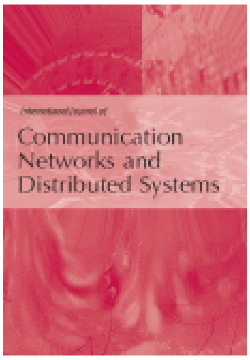


International Journal of Communication Networks and Distributed Systems

ISSN online: 1754-3924 - ISSN print: 1754-3916
https://www.inderscience.com/ijcnds

A hybrid zone-based routing protocol based on ZRP and DSR for emergency applications

Sanjoy Debnath, Wasim Arif

DOI: 10.1504/IJCNDS.2025.10061546

Article History:

Received:	01 October 2023
Last revised:	23 November 2023
Accepted:	15 December 2023
Published online:	02 December 2024

A hybrid zone-based routing protocol based on ZRP and DSR for emergency applications

Sanjoy Debnath*

Department of Electronics and Communication Engineering,
Vel Tech Rangarajan Dr. Sagunthala R&D Institute
of Science and Technology,
Tamil Nadu, 600062, India
Email: sanjoydebnath80@gmail.com
*Corresponding author

Wasim Arif

Department of Electronics and Communication Engineering,
National Institute of Technology Silchar,
Assam, 788010, India
Email: arif@ece.nits.ac.in

Abstract: Mobile ad-hoc networks (MANET) can be rethought for use in disaster relief operations due to their attractive features, such as no infrastructure, fast deployment, and self-organisability. It has also been observed that improving scalability, mobility, bandwidth, and energy efficiency has always been a challenging aspect of ad-hoc routing protocols like MANET. This paper presents a comprehensive survey of all the promising routing protocols in MANET, considering key constraints such as energy efficiency and throughput delivery in disaster relief operations. After that, we proposed HZDL, a hybrid routing protocol based mainly on ZRP and DSR with cluster hierarchy features from the LEACH algorithm. The key controlling parameters include the mobile node's processing speed, background running applications, data storage capacity, and residual battery power. The results of a comprehensive simulation encompassing several performance measurement matrices reveal that the proposed algorithm provides significantly improved results towards improving the node's lifetime and achievable throughput.

Keywords: MANET; mobile ad-hoc networks; hybrid routing protocol; energy efficiency; disaster management.

Reference to this paper should be made as follows: Debnath, S. and Arif, W. (2025) 'A hybrid zone-based routing protocol based on ZRP and DSR for emergency applications', *Int. J. Communication Networks and Distributed Systems*, Vol. 31, No. 1, pp.1–18.

Biographical notes: Sanjoy Debnath received his MTech in 2015 and completed his PhD in 2021 from the National Institute of Technology Silchar, India, in Electronics and Communication Engineering. He is currently employed as an Assistant Professor at Vel Tech Rangarajan Dr. Sagunthala R & D Institute of Science and Technology, Chennai, India. His research interests include optimal network planning and resource allocation in heterogeneous wireless networks through the development of efficient meta-heuristic optimisation algorithms.

Wasim Arif received his MTech from Jadavpur University, India in the department of Electronics and Tele-Communication Engineering. He has completed PhD in Engineering from National Institute of Technology Silchar. He is currently working as an Assistant Professor (Grade-I) in the department of ECE of NIT Silchar, India. His research interest includes wireless communication, cognitive radio, spectrum sharing and mobility, resource allocation, signal processing for bio-medical imaging, IOT and ML based system design.

1 Introduction

Mobile ad-hoc networks (MANET), with its diverse benefits such as infrastructure-less architecture, rapid deployment, and ease of use, have become very promising technique for emergency communication. The enriching capabilities of MANET makes it suitable for emergency application in future wireless communication with the advent of IoT network (Quy et al., 2023). MANET deals with the resolution of the protocols that control the transmission from one node to all other nodes in the network. Despite several benefits like the requirement of fewer resources, operation in the distributed frame, and easy-to-deploy lightweight terminals, MANET faces the problem in the evaluation of dynamic discovery of the most efficient route between two nodes within the network. It is observed that in any emergency situation where a mobile device becomes unreachable, the network should initiate a search and rescue process to reach the victims in a short period of time. Based on network architecture, routing protocols are classified as hierarchical, flat, and geographic position based routing (Gorantala, 2006; Royer and Toh, 1999; Murthy and Manoj, 2004). For an update of routing information, subject to change in the network nodes, proactive routing protocols have to maintain routes to all other nodes in the network. In contrast, reactive routing protocol does the route establishment work when there is a need. Thus, taking advantage of both, an efficient hybrid routing protocol needs to be designed, considering the situation of emergency communication under the key constraint of energy efficiency.

Reactive routing protocols (On Demand): In reactive routing protocols, ad-hoc on demand distance vector (AODV) (Perkins et al., 2003) and dynamic source routing (DSR) (Johnson et al., 2004) are popular for their simplicity in topology architecture. In AODV, Perkins et al., suggest that when a link breaks, all the neighbouring nodes of the affected nodes get notified through route reply RERR message so that they are able to invalidate the paths to the affected nodes and find alternative paths. The disadvantage is that it performs better only in low traffic. On the other hand, in DSR, every node stores the recently discovered paths in its cache memory. On expiry of the catch, route request (RREQ) and route reply (RREP) messages are used to discover the new route.

Proactive routing protocols: It is a table driven routing protocol designed to maintain a routing table periodically to note the small changes in the route. Since, in proactive routing protocols, routes between every mobile node are predefined, it would be easier to connect all the people in the affected area in an emergency scenario. However, continuous updates of routes create significant overhead, resulting in increased consumption of energy and bandwidth. These routing protocols do not function properly in large and highly dynamic scenarios. Destination-sequenced distance vector (DSDV) (Perkins and Bhagwat, 1994) and optimal link state routing (OLSR) (Clausen and Jacquet, 2003) are two well-known protocols in proactive routing.

In DSDV, a sequence number is used to manage the route while avoiding loops. These types of table-based routing protocols are not suitable for dynamic routing in wide area networking, as they require frequent updates of both sequence numbers and tables. In contrast, OLSR is an improved version of classical link-state routing designed for large-area networking. OLSR employs multipoint relaying (MPR) for packet forwarding, where MPR is solely responsible for managing the control frame overhead and ensuring accurate message delivery.

Hybrid, hierarchical, and position-based routing protocols: Hybrid routing protocols are designed to get efficient routing while mixing the key characteristics of two or three protocols. Generally, it includes the latency of proactive and more overhead of reactive protocols. The RREQ packets generated by several nodes in reactive routing protocols create heavy traffic and communication failures. Similarly, proactive routing protocols also lead to massive congestion due to changing topology. Therefore, the use of hybrid routing protocols in disaster scenarios could reduce control overhead.

To reduce overhead and latency, Zygmunt et al. (2002) proposed ZRP, operates proactively within the zonal area and reactively for out-of-zone areas. It has been observed that ZRP is not efficient enough for large-area networking, where its characteristics resemble those of proactive routing protocols.

However, hierarchical routing is designed to reduce routing overhead through clustering. Low-energy adaptive clustering hierarchy (LEACH) is a popular cluster based protocol (Heinzelman et al., 2000). In the cluster-based routing protocol (CBRP), the cluster head (CH) is identified based on specific key criteria (Jiang et al., 1998). The CH forwards packets from neighbouring nodes within the zone to the gateway node. The hierarchical routing protocols may perform better in emergency and rescue operations. Since the entire network is divided into some small clusters, management and maintenance of the large network through each cluster head is faster. Thus, communication between victims in disaster areas is more effortless. The primary disadvantage of this protocol is that the overhead increases as the cluster size increases.

The position-based routing (PBR) protocol utilises the node's position to update the routing table, which needs periodic updates for finding the optimal route (Stojmenovic, 2002). In PBR, Ko and Vaidya (1998) suggested the location aided routing protocol (LAR), which employs GPS-based routing, utilising route discovery packets to evaluate the optimal route within a zone. On the other hand, Karp and Kung (2000) proposed the greedy perimeter stateless routing protocol (GPSR) algorithm that incorporates the geographical location of the closest neighbour node in the packets during the route discovery process. The iterative repetition of this process in a greedy manner facilitates the evaluation of the optimal route.

The rest of the paper is organised as follows: Section 2 presents the literature related to elementary MANET-based routing protocols and related work in emergency response/rescue operations based on ad-hoc routing. Section 3 provides the description and formulation of the proposed algorithm. Section 4 consists of results and discussion, and Section 5 draws the conclusion of the paper.

2 Related work

In an emergency situation, reactive routing protocols prove to be energy-efficient since the periodic update of routing tables is unnecessary, leading to reduced control overhead. Consequently, the battery life of mobile nodes is preserved. The only difficulty with reactive routing protocols is the latency.

Routing protocols based on MANETS, namely AODV, DSDV, and CBRP, are simulated and analysed using a random waypoint mobility model, and results demonstrate the outperforming characteristics of CBRP as compared to AODV and DSDV (Quispe and Luis, 2014; Bai and Helmy, 2004). The performance of three routing protocols, namely AODV, LAR, and DYMO, are analysed to test the performance in emergency communication. Observation outcomes demonstrate that the performance of LAR is better than AODV and DYMO (Chakeres and Perkins, 2006; Srivastava et al., 2014). An integrated energy efficient (E2) mechanism with CML, namely E2CML, is proposed by Ramrekha et al. (2012), which validates its outperformance against AODV and OLSR algorithms in a disaster scenario. Macone et al. (2013) proposed an energy-efficient proactive routing protocol called MQ-Routing, which is an extension of Q-Routing (Boyan and Littman, 1994) designed for critical scenarios. The effectiveness of the Q-Routing algorithm is demonstrated by Bai and Helmy (2004) through a comprehensive comparative analysis of OLSR and Q-Routing based on diverse network parameters, considering a random waypoint mobility model. Energy efficient routing protocol ensures a hostile environment for secure data transmission in MANET (Rajendra Prasad and Shivashankar, 2022). Based on the prominent network characteristics such as battery drain rate, availability of links, and network load, the design of an algorithm could be highly effective for energy efficiency (Kumar and Kukunuru, 2021). Similarly, the routing overhead also deteriorates the energy efficiency of the network. To overcome this problem, Alqahtani (2021) suggested EECALB-AOMDV, a modified ad-hoc on-demand multiple path distance vector (AOMDV) routing protocol, in which the balancing between the routing overhead and successful transmission is established through optimising route discovery. The limitation of the suggested algorithm lies in the complexity that arises in route discovery.

The literature demonstrates that reactive and hybrid routing protocols in MANET are particularly effective for public safety networks (Onwuka et al., 2011). Tsai and He (2010) proposed H-MAODV, a distance vector based routing protocol, to demonstrate the high scalability of multicast routing in WiFi and WiMAX networks. A routing protocol offers countless benefits for effective rescue operations in any emergency. Hafslund et al. (2005) proposed an improved and robust network to provide voice based rescue service in a network run on OLSR routing protocol. Energy is one of the primary constraints in public safety networks; thus, to find an efficient route from source to destination, a DSR based energy efficient routing protocol is proposed by Doshi et al. (2002) to get service in rescue. For maximum network lifetime, the MRPC algorithm is designed by Misra and Banerjee (2002) to provide reliable service in emergencies with sustainable nodes. A node's energy balancing is also a prior task to establish a sustainable network. Nodes having low energy backup must deal with less overhead. EAODV, an enhanced version of the AODV routing protocol, is designed to achieve balancing of node's energy by offloading the overhead from nodes with minimal energy. Murugan and Shanmugavel (2008) proposed a modified DSR algorithm by circulating the residual energy information in the form of RREQ (Route Request) packets, and the optimal route is selected based on the highest energy level. While distributing the load of one node, Venkatesh and Chakravarthi (2022) investigate the network lifetime maximisation probability. However, the investigation on the evaluation of the residual energy of a node and the complete route energy is a promising technique that still needs to be solved towards the improvement of overall lifetime of the network.

In routing, intermediate nodes will not retransmit the broadcasting packet if their residual energy falls below a certain threshold. To decrease energy consumption in forwarding packets, EPAR is proposed by Shivashankar et al. (2014) to improve the overall network lifetime. Considering the total energy consumption for successful packet delivery, CMMBCR is proposed by Toh (2001) to maximise lifetime and resilience in the network. During packet transmission, the evaluation of total transmit power cost is conducted under the constraint that all intermediate nodes have energy levels higher than the threshold. Consequently, packets are forwarded through a path that ensures overall energy efficiency. Vijayakumar and Ravichandran (2011) introduces EELAR, a location-aided routing protocol designed for maximal energy efficiency. The concept involves finding optimal routes for smaller regions to reduce node overhead and preserve residual energy.

To determine the best route based on throughput, delay, and eligible connecting nodes over a period of time, Veeraiah et al. (2021) proposed a trust-based secure energy-efficient hybrid routing protocol with a cat slap single-player algorithm. In the suggested algorithm, first, the best cluster head (CH) is evaluated based on the Fuzzy clustering and gained trust; thereafter, the best route is determined by the designed routing algorithm. The efficacy of such an algorithm lies in the evaluation of cluster head (CH) from a set of nodes acting as a dataset. Towards that, the Fuzzy C-mean clustering is used by Srilakshmi et al. (2021) at the initial phase to find the CH in accordance with the predicted-based decision taken on direct, indirect, and recent trust. After the evaluation of CH, the designed routing protocol utilised a hybrid Genetic Algorithm (GA) with Hill Climbing (GAHC) algorithm to find the optimal routing routes. The suggested algorithm claims an 89% packet delivery ratio with a maximum throughput of 0.85 bps while consuming 0.10 milli-joules of energy.

Towards the maximisation of energy efficiency, utilisation of bio-inspired algorithm and hybridisation of bio-inspired meta-heuristic state-of-the-art algorithm with the popular on-demand routing protocol provides a promising solution. Sarhan and Sarhan (2021) proposed EHO-AOMDV, a hybrid routing protocol designed on the platform of elephant herding optimisation and Ad Hoc On-Demand Multipath Distance Vector, to minimise routing cost and improve energy efficiency. However, in multipath routing, the suggested algorithm faces the problem of high node overhead while updating the residual energy, which deteriorates the network efficacy. The formation of cluster and the selection of corresponding cluster head is essential for the improvement of energy efficiency (Rajakumar et al., 2021). The meta-heuristic grey wolf optimisation (GWO) algorithm is used here as a selection tool for effective energy efficiency. Gandhi et al. (2022) proposed ACO-HAS: an ant colony based routing algorithm for the minimisation of energy consumption in MANET. Consequently, Halhalli et al. (2021) proposed an atom whale optimisation algorithm (AWOA), utilising a less complex WOA algorithm for a trust-based, secure, and effective routing protocol. In the suggested algorithm to evaluate the optimal route, atom search optimisation (ASO) is hybridised with WOA to get a balanced data forwarding rate, successful cooperation frequency, and encounter rate. Similarly, a hybrid algorithm based on TORA and PSO is presented by Jamali et al. (2013), where optimisation is used on the TORA algorithm to select the optimal energy-efficient route. The suggested algorithm makes the route selection process an optimisation problem on the constraint of route length and energy efficiency. Due to less complexity and high exploration rate of PSO, Ambika and Banga (2020) proposed a hybrid routing protocol of PSO and fuzzy logic for optimally selecting the parameter for energy efficient routing in the multi-protocol label switching (MPLS) paradigm of routing. The optimally selected node for routing will ensure the proper balancing between the node lifetime and successful data delivery at the cost of high network overhead. As PSO faces the issue of local convergence due to lack of balancing between exploration and exploitation, the proposed algorithm may not always ensure the optimal routing path.

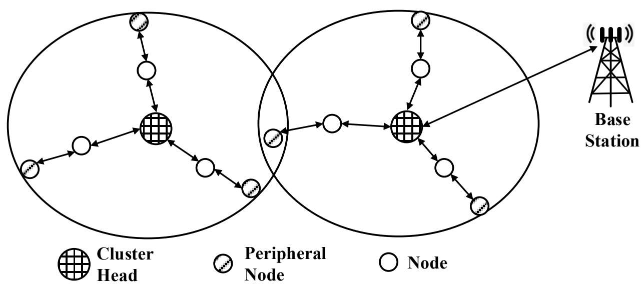
To improve the energy utilisation and data delivery rate in multipath routing, Chandravanshi et al. (2022) suggested MMEE algorithm in which route selection is performed on the basis of the predicted energy consumption per packet and queue length. Prediction of the near-future state of a network with QoE-based multipath routing protocol is proposed by Zhang et al. (2020). The presented work described the improvement of successful transmission of data with high quality of service, but in this improvement, authors did not consider the critical constraints of MANET like energy efficiency and node lifetime. Based on the prediction methodology, an obstacle-aware multipath routing protocol is proposed by Pattnaik et al. (2021) to find an effective multipath while avoiding obstacles in terrain. The suggested algorithm deals with the evaluation of optimal routing paths based on the prediction of mobility, path availability, and the duration of connectivity. The fundamental limitation of such algorithms lies in the failure of prediction. Selecting the node having maximum energy for the optimal route discovery is a common practice. Towards that, Kumar and Dubey (2016) suggested an algorithm for routing considering the nodes having the highest energy. However, the limitation of the proposed algorithm lies in the occurrence of delay in route discovery.

3 Proposed work

An efficient routing protocol, in terms of energy consumption, must incorporate key parameters from both proactive and reactive routing protocols. Residual energy, routing overhead, and bandwidth limitations are the primary constraints in MANET. In this work, we have developed a novel routing protocol that can overcome the mentioned constraints while retaining valuable features from reactive, proactive, cluster-based hierarchical routing protocols. The proposed algorithm considers all the pros and cons of the algorithms mentioned in the literature to ensure reliable and easily deployable routing in all critical emergency circumstances. The proposed algorithm operates in two phases, i.e., the inner cluster communication phase (*Phase 1*) and the outer cluster communication phase (*Phase 2*).

***Phase 1*:** In inner cluster communication, we propose an energy-efficient routing protocol based on the DSR routing protocol, while for outer cluster routing, we collaborate with ZRP and LEACH protocols. In this composition, we propose to keep the size of the zone as small as possible to minimise the energy consumption and overhead of the node. Two peripheral nodes from the cluster head are considered as the coverage radius of one zone. Figure 1 shows the schematic diagram of the proposed routing protocol.

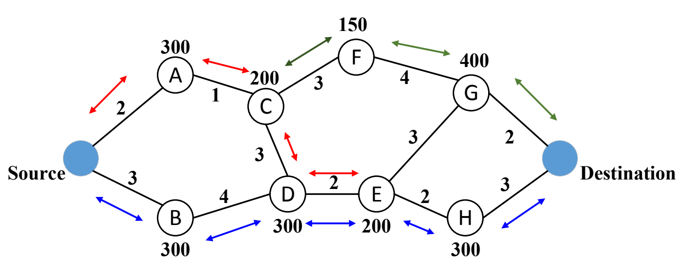
Figure 1 Diagram of the proposed routing



Peripheral nodes serve as the gateway nodes for inter zone communication and should connect to at least one cluster head from all connecting zones, which, in turn, is connected to the base transceiver station (BTS) of the backbone communication network for global communication.

Phase 1 of the algorithm focuses on inner cluster routing, involving energy-efficient route selection to enhance the node's lifetime. Selecting optimal nodes for route discovery by maintaining an energy threshold for each node can significantly improve the service route lifetime. Figure 2 displays the route discovery diagram, where the decimal marking above each node represents its residual energy.

Figure 2 Route discover diagram (see online version for colours)



It is proposed that to locate the destination, data packets should follow the optimal route where the overall route cost in energy, as well as the energy of each node, must meet the threshold energy constraint. By balancing the residual energy (RE) of a node, the optimal route is discovered and dynamically managed for long-term sustainability.

Suppose the overall energy threshold for a route is 1000 joules, with each node having a threshold of 200 joules. Based on the above route diagram, there are eight possible routes from the source to the destination, for example.

Based on the predefined energy threshold for a node (200) and route (1000), it is observed that Route 2 is deemed the most favourable route due to its minimal distance cost of 12 compared to other routes. However, as one node has residual energy below the threshold, this particular route is excluded and not considered in the computation of route discovery.

Route map	*Route cost* (*Distance*)	*Route cost* (*Energy*)
Route–1: Source – A – C – D – E – H – Destination	13	1300
Route–2: Source – A – C – F – G – Destination	12	1050
Route–3: Source – A – C – F – G – E – H – Destination	16	1550
Route–4: Source – A – C – D – E – G – Destination	13	1400
Route–5: Source – B – D – E – H – Destination	14	1100
Route–6: Source – B – D – C – F – G – Destination	19	1350
Route–7: Source – B – D – E – G – Destination	14	1200
Route–8: Source – B – D – C – F – G – E – H – Destination	25	1850

Furthermore, the algorithm favours Route 1, with a distance cost of 13 and residual energy (RE) of 1300, over Route 5, which has a distance cost of 14 and RE of 1100. Although all nodes in Route 5 have RE greater than the threshold (200), the algorithm selects Route 1 as the optimum route for communication because the total residual energy of Route 1 is higher as compared to Route 5. The proposed algorithm will consider the route as optimum if the route cost in terms of residual energy is maximum and distance or hop count is minimum.

The incorporation of the RE parameters in the proposed algorithm requires the periodic update of nodes' energy consumption matrices. Therefore, each node will update its energy consumption status based on the currently processed overhead parameters. The energy consumption of a node depends primarily on the transmission power (*Pt*) and the processing overhead. This consumption can be calculated using the following formula.

$$Energy = Power \times Time \tag{1}$$

Where the time needed for handling a data packet is:

$$Time = \frac{8 \times Packet\ size}{Bandwidth} \tag{2}$$

The total energy consumption E_T of a node to forwarding a data packet is

$$E_T = E_r + E_t \tag{3}$$

where E_t and E_r indicate the amount of energy consumed by a node in transmission and receiving and can be calculated as

$$\begin{aligned} E_t &= P_t \times 8 \times Packet\ size / Bandwidth \\ E_r &= P_r \times 8 \times Packet\ size / Bandwidth \end{aligned} \tag{4}$$

where P_t and P_r indicate the transmission power and the receiving power. Thus, the corresponding RE of a node can be calculated as

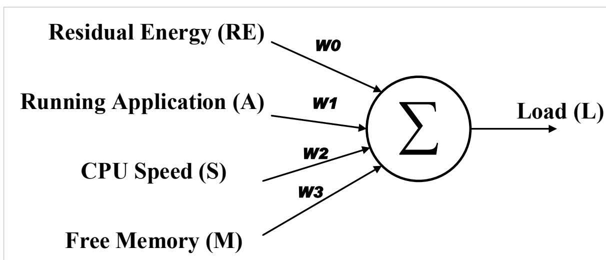
$$\text{RE} = E\,(Available) - E_T \tag{5}$$

In the computation of the overall node overhead (L), the proposed algorithm includes the residual energy (RE), background application (A), CPU speed (S), and free memory space (M) of the corresponding node as depicted in Figure 3.

$$L = RE \times w_0 + A \times w_1 + S \times w_2 + M \times w_3 \tag{6}$$

The final decision regarding the inclusion of a particular node in route planning depends entirely on the load parameter (L). In route planning, a node in the network is considered in two states: active or inactive. If the RE of a node is greater than the threshold value, the node is considered active; otherwise, it is considered an inactive node. The inactive node can still be included in route planning under worst-case conditions.

Figure 3 Parameter with corresponding weight to calculate load



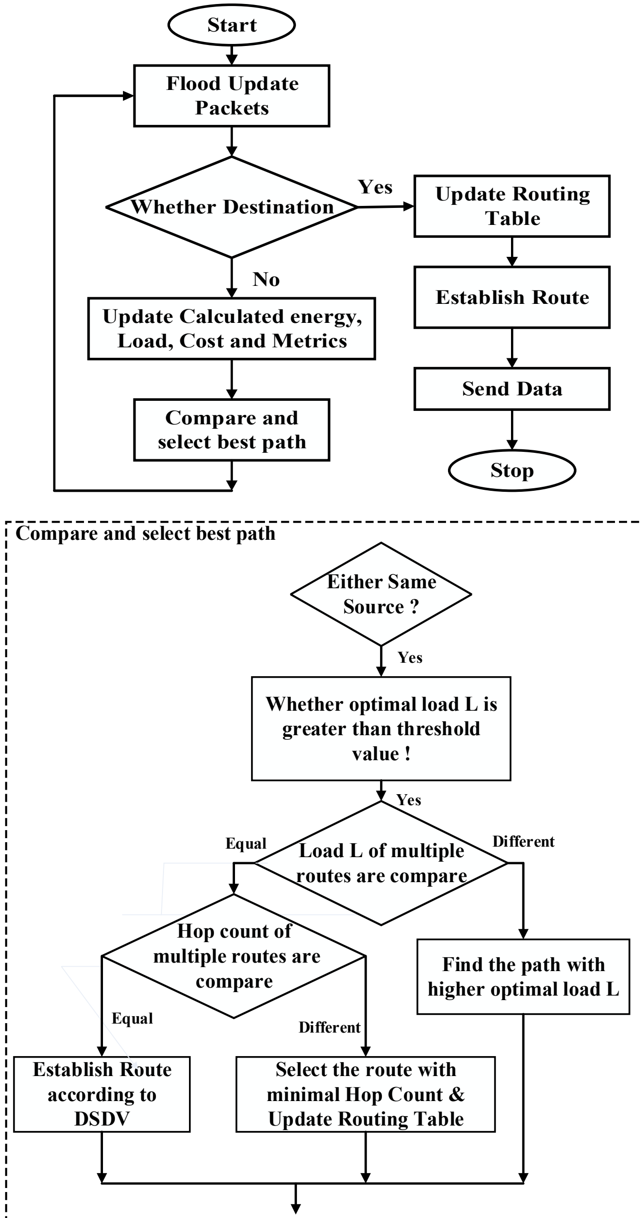
Phase 2: Outer cluster communication is establish through ZRP and clustering hierarchy inspired from LEACH algorithm. Here, at every small time interval Δt or when the cluster head node is exhausted, i.e., the RE threshold (t) is reached, a new master node among the existing nodes in the zone is selected as a cluster head (CH) again. This allows the routing to continue through the CH, which possesses knowledge of all the slave nodes. In this strategy, the GPS location of the CH in every cluster is periodically updated to a nearby base station, ensuring that the CH location of one cluster is known to all the other nodes.

The flowchart of the proposed algorithm's flowchart is shown in the Figure 4.

ZRP, with the key features of both reactive (DSR) and pro-active (LEACH) establishes a reliable route discovery while ensuring the maximum lifetime. The proposed algorithm incorporates the key feature of DSR to include catch memory for storing the optimal path and LEACH for adopting clustering hierarchy to update the CH. The CH forwards packets from neighbouring nodes within the zone to the gateway node.

Description: The update packets of each node are flooded in the network to strategically update the nodes. If the destination node is in the same cluster, one node will update its table and send the data after evaluating the intermediate routes. Suppose the initial attempt at packet delivery does not find the destination in the same cluster. In such a case, the cluster hierarchy process of LEACH is incorporated for inter-cluster communication by periodically updating the CH and node energy cost matrices. The corresponding CH will establish the route through communication with the CH of the nearby cluster for successful packet delivery.

Figure 4 Flow chart of the proposed algorithm



The compare and select block mentioned in the main flowchart is described in the algorithm table with three key steps.

Algorithm of the compare and select best path
If the optimal load L is higher than threshold value
1. Check whether load *L* of all the multiple path are same or not.
2. *If* two or more routes are having equivalent load: *Then,* select route with least number of hop count *Otherwise* Route with higher optimal Load will be considered.
3. *If* the number of hop count are also same: *Then,* select the route according to DSDV algorithm *Otherwise* Route with least number of hop count will be considered.

In Step 1, the load (L) of multiple possible paths is evaluated and compared. Then, in Step 2, the route with the minimal load is selected. If multiple routes have the same load, the route with the least hop count is chosen. After that, in Step 3, the optimal route is found if the number of hop counts is also the same. If the hop count is the same, the route with the minimum distance cost will be selected according to the DSDV algorithm. Otherwise, the route with the minimal hop count is chosen.

The preference order for selecting optimal route is as follows

$$\textit{higher energy} > \textit{optimal load} > \textit{least hop count} > \textit{least distance cost}$$

Under the consideration of the mentioned criteria, each route discovery is accomplished towards effective data delivery and energy efficiency. In the proposed algorithm, DSR will ensure the on-demand traffic, and ZRP will ensure the zone size for faster and more efficient delivery of data. The limitation of the algorithm lies in the size of the cluster. Observed that large size cluster is not suitable for energy efficient routing because of continuous update in the table.

4 Results and discussion

In this work, the Network Simulator 2 (NS 2.35 platform is utilised for the simulation and analysis of the proposed routing algorithm. Here, we consider both the proactive and reactive strategies of routing in a concise manner to design the proposed hybrid routing protocol. Thereby, a detailed comparison is performed among AODV, DSR, and EAODV for the validation and performance analysis of the proposed algorithm. The summary of all the assumed parameters in our work is given in Table 1.

Considering the above-given parameters, first, we analyse the packet delivery ratio (*PDR*), average throughput, and average end-to-end delay (*E2ED*) acquired by all the considered algorithms while sending packets from source to destination. The comparative analysis is conducted with an increasing number of nodes, ranging from 30 to 60, as indicated in Tables 2–5. These tables correspond to scenarios with 30, 40, 50, and 60 nodes, respectively.

Table 1 Simulation parameter

Parameters	*Value*
Channel type	Channel/Wireless Channel
Radiopropagation model	Two Ray Ground
Network interface type	Phy/Wireless Phy
Mac protocol type	IEEE 802.11
Interface queue type	Queue/Drop Tail/Pri Queue
Link layer type	LL
Antenna	Antenna/Omni antenna
Maximum packet in queue	50
Routing protocols	AODV, DSR, EAODV
Number of mobile nodes	36,43,55,76
Simulation time	200 s
TCP packet size	500 Byte
Traffic type	FTP
Packet type	TCP
Topology size	1221*600, 3118*650, 1700*500, 1864*650

Table 2 Variations of PDR, avg. E2ED and avg. throughput with 30 nodes

	Packet sent	*Packet received*	*Packet dropped*	*Packet delivery ratio* (%)	*Avg. throughput* (kbps)	*Avg. end to end delay* (second)
AODV	87	82	5	94.25	53	0.8
DSR	96	80	16	83.33	59	2.9
EAODV	150	143	7	95.33	56	0.6
Proposed	132	126	6	93.18	59	0.7

Table 3 Variations of PDR, avg. E2ED and avg. throughput with 40 nodes

	Packet sent	*Packet received*	*Packet dropped*	*Packet delivery ratio* (%)	*Avg. throughput* (kbps)	*Avg. end to end delay* (second)
AODV	145	135	10	93.10	49	2.9
DSR	151	116	35	76.82	53	4.2
EAODV	167	155	12	92.81	53	1.6
Proposed	161	151	10	93.79	54	1.45

It is observed that the proposed HZDL algorithm is superior to AODV, DSR, and EAODV in all the aforementioned criteria of *PDR*, average throughput, and E2ED. In any emergency, an algorithm must fulfil the criteria of successful packet delivery, throughput, and delay while maintaining the node's lifetime. Possessing better PDR and less delay shows the applicability of the algorithm in any emergency situation. The limitation of the proposed algorithm lies in high complexity and overhead, which arises in the large size of the network, where the continuous update process reduces the efficacy of the algorithm.

Table 4 Variations of PDR, avg. 2ED and avg. throughput with 50 nodes

	Packet sent	*Packet received*	*Packet dropped*	*Packet delivery ratio* (%)	*Avg. throughput* (kbps)	*Avg. end to end delay* (second)
AODV	187	172	15	91.97	47	5.7
DSR	194	146	48	75.25	52.7	5.4
EAODV	197	182	15	92.38	52	2.8
Proposed	191	176	15	92.15	53	2.6

Table 5 Variations of PDR, avg. E2ED and avg. Throughput with 60 nodes

	Packet sent	*Packet received*	*Packet dropped*	*Packet delivery ratio* (%)	*Avg. throughput* (kbps)	*Avg. end to end delay* (second)
AODV	215	192	23	89.30	41.5	6.4
DSR	221	163	58	73.75	50	7
EAODV	229	209	20	91.26	51.2	3.6
Proposed	219	198	21	90.41	52	4.8

It is observed from Figures 5–7 that the performance of the proposed algorithm is comparatively better than the AODV, EAODV, and DSR. The packet delivery ratio depicts the successful delivery of packets and signifies the algorithm's efficacy. Note that the proposed protocol has a starting PDR of 96% for 20 nodes and gradually decreases to 90% for 60 nodes. It is observed that the proposed algorithm has a significant betterment in data delivery as compared to DSR (87% for 20 nodes). It is perceived that the proposed algorithm exhibits a reportedly similar improvement in comparison to AODV and EAODV (Figure 5).

Figure 5 Results of packet delivery ratio vs. number of node (see online version for colours)

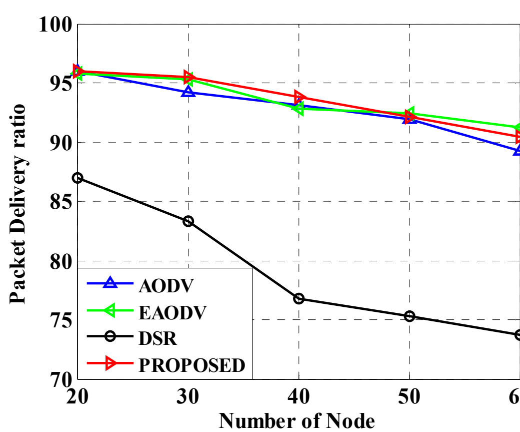


Figure 6 Results of avg. throughput vs. number of nodes (see online version for colours)

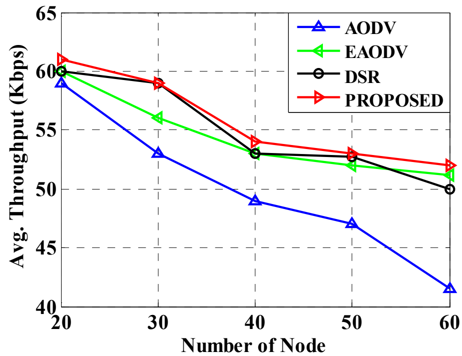


Figure 7 Results of end to end delay vs. number of node (see online version for colours)

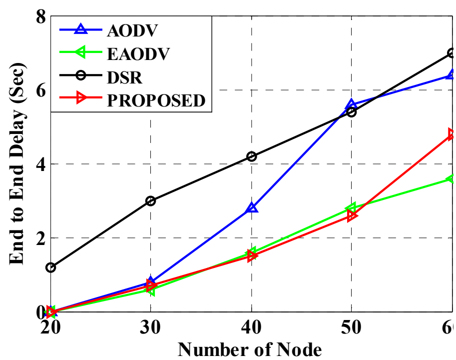


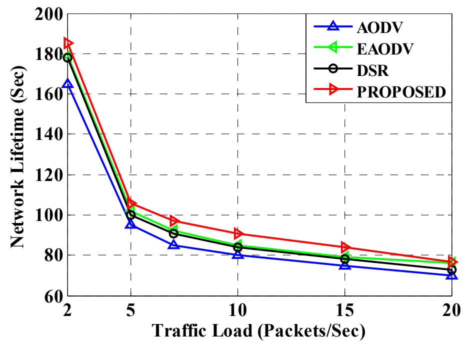
Figure 6 plots the average throughput achieved compared to the number of nodes. Average throughput has a trade-off with the number of nodes in the network. It is observed that the throughput characteristics of all the algorithms degrade with the increasing number of nodes in the network. It is further observed that the proposed algorithm shows a significant improvement over AODV and nearly similar results in comparison to DSR and EAODV. The proposed algorithm exhibits throughput ranging from 61 Kbps to 52 Kbps as the number of nodes increases from 20 to 60, which is approximately 20% better than AODV and 2% better than DSR and EAODV.

Thereafter, we evaluate the end-to-end delay (E2ED) with various numbers of nodes and observe that the performance of DSR is worse compared to all the considered algorithms. It is noted from Figure 7 that the proposed protocol experiences an increase in E2ED from 0 s to 4.8 s with the rising number of nodes from 20 to 60. In contrast, the E2ED of DSR increases from 1.2 s to 7 s, from 0 s to 3.6 s for EAODV, and from 0 s to 6.4 s for AODV as the number of nodes increases from 20 to 60. The results depict the superiority of the proposed algorithm in terms of E2ED.

After that, the analysis of network lifetime in relation to network traffic is performed. The network lifetime is a parameter that largely depends on users accessing the network's resources.

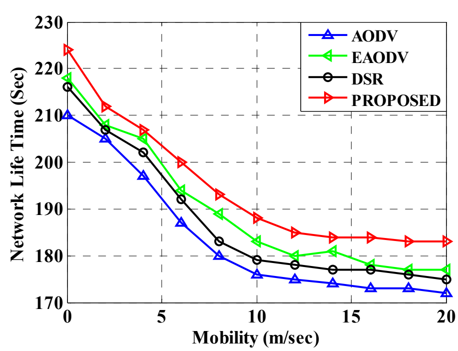
It is observed from Figure 8 that with the increasing network traffic, the node's lifetime decays exponentially. This decay resembles the processing power required to handle the traffic load, resulting in a decrease in node lifetime. The observed result intuitively justifies the theory of network processing power, and the proposed algorithm offers comparatively better results than EAODV, DSR, and AODV.

Figure 8 Results of traffic load vs. network lifetime (see online version for colours)



Lastly, we analyse the normalised node lifetime with respect to the increasing mobility of the nodes in the network and plotted that in Figure 9. Mobility resembles the change of location of the nodes; with that, frequent handovers and processing are required in the ongoing traffic load. In critical situations like a disaster, we need to consider the node lifetime with the increasing number of nodes in the network. The growing number of nodes and their mobility increases the network overhead in the Ad-hoc network, resulting in the minimisation of node lifetime. Thus, we conduct an analysis of network lifetime with the mobility of the nodes. It is observed that the proposed algorithm outperforms EAODV, DSR, and AODV.

Figure 9 Results of network life time vs. node mobility (see online version for colours)



5 Conclusion

In severe emergencies with a high density of nodes generating high traffic, an energy efficient forwarding method is required to prevent the exhaustion of a node's limited battery. To address this, we propose a hybrid energy-efficient routing protocol based on ZRP and DSR, incorporating the additional feature of a cluster-based hierarchy to enhance both network and node lifetimes. Through a comprehensive competitive analysis, we observe that the proposed algorithm outperforms DSR, EAODV, and AODV in terms of end-to-end delay, throughput, network lifetime, and energy consumption. Specifically, the proposed algorithm demonstrates a 2% higher average throughput achievement compared to the reportedly second-best algorithm, DSR. Furthermore, it surpasses AODV and DSR in end-to-end delay by 16% and 22%, respectively. In the evaluation of normalised lifetime, we observe that the proposed algorithm outperforms AODV, EAODV, and DSR by 6%, 2.6%, and 3.5%, respectively. Therefore, the proposed algorithm is comparatively superior to all the considered algorithms, contributing to an optimal network lifetime. These results highlight the suitability of the proposed algorithm in emergency situations where network life is of utmost priority.

References

Alqahtani, A.S. (2021) 'Enhanced energy and channel aware load balancing AOMDV protocol for efficient packet transmission in MANET', *International Journal of Ultra Wideband Communications and Systems*, Vol. 4, Nos. 3–4, 19 November, pp.156–160, https://doi.org/10.1504/IJUWBCS.2021.119138

Ambika, B.J. and Banga, M.K. (2020) 'A novel energy efficient routing algorithm for MPLS-MANET using fuzzy logic controller', *International Journal of Information and Computer Security*, Vol. 14, No. 1, 17 December, pp.20–39, https://doi.org/10.1504/IJICS.2021.112206

Bai, F. and Helmy, A. (2004) *A Survey of Mobility Models in Wireless Ad-Hoc Networks*, University of Southern California, USA, https://api.semanticscholar.org/CorpusID: 5556017

Boyan, J.A. and Littman, M.L. (1994) 'Packet routing in dynamically changing networks: a reinforcement learning approach', *Advances in Neural Information Processing Systems*, Vol. 6, pp.671–678.

Chakeres, I.D. and Perkins, C.E. (2006) *Dynamic MANET on Demand* (*DYMO*) *Routing Protocol*, Internet-Draft Version 6, IETF, October.

Chandravanshi, K., Soni, G. and Mishra, D.K. (2022) 'Design and analysis of an energy-efficient load balancing and bandwidth aware adaptive multipath N-channel routing approach in MANET', *IEEE Access*, Vol. 10, pp.110003–110025, doi: 10.1109/ACCESS.2022.3213051.

Clausen, T. and Jacquet, P. (2003) *Optimized Link State Routing Protocol (OLSR)*, RFC 3626 IETF, October.

Doshi, S., Bhandare, S. and Brown, T.X. (2002) 'An on-demand minimum energy routing protocol for a wireless ad hoc network', *Mobile Computing and Communications Review*, Vol. 6, No. 3, pp.50–66, https://doi.org/10.1145/581291.581300

Gandhi, R., Rajkumar, T., Chandramohan, J. and Guha, T. (2022) 'Energy consumption reduction using ant colony optimization in manet using machine learning techniques', *2022 IEEE 2nd Mysore Sub Section International Conference (MysuruCon)*, Mysuru, India, pp.1–5, doi: 10.1109/MysuruCon55714.2022.9972456.

Gorantala, K. (2006) *Routing Protocols in Mobile Ad Hoc Networks*, Master Thesis in Compting Science, Umea University, 15 June.

Hafslund, A., Hoang, T.T. and Kure, O. (2005) 'Push-to-talk applications in mobile ad hoc networks', *Proceedings of the IEEE 61st Vehicular Technology Conference,* Stockholm, Sweden, Vol. 4, pp.2410–2414, doi: 10.1109/VETECS.2005.1543767.

Halhalli, S.R., Sugave, S.R. and Jagdale, B.N. (2021) 'Optimisation driven-based secure routing in MANET using atom whale optimisation algorithm', *International Journal of Communication Networks and Distributed Systems*, Vol. 27, No. 1, 19 May, pp.77–99, https://doi.org/10.1504/IJCNDS.2021.116484

Heinzelman, W.R., Chandrakasan, A. and Balakrishnan, H. (2000) 'Energy-efficient communication protocol for wireless microsensor networks', *Proceedings of the 33rd Annual Hawaii International Conference on System Sciences,* Maui, HI, USA, Vol. 2, p.10, doi: 10.1109/HICSS.2000.926982.

Jamali, S., Rezaei, L. and Gudakahriz, S.J. (2013) 'An energy-efficient routing protocol for MANETs: a particle swarm optimization approach', *Journal of Applied Research and Technology*, Vol. 11, No. 6, pp.803–812, https://doi.org/10.1016/S1665-6423(13)71586-4

Jiang, M., Li, J. and Tay, Y.C. (1998) *Cluster Based Routing Protocol* (*CBRP*) *Functional Specification*, IETF MANET Working Group INTERNET Draft, August.

Johnson, D.B., Maltz, D.A. and Hu, Y.C. (2004) *The Dynamic Source Routing Protocol for Mobile Ad Hoc Networks* (*DSR*), IETF MANET Working Group INTERNET Draft, July.

Karp, B. and Kung, H.T. (2000) 'Greedy perimeter stateless routing for wireless networks', *Proc. 6th Annual ACM/IEEE Int'l. Conf. Mobile Comp. Net.,* August, Boston, MA, pp.243–254, https://doi.org/10.1145/345910.345953

Ko, Y. and Vaidya, N.H. (1998) 'Location-aided routing (LAR) in mobile ad hoc networks', *Wireless Networks*, Vol. 6, pp.307–321, https://doi.org/10.1023/A: 1019106118419

Kumar, C.N. and Kukunuru, N. (2021) 'Energy efficient disjoint multipath routing protocol using simulated annealing in MANET', *Wireless Pers Commun.*, Vol. 120, pp.1027–1042, https://doi.org/10.1007/s11277-021-08502-3

Kumar, M. and Dubey, G.P. (2016) 'Energy efficient multipath routing with selection of maximum energy and minimum mobility in MANET', *2016 International Conference on ICT in Business Industry and Government (ICTBIG)*, Indore, India, pp.1–6, doi: 10.1109/ICTBIG. 2016.7892722.

Macone, D., Oddi, G. and Pietrabissa, A. (2013) 'MQ-routing: mobility-, GPS-and energy-aware routing protocol in MANETs for disaster relief scenarios', *Ad Hoc Networks*, Vol. 11, No. 3, pp.861–878, https://doi.org/10.1016/j.adhoc.2012.09.008

Misra, A. and Banerjee, S. (2002) 'MRPC: maximizing network lifetime for reliable routing in wireless environments', *2002 IEEE Wireless Communications and Networking Conference Record. WCNC 2002 (Cat. No. 02TH8609),* Orlando, FL, USA, Vol. 2, pp.800–806, doi: 10.1109/WCNC.2002.993371.

Murthy, C.S.R. and Manoj, B.S. (2004) *Mobile Ad Hoc Networks Architectures & Protocols*, Pearson Education, New Delhi.

Murugan, K. and Shanmugavel, S. (2008) 'Delay and traffic based on-demand routing algorithms for improving energy efficiency in mobile ad hoc networks' *International Journal of Wireless and Mobile Computing*, Vol. 2, No. 4, 21 January, pp.362–372, https://doi.org/10.1504/ IJWMC.2007.016728

Onwuka, E., Folaponmile, A. and Ahmed, M. (2011) 'Manet: A reliable network in disaster areas', *Journal of Research In National Development, Transcampus*, Vol. 9, No. 2, pp.105–113.

Pattnaik, P.K., Panda, B.K. and Sain, M. (2021) 'Design of novel mobility and obstacle-aware algorithm for optimal MANET routing', *IEEE Access*, Vol. 9, pp.110648–110657, doi: 10.1109/ACCESS.2021.3101850.

Perkins, C., Royer, E.B. and Das, S. (2003) *Ad Hoc On-Demand Distance Vector* (*AODV*) *Routing – Internet Draft*, RFC. 3561, IETF Network Working Group, July, https://datatracker.ietf. org/doc/rfc3561/

Perkins, C.E. and Bhagwat, P. (1994) 'Highly dynamic Destination sequenced distance vector routing (DSDV) for mobile computers', *Proc. of ACM SIGCOMM'94*, London, England, UK, pp.234–244, https://doi.org/10.1145/190314.190336

Quispe, L.E. and Luis, M.G. (2014) 'Behavior of ad hoc routing protocols, analyzed for emergency and rescue scenarios, on a real urban area', *Expert Systems with Applications*, Vol. 41, No. 5, pp.2565–2573, https://doi.org/10.1016/j.eswa.2013.10.004

Quy, V.K., Ban, N.T., Van Anh, D., Quy, N.M. and Nguyen, D.C. (2023) 'An adaptive gateway selection mechanism for MANET-IoT applications in 5G networks', *IEEE Sensors Journal*, Vol. 23, No. 19, 1 October, pp.23704–23712, doi: 10.1109/JSEN.2023.3307617.

Rajakumar, R., Dinesh, K. and Vengattaraman, T. (2021) 'An energy-efficient cluster formation in wireless sensor network using grey wolf optimization', *International Journal of Applied Management Science*, Vol. 13, No. 2, 15 July, pp.124–140, https://doi.org/10.1504/IJAMS.2021.116496

Rajendra Prasad, P. and Shivashankar (2022) 'Enhanced energy efficient secure routing protocol for mobile ad-hoc network', *Global Transitions Proceedings*, Vol. 3, No. 2, pp.412–423, https://doi.org/10.1016/j.gltp.2021.10.001

Ramrekha, T.A., Talooki, V.N., Rodriguez, J. and Politis, C. (2012) 'Energy efficient and scalable routing protocol for extreme emergency ad hoc communications', *Mobile Networks and Applications*, Vol. 17, No. 2, pp.312–324, https://doi.org/10.1007/s11036-011-0336-0

Royer, E.M. and Toh, C-K. (1999) 'A review of current routing protocols for ad-hoc mobile wireless networks', *IEEE Personal Communications Magazine,* April, pp.46–55, http://www.cs.ucsb.edu/~eroyer/publications.html

Sarhan, S. and Sarhan, S. (2021) 'Elephant herding optimization ad hoc on-demand multipath distance vector routing protocol for MANET', IEEE Access, Vol. 9, pp.39489–39499, doi: 10.1109/ACCESS.2021.3065288.

Shivashankar, Suresh, H.N., Varaprasad, G. and Jayanthi, G. (2014) 'Notice of violation of IEEE publication principles: designing energy routing protocol with power consumption optimization in MANET', *IEEE Transactions on Emerging Topics in Computing*, Vol. 2, No. 2, pp.192–197, June, doi: 10.1109/TETC.2013.2287177.

Srilakshmi, U., Veeraiah, N., Alotaibi, Y., Alghamdi, S.A., Khalaf, O.I. and Subbayamma, B.V. (2021) 'An improved hybrid secure multipath routing protocol for MANET', *IEEE Access*, Vol. 9, pp.163043–163053, doi: 10.1109/Access.2021.3133882.

Srivastava, A., Kumar, D. and Gupta, S.C. (2014) 'Modelling mobility in emergency scenario for MANET applications', *2014 Recent Advances in Engineering and Computational Sciences* (*RAECS*), Chandigarh, pp.1–6, doi: 10.1109/Raecs.2014.6799599.

Stojmenovic, I. (2002) 'Position based routing in ad-hoc networks', *IEEE Communications Magazine*, Vol. 40, No. 7, July, pp.128–234, doi: 10.1109/MCOM.2002.1018018.

Toh, C.K. (2001) 'Maximum battery life routing to support ubiquitous mobile computing in wireless ad-hoc networks', *IEEE Communications Magazine*, Vol. 39, No. 6, June, pp.138–147, doi: 10.1109/35.925682.

Tsai C-S. and He, C-Y. (2010) 'A novel group communication or disaster positioning in mobile ad hoc network', *IEEE International Conference on Computing and Communication Technologies, Research, Innovation, and Vision for the Future* (*RIVF*), Hanoi, Vietnam, pp.1–4, doi: 10.1109/RIVF.2010.5633127.

Veeraiah, N., Khalaf, O.I., Prasad, C.V.P.R., Alotaibi, Y., Alsufyani, A., Alghamdi, S.A. and Alsufyani, N. (2021) 'Trust aware secure energy efficient hybrid protocol for MANET', *IEEE Access*, Vol. 9, pp.120996–121005, doi: 10.1109/ACCESS.2021.3108807.

Venkatesh, T. and Chakravarthi, R. (2022) 'An energy efficient algorithm in MANET using monarch butterfly optimization and cluster head load distribution', *2022 International Conference on Communication, Computing and Internet of Things* (*IC3IoT*), Chennai, India, pp.1–5, doi: 10.1109/IC3IOT53935.2022.9767917.

Vijayakumar, H. and Ravichandran, M. (2011) 'Efficient location management of mobile node in wireless mobile ad-hoc network', *2011 National Conference on Innovations in Emerging Technology,* Erode, India, pp.77–84, doi: 10.1109/Ncoiet.2011.5738838.

Zhang, T., Zhao, S. and Cheng, B. (2020) 'Multipath routing and MPTCP-based data delivery over MANETs', *IEEE Access*, Vol. 8, pp.32652–32673, doi: 10.1109/ACCESS.2020.2974191.

Zygmunt, J.H., Pearlman, M.R. and Samar, P. (2002) *The Zone Routing Protocol* (*ZRP*) *for Ad Hoc Networks*, RFC 2026 IETF, July.