Indonesian Journal of Electrical Engineering and Computer Science
Vol. 27, No. 2, August 2022, pp. 842~848
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v27.i2.pp842-848

Routing protocols for hybrid wireless networks: a brief review

Miaad Husam Mahdi, Ibrahim Adel Ibrahim
Department of Computer Engineering, University of Technology- Iraq, Baghdad, Iraq

Article Info

Article history:

Received Apr 8, 2022
Revised Jun 9, 2022
Accepted Jun 16, 2022

Keywords:

Base stations
Hybrid wireless networks
routing protocols
Mobile Ad hoc networks relay
Scalability

ABSTRACT

Hybrid wireless networks (HWNs) are resulted from the integration of a mobile Ad hoc networks (MANET) and an infrastructure wireless networks. These networks have received increasing interest from researchers for their superior performance and reliability. Packet routing protocols in hybrid wireless networks are important to increase the capacity and scalability of these networks, therefore, several routing protocols have been proposed. Routing protocols in HWNs are designed and implemented from combining the cellular transmission mode with the Ad hoc transmission mode. To route a message to the intended recipient of the sender, hybrid wireless networks use multi-hop technology. However, the source node needs relay nodes, which may be either adjacent nodes or base stations depending on set of parameters like bandwidth, load balancing, or the nearest node. This paper explores routing protocols for hybrid wireless networks and the techniques to enhance the security, performance, and capacity of these routing protocols.

Corresponding Author:

Miaad Husam Mahdi
Department of Computer Engineering, University of Technology- Iraq
Baghdad, Iraq
Email: ce.20.06@grad.uotechnology.edu.iq

1. INTRODUCTION

Hybrid wireless networks have a superior network structure for the future generation of wireless networks [1]. Hybrid wireless network merge the mobile ad-hoc network with the infrastructure wireless network. Wireless devices, like smartphones, tablets, and laptop computers, have an infrastructure interface as well as an ad-hoc interface. The number of wireless devices has been rapidly expanding in recent years. Therefore, the need transmission structure of hybrid networks is increasing. Such a network combines the inherent benefits and overcomes the shortcomings of mobile ad-hoc networks and infrastructure wireless networks in a synergistic manner.

In mobile ad-hoc networks (MANET), no centralized control infrastructure is available, therefore, packets are routed to their destination via intermediate nodes in a multi-hop fashion. Route maintenance or on-demand route discovery is required for multi-hop routing [2]–[6]. However, MANET is not reliable like infrastructure wireless networks because messages are sent via wireless channels and over dynamic routing paths. Moreover, due to their multi-hop transmission capability, MANETs are only appropriate for local area data transfer. Many features made Ad hoc networks a robust technology such as self-configuration, inherent flexibility, and ease of maintenance [7]. The main problem of MANET is discovering the route of the destination node; therefore many schemes are proposed to tackle this problem [8]. Also another challenges for MANET is the reliable communication and security issues like authenticating, integration and confidentiality of the packets [9]. The performance of energy routing protocols focused on many metrics such as throughput, delay and packet delivery [10], [11]. The scalability has an important role in position-based Ad hoc routing protocols [12].

The primary mode of infrastructure wireless network such as cellular network is wireless communication. The nodes of theses network can exchange data with each other via base stations (BSes).

Channel access efficiency and higher message transmission reliability can be provided in infrastructure wireless networks because of the long-distance one-hop transmission between mobile nodes and BSes. However, they suffer from higher power dissipation on mobile nodes as well as the single point of failure concern [13]–[16]. Although the catenarian-trim medley (CTM) routing protocol balances energy consumption but the delay is increased considerably during transmission of data [17]–[23]. Since wireless sensor networks are deployed in healthcare, defense and other applications, it subject to many security attacks. So, different reputation-based systems are developed to monitor un normal activities [24]–[28].

MANET's bandwidth, capacity, and poor connection are among the challenges it faces. In contrast, in an infrastructure network, mobile nodes have a one-hop path to the base station and function in a non-autonomous way. It produce a weak communication when an allotted channel in a certain cell is over-utilized. Handoff and base station problems due to traffic overhead are the two most significant difficulties in cellular networks. Hybrid wireless networks have solved the shortcomings of both networks [29]–[32].

The wireless network throughput of data transmission is influenced by a routing protocol. Most existing routing protocols in HWNs essentially mix Ad hoc transmission mode in mobile Ad hoc networks with the cellular transmission mode in infrastructure Wireless networks [33], [34]. Routing protocols are further classified into three kinds: proactive (table-driven), reactive (on-demand), and hybrid. In reactive routing protocols, when a source mobile node (MN) wants to transfer data packets, it discovers a route to the destination. So, there are two parts in this scheme: route maintenance and route discovery. (AODV) and (DSR) are two well-known reactive routing techniques [35]–[38]. Control packets were broadcasted during the route discovery phase to decrease network load. Because of the extremely mobile nature of mobile Ad hoc networks, the path to the intended destination is easily lost. As a result, a path maintenance phase is employed to maintain routes operationally. A table for the whole network is maintained by the MN that utilized a proactive routing protocol. The benefit of this scheme is that the path from a source MN to the inteneded destination is ready before initiating the data transmission process. However, it has the drawback of having a high overhead due to the periodic broadcast for control packets used to maintain the routing tables. One of the proactive routing protocols is destination sequence vector (DSDV). Finally, one of the hybrid routing protocols is the zone routing protocol (ZRP). This protocol makes an effort to adopt both reactive and proactive routing. Each MN keeps an area of neighboring MNs within (n) hops from it. This is the MN's inner zone, where it behaves as a proactive and reactive scheme when wants to exchange data with a MN far away of this area or zone. As a result, each node in its inner zone transmits broadcast packets on a regular basis in order to establish a routing table of all MNs inside this area or zone. When a node tries to send data to the desired node that sits outside of its zone, it initiates a routing detection or discovery phase to set up the route and maintain a route in case of breakdown links. However, it still has the drawback of proactive and reactive protocols in terms of control overhead and end-to-end delay. [39]–[44]. The primary goal of this study is to review the research papers on routing protocols that were used for packet routing in hybrid networks.

2. BACKGROUND AND RELATED WORK

The routing protocols used with the hybrid networks merge the advantages of both infrastructure wireless networks and mobile Ad hoc networks. However, these protocols inherit the Ad hoc networks' drawbacks. Shen *et al.* [45], [46] in 2015 and 2009 presented A distributed three-hop routing protocol (DTR) for networks that used hybrid wireless networks. DTR cuts up the stream of the message by the source into segments then sends these segments concurrently to different base stations as shown in Figure 1. DTR routing protocol makes full use of base stations and increases the throughput of the network. Moreover, this protocol reduced overhead by removing route discovery and maintenance. Also, the DTR protocol avoided overloading base stations because it has a congestion control algorithm.

In 2016, Poovila [47] try to enhance an efficient routing protocol through combining Ad hoc and infrastructure networks' routing protocols to increase the throughput of data transmitted between the sender and the receiver. Based on the simulation results, which included merging the advantages of trading market management and distributed routing algorithm (DRA), a high throughput was obtained. However, there is an issue related to the inheritance of the disadvantages of Ad hoc networks, this issue still appears in the suggested system, even though the process of combining has been achieved. In addition, security issues have been considered by using asymmetric key cryptography algorithm (RSA) for data confidentiality.

The combination of both MANET and infrastructure network formed hybrid networks. This combination has inherited the problem of race conditions and invalid reservation of MANET. Guaranteeing the quality of service (QOS) for hybrid networks is stills a big problem. In 2018, Mohammadani *et al.* [48], simulated both (AODV+ and DSDV) Ad hoc routing protocols with different network complexities in hybrid systems. They found that DSDV routing protocol performed ineffectively compared with the AODV+ routing protocol in terms of jitter, PLR, and PDR [49].

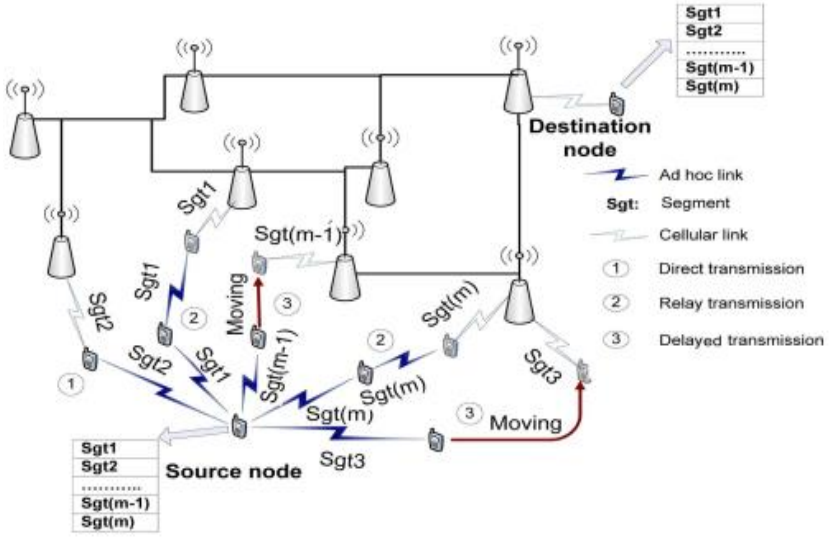

Figure 1. DTR protocol data transmission [46]

Network nodes can be classified into static nodes as well as dynamic nodes. The static node will have zero moves for example ground stations. In contrast, dynamic nodes, which are characterized by their movement, such as aircraft. Guo *et al.* [50], propose (HODVM) routing protocol for (HWSO). That is separating the network to backbone network (all static nodes are linked together using simple wireless connectivity) and non-backbone network (all dynamic and static nodes are linked together via transient wireless connections) to carry out the static and dynamic routing, respectively. The simulation results reveal that, as compared to the prior routing protocols, HODVM has higher scalability when the network size or topology changes.

Malicious attacks on hybrid networks disrupt routing by losing packets, modifying them, and selectively forwarding them. These types of assaults cause network links to fail. In these networks, link failures are the primary cause of packet loss and network instability. The lifespan of the network, as well as the performance of the route, are both impacted by link failures. In 2019, Kumar and Mohideen [51], proposes (SARP-HWNs) routing protocols to minimize link failure in the present routing path and can provide quick recovery, enhance throughput, decrease end-to-end latency, optimize the lifetime of the routing path without compromising energy consumption, and QoS/QoE when compared to other existing strategies [52].

QoS-oriented distributed routing protocol (QOD) is a QoS-oriented distributed routing technology suggested to improve hybrid networks' QoS capabilities. QOD converts the packet routing problem to a resource scheduling problem by utilizing the network's lesser transfer hops and anycast transmission features. To fulfill the transmission delay requirement, QOD contains a QoS-guaranteed neighbor selection algorithm, mobility-based segment resizing algorithm, and a distributed packet scheduling technique to further minimize transmission time. In order to minimize transmission time, a method that adaptively modifies segment size based on node mobility is used. According to simulation results, Li and Shen [53]–[55] inferenced that QOD may give stronger QoS performance in terms of latency, overhead, scalability, and dynamic resilience compared to a resource reservation-based mechanism.

In a disaster and harm assessment, information needs to be collected faster and more stable for sharing the accident information and surrounding situations. To achieve that, Fujiwara and Watanabe [56], proposed a routing protocol to carry out unicast communication which is called enhanced communication scheme combining centralized and Ad hoc networks (ECCA) for hybrid wireless networks. HWNs routing protocol maintain the link between nodes and base stations. When this link is disconnected due to disasters, the routing protocol allows the node to connect with the base station by its neighboring nodes instead of asking for a route.

Shen *et al.* [57] Proposed a method of a P2P-based market-directed routing technique for boosting throughput performance by eliminating issues such as route maintenance and route discovery. This approach simply mixes the numerous routing strategies that cause congestion and overhead concerns in Ad hoc routing protocols. In this system, the nodes were distributed according to the supplied coordinates and broadcast/flooded the messages to all of their nearby nodes. The distance between neighboring nodes will be determined using the distance formula. Base stations were placed in the center of the nodes. The BSes will communicate with one another during the procedure. Because MDR is not employed in this procedure, it results in low routing efficiency, high packet loss, and node energy consumption when moving packets from source to destination.

The suggested MDR system makes use of widely available BSes to produce efficient data routing, reputation management, and trading market management (TMM). MDR consists of four components locality aware P2P-based infrastructure (LP2P), trading market management (TMM). Efficient and accurate reputation management (EARM) and distributed routing algorithm (DRA).

Rajapurohit *et al.* [58] suggested a QoS-oriented data transmission approach that achieves high quality based on QoS in HWN by minimizing data packet transmission latency during the interaction. When a client is not present within the coverage zone of the access point range, the QoS-oriented data transmission approach is employed to change from the issue of packet routing to the issue of dynamic resource scheduling. As a result, the source node chooses the neighbour node depending on important criteria such as latency and bandwidth. It recovers invalid reservation problems and race conditions by employing this strategy. Finally, in order to enhance QoS in a fast-changing system, the packet resizing technique for optimizing the scheduling of intermediate nodes and packet scheduling method for choosing neighbor nodes are included. As a result, great throughput is also achieved in hybrid wireless networks.

Sun and Belding-Royer [59] proposed two routing schemes to get better performance for combating the limitations of hybrid wireless network that appropriate different traffic patterns. He showed that when there are short internet based sessions utilizing a default router produces better performance with fewer routing table entries, lower latency, and flexible control overhead. However, when the internet traffic is accidental occurrence and the local traffic is high, a better performance is obtained with high throughput and low control overhead.

Channel congestion of routing impacts hybrid wireless networks, which are making it difficult to guarantee the transmission reliability of the network. An efficient routing protocol (ERP) was proposed to improve the communication reliability of networks. To send data to a base station, the routing protocol selects the node with the largest channel capacity ensuring that a message is reliably delivered to its intended recipient. Comparative results with other protocols showed that ERP can enhance the throughput capacity and minimize the congestion of hybrid wireless networks [60].

Aakasham and Mugunthan [61] suggested a secure quality of service oriented distributed routing protocol (SQOD) for hybrid wireless networks. This protocol implicated two schemes which are the QoS-oriented distributed routing protocol (QOD) and (EAACK). QOD is proposed to minimize transmission time, transmission delay and to maximize transmission throughput. EAACK is used to perform intrusion-detection system. SQOD can accomplish high mobility-resilience, adaptability, and contention reduction, according to experimental results [62]. The objectives and obtained results of each routing protocol are summarized in the Table 1.

Table 1. Summary of the routing protocols of hybrid wireless networks

Reference	Authors	Years	Objectives	Simulation	Results
[51]	Kumar and Mohideen	2019	The goals of this routing protocol are: - Avoiding link failure - Quick recovery - Enhance the throughput - Minimize end to end delay	Network Simulator (NS2)	Secure aware routing protocol for hybrid wireless networks (SARP-HWNs) enhanced the QoS metrics.
[48]	Mohammadani *et al.*	2018	Using of two Ad Hoc routing protocols (DSDV and AODV+) in hybrid systems with different network complexities	-	The latency of the DSDV protocol is better than that of AODV+ protocol but the AODV+ protocol performed somewhat well to DSDV.
[63]	Li and Shen	2010	The purpose was to enhance the QoS capability of hybrid networks.	-	The QoS support capability of hybrid networks are improved.
[45]	Shen *et al.*	2015	Proposed DTR routing protocol for hybrid wireless networks	NS2	Enhance the scalability and the throughput of HWNs.
[50]	Guo *et al.*	2010	Propose a new routing protocol which is the Hybrid On-demand Distance Vector Multi-path (HODVM)	NS2	Respecting to the network size, the HODVM routing protocol has better scalability in comparison with other traditional routing protocols.
[64]	Mahmoud *et al.*	2014	Propose lightweight protocol for: - Securing communication - Preserving users' anonymity - Location privacy.	NS2	Proposed protocol: - Has low overhead - Maintain the node's privacy

3. CONCLUSION

In recent years, hybrid wireless networks have gotten big attention. A HWNs put together the advantages of a mobile ad-hoc network and an infrastructure wireless network to maximize the system's throughput capacity. Different routing protocols and techniques are explored in this paper. Some of them discussed the hybrid networks and the routing protocols utilized by these networks, while other research dealt with topics to provide security for routing protocols to enhance the security of these networks. Various strategies have been used to improve throughput by minimizing latency, traffic prevention, as well as overhead at base stations.

REFERENCES

[1] H. Luo, R. Ramjee, P. Sinha, L. Li, and S. Lu, "UCAN: A unified cellular and ad-hoc network architecture," in *Proceedings of the Annual International Conference on Mobile Computing and Networking*, 2003, pp. 353–367, doi: 10.1145/938985.939021.

[2] C. E. Perkins, P. Bhagwat, C. E. Perkins, P. Bhagwat, C. E. Perkins, and P. Bhagwat, "Highly dynamic (DSDV) for mobile computers routing," in *Proc. ACM SIGCOMM94, London, UK*, 1994, vol. 24, no. 4, pp. 234–244, doi: 10.1145/190314.190336.

[3] D. A. Johnson, B. David, and Maltz, "Dynamic source routing in ad hoc wireless networks," in *Mobile computing*, 1996, pp. 153–181.

[4] V. D. Park and M. S. Corson, "Highly adaptive distributed routing algorithm for mobile wireless networks," in *Proc. - IEEE INFOCOM*, vol. 3, pp. 1405–1413, 1997, doi: 10.1109/infcom.1997.631180.

[5] J. H. Majeed, N. A. Habeeb, and W. K. Al-Azzawi, "Performance investigations of internet protocol versions for mobile Ad-hoc network based on qualnet simulator," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 21, no. 1, pp. 497–504, 2021, doi: 10.11591/ijeecs.v21.i1.pp497-504.

[6] M. Mohanapriya, N. Joshi, and M. Soni, "Secure dynamic source routing protocol for defending black hole attacks in mobile Ad hoc networks," *Indonesian Journal of Electrical Engineering and Computer Science*., vol. 21, no. 1, pp. 582–590, 2021, doi: 10.11591/ijeecs.v21.i1.pp582-590.

[7] B. U. I. Khan, R. F. Olanrewaju, F. Anwar, A. R. Najeeb, and M. Yaacob, "A survey on MANETs: architecture, evolution, applications, security issues and solutions," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 12, no. 2, pp. 832–842, 2018, doi: 10.11591/ijeecs.v12.i2.pp832-842.

[8] N. N. Alleema and D. S. Kumar, "Cooperative and fresher encounter algorithm for reducing delay in MANET," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 14, no. 3, pp. 1258–1265, 2019, doi: 10.11591/ijeecs.v14.i3.pp1258-1265.

[9] U. Kumaran, A. Ramachandran, J. Jegan, and E. K. Subramanian, "Enhanced routing for secured ad-hoc network," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 19, no. 2, pp. 949–956, 2020, doi: 10.11591/ijeecs.v19.i2.pp949-956.

[10] M. A. Saad, H. J. Alhamdane, S. A. H. Ali, M. M. Hashim, and B. Hasan "Total energy consumption analysis in wireless mobile ad hoc network with varying mobile nodes," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 20, no. 3, pp. 1397–1405, 2020, doi: 10.11591/ijeecs.v20.i3.pp1397-1405.

[11] A. Sangeetha and T. Rajendran, "Levenberg-Marquart logistic deep neural learning based energy efficient and load balanced routing in MANET," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 23, no. 2, pp. 1002–1010, 2021, doi: 10.11591/ijeecs.v23.i2.pp1002-1010.

[12] R. B. Al-Bayram and R. M. Abdullah, "Network size variation of geographical aided routing protocols in MANET," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 21, no. 1, pp. 420–428, 2021, doi: 10.11591/ijeecs.v21.i1.pp420-428.

[13] R. Chang, W. Chen, and Y. Wen, "Hybrid wireless network protocols," in *IEEE Transactions On Vehicular Technology*, vol. 52, no. 4, pp. 1099–1109, 2003, doi: 10.1109/TVT.2002.807126.

[14] I. Yousif Ibrahim and S. Kurnaz, "A new distributed denial-of-service detection system in cloud environment by using deep belief networks," *Commun.Fac.Sci.Univ.Ank.Series A2-A3*, vol. 63, no. 1, pp. 17–24, 2021, doi: 10.33769/aupse.697067.

[15] W. Dai, I. Ibrahim, and M. Bassiouni, "An improved replica placement policy for hadoop distributed file system running on cloud platforms," *Proc. - 4th IEEE Int. Conf. Cyber Secur. Cloud Comput. CSCloud 2017 3rd IEEE Int. Conf. Scalable Smart Cloud, SSC 2017*, 2017, pp. 270–275, doi: 10.1109/CSCloud.2017.65.

[16] I. A. Ibrahim, W. Dai, and M. Bassiouni, "Intelligent data placement mechanism for replicas distribution in cloud storage systems," in *Proceedings - 2016 IEEE International Conference on Smart Cloud, SmartCloud 2016*, 2016, pp. 134–139, doi: 10.1109/SmartCloud.2016.23.

[17] V. K. Sharma, A. Sharma, K. Ntalianis, and K. Verma, "CTMRS: catenarian-trim medley routing system for energy balancing in dispensed computing networks," *IEEE Trans. Netw. Sci. Eng.*, 2022, doi: 10.1109/TNSE.2021.3140139.

[18] V. K. Sharma, Saurabh and K. Verma, "An integrated exploration on internet of things and wireless sensor networks," *Wirel. Pers. Commun.*, pp. 1–36, 2022, doi: 10.1007/s11277-022-09487-3.

[19] C.-T. Verma, V. Kumar and K. Ntalianis, Moreno, and C. M. Yang, "Next-generation internet of things and cloud security solutions," *Int. J. Distrib. Sens. Networks*, vol. 15, 2019, doi: 10.1177/1550147719835098.

[20] N. P. Verma, V. Kumar, K. Ntalianis, S. Singh, and N. P. Pathak, "Data proliferation based estimations over distribution factor in heterogeneous wireless sensor networks," *Comput. Commun.*, vol. 124, pp. 111–118, 2018, doi: 10.1016/j.comcom.2017.09.017.

[21] V. K. Verma, "Pheromone and path length factor-based trustworthiness estimations in heterogeneous wireless sensor networks," *IEEE Sens. J.*, vol. 17, pp. 215–220, 2016, doi: 10.1109/JSEN.2016.2627041.

[22] N. P. Verma, V. Kumar, S. Singh, and N. P. Pathak, "Towards comparative evaluation of trust and reputation models over static, dynamic and oscillating wireless sensor networks," *Wirel. Networks*, vol. 23, pp. 335-343, 2017, doi: 10.1007/s11276-015-1144-4.

[23] N. P. Verma, V. Kumar, S. Singh, and N. P. Pathak, "Analytical event based investigations over delphi random generator distributions for data dissemination routing protocols in highly dense wireless sensor network," *Wirel. Pers. Commun.*, vol. 87, pp. 1209-1222, 2016, doi: 10.1007/s11277-015-3049-z.

[24] N. P. Verma, V. Kumar, S. Singh, and N. P. Pathak, "Impact of malicious servers over trust and reputation models in wireless sensor networks," *Int. J. Electron.*, vol. 103, pp. 530-540, 2016, doi: 10.1080/00207217.2015.1036803.

[25] N. P. Verma, V. Kumar, S. Singh, and N. P. Pathak, "Comprehensive event based estimation of sensor node distribution strategies using classical flooding routing protocol in wireless sensor networks," *Wirel. networks*, vol. 20, pp. 2349-2357, 2014, doi: 10.1007/s11276-014-0739-5.

[26] N. P. Verma, V. Kumar, S. Singh, and N. P. Pathak, "Collusion based realization of trust and reputation models in extreme fraudulent environment over static and dynamic wireless sensor networks," *Int. J. Distrib. Sens. Networks*, vol. 10, 2014, doi: 10.1155/2014/672968.
[27] N. P. Singh, V. Kumar, S. Singh, and N. P. Pathak, "Sensors augmentation influence over trust and reputation models realization for dense wireless sensor networks," *IEEE Sens. J.*, vol. 15, pp. 6248--6254, 2015, doi: 10.1109/JSEN.2015.2448642.
[28] N. P. Verma, V. Kumar, S. Singh, and N. P. Pathak, "Optimized battery models observations for static, distance vector and on-demand based routing protocols over 802.11 enabled wireless sensor networks," *Wirel. Pers. Commun.*, vol. 81, no. 2, pp. 503-517, 2015, doi: 10.1007/s11277-014-2141-0.
[29] D. N. Kanellopoulos, "Congestion control for NDN-based MANETs: Recent advances, enabling technologies, and open challenges," *J. Organ. End User Comput.*, vol. 33, no. 5, pp. 1–24, 2021, doi: 10.4018/JOEUC.20210901.oa6.
[30] J. I. Naser and A. J. Kadhim, "Multicast routing strategy for SDN-cluster based MANET," *International Journal of Electrical and Computer Engineering*., vol. 10, no. 5, pp. 4447–4457, 2020, doi: 10.11591/ijece.v10i5.pp4447-4457.
[31] I. A. Ibrahim and M. Bassiouni, "Improvement of job completion time in data-intensive cloud computing applications," *J. Cloud Comput.*, vol. 9, no. 1, 2020, doi: 10.1186/s13677-019-0139-6.
[32] W. Dai, I. Ibrahim, and M. Bassiouni, "An improved straggler identification scheme for data-intensive computing on cloud platforms," in *2017 IEEE 4th International Conference on Cyber Security and Cloud Computing (CSCloud)*, 2017, pp. 211-216, doi: 10.1109/CSCloud.2017.64.
[33] M. E. Hameed, M. M. Ibrahim, N. A. Manap, and M. L. Attiah, "Comparative study of several operation modes of AES algorithm for encryption ECG biomedical signal," *International Journal of Electrical and Computer Engineering*, vol. 9, no. 6, pp. 4850–4859, 2019, doi: 10.11591/ijece.v9i6.pp4850-4859.
[34] W. Dai, I. Ibrahim, and M. Bassiouni, "Improving load balance for data-intensive computing on cloud platforms," *Proc. - 2016 IEEE Int. Conf. Smart Cloud, SmartCloud 2016*, 2016, pp. 140–145, doi: 10.1109/SmartCloud.2016.44.
[35] M. Hamad, M. Hatem and A. Baker, M. Mortaja, "DLU-position-based routing protocol in a hybrid network environment," pp. 163–181, 2018, doi: 10.1007/978-0-387-79148-7_10.
[36] M. A. Jubair *et al.*, "Competitive analysis of single and multi-path routing protocols in MANET," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 19, no. 1, pp. 293–300, 2020, doi: 10.11591/ijeecs.v19.i1.pp293-300.
[37] F. Aina, S. Yousef, and O. Osanaiye, "Analysing admission control for aodv and dsr routing protocol in mobile ad-hoc network," *Bull. Electr. Eng. Informatics*, vol. 10, no. 5, pp. 2667–2677, 2021, doi: 10.11591/eei.v10i5.3171.
[38] S. Munira, S. Humaira, S. Fahin, A. Siddik, and A. K. M. F. Haque, "DSR and OLSR routing protocol based performance evaluation and integration on MIP with MANET," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 17, no. 3, pp. 1306–1312, 2019, doi: 10.11591/ijeecs.v17.i3.pp1306-1312.
[39] G. M. Walunjkar and K. R. Anne, "Performance analysis of routing protocols in MANET," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 17, no. 2, pp. 1047–1052, 2020, doi: 10.11591/IJEECS.V17.I2.PP1047-1052.
[40] M. Belkheir, M. Rouissat, A. Mokaddem, M. Bouziani, and A. Zerroug, "LE-OLSR protocol performance evaluation in various energy conditionsof mobile ad-hoc and sensor wireless networks," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 19, no. 3, pp. 1391–1398, 2020, doi: 10.11591/ijeecs.v19.i3.pp1391-1398.
[41] M. J. Abbas, H. M. Turki Alhilfi, and T. Sutikno, "Performance evaluation of two models in the reactive routing protocol in manets," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 21, no. 1, pp. 391–397, 2021, doi: 10.11591/ijeecs.v21.i1.pp391-397.
[42] H. M. Haglan *et al.*, "Analyzing the impact of the number of nodes on the performance of the routing protocols in manet environment," *Bulletin of Electrical Engineering and Informatics*, vol. 10, no. 1, pp. 434–440, 2021, doi: 10.11591/eei.v10i1.2516.
[43] H. M. Haglan, S. Yussof, K. W. Al-Ani, H. S. Jassim, and D. A. Jasm, "The effect of network size and density to the choice of zone radius in ZRP," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 20, no. 1, pp. 206–213, 2020, doi: 10.11591/ijeecs.v20.i1.pp206-213.
[44] K. W. Al-Ani, S. Yussof, H. M. Haglan, H. Shaker, and L. M. Alani, "Determining an optimum zone radius for zone routing protocol (ZRP) based on node mobility," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 21, no. 2, pp. 1230–1237, 2020, doi: 10.11591/ijeecs.v21.i2.pp1230-1237.
[45] L. Shen, H. Li, and Z. Yu, "A distributed three-hop routing protocol to increase the capacity of hybrid wireless networks," *IEEE Trans. Mob. Comput.*, vol. 14, no. 10, pp. 1975–1991, 2015, doi: 10.1109/TMC.2015.2388476.
[46] Z. Li and H. Shen, "A distributed three-hop routing protocol to increase the capacity of hybrid wireless networks," in *2009 International Conference on Parallel Processing*, 2009, vol. 14, no. 10, pp. 277-284, doi: 10.1109/TMC.2015.2388476.
[47] N. S. Kavitha and G. Poovila, "Routing protocols in hybrid wireless networks – survey," *Int. J. Latest Trends Eng. Technol. Routing*, vol. 6, no. 2, pp. 407-410, 2016.
[48] K. H. Mohammadani, S. Abbasi, N. A. Memon, Z. A. Bhutto, and I. R. Memon, "Simulation analysis of routing protocols in hybrid wireless network," *Sindh Univ. Res. J. -Science Ser.*, vol. 50, no. 001, pp. 165–170, 2018, doi: 10.26692/surj/2018.01.0029.
[49] V. K. Verma, S. Singh, and N. P. Pathak, "Analysis of scalability for AODV routing protocol in wireless sensor networks," *Optik (Stuttg).*, vol. 125, no. 2, pp. 748–750, 2014, doi: 10.1016/j.ijleo.2013.07.041.
[50] L. Guo *et al.*, "Design on routing protocol in hybrid wireless self-organizing networks," *Proc. - 2010 2nd IEEE Int. Conf. Netw. Infrastruct. Digit. Content, IC-NIDC 2010*, 2010, pp. 569–573, doi: 10.1109/ICNIDC.2010.5657832.
[51] A. V. Kumar and S. K. Mohideen, "Security aware routing protocol for hybrid wireless network (SARP-HWNs) via trust enhanced mechanism," *Int. J. Bus. Data Commun. Netw.*, vol. 15, no. 1, pp. 34–57, 2019, doi: 10.4018/IJBDCN.2019010103.
[52] S. Laqtib, K. El Yassini, and M. L. Hasnaoui, "Link-state QoS routing protocol under various mobility models," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 16, no. 2, pp. 906–916, 2019, doi: 10.11591/ijeecs.v16.i2.pp906-916.
[53] Z. Li and H. Shen, "A QoS-oriented distributed routing protocol for hybrid wireless networks," *IEEE Trans. Mob. Comput.*, vol. 13, no. 3, pp. 693–708, 2014, doi: 10.1109/TMC.2012.258.
[54] U. K. Thakur and C. G. Dethe, "Routing protocol in hybrid wireless network which increases quality of service," *IEEE Int. Conf. Information, Commun. Instrum. Control. ICICIC 2017*, vol. 2018-Janua, pp. 1–4, 2018, doi: 10.1109/ICOMICON.2017.8279053.
[55] K. Radha, Dr P and Malarvizhi, "A qos-oriented distributed routing protocol for hybrid wireless networks with qualified neighbor node selection," *Int. Res. J. Eng. Technol. e-ISSN*, vol. 2, no. 6, pp. 2395-0056, 2015, doi: 10.1109/TMC.2012.258.
[56] T. Fujiwara and T. Watanabe, "An ad hoc networking scheme in hybrid networks for emergency communications," *Ad Hoc Networks*, vol. 3, no. 5, pp. 607–620, 2005, doi: 10.1016/j.adhoc.2004.08.007.
[57] H. Shen, Z. Li, and L. Yu, "A P2P-based market-guided distributed routing mechanism for high-throughput hybrid wireless networks," *IEEE Trans. Mob. Comput.*, vol. 14, no. 2, pp. 245-260, 2014, doi: 10.1109/TMC.2014.2320255.
[58] A. P. Rajapurohit, "Data transmission protocol for hybrid wireless networks with QoS assurance," *Int. J. Innov. Res. Adv. Eng.*, vol. 2, no. 4, 2015.

[59] Y. Sun and E. M. Belding-Royer, "Application-oriented routing in hybrid wireless networks," *IEEE Int. Conf. Commun.*, vol. 1, pp. 502–506, 2003, doi: 10.1109/icc.2003.1204227.
[60] Z. Li and H. Shen, "An efficient routing protocol to increase the communication reliability of multi-hop cellular networks," 2008, doi: 10.1109/MILCOM.2008.4753601.
[61] S. Aakasham and S. R. Mugunthan, "A secure QoS oriented distributed routing protocol for hybrid wireless networks," *Int. J. Appl. Eng. Res.*, vol. 10, no. 20, pp. 18169–18175, 2015, doi: 10.17148/ijarcce.2015.4112.
[62] Y. N. Hatif, Y. A. Abbas, and M. H. Ali, "Lightweight ANU-II block cipher on field programmable gate array," *International Journal of Electrical and Computer Engineering*, vol. 12, no. 3, pp. 2194–2205, 2022, doi: 10.11591/ijece.v12i3.pp2194-2205.
[63] Z. Li and H. Shen, "A QoS-oriented distributed routing protocol for hybrid wireless networks," *IEEE Trans. Mob. Comput.*, vol. 13, no. 3, pp. 693–708, 2014, doi: 10.1109/TMC.2012.258.
[64] M. M. E. A. Mahmoud, S. Taha, J. Misic, and X. Shen, "Lightweight privacy-preserving and secure communication protocol for hybrid Ad Hoc wireless networks," *IEEE Trans. Parallel Distrib. Syst.*, vol. 25, no. 8, pp. 2077–2090, 2014, doi: 10.1109/TPDS.2013.298.

BIOGRAPHIES OF AUTHORS

Miaad Husam Mahdi received the B.Sc. (1st Class Hons.) Degree in Computer Engineering from University of Diyala, Iraq, in 2015. He is a staff member in Diyala University, Iraq. He is currently a M.Sc. student at the University of Technology, Computer Engineering Department, Iraq. His research interests are in computer engineering, computer networks, cryptography, FPGA, wireless ad-hoc networks and image processing. She can be contacted at email: ce.20.06@grad.uotechnology.edu.iq.

Ibrahim Adel Ibrahim received the B.Sc. degree in Computer Engineering Department from college of Engineering, Mustansiriyah University, Iraq, the M.Sc. degree in Computer Engineering, University of Technology, Iraq, and the Ph.D. degree in Computer Engineering, Florida, USA, 2019. He has supervised and co-supervised masters' students. He has authored or coauthored more than 9 publications with 6 H-index and more than 110 citations. His research interests include cloud computing networks, mobile cloud computing, Big Data, and computer networks. He can be contacted at email: Ibrahim.a.almotairi@uotechnology.edu.iq.