Centralized Multicasting AODV Routing Protocol Optimized for Intermittent Cognitive Radio Ad Hoc Networks

Phetho Phaswana and Mthulisi Velempini(✉)

Department of Computer Science, University of Limpopo, Polokwane, South Africa
mthulisi.velempini@ul.ac.za

Abstract. The advancement of wireless technology is affected by Spectrum scarcity and the overcrowding of free spectrum. Cognitive Radio Ad Hoc Networks (CRAHNs) have emerged as a possible solution to both the scarcity and overcrowding challenges of the spectrum. The CRAHNs ensure that the Secondary Users (SUs) do co-exist with Primary Users (PUs) in a non-interfering manner. The SUs access the licensed spectrum opportunistically when they are idle. CRAHNs have many use cases which include intermittent networks here referred to as intermittent CRAHNs (ICRAHNs). For example, the Military (MCRAHNs). MCRAHN is complex and characterized by a dynamic topology which is subject to frequent partitioning and route breakages due to attacks and destruction in combat.

This study optimizes the routing protocols for intermittent networks such as the MCRAHNs. ICRAHN routing is a challenge due to the network's intermittent attribute, which is subject to destruction in the case of MCRAHN which is characterized by frequent link breakages. The performance of the proposed routing scheme was evaluated through network simulations using the following metrics: throughput, and Routing Path delay, Node Relay delay, Spectrum Mobility delay. The simulation results show that the MAODV is the best-performing algorithm.

Keywords: Cognitive Radio Ad Hoc Networks · Intermittent Networks · Primary Users · Secondary Users · Spectrum Scarcity

1 Introduction

The emergence of the Fourth Industrial Revolution, the Internet of Things (IoT) and blockchain technologies which require a high-speed network (Internet) connectivity and spectrum have led to spectrum scarcity. Unfortunately, network connectivity depends on the availability of the spectrum and a stable network. To address these challenges of spectrum scarcity, the Federal Communication Commission (FCC) designed a framework which allows secondary users (SUs) to use the licensed spectrum opportunistically when not in use [1].

Routing in intermittent mobile networks is a challenge since there are no guaranteed routing paths. The nodes can be destroyed during the attack while they are relaying packets. This challenge has severe consequences in Intermittent Military Cognitive Radio Ad

© ICST Institute for Computer Sciences, Social Informatics and Telecommunications Engineering 2023
Published by Springer Nature Switzerland AG 2023. All Rights Reserved
J. Taheri et al. (Eds.): MobiCASE 2022, LNICST 495, pp. 31–40, 2023.
https://doi.org/10.1007/978-3-031-31891-7_3

Hoc Networks (IMCRAHNs) nodes such as tankers and aircraft which can be destroyed in combat resulting in the partitioning of the network during a critical phase of the battle. In some cases, routing may be impossible. Longer delays in routing may be incurred resulting in packet-timeout, increased packet drop rate and the degradation of the performance of the network. The delays in IMCRAHNs caused by the destruction of nodes also increase the Routing Path (RP) delay, Spectrum Mobility (SM) delay and Node Relay (NR) delay. The destruction of nodes, therefore, has a ripple effect on the IMCRAHNs. Furthermore, it also affects the achievable throughput as the packet drop rate increases.

The design of routing algorithms in IMCRAHNs requires a dynamic and robust technique which addresses the destruction of nodes and avoids incomplete paths while employing flexible and proactive recovery mechanisms. Several routing protocols exist which are designed to address the IMCRAHNs routing challenges. Unfortunately, current routing algorithms are not optimized for IMCRAHNs routing challenges such as delays. There is a need to optimize routing protocols for Delay Tolerant Networks (DTNs) such as the IMCRAHNs [2]. The routing protocols should reduce delays while improving achievable throughput.

2 Related Work

The routing paths in IMCRAHNs are nondeterministic which degrades the efficiency of routing protocols. Unfortunately, the existing routing protocols are not optimized for IMCRAHNs. We review schemes which were designed to mitigate the effects of SM, RP and NR delays in IMCRAHNs. It was observed that the IMCRAHNs delay is longer than the one for CRAHNs as a result, the IMCRAHNs are categorized as DTNs [3].

The mobility of nodes is also a challenge in ad hoc networks which negatively impacts the performance of routing algorithms. However, the location of nodes, the topology of the ad hoc network and the frequency of changes in the topology determine the routing approach. The design of routing algorithms is also complicated by the size of networks and transmission range. For example, Geo-routing (Geographic routing) is optimized for either geographical or zonal routing. In Geo-routing, packets are broadcasted towards the direction of the zone within which a destination node is likely to be encountered [4].

The Ad Hoc On-Demand Distance vector (AODV) routing algorithm is one of the common MANET routing algorithms [5]. The AODV is being considered for IMCRAHNs and its performance is encouraging. The reactive nature of AODV makes it more suitable for IMCRAHNs which is characterized by dynamic spectrum channel switching.

The Internet Protocol spectrum-aware geographic-based routing protocol (IPSAG) was proposed in [6]. The IPSAG is a geographical and spectrum-aware protocol which employs zonal routing using multicasting. IPSAG relies on prior knowledge of the spectrum and the geographical location of nodes for effective routing. For an effective relay of packets, all the nodes in IPSAG are expected to store the geographical locations of nodes in their neighbourhood or zone. In IPSAG, nodes employ the Greedy forwarding strategy to relay packets according to geographical location information. The nodes forward packets towards the direction of the destination node. The next hop node is expected to be closest to the destination and should have the best spectral quality. If a node has two options to relay packets, spectral density is used as a tie-breaker.

The performance of IPSAG was evaluated against the following routing protocols: The Spectrum Aware Routing for Cognitive Ad-hoc Networks (SEARCH) and the AODV. The results of IPSAG show that it is superior in terms of efficiency. IPSAG incorporates the Common Spectrum Opportunities technique which is used for routing decisions. A node with similar spectrum opportunities to the ones of the relay node is selected for data transmission to avoid channel switching costs [7] and the associated delays.

Though IPSAG was evaluated to be the best protocol, it is likely to drop many packets in intermittent networks with no guaranteed routes. It is not designed to buffer packets until routes are re-established.

The functionality of AODV and its use of sequence numbers to maintain the freshness of routing paths is relevant to IMCRAHNs. It plays a fundamental role in route discovery. When a node receives a Route Request (RREQ), it compares its sequence number to the sequence number of the RREQ. The establishment of the routing path is based on the greater sequence number [8].

Multicasting AODV (MAODV) is a version of AODV and it broadcasts packets to a given segment of the network [9]. However, MAODV does not perform well in repairing routes caused by breakages of relay nodes in IMCRAHNs. In the event of link breakages, the MAODV resumes transmission from the source node instead of continuing from the last relay node.

In WCETT, the best path is selected using the on-demand weighted cumulative expected metric [10]. The routing process is initiated by broadcasting the RREQ. The weighted cumulative transmission time is contained in the RREQ. The RERR is sent when the sequence number of the destination is equal to or less than the one in the route entry. When the RREQ is received, the decision to send an RREP is based on the cost of the RREQ. It should be less than the one of the previous RREQ which has the same sequence number. The paths with the lowest cost are selected.

3 System Model

The algorithms were simulated in three scenarios with 6, 35 and 70 nodes and the simulations were run for 100, 300 and 500 simulation seconds respectively. The simulation times were varied to evaluate effectively the performance of the algorithms. Table 1 presents the values of parameters used in the study [11]. The following metrics were considered: Routing Path delay, Spectrum Mobility delay and Node Relay delay. The metrics are all delay related which are critical in military intermittent networks. Delay tolerate routing schemes are therefore desirable. Therefore, the selection of metrics was informed by a need to reduce delay in IMCRAHNs. Delays in communication in IMCRAHNs may be critical which may result in the loss of life and the destruction of the equipment.

Table 1. The Simulation parameters

Number of Nodes	6, 35, 70
Simulation Time(s)	100 s, 300 s, 500 s
Size of the Packets (bytes)	512
Simulation Grid (m × m)	500 × 500
Traffic Rate/ Rate	Constant Bit Rate (CBR) 4 packets/s
Nodes Velocity (m/s)	12–15
Range of Transmission (m)	90, 120, 150, 180
Number of connections	15, 25, 35
Pause Time (s)	0, 50, 100, 250, 350, 500
Number of Radios	2
Routing Algorithms	AODV, MAODV
Antenna	Omni-directional
MAC Standard	IEEE 802.11b
Number of Pus	6 (For each set of nodes)
Number of SUs	4, 33, 68 (For each set of nodes)

4 Results

We evaluated the effectiveness of the multicasting routing protocol. The MAODV was evaluated and compared to AODV. Figure 1 depicts the RP delay simulation results for MAODV and AODV routing protocols. Figure 1 shows that for scenarios with 6 and 70 nodes, AODV performed poorly in comparison to MAODV. The performance of the AODV is depicted by the maroon curves. The MAODV incurred less RP delay than AODV because it broadcasts packets to a given zone within which the destination node can be reached or a zone closest to the destination node. Within a zone, paths leading to the destination node are selected while broken links are avoided [12].

MAODV is, therefore, a zonal or geographical-based routing protocol, however, in IMCRAHNs, the possibility of route destruction complicates routing. Furthermore, delays and routing overheads are incurred when the whole network is considered for routing. However, the results in Fig. 1 are clustered as a result, we also analyzed the average performance of these schemes in Fig. 2. Furthermore, Fig. 1 is also presented in Appendix A with high resolution.

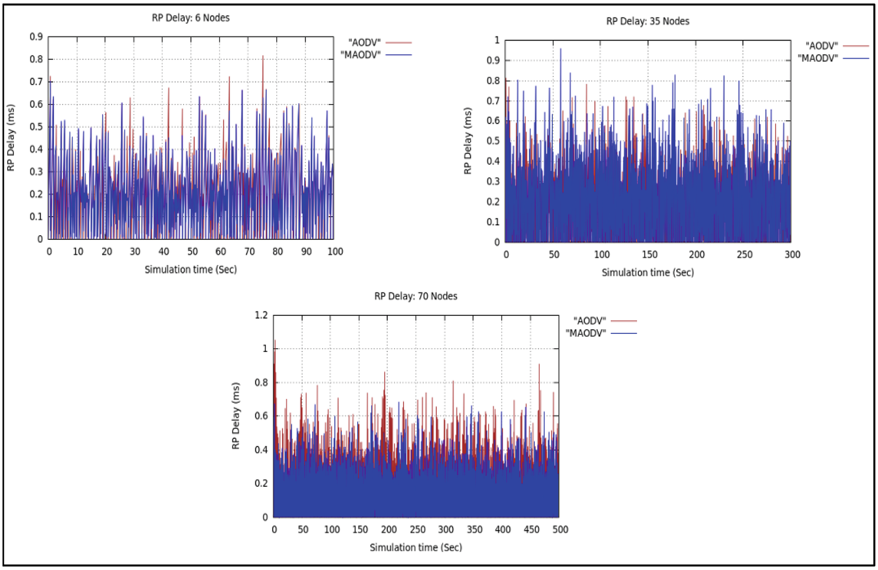


Fig. 1. RP simulation Results

Figure 2 presents the average RP delay results. The average results show that for all the scenarios, the AODV routing protocol experienced more RP delay-related challenges than the MAODV routing protocol. The good performance of the MAODV can be attributed to its effective routing approach discussed under Fig. 1 results and the fact that it is optimized for IMCRAHNs.

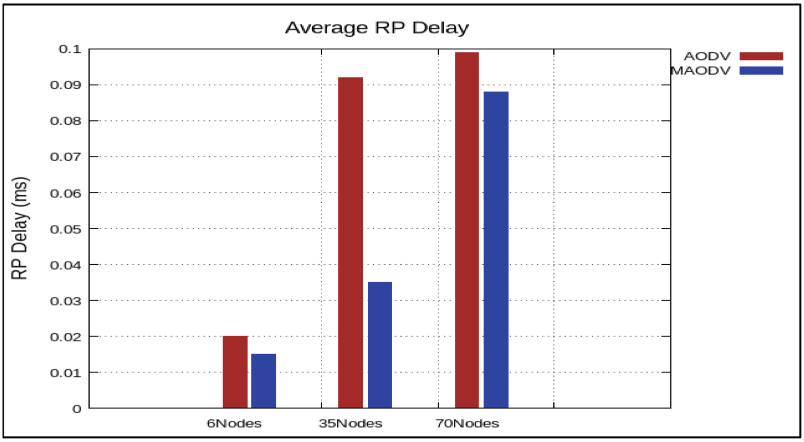


Fig. 2. Average RP delay results

4.1 Throughput Simulation Results for MAODV and AODV

We also evaluated the performance of the schemes based on the achievable throughput in Fig. 3.

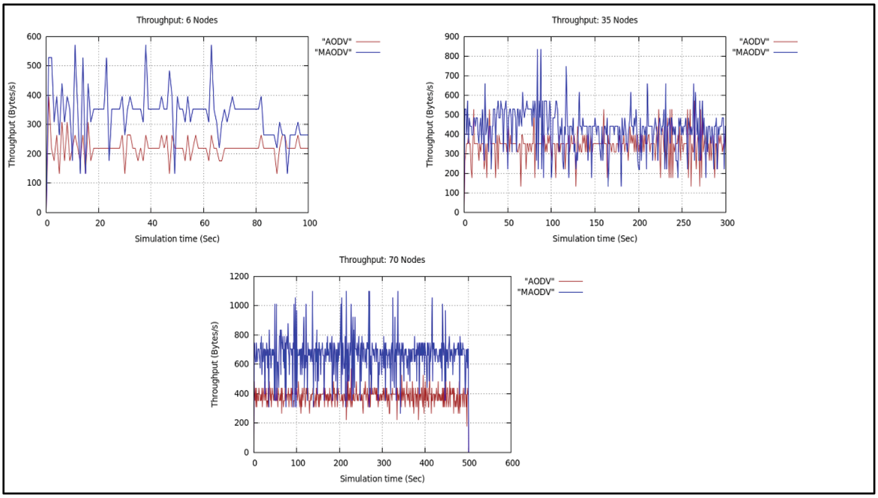


Fig. 3. Throughput Simulation Results

Figure 3 depicts the achievable throughput results of all the network scenarios. The results show that the MAODV achieved more throughput compared to the AODV routing protocol. The multicasting in IMCRAHNs increases the packet delivery success rate when packets are broadcasted in a specific zone within which a destination node can be reached or in the zone closest to the destination node [13]. Zonal routing facilitates faster route discovery and recovery processes. Multicast routing is also subjected to fewer dropped packets because of zonal routing in a small, localized area.

Figure 3 shows that MAODV had three drops in achievable throughput for the scenario with 6 nodes: for the 0–20 and 40–60 epochs. These are caused by the unavailability of routing paths in the given zone during these epochs. The same gaps were experienced for a scenario with 70 nodes. These gaps were caused mainly by the destruction of nodes and routes.

4.2 The SM Delay Simulation Results of the MAODV and AODV Routing Protocols

In this Sub-Section, we present the spectrum mobility delay results and these are depicted in Fig. 4.

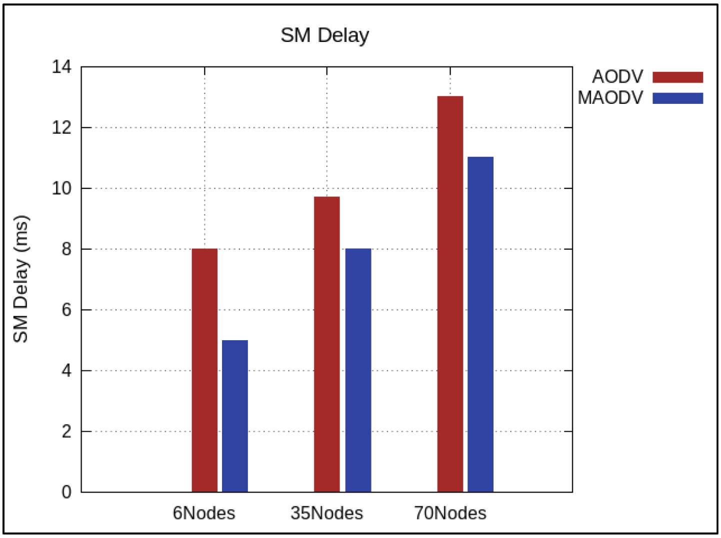


Fig. 4. SM delay simulation Results

Figure 4 shows the SM delay results in which the MAODV was superior to the AODV. Spectrum mobility causes the unavailability of routes and the frequency of this occurrence degrades the performance of the network. However, both MAODV and AODV are impacted negatively by the SM delay. The MAODV is more efficient because it guarantees route availability before the transmission can take place. As a result, the MAODV has a high likelihood of routes being available. Spectrum mobility is a challenge in IMCRAHNs because a channel detected to be available during sensing can become unavailable just before transmission takes place. If this happens, an affected route cannot be used for data transmission. However, this is minimized in IMCRAHNs through the implementation of zonal routing which increases the availability of routing paths for longer periods. As a result, MAODV incurs less SM delay than the AODV routing protocol.

4.3 The NR Delay Simulation Results of the MAODV and AODV Routing Protocols

In this Section, the schemes were evaluated using the Node Relay delay metric and the results are shown in Fig. 5.

Figure 5 shows that the MAODV performs better in all aspects. The MAODV routing protocol incurs the least NR delay compared to the AODV routing protocol because, in IMCRAHNs, zonal routing enables routes to be discovered and repaired faster.

The low NR delay in MAODV is because there is a positive correlation between NR delay and SM delay. For a packet to be relayed, the node first accesses the spectrum. As a result, the factors which affect the SM delay also impact negatively the NR delay. A node therefore, can only relay a packet when the spectrum is available for data transmission [14].

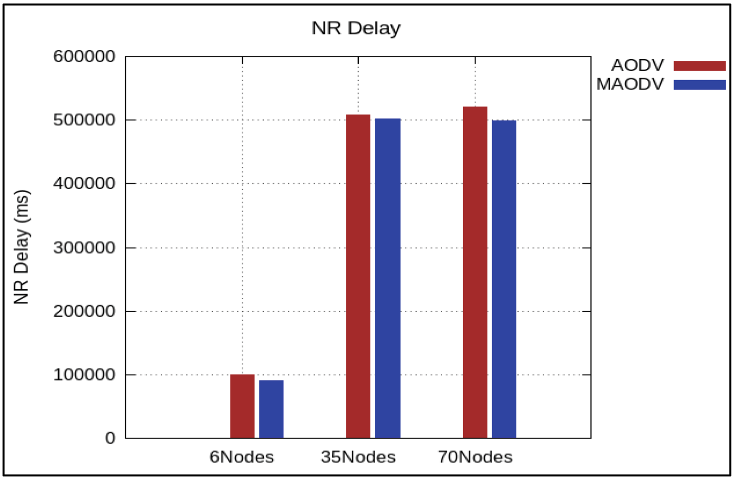


Fig. 5. NR Delay Simulation Results

The results presented in Figs. 1, 2, 3, 4 and 5 show that the MAODV routing protocol is superior to the AODV routing protocol in all the simulation scenarios. The MAODV achieved better results in IMCRAHNs routing largely because of the multicasting technique in a localized and focused zone. In a Multicasting based routing strategy, a network is fragmented logically into smaller zones which contain the destination node or which are closest to the destination node. The relaying of packets is therefore informed by the proximity of the destination node to or within a given zone.

5 Conclusion

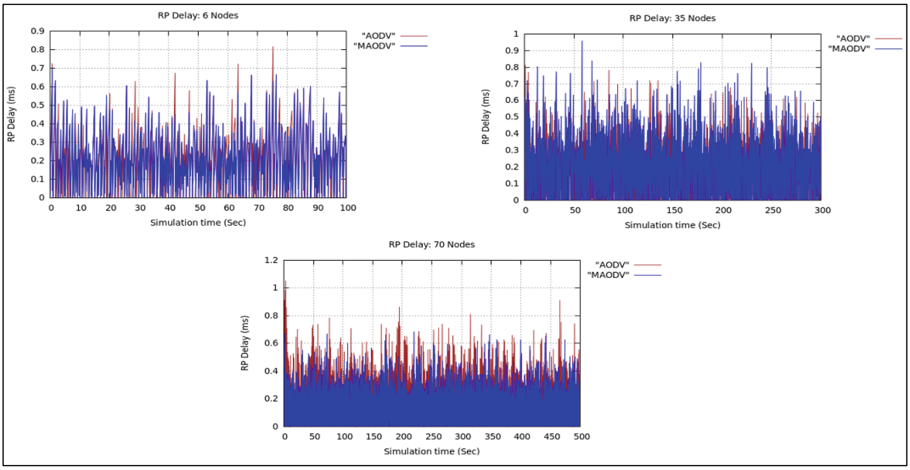
The simulation results of the study show that the multicasting routing technique implemented in MCRAHNs is more efficient. Zonal or geographical routing facilitates faster discovery of routing paths while enabling faster recovery of broken routing paths. As a result, the MAODV outperformed AODV.

Figures 1 and 3 also show that for RP delay and throughput simulation results, there were broken routes which were encountered. These are denoted by the drop in achievable throughput in the throughput results. However, despite these challenges of route breakages, the MAODV still performed better. The results show that the MAODV did experience some route breakages which it repaired faster within a given zone.

In the case of SM and NR delay, the results show that the increase in delay is positively correlated with the increase in the number of transmitting nodes. However, in NR and SM delay simulation results, the MAODV routing protocol outperformed the AODV routing protocol. The MAODV routing protocol is more robust and resilient compared to the AODV routing protocol. The implementation of multicasting routing technique ensures that routes in a given zone are available for a longer period which improves MAODV performance. The zonal routing and the use of stable routes reduce SM and NR delays given a higher probability of availability of routing paths for longer durations which in turn, improves the utilization of idle channels.

Acknowledgement. This work was supported by the National Research Foundation of South Africa (Grant Number: 114155).

A Appendix



References

1. An, B.: A stability-based spectrum-aware routing protocol in mobile cognitive radio ad-hoc networks. In: 2014 International Symposium on Computer, Consumer and Control, pp. 1014–1017. IEEE (2014)
2. Liu, C., Zhang, G., Guo, W., He, R.: Kalman prediction-based neighbor discovery and its effect on routing protocol in vehicular ad hoc networks. IEEE Trans. Intell. Transp. Syst. **21**(1), 159–169 (2019)
3. Tang, F., et al.: Delay-minimized routing in mobile cognitive networks for time-critical applications. IEEE Trans. Industr. Inf. **13**(3), 1398–1409 (2017)
4. Huang, J., Wang, S., Cheng, X., Liu, M., Li, Z., Chen, B.: Mobility-assisted routing in intermittently connected mobile cognitive radio networks. IEEE Trans. Parallel Distrib. Syst. **25**(11), 2956–2968 (2014)
5. Zhang, L., Zhuo, F., Bai, C., Xu, H.: Analytical model for predictable contact in intermittently connected cognitive radio ad hoc networks. Int. J. Distrib. Sens. Netw. **12**(7), 1–12 (2016)
6. Ghafoor, H., Koo, I.: Spectrum and connectivity aware anchor-based routing in cognitive vehicular ad hoc networks. In: 2016 Eighth International Conference on Ubiquitous and Future Networks (ICUFN), pp. 679–684. IEEE (2016)
7. Velempini, M., Dlodlo, M.E.: A multiple channel selection and coordination MAC scheme. In: 2009 Second International Conference on Advances in Mesh Networks, pp. 126–131 (2009). https://doi.org/10.1109/MESH.2009.30

8. Landmark, L., Larsen, E., Hauge, M., Kure, Ø.: Resilient internetwork routing over heterogeneous mobile military networks. In: MILCOM 2015–2015 IEEE Military Communications Conference, pp. 388–394. IEEE (2015)
9. Vang, Y., Saavedra, A., Yang, S.: Ferry enhanced improved PRoPHET routing protocol. In: 2015 IEEE 12th International Conference on Mobile Ad Hoc and Sensor Systems, pp. 567–572. IEEE (2015)
10. Melvin, S., Lin, J., Kim, S., Gerla, M.: Hitchhiker: a wireless routing protocol in a delay tolerant network using density-based clustering. In: 2018 IEEE 88th Vehicular Technology Conference (VTC-Fall), pp. 1–5. IEEE (2019)
11. Wu, Y., Deng, S., Huang, H.: Control of message transmission in delay/disruption tolerant network. IEEE Trans. Comput. Soc. Syst. **5**(1), 132–143 (2018)
12. Chen, Y.H., Wu, E.H.K., Lin, C.H., Chen, G.H.: Bandwidth-satisfied and coding-aware multicast protocol in MANETs. IEEE Trans. Mob. Comput. **17**(8), 1778–1790 (2018)
13. Huang, W., Ma, Z., Dai, X., Xu, M.: Connectivity probability based spray and wait routing algorithm in mobile opportunistic networks. In: 2018 IEEE SmartWorld, Ubiquitous Intelligence & Computing, Advanced & Trusted Computing, Scalable Computing & Communications, Cloud & Big Data Computing, Internet of People and Smart City Innovation (SmartWorld/SCALCOM/UIC/ATC/CBDCom/IOP/SCI), pp. 1636–1642. IEEE (2018)
14. Alresaini, M., Wright, K.L., Krishnamachari, B., Neely, M.J.: Backpressure delay enhancement for encounter-based mobile networks while sustaining throughput optimality. IEEE/ACM Trans. Netw. **24**(2), 1196–1208 (2016)
15. Hai, L., Gao, Q., Wang, J., Zhuang, H., Wang, P.: Delay-optimal back-pressure routing algorithm for multihop wireless networks. IEEE Trans. Veh. Technol. **67**(3), 2617–2630 (2018)
16. Patel, R., Patel, N., Patel, S.: An approach to analyze behavior of network events in NS2 and NS3 using AWK and Xgraph. In: Fong, S., Akashe, S., Mahalle, P.N. (eds.) Information and Communication Technology for Competitive Strategies. LNNS, vol. 40, pp. 137–147. Springer, Singapore (2019). https://doi.org/10.1007/978-981-13-0586-3_14
17. Prashanthi, G., Rao, A.V.: A survey on relay selection for geographical forwarding in sleep-wake cycling wireless sensor networks. Int. J. Res. **5**(7), 229–237 (2018)
18. Malhotra, S., Trivedi, M.C.: Authentication, KDC, and key pre-distribution techniques-based model for securing AODV routing protocol in MANET. In: Panigrahi, B., Trivedi, M., Mishra, K., Tiwari, S., Singh, P. (eds.) Smart Innovations in Communication and Computational Sciences. Advances in Intelligent Systems and Computing, vol. 669, pp. 175–186. Springer, Singapore (2019). https://doi.org/10.1007/978-981-10-8968-8_15
19. Jhajj, H., Datla, R., Wang, N.: Design and implementation of an efficient multipath AODV routing algorithm for MANETs. In: 2019 IEEE 9th Annual Computing and Communication Workshop and Conference (CCWC), Las Vegas, NV, USA, pp. 0527–0531 (2019)