Optimized reduction approach of congestion in mobile ad hoc network based on Lagrange multiplier

Marwa K. Farhan[1], Muayad S. Croock[2]
[1]Department of Information and Communication, College of Information Engineering, Al-Nahrain University, Baghdad, Iraq
[2]Control and Systems Engineering Department, University of Technology-Iraq, Baghdad, Iraq

Article Info

Article history:

Received Aug 9, 2021
Revised Jul 10, 2022
Accepted Jul 29, 2022

Keywords:

Congestion optimization
D2D communication
Lagrange multipliers
Mobile ad hoc network
Routing

ABSTRACT

Over the past decades, computer networks have experienced an outbreak and with that came severe congestion problems. Congestion is a crucial determinant in the delivery of delay-sensitive applications (voice and video) and the quality of the network. in this paper, the Lagrangian optimization rate, delay, packet loss, and congestion approach (LORDPC) are presented. A congestion avoidance routing method for device-to-device (D2D) nodes in an ad hoc network that addresses the traffic intensity problem. The method of Lagrange multipliers is utilized for active route election to dodge heavy traffic links. To demonstrate the effectiveness of our proposed method, we applied extensive simulation that presents path discovery and selection. Results show that LORDPC decreases delay and traffic intensity while maintaining a high bitrate and low packet loss rate and it outperformed the ad hoc on-demand distance vector (AODV) protocol and the Lagrangian optimization rate, delay, and packet loss, approach (LORDP).

Corresponding Author:

Marwa K. Farhan
Department of Information and Communication, College of Information Engineering, Al-Nahrain University
Al Jadriyah Bridge, Baghdad 64074, Iraq
Email: marwa.k.farhan@gmail.com

1. INTRODUCTION

Mobile ad hoc networks (MANETs) are peer-to-peer multi-hop wireless networks that consist of mobile platforms. These platforms include mobile devices, laptops, tablets, or a router with multiple hosts and wireless communication devices (nodes) that move freely and arbitrarily. Wireless MANETs can be employed with/without the assistance of available infrastructure and all nodes operate in an ad hoc mode and establish a dynamic network without any existing infrastructure or topology. Ad hoc nodes are robust, flexible, and low-cost solution due to their ability to adapt to frequent and unpredictable topology changes as well as they do not run-on costly network switches or access and control points. For such mentioned features, the wireless Ad hoc networks have leaped into the business, health, military, and personal communication sectors.

Route management is very challenging in such systems due to the network topology's frequent updates where active routes may be disconnected as mobile nodes move from one place to another [1] and statistics often vary randomly. Moreover, the congestion issue rises as an undesired situation in network systems as parts of the networked system are loaded with more traffic than their capacity which can cause consumption of critical resources of the system. Therefore, a congestion control mechanism is required to ensure that the resources are optimally used and the system is fully utilized within the given quality-of-service (QoS) circumstances. Such congestion control algorithms are employed during node-to-node routing; thus, congestion occurs on every hop and is called the hop-to-hop congestion control method.

The recognition of wireless ad hoc network technology in the market has managed the urge to investigate the effects of routing techniques [2] and congestion on ad hoc networks. Thus, many congestions control and avoidance routing schemes have been investigated so for. For example, Karthikeyan and Dalin [3] utilized energy harvesting for MANETs and internet of things (IoT) applications. They applied this idea to the dynamic congestion control routing scheme in MANET. They evaluated their work using routing overhead ratio, energy consumption ratio, and throughput ratio and found its throughput-perfect booking plans for remote systems. In [4], the authors presented a channel contention based routing (CCBR) protocol that determined a least crowded path between the endpoints to reduce packet delay and routing overhead as well as increase the packet delivery ratio. The intermediate node assesses channel contention and sends feedback to the source node that can choose the least contended route. results show that CCBR advantage over ad hoc on-demand distance vector (AODV) in end-to-end delay, routing overhead, and packet delivery ratio. Krishnamoorthy *et al.* [5] presented a link matrix method for MANET to minimize congested paths depending on the level of the node before the distortion to earn better ability of the system. They analyzed and compared its effectiveness with capacity optimized cooperative communication. Their method improved throughput, delay, energy, overhead, and packet delivery ratio. Bhardwaj and El-Ocla [6] combined the ad hoc on-demand multipath distance vector with fitness function (AOMDV-FFn) and ad hoc on-demand multipath distance vector with genetic algorithm (AOMDV-GA) to optimize the route. These protocols select the highest fitness value route using the optimization process using maximum residual energy and the shortest path. They utilized the transmission control protocol (TCP) congestion control enhancement for random loss in the fitness function to get the routes efficiently and compared their work with other preferred protocols. In [7], the authors suggested a topological adaptive Ad hoc on-demand multipath distance vector (AOMDV) routing scheme that supports QoS for high-speed node movement. The path is selected based on bandwidth, residual energy, queuing length, link stability, and link interrupt prediction method. Results showed that end-to-end delay, packet delivery ratio, and throughput of the presented scheme are greatly improved and their scheme supports QoS for high-speed MANET. Hanin *et al.* [8] suggested a new optimization cross-layer method to develop TCP decision-making with changes to IEEE 802.11 MAC. Their goal is to reduce the retransmissions of dropped packets and energy depletion and enhance QoS MANET. Simulations showed that their suggested approach performed significantly better than TCP in MANETs, and also enhanced the throughput, energy depletion, and ease of transmission using routing protocol.

Moreover, Gawas *et al.* [9] suggested novel congestion, delay, and multi-rate routing protocol that operate across the network layer, Media access control, and physical layer to improve network performance in MANETs. Their method discovers routes through less congested nodes and optimizes data rates of the links based on the delay value. Performance simulation highlights the significance of the cross-layer method. In study [10], the authors proposed a second-order congestion control and power allocation method to maximize the network utility framework of wireless ad hoc networks. They updated primal variables and dual variables based on their Newton direction to reach a faster convergence speed. Results show improved energy efficiency and faster convergence speed. Akhtar *et al.* [11] proposed a bandwidth-aware routing scheme for congestion avoidance. They assessed the bandwidth capacity and queue spaces to cache the information. Their method feedbacks the source to adjust the data rate based on the availability of bandwidth and queue in the path. simulations proved the improvement of their scheme in throughput, packet delivery ratio, end-to-end delay, and the probability of congested nodes. improvement of basic routing protocol AODV. A congestion control mechanism was suggested in [12] depending on the node’s status (node queue length, channel employment, and residual energy) using fuzzy logic control. Adaptive network coding and data recovery from neighboring nodes are used for congested areas to reduce transmissions and recovery time. Their methods are simulated and compared with basic AODV to show improved scalability performance of routing protocol. Mobility, residual energy, and link quality multipath a routing method was proposed in MANETs in [13], The optimal route is determined with energized nodes to attain the stability and lifetime of the network. They used a Q-learning algorithm for optimal nodes selection nodes based on mobility, energy level, and link quality. Simulation of the proposed routing method indicates a significant reduction in energy cost, end-to-end delay, packet loss ratio, and convergence time. Wang and Song [14] produced a novel end-to-end congestion control (ECCO) method that utilized spectrum sensing, licensed user activities, and channel rendezvous features in multi-hop cognitive radio ad hoc networks. They derived the average round trip time for a packet and simulation showed the effectivity of their congestion control method over the existing mechanisms in terms of higher end-to-end throughput.

Meanwhile, Chaudhry and Tapaswi [15] suggested energy conserving power and rate control scheme with average delay and outage probability constraints to adapt channel changes and improve the network performance (throughput, delay, and consumed energy). Their method employed an adaptive grey wolf to optimize delay and energy constraints. Simulation results showed the effectiveness of the proposed approach over dynamic rate and power allocation algorithm in rate-effective maximization and energy-conserving and rate control. Arika *et al.* [16] developed a congestion adaptive routing method for throughput optimization with congestion constraints for high overhead, packet loss, and delay in mobile ad hoc networks. The results obtained shows improvement in congestion control and reduced energy consumption. Sharma *et al.* [17] proposed a congestion control technique in mobile ad hoc networks using clustering and queuing techniques that depend on nodes' mobility and environments causing unpredictable queue size. simulated results are compared with congestion control technique; neighborhood random early detection queuing technique and showed their methods improvement. Also, Gowtham and Subramaniam [18] suggested across layer approach for congestion control and packet recovery in MANET. The model can trade efficiency and peer-to-peer recovery and assigned traffic congestion rate priority. Result performed result than existing schemes. Amuthan *et al.* [19] presented a dynamic multi-stage tandem queue congestion adaptive routing (DTQCAR) that sends an alert to neighboring nodes to adjust routes when congestion level is reached. Then neighbors locate congestion-free paths. simulation results confirm a better performance than other congestion control algorithms in terms of packet delivery ratio. Furthermore, Alhosainy and Kunz [20] solved the congestion-contention distribution control and multipath routing problem for multi hop wireless ad-hoc networks. Their solution was across the transport, network, and medium access control (MAC) layer. Their problem was a non-convex and non-separable utility maximization optimization and they proposed a distributed method to attain the optimal solution for concave functions. Alhosainy and Kunz [21] modified the cuckoo search algorithm (CSA) with position updating from the differential evolution (DE) algorithm. the CSA is the main search procedure directed by the DE updating method. MANETs simulations compared with some of the existing techniques and demonstrated the advancement of the proposed method to find an optimum route that satisfies QoS constraints. Finally, Huang *et al.* [22] proposed a novel clustering-hierarchical routing algorithm for large-scale mobile ad hoc networks. The cluster consisted of a cluster head, cluster gateway nodes, cluster guest nodes, and cluster members. The proposed hybrid protocol uses a proactive scheme between nodes within a cluster and a reactive approach between clusters. Simulation provides superior performance of the proposed clustering-hierarchical routing protocol over the existing clustering algorithm and routing protocol.

We can see that congestion control is a major challenge for researchers in an ad hoc wireless environment. In wireless networks, the congestion control methods are more complex than the conventional wired networks, and it is even harder to manage congestion in the case of ad-hoc networks where every node behaves like a router. The purpose of our research is to study node statistics in an ad-hoc environment concerning the node's power, channel fading, and noise effect and perform route discovery and selection accordingly. This will conduct a measurement calculation of the nodes' bitrate, nodal delay, the ratio of packet loss, and congestion due to queuing duration. The congestion will differ at the node level based on network topology, mobility, and channel utilization. We designed and simulated ad hoc network environments with many nodes and then performed measurement calculations for parameters like bitrate, transmission, and propagation delays, packets dropped ratio, and congestion queuing delay.

2. RESEARCH METHOD

2.1. System model

To present the mathematical modeling and formulating of the proposed system, we embraced device-to-device communication using an ad-hoc environment that is constructed of nodes $\mathcal{N}$ and is correlated with $\mathscr{L}$ links. Our presented algorithm is concerned with electing a path in an ad hoc network that achieves the optimum function based on link quality. This objective function is constructed of one main assignment and three constraints in such a way that it maintains optimum trade-off between these elements. Table 1 epitomizes the essential notations and corresponding simplification, used throughout the paper. The main aim is to maximize the bit rate for available paths restricted by minimizing the latency, the packet loss ratio, and traffic intensity. In other words, queuing delay causing congestion in a network and mathematically modeled as:

$$max \ \sum_{i=1}^{\mathcal{N}} \text{Ʀ}_i$$

Subject to constraints for each $\mathcal{N}$ path:

$$min \sum_{i=1}^{\mathcal{N}} \delta_i + min \sum_{i=1}^{\mathcal{N}} \psi_i + min \sum_{i=1}^{\mathcal{N}} \hat{\text{I}}_i$$

By applying the multi-objective approach combined with the Lagrange multipliers optimization method to the above model, we build the objective function using gradients of the functions as shown in:

$$\mathcal{L}\,\mathcal{F} = \nabla \text{ Bit rate} - \lambda \nabla \text{ Nodal delay} - \mu \nabla \text{ Packet loss} - \nu \nabla \text{ Traffic intensity}$$

The transmission rate Ʀ is expressed using Shannon's equation [23], While the transmission delay and propagation delay together accumulate to give a nodal delay as well as taking into consideration the traffic intensity affected by queuing delay [24]. Moreover, the packet loss rate ψ can be formed as a function of SNR utilized in transmitting packets over a link $\mathcal{L}$ [25]. As a result, the objective function is represented by:

$$\mathcal{L}\,\mathcal{F} = \nabla\left[\omega\, log_2\left(1+\frac{p\times H}{\sigma}\right)\right] - \lambda\,\nabla\left[\frac{Ł}{Ʀ}+\frac{\varphi}{\zeta}\right] - \mu\,\nabla\left[\alpha\, Ł\, exp\left(-\beta\frac{(p\times H)}{\sigma}\right)\right] - \nu\,\nabla\left[\frac{Ł*\varepsilon}{Ʀ}\right]$$

Now, let us construct the Lagrangian-objective function by taking the partial derivative with respect to the packet length (Ł) and setting it equal to zero to get (1).

$$\frac{\partial\mathcal{L}\,\mathcal{F}}{\partial Ł} = \sum_{i=1}^{\mathcal{N}}\frac{\partial Ʀ_i}{\partial Ł} - \sum_{i=1}^{\mathcal{N}}\lambda_i\frac{\partial\delta_i}{\partial Ł} - \sum_{i=1}^{\mathcal{N}}\mu_i\frac{\partial\psi_i}{\partial Ł} - \sum_{i=1}^{\mathcal{N}}\nu_i\frac{\partial Î_i}{\partial Ł} \quad (1)$$

$$zero = \sum_{i=1}^{\mathcal{N}}[zero]_i - \sum_{i=1}^{\mathcal{N}}\left[\lambda_i\frac{1}{\omega\times log_2\left(1+\left(\frac{p\times H}{\sigma}\right)\right)}\right]_i - \sum_{i=1}^{\mathcal{N}}\left[\mu_i\left[\alpha\, exp\left(-\beta\frac{p\times H}{\sigma}\right)\right]\right]_i - \sum_{i=1}^{\mathcal{N}}\left[\nu_i\frac{\varepsilon}{\omega\times log_2\left(1+\left(\frac{p\times H}{\sigma}\right)\right)}\right]_i \quad (2)$$

Solving (2), we get λ (3):

$$\lambda = -\mu\left[\omega\ \alpha\ exp\left(-\beta\frac{p\times H}{\sigma}\right)\ log_2\left(1+\left(\frac{p\times H}{\sigma}\right)\right)\right] - \nu\,[\varepsilon] \quad (3)$$

Next is to prepare the partial derivative objective equation with respect to transmission power (p) and set it to zero as shown in:

$$\frac{\partial\mathcal{L}\,\mathcal{F}}{\partial p} = \sum_{i=1}^{\mathcal{N}}\frac{\partial Ʀ_i}{\partial p} - \sum_{i=1}^{\mathcal{N}}\lambda_i\frac{\partial\delta_i}{\partial p} - \sum_{i=1}^{\mathcal{N}}\mu_i\frac{\partial\psi_i}{\partial p} - \sum_{i=1}^{\mathcal{N}}\nu_i\frac{\partial Î_i}{\partial p} \quad (4)$$

$$zero = \sum_{i=1}^{\mathcal{N}}\left[\frac{\omega\times H}{\sigma\times \text{Ln}2\times\left(1+\left(\frac{p\times H}{\sigma}\right)\right)}\right]_i - \sum_{i=1}^{\mathcal{N}}\left[\lambda_i\frac{-Ł\times H}{\omega\times\sigma\times \text{Ln}2\times\left(1+\left(\frac{p\times H}{\sigma}\right)\right)\times\left(\log_2\left(1+\left(\frac{p\times H}{\sigma}\right)\right)\right)^2}\right]_i - \sum_{i=1}^{\mathcal{N}}\left[\mu_i\left[\frac{-(\alpha\times Ł\times\beta\times H)}{\sigma}exp\left(-\beta\frac{p\times H}{\sigma}\right)\right]\right]_i - \sum_{i=1}^{\mathcal{N}}\left[\nu_i\frac{-Ł\times\varepsilon\times H}{\omega\times\sigma\times \text{Ln}2\times\left(1+\left(\frac{p\times H}{\sigma}\right)\right)\times\left(\log_2\left(1+\left(\frac{p\times H}{\sigma}\right)\right)\right)^2}\right]_i \quad (5)$$

Further solving (5), we get μ equation in terms of λ and ν:

$$\mu = \frac{\frac{-\omega}{\text{Ln}2\times\left(1+\left(\frac{p\times H}{\sigma}\right)\right)} - \lambda\left[\frac{Ł}{\omega\times \text{Ln}2\times\left(1+\left(\frac{p\times H}{\sigma}\right)\right)\times\left(\log_2\left(1+\left(\frac{p\times H}{\sigma}\right)\right)\right)^2}\right] - \nu\left[\frac{Ł\times\varepsilon}{\omega\times \text{Ln}2\times\left(1+\left(\frac{p\times H}{\sigma}\right)\right)\times\left(\log_2\left(1+\left(\frac{p\times H}{\sigma}\right)\right)\right)^2}\right]}{\left[(\alpha\times Ł\times\beta)\,exp\left(-\beta\frac{p\times H}{\sigma}\right)\right]} \quad (6)$$

The next step is to implement the partial derivative with respect to the bandwidth (ω) and also set it equal to zero to get ν (7), (8):

$$\frac{\partial\mathcal{L}\,\mathcal{F}}{\partial\omega} = \sum_{i=1}^{\mathcal{N}}\frac{\partial Ʀ_i}{\partial\omega} - \sum_{i=1}^{\mathcal{N}}\lambda_i\frac{\partial\delta_i}{\partial\omega} - \sum_{i=1}^{\mathcal{N}}\mu_i\frac{\partial\psi_i}{\partial\omega} - \sum_{i=1}^{\mathcal{N}}\nu_i\frac{\partial Î_i}{\partial\omega} \quad (7)$$

$$zero = \sum_{i=1}^{\mathcal{N}} \left[log_2 \left(1 + \left(\frac{p \times H}{\sigma}\right)\right)\right]_i - \sum_{i=1}^{\mathcal{N}} \left[\lambda_i \frac{- \text{Ł}}{\omega^2 \times log_2\left(1+\left(\frac{p \times H}{\sigma}\right)\right)}\right]_i - \sum_{i=1}^{\mathcal{N}} [\, \mu_i [\, zero]\,]_i - \sum_{i=1}^{\mathcal{N}} \left[\nu_i \frac{-(\text{Ł} \times \varepsilon)}{\omega^2 \times log_2\left(1+\left(\frac{p \times H}{\sigma}\right)\right)}\right]_i \tag{8}$$

Further solving (5), yields ν (9):

$$\nu = \frac{\left[- \omega^2 \left(\log_2\left(1+\left(\frac{p \times H}{\sigma}\right)\right)\right)^2 \right] - \lambda\, [\text{Ł}]}{(\text{Ł} \times \varepsilon)} \tag{9}$$

by substituting λ from (3) into μ from (6), we get the final equation to calculate the value of μ for each path i as shown in (10).

$$\mu = \frac{\omega \; log_2\left(1+\left(\frac{p \times H}{\sigma}\right)\right)}{(\alpha \times \text{Ł}) \times exp\left(-\beta \frac{p \times H}{\sigma}\right) \times \left(1 - \left(\beta \times \text{Ln}2 \times \left(1+\frac{p \times H}{\sigma}\right) \times log_2\left(1+\left(\frac{p \times H}{\sigma}\right)\right)\right)\right)} \tag{10}$$

Then assume that λ is a unity to solve for the other Lagrange multipliers ν for each path i available. Finally, the calculated μ and ν along with λ are plugged back into the objective function and also in our program. The optimum path represents the path that achieves the maximum objective from the source node Src to the destination node Dest.

Table 1. List of notations

Symbol	Semantics	Symbol	Semantics
p	Power available for data transmission	Î	Traffic intensity of congestion
ω	Bandwidth allocated for the network	λ , μ , ν	Lagrange multipliers
σ	Noise power generated by the channel	Ł	Packet length
H	Random variable represents the channel fading	φ	Length of the physical medium
$\mathcal{L}$	Number of available links	ζ	Propagation speed of the medium
$\mathcal{L}\,\mathcal{F}$	Lagrangian objective function	ε	Packet average arrival rate
Ʀ	Bit rate calculated for transmission	α , β	Packet loss ratio model parameters
δ	Total delay calculated	$\mathcal{N}$	Number of nodes in the ad-hoc network
Ψ	Probability of packets loss calculated		

2.2. Lagrangian optimization rate, delay, packet loss, and congestion algorithm

In this section, we present a Lagrangian optimization rate, delay, packet loss, and congestion algorithm (LORDPC). LORDPC is an especially designed congestion control algorithm of an ad hoc network to track statistics of resource information and to compute the optimal solution based on the cumulative objective function, which is the best possible solution starting from the source node to the destination node as the problem proved. The numerical evaluation of all required parameters is assigned a route discovery procedure, for each of the $\mathcal{N}$ nodes to explore all available $\mathcal{L}$ links connected to the corresponding node. These parameters address the significance of every connected link related to that node. The process of surveying endures calculations for the bit rate Ʀ to be transmitted by, the total delay δ consumed, the packet loss rate ψ undertaken by the specified link as well as congestion intensity produced by queuing delay Î. Furthermore, we acquired the objective function $\mathcal{L}\,\mathcal{F}$ for each of these available links that reflect the satisfaction of a source node with the resource allocation. Last but not least, we attained the accumulative objective function $\mathcal{L}\,\mathcal{F}$ for all possible source-destination combinations. Based on the computation provided, each source node is responsible for selecting the optimum path that leads to the destination node Dest. The decision is made based on the maximum accumulative objective function gained and its correlated link is elected. Algorithm 1 explains the LORDPC procedure.

Algorithm 1. LORDPC

```
Input: SrcN, DestN
Output: the optimum path from SrcN to DestN
Explore Node's Readings (SrcN, DestN, nodes (location and speed))
Calculate nodes connectivity using Euclidean distance φ
Apply route discovery procedure to construct routing list of all possible paths from SrcN
to DestN
```

```
for all nodes' available links
         Calculate bit rate Ʀ
         Calculate transmission, propagation delay, and nodal delay δ
         Calculate packet loss rate ψ
         Determine Lagrange Multipliers λ, μ, ν
         Calculate the Lagrange objective function ℒℱ
         Insert all the above calculations in the routing table
End for
For all possible paths from SrcN to DestN
         Calculate cumulative objective function ℒℱ
End for
If all cumulative objective function ℒℱ is the equal
       optimum path=min Î
Else
        optimum path=max cumulative ℒ.ℱ
End if
```

3. RESULTS AND DISCUSSION

To test the obtained optimization formula, a simulation screening is performed with the conventional AODV and LORDP algorithm [26], [27]. We considered implementing the underlying algorithms at randomly distributed 25 nodes, in a 100 m^2 coverage area. We involve source and destination nodes to perform a route discovery procedure for all their possible paths and then apply the selection mechanism of each algorithm accordingly. We adopted the scenario underlying the signal-to-noise ratio SNR ranging from 0 to 25 in step 5. Each node states its generated transmission power, channel effect, and noise of the channel. Some of these nodes are assumed to be congested and hold decaying reads regarding bit rate, node delay, packet loss ratio, and congestion queuing delay.

In our scenario, we performed an intensive simulation to test the average parameter calculation where we condense 500 trials for the same value signal-to-noise ratio. The increment of the signal-to-noise ratio affects the average parameter calculation. As shown, Figure 1 represents the bit rate measurement algorithms of the selected paths with the decaying nodes being injected for LORDPC, AODV, and LORDP. It can be observed that our congestion avoidance LORDPC path achieves the highest value with an increasingly acquired bit rate over conventional AODV and LORDP paths. Figure 2 shows the sum of transmission and propagation delays to construct the nodal delay. By noting the decreasing bars, our LORDPC selected path consumes less period to transmit packets over the selected path as compared to the paths taken by the AODV and LORDP paths. Figure 3 shows the values in descending bars in terms of the packet loss rate where we can notice the LORDPC path represent the path with the lowest packet loss rate of selected paths between the AODV and LORDP. Finally, the intensity of traffic that causes congestion due to queuing delays is shown in Figure 4. Where again LORDPC path shows its advancement over the other two methods by choosing the path with the least queuing delays and less congestion by extent.

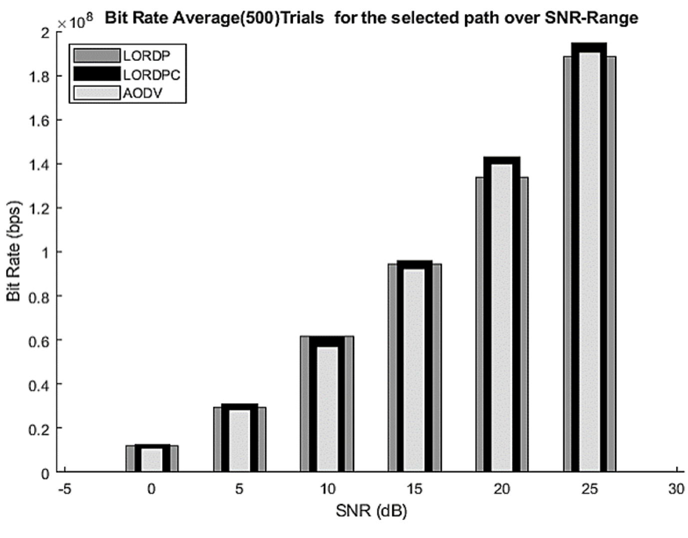

Figure 1. LORDP, LORDPC, and AODV bit rates with decaying nodes

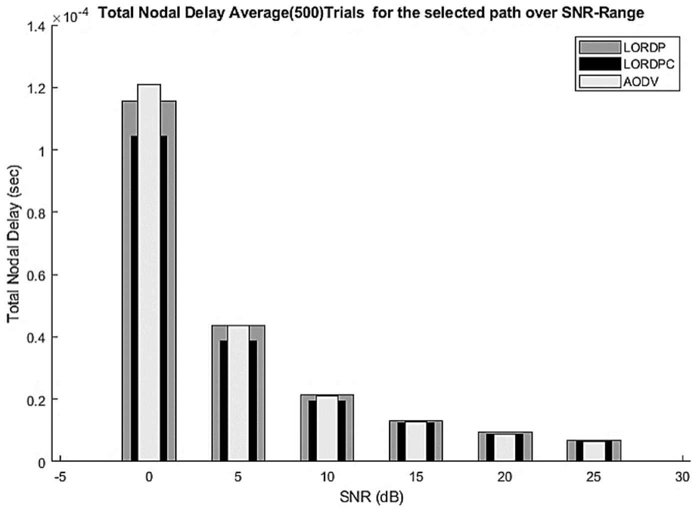

Figure 2. LORDP, LORDPC, and AODV nodal delay with decaying nodes

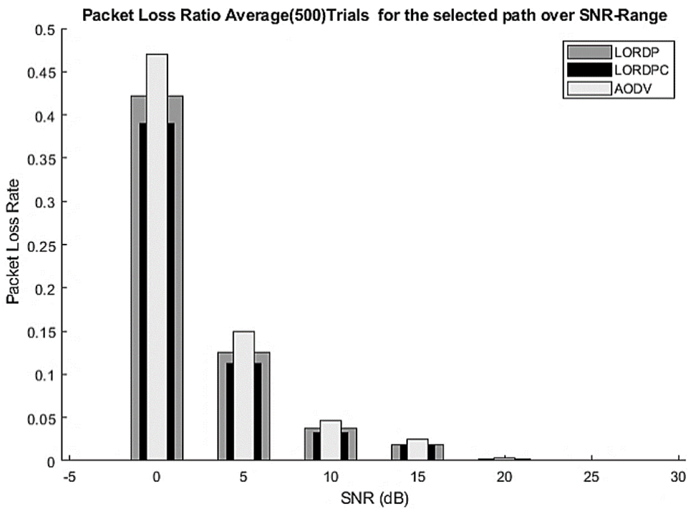

Figure 3. LORDP, LORDPC, and AODV packet loss ratio with decaying nodes

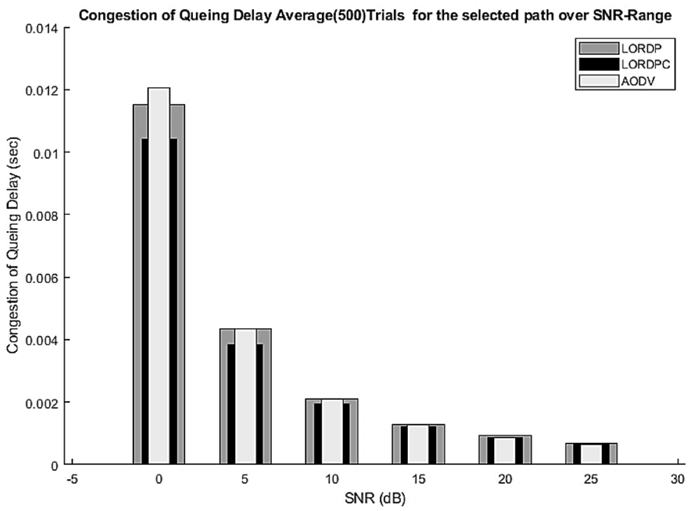

Figure 4. LORDP, LORDPC, and AODV congestion of queuing delay

4. CONCLUSION

Most popular MANET routing algorithms are intended to acquire the shortest route as well as minimum hop counts. However, the shortest course may not always supply the best solution, especially for delay-sensitive applications or when there are congested nodes over those paths. Congestion is an undesired circumstance of a network with limited resources where nodes have different power, channel effect, rates, and delays. Congestion control has been a critical manner and a key to network performance in communication networks. A network link is considered to be congested when it is loaded with packets close to the qualification of the link and the queuing duration for those packets are ascending. This paper identifies optimized resource allocation routing problems over ad hoc networks and investigates the effect of node power level, channel effect, bitrate, nodal delay, packet loss we well as queuing delay causing congestions on a network. We designed a method for locating the optimum solution by utilizing an objective function that is limited by some constraints. Our main assignment is to maximize the bit rate while minimizing the values of the nodal delay, packet loss rate, and congestion caused by queuing delays. we proposed an optimal routing algorithm that runs through every node starting from the source node and reaching out to the destination node using the Lagrange multiplier method. The optimal route of path selection represented the best possible solution that verifies the objective function and its trade-offs. We consider the case where each packet is modulated and passed over a Rayleigh fading channel. Simulation results demonstrate the significance of objectifying the congestion caused by the duration of queuing packets in a node. The larger the queuing delay the more degradation in network performance. Our proposed method LORDPC addresses the optimum path to serve the desired objective function superiority over other compared methods (AODV and LORDP).

REFERENCES

[1] R. R. Roy, *Handbook of mobile ad hoc networks for mobility models*. Boston, MA: Springer US, 2011, doi: 10.1007/978-1-4419-6050-4.

[2] M. K. Farhan and M. S. Croock, “Routing techniques study for D2D in MANET based environment : a survey and open issues,” *International Journal of Innovation Engineering and Science Research*, vol. 3, no. 4, pp. 13–23, 2019.

[3] M. M. Karthikeyan and G. Dalin, *Dynamic congestion control routing algorithm for energy harvesting in MANET*, vol. 173, Singapore: Springer Singapore, 2021, doi: 10.1007/978-981-33-4305-4_2.

[4] N. Mast *et al.*, “Channel contention-based routing protocol for wireless ad hoc networks,” *Complexity*, vol. 2021, pp. 1–10, Jan. 2021, doi: 10.1155/2021/2051796.

[5] D. Krishnamoorthy *et al.*, “An effective congestion control scheme for MANET with relative traffic link matrix routing,” *Arabian Journal for Science and Engineering*, vol. 45, no. 8, pp. 6171–6181, Aug. 2020, doi: 10.1007/s13369-020-04511-9.

[6] A. Bhardwaj and H. El-Ocla, “Multipath routing protocol using genetic algorithm in mobile ad hoc networks,” *IEEE Access*, vol. 8, no. November, pp. 177534–177548, 2020, doi: 10.1109/ACCESS.2020.3027043.

[7] Z. Chen, W. Zhou, S. Wu, and L. Cheng, “An adaptive on-demand multipath routing protocol with QoS support for high-speed MANET,” *IEEE Access*, vol. 8, pp. 44760–44773, 2020, doi: 10.1109/ACCESS.2020.2978582.

[8] M. H. Hanin, M. Amnai, and Y. Fakhri, “New adaptation method based on cross layer and TCP over protocols to improve QoS in mobile ad hoc network,” *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 11, no. 3, pp. 2134–2142, Jun. 2021, doi: 10.11591/ijece.v11i3.pp2134-2142.

[9] M. A. Gawas, L. J. Gudino, and K. R. Anupama, “Congestion-adaptive and delay-sensitive multirate routing protocol in MANETs: a cross-layer approach,” *Journal of Computer Networks and Communications*, vol. 2019, pp. 1–13, May 2019, doi: 10.1155/2019/6826984.

[10] W. Feng, Y. Xu, X. Xu, M. Zhao, and Y. Yao, “An energy-efficient and fast convergent resource allocation algorithm in distributed wireless ad hoc networks,” *IEEE Access*, vol. 7, pp. 17133–17148, 2019, doi: 10.1109/ACCESS.2019.2894874.

[11] N. Akhtar, M. A. Khan, A. Ullah, and M. Y. Javed, “Congestion avoidance for smart devices by caching information in MANETS and IoT,” *IEEE Access*, vol. 7, pp. 71459–71471, 2019, doi: 10.1109/ACCESS.2019.2918990.

[12] N. Kaur and R. Singhai, “Analysis of traffic impact on proposed congestion control scheme in AODV,” *Wireless Personal Communications*, vol. 109, no. 2, pp. 1395–1418, Nov. 2019, doi: 10.1007/s11277-019-06618-1.

[13] V. Tilwari, K. Dimyati, M. H. D. Hindia, A. Fattouh, and I. Amiri, “Mobility, residual energy, and link quality aware multipath routing in MANETs with Q-learning algorithm,” *Applied Sciences*, vol. 9, no. 8, Apr. 2019, doi: 10.3390/app9081582.

[14] D. Wang and Y. Song, “ECCO: a novel end-to-end congestion control scheme in multi-hop cognitive radio ad hoc networks,” *IEEE Transactions on Cognitive Communications and Networking*, vol. 5, no. 1, pp. 93–102, Mar. 2019, doi: 10.1109/TCCN.2018.2889337.

[15] R. Chaudhry and S. Tapaswi, “Bio-inspired energy conserving adaptive power and rate control in MANET,” *Computing*, vol. 101, no. 11, pp. 1633–1659, Nov. 2019, doi: 10.1007/s00607-018-0676-8.

[16] R. N. Arika, A. Mindila, and W. Cheruiyot, “Development of a congestion adaptive routing algorithm for MANET throughput optimization,” *Journal of Network Communications and Emerging Technologies (JNCET)*, vol. 7, no. 2, pp. 19–26, 2017

[17] S. Sharma, D. Jindal, and R. Agarwal, “Analysing mobile random early detection for congestion control in mobile ad-hoc network,” *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 8, no. 3, pp. 1305–1314, Jun. 2018, doi: 10.11591/ijece.v8i3.pp1305-1314.

[18] M. S. Gowtham and K. Subramaniam, “Congestion control and packet recovery for cross layer approach in MANET,” *Cluster Computing*, vol. 22, no. 5, pp. 12029–12036, Sep. 2019, doi: 10.1007/s10586-017-1548-2.

[19] A. Amuthan, N. Sreenath, P. Boobalan, and K. Muthuraj, “Dynamic multi-stage tandem queue modeling-based congestion adaptive routing for MANET,” *Alexandria Engineering Journal*, vol. 57, no. 3, pp. 1467–1473, Sep. 2018, doi: 10.1016/j.aej.2017.03.026.

[20] A. Alhosainy and T. Kunz, “Joint optimal congestion, multipath routing, and contention control for wireless ad hoc networks,” *IEEE Communications Letters*, vol. 21, no. 12, pp. 2670–2673, Dec. 2017, doi: 10.1109/LCOMM.2017.2739139.

[21] S. Rajalakshmi and R. Maguteeswaran, "Quality of service routing in manet using a hybrid intelligent algorithm inspired by cuckoo search," *Scientific World Journal*, vol. 2015, 2015, doi: 10.1155/2015/703480.
[22] J. Huang, X. Fan, X. Xiang, M. Wan, Z. Zhuo, and Y. Yang, "A clustering routing protocol for mobile ad hoc networks," *Mathematical Problems in Engineering*, vol. 2016, pp. 1–10, 2016, doi: 10.1155/2016/5395894.
[23] D. Tse and P. Viswanath, *Fundamentals of wireless communication*, vol. 9780521845. Cambridge University Press, 2005, doi: 10.1017/CBO9780511807213.
[24] J. F. Kurose and K. W. Ross, *Computer networking - a top-down approach*. United States of America: Addison-Wesley, 2013.
[25] S. Fu, Y. Zhang, M. Ceriotti, Y. Jiang, M. Packeiser, and P. J. Marron, "Modeling packet loss rate of IEEE 802.15.4 links in diverse environmental conditions," in *2018 IEEE Wireless Communications and Networking Conference (WCNC)*, Apr. 2018, pp. 1–6, doi: 10.1109/WCNC.2018.8377111.
[26] M. K. Farhan and M. S. Croock, "Optimal resource allocation for route selection in ad-hoc networks," *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, vol. 19, no. 4, pp. 1197–1207, Aug. 2021, doi: 10.12928/telkomnika.v19i4.18521.
[27] M. K. Farhan and M. S. Croock, "Optimized routing algorithm for maximizing transmission rate in D2D network," *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*, vol. 23, no. 1, pp. 575–582, Jun. 2021, doi: 10.11591/ijeecs.v23.i1.pp575-582.

BIOGRAPHIES OF AUTHORS

Marwa K. Farhan received the B.Sc. and M.Sc. degrees in computer engineering from Al-Nahrain University, Iraq, in 2005 and 2008 respectively, and Ph.D. degree in information and communication engineering from Al-Nahrain University, Iraq, in 2022. Currently, she is a Lecturer at the Iraqi Ministry of Higher Education and Scientific Research/ Scholarship and Cultural Relationships Directorate. Her research interests include computer networks, mobile ad-hoc networks, and resource optimization. She can be contacted at email: marwa.farhan@coie-nahrain.edu.iq.

Muayad S. Croock earned his Ph.D. (2012) in Computer Engineering at Newcastle University, School of Electrical, Electronics and Computer Engineering. He finished his M.Sc. degree in Computer Engineering from University of Technology-Iraq (2003), and a B.Sc. degree in Computer Engineering from the University of Technology (1998). Dr. Muayad is a staff member at University of Technology since 2004, where he currently holds assistant professor in Software Engineering. His research interest includes software engineering, security, and wireless sensor networks. He can be contacted at email: muayad.s.croock@uotechnology.edu.iq.