the packet loss (thus, minimising the number of retransmission) frequency of route construction process (which curtails the amount of routing control packets). Due to this, the consumed energy is minimised which leads to prolonged network lifetime.

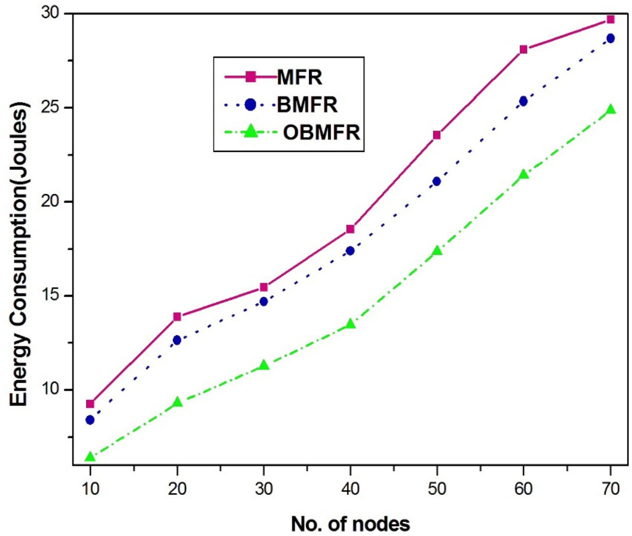

Figure 15. Energy consumption

CONCLUSION

To optimise the routing performance in MANET, an adaptive Optimised Border-node based Most Forward within Radius (OBMFR) mechanism is proposed. Multiple constraints, such as region, residual energy, mobility speed and queue length are fed into fuzzy controller along with the proposed fuzzy rules to select the best candidate node to forward data from source to destination. From the simulation results, it is inferred that the proposed OBMFR provides more stability and reliable routing path by minimising the number of route reconstruction. It further leads to less energy consumption by reducing routing control overheads.

REFERENCES

Awad, A., Thiel, A. M., & Dressler, F. (2011). Reactive virtual position-based routing in wireless sensor networks. In *International Conference on Computer Communications and Networks* (pp. 1-6). IEEE.

Babu, S. S., Raha, S., Naskar, M, Alfandi, K.O., & Hogrefe, D. (2012). Fuzzy logic election of node for routing in WSNs. In *IEEE International Conference on Trust, Security and Privacy in Computing and Communication*s (pp. 1279-1284). IEEE.

Bae I. H., & Olariu, S. (2013). Design and evaluation of Hi-CAST and its variants for safety message dissemination in VANET. In *International Conference on Control, Automation and Systems* (pp. 800-806). IEEE.

Balázs L. K., Kóczy J. T., & Botzheim, J. (2008). Comparison of fuzzy rule-based learning and inference systems. In *International Symposium of Hungarian Researchers on Computational Intelligence and Informatics* (pp. 61-75). CINTI.

Boukerche, A., Turgut, B., Aydin, N., Ahmad, M. Z, Bölöni, L., & Turgut, D. (2011). Routing protocols in ad hoc networks: A survey. *Computer Networks, 55*(13), 3032–3080.

Conti, M., & Giordano, S. (2014). Mobile ad hoc networking: milestones, challenges, and new research directions. *Communications Magazine, 52*(1), 85-96.

Daniel, A. K., Singh, R., & Khan, Z. (2010). Position based multicast routing protocol for AD-hoc wireless network using backpressure restoration. In *International Conference on Computer Engineering and Technology* (pp. 458-462). IEEE.

De Rango, F., Iera, A, Molinaro, A., & Marano, S. (1998). A modified location-aided routing protocol for the reduction of control overhead in Ad-hoc wireless networks. In *International Conference on Telecommunications* (pp. 1033-1037). IEEE.

Gupta A. K., Sadawarti, H., & Verma, A. K. (2011). Review of various routing protocols for MANET. *International Journal of Information and Electronics Engineering, 1*(3), 251-259.

Hong X., Xu, K., & Gerla, M. (2002). Scalable routing protocols for mobile Ad Hoc networks. *IEEE Network Magazine, 16*(4), 11-21.

Husain A., Raw R. S., Kumar, B., & Doegar, A. (2011). Performance comparison of topology and position based routing protocols in vehicular network environments. *International Journal of Wireless and Mobile Networks, 3*, 289-303.

Khan, J. A., & Alnuweiri, H. M. (2004). A fuzzy constraint-based routing algorithm for traffic engineering. In *IEEE Global Telecommunications Conference* (pp. 1366-1372). IEEE.

Ko, Y. B., & Vaidya. N. H. (2000). Location Aided Routing (LAR) in mobile ad hoc networks. *Wireless Networks, 6*(4), 307-321.

Luo, J., Hu, J., Wu, D., & Li, R. (2015). Opportunistic routing algorithm for relay node selection in wireless sensor networks. *IEEE Transactions on Industrial Informatics, 11*(1), 112-121.

Mao, X., Tang, S., Xu., X, Li, X., & Ma, H. (2011). Energy efficient opportunistic routing in wireless sensor networks. *IEEE Transactions on Parallel and Distributed Systems, 22*, 1934–1942.

Mauve, M., Widmer, J., & Hartenstein, H. (2001). A survey on position-based routing in mobile ad hoc networks. *IEEE Network Magazine, 15*(6), 30-39.

Mostafaa, A., Vegnib, A. M., & Bandaranayakea, A.D. P. (2014). QoS-aware node selection algorithm for routing protocols in VANETs. *Procedia Computer Science, 40*, 66-73.

Omer, K. A. A. (2010). Analytical study of MFR routing algorithm for mobile Ad hoc networks. *Journal of King Saud University - Computer and Information Sciences, 22*, 29-35.

Patil, R., & Damodaram, A. D. R. (2009). Cross layer AODV with position based forwarding arouting for mobile adhoc network. In I*EEE Conference on Wireless Communication and Sensor Networks* (pp. 1-6). IEEE.

Raw, S., & Lobiyal, D. K. (2010). B-FMR routing protocol for vehicular Adhoc networks. In *International conference on Networking and Information Technology* (pp. 420-423).

Royer, E. M., & Toh, C. K. (1999). A review of current routing protocols for ad hoc mobile wireless networks. *Personal Communications, 6*(2), 46-55.

Ruiz, P. M., Cabrera, V., Martinez, J. A., & Ros, F.J. (2010). BRAVE: Beacon-less routing algorithm for vehicular environments. In *IEEE International Conference on Mobile Adhoc and Sensor Systems* (pp. 709-714). IEEE.

Swain, J., Pattanayak, B. K., & Pati, B. (2017). Study and analysis of routing issues in MANET. In *International Conference on Inventive Communication and Computational Technologies (ICICCT)* (pp. 506-509). IEEE.

Taha, A., Alsaqour, R., Uddin, M., Abdelhaq, M., & Saba, T. (2017). Energy efficient multipath routing protocol for mobile Ad-Hoc network using the fitness function. *IEEE Access, 5*, 10369-10381.

Takagi, H., & Kleinrock, L. (1984). Optimal transmission ranges for randomly distributed packet radio terminals. *IEEE Transaction on Communication, 32*(3), 246-257.

Wong, Y., & Wong, W. (2002). A fuzzy decision based routing protocol for MANET. In I*EEE International Conference on Networks* (pp. 317-322). IEEE.