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Optimal resource allocation for route selection in ad-hoc networks

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ABSTRACT

Nowadays, the selection of the optimum path in mobile ad hoc networks (MANETS) is being an important issue that should be solved smartly. In this paper, an optimal path selection method is proposed for MANET using the Lagrange multiplier approach. The optimization problem considers the objective function of maximizing bit rate, under the constraints of minimizing the packet loss, and latency. The obtained simulation results show that the proposed Lagrange optimization of rate, delay, and packet loss algorithm (LORDP) improves the selection of optimal path in comparison to ad-hoc on-demand distance vector protocol (AODV). We increased the performance of the system by 10.6 Mbps for bit rate and 0.133 ms for latency.

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1. INTRODUCTION

Mobile ad- hoc networks (MANET) is a self-configured and infrastructure-free network that is based on ad-hoc communications. The routing in mobile ad-hoc networks is very defiance due to the persistent updates in topologies, and active routes may be disconnected due to wireless device mobility from one place to another [1]. These wireless nodes operate as a host and as a router to allow the internal communications available. Therefore, each node interacts in the routing process to deliver a packet to the destination node. Mobility, topology changes, power and resource shortage, non-centralized control are all MANET environment properties. Such characteristics provoke the urge to design a routing protocol that agrees with some terms. The route selection protocol must be qualified to adapt to these variations by continually monitoring the link state and perform routes accordingly [2] different issues were addressed in the prior research area, yet such thriving network business subjects to continuous improvements and enhancement in terms of QoS and QoE. The process of transferring data packets from source point to destination point that subject to resource constraints, such as energy, delay, bit rate, packet loss rate, and cost should include the use of optimization methods in the routing process [3].

Thus, we introduce a method based on Lagrange optimization that selects the optimal route from the device to other devices in a MANET. Specially designed to satisfy the desired objective function based on supplementary routing requirements. Where data packets are sent using routes from the routing table that are selected based on the requested characteristics. The aim is to maximize the bit rate from node to node and minimize the total delay and packet loss probability in wireless data transmission. Therefore, this paper addresses a theoretical and practical scenario. Prior efforts in research field have been invested to address a diverse issue in the optimal route policies and methods in terms of various objectives (minimizing the duration or minimizing the energy consumption or even number of hops). A series of works have been investigated and New technologies, as well as techniques, have been exploited in the prior work [3]. Authors of [4] addressed direct end devices communication in case of restricted connectivity to the cellular network due to disasters or emergencies. For the performance evaluation of QoS in ad-hoc networks and constraint satisfaction in ad-hoc on-demand distance vector protocol (AODV) protocol, the authors of [5] enhanced the conventional cuckoo search algorithm to chose the QoS path based on the routing load, residual energy, and hop count. Moreover, researchers of [6] introduced a novel QoS routing in MANETs using emergent intelligence. For data loss minimization, and energy-efficient clustering was introduced using PSO and fuzzy optimization. In terms of disaster response, the authors of [7] focused on D2D communications to extend the base station's coverage. They used controller-assisted routing to increase the total throughput to maximum using ant colony optimization. Also, the authors of [8] formulated a quality of experience routing over wireless multi-hop networks under time-constraints. They proposed a heuristic algorithm to speed up finding solutions. For writers to enhance the capacity of traffic offloading for cellular- D2D relays, authors of [9] introduced a three D2D communication model.

On the other hand, in [10] the authors utilized the OLSR routing algorithm to build a multi-hop D2D communications platform based on smartphones to expand the single-hop D2D scenarios. They measure performances of energy consumption, coverage, network latency, and link quality. In [11], the authors introduced a reliability-aware AODV by conferring stability to paths. The selected routes are restricted with bandwidth and end-to-end delay. The researcher in [12] proposed trust and prevent parameters against malicious networks to identify a secure route. The delivery rate increases more significantly when malicious nodes increase using the proposed method than that of the AODV and TVAODV. The authors of [13] introduced a hybrid OLSRv2 that is multipath energy and QoS-aware to solve the limitation of energy resources, nodes mobility, and traffic congestion. The researcher in [14] presented a MATLAB-based ad-hoc on-demand distance vector simulation presented to provide a meaningful method of demonstrating basic routing concepts and facilitating visual learning. The authors of [15], proposed a virtual Ad hoc routing protocol to increase security and scalability. They also developed a source-routing protocol that achieved better scalability and lowers consumed power. Also, the authors of [16] introduced mobility-energy improved ant colony optimization routing method. The method speeded up the routing algorithm and reduced the route discovery packets. A network coding-based routing protocol was proposed in [17] to reduce latency and traffic load for transmission of online gaming. They proposed a medium access scheduling in device to device infrastructure and also considered problems of packet loss.

In terms of optimal routes, the authors of [18] proposed a performance-on-demand routing protocol. The route is selected by hop number and throughput. The throughput condition means to achieve the minimum threshold with the highest throughput of the entire route among candidate. A new concept of route availability was presented in [19] as a measurement of route no uniformity in a MANET as it represents the QoS or QoE of video streaming. They confirmed two QoS metrics and founded that route availability is affected by changes in video quality. More on videos over MANETs, authors of [20] streamed high definition videos. They designed a transmission system followed by a distortion system to evaluate the packet-loss rate and end-to-end delay and improved QoS and QoE. An optimized routing method was proposed in [21] to enhance the performance of the network that was subjected to the maximum bit rate, minimum packet loss rate, and minimum delay. The path selection relies on the weighted Sum optimization method, the non-dominated sorting -GeneticII, and weighted sum-genetic optimization. Network assisted-routing for device-to-device architectures of 5G was introduced in [22] to extend the base stations coverage. NAR took in consideration that communications of D2D are managed by base stations.

Eventually, the researchers in [23] modeled a D2D-QoS routing. They assigned the QoS in terms of delay, bandwidth, and packet loss rate. The routing path was allocated according to dynamic environments. Moreover, the authors in [24] developed a Bayesian framework to assign the amount of permeable water in a porous structure using clustering and geometry values of the pore-throat network. Several clustering criteria were used (edge betweenness, short random walks, and greedy and multi-level modularity optimization). They've created a micro networks database for micro-scale porous structures to be the primary input for the Bayesian method. In [25], the author concluded continuities and discontinuities, in both the realization of technology and science as well as on the role of ethics in this revolutionary process. He also concluded that human values must be incorporated with technology should and should be enriched from several cultural areas. The authors of [26] used statistical tests to address the best method of estimation. Tests like the Lagrange multiplier Breusch-Pagan test, the F test, and the Hausman test were used and resulted in a panel data prototype with different effects for individuals. In [27], the writer's analysis aims to develop a base for decision-making in terms of mergers and acquisitions for manufacturing companies. This can be done by performing a scorecard model to allow the potential acquirer to apply an overall analysis of the existing data. It also runs an insight for the future using a standardized and efficient approach to positively affect the achieve-rate of mergers and acquisition transactions.

Finally, the authors of [28] composed cellular networks of D2D pairs where relays are arranged in clusters. They investigate D2D communication optimal routing in the existence of interference. Optimal routing was included to select the highest end-to-end SINR path.

2. RESEARCH METHOD

In this section, we present the system model and formulation of the problem. In another meaning, the formulation of the presented problem is introduced. The Lagrange multiplier method is adopted in this formulation as an objective funation and constraints.

2.1. System model

We consider a MANET that is composed of a set of nodes $\mathcal{N} = \{1,2,3, \dots, \mathcal{K}_{\mathcal{N}}\}$ that are connected by a set of available links $\mathcal{L} = \{1,2,3, \dots, \mathcal{K}_{\mathcal{L}}\}$ and represents a device-to-device communication over the ad-hoc environment. Each source node Src emits one flow to the destination node Dest using one or more of the available links in routing. Due to the frequent updates in topologies in the network, the routing method needs to be improved and optimized accordingly. Assume that the source node performs data transmission with ꝑ watt power over an ω bandwidth, and subject to σ watt transmission noise. We include a fading factor $\hbar$ to reflect the effect of channel fading, at which the transmitting node routes data packets to the receiving node.

Each of the nodes $\mathcal{N}$ inject data packets into the network with specific power ꝑ and is exposed to an amount of noise σ. We assigned a surveying procedure, for each of the $\mathcal{N}$ hops, that explore all available $\mathcal{L}$ links connected to the corresponding hop. This surveying procedure addresses parameters that measure the significance of every connected link related to that hop. The process of surveying endures calculations for the bit rate Ʀ to be transmitted by, the total delay δ consumed, and the probability of packet loss ψ undertaken by the specified link. Furthermore, we attain an objective function $\mathcal{L}.\mathcal{F}$ computation for each of these connected links that reflect the satisfaction of a source with the resource allocation. Based on the above-mentioned computation, each hop is responsible for selecting the optimum link that leads to the destination node Dest required by the source node Src. The decision is made based on the maximum scored objective function and its correlated link is elected. Our formulated optimization model in section 3.2 is based on hop-by-hop optimization control, therefore, its suitable for scenarios of diverse routes. Table 1 summarizes the main notations and their corresponding definition that are used throughout the paper.

Table 1. List of notations

Symbol	Semantics
ꝑ	Power available for data transmission
ω	Bandwidth allocated for the network
σ	Noise power generated by the channel
$\hbar$	Random variable represents the channel fading
$\mathcal{L}$	Number of available links
$\mathcal{L}.\mathcal{F}$	Lagrangian objective function
Ʀ	Bit rate calculated for transmission
δ	Total delay calculated
ψ	Probability of packets loss calculated
λ , μ	Lagrange multipliers
φ	Length of the physical medium
ζ	Propagation speed of the medium
α	Packet average arrival rate
$\mathcal{N}$	Number of Nodes in the ad-hoc network

2.1.1. Transmission rate

We consign ꝑ denote the power used for transmission over a bandwidth ω of the link $\mathcal{L}$, and let $\hbar$ reflect fading factor, whereas σ is the noise power. The relationship between the transmission rate and allocated power in fading channels typically a concave function. The transmission rate Ʀ expressed below [29]:

$$Ʀ = \omega \log_2 \left(1 + \frac{ꝑ \hbar}{\sigma} \right) \quad (1)$$

2.1.2. Total nodal delay

Now we involve the delay property to be reflected in the constraints of the objective function. As packets start their journey from the source node Src through a multi-hop reaching the destination node Dest. Whereas at each node, packets endure a nodal delay that consists of several types of delays along the path. The most influential are the transmission delay, propagation delay, and queuing delay, and together accumulate to give a total nodal delay [30]. Delay is an influential design consideration in some real-time applications. Thus, the total nodal delay δ over a link $\mathcal{L}$ is expressed as [30]:

$$\delta_{\mathcal{L}\ \text{nodal}} = \delta_{\mathcal{L}\ \text{transmission}} + \delta_{\mathcal{L}\ \text{propagation}} + \delta_{\mathcal{L}\ \text{queue}} \tag{2}$$

where as the amount of time required to push all of the packet's bits into the link $\mathcal{L}$ represents the transmission delay. It depends on the length of the packet of ƚ bits at a transmission rate Ʀ of the link as shown below [30]:

$$\delta_{\text{transmission}} = \frac{ƚ}{Ʀ} \tag{3}$$

and the time imposed to spread from the beginning of the link $\mathcal{L}$ to the next-hop exhibits the propagation delay. As bits are transmitted over a distance φ between two hops at a physical medium with a propagation speed ζ on a link $\mathcal{L}$. The propagation delay is written as [30]:

$$\delta_{\text{propagation}} = \frac{\varphi}{\zeta} \tag{4}$$

as packets suffer output buffer queuing delay which is the period of waiting to be transmitted onto the link $\mathcal{L}$. Such delay is variable and relies on the congestion level of the network. Unlike previously mentioned delays, the queuing delay varies from one packet to another. As packets arrive at an empty queue at the same time, the first packet suffers zero queuing delays, while the last packet suffers queuing delay as it waits for the earlier packets to be transmitted. Therefore, an average queuing delay is considered. it expressed by the length of the packet of ƚ bits and the average rate at which packets arrive at the queue α at a Ʀ transmission rate as follows [30]:

$$\delta_{\text{queue}} = \frac{ƚ \times \alpha}{Ʀ} \tag{5}$$

Therefore, the total delay represents the sum of all as shown [30]:

$$\delta_{\text{nodal}} = \frac{ƚ}{Ʀ} + \frac{\varphi}{\zeta} + \frac{ƚ * \alpha}{Ʀ} \tag{6}$$

$$\delta_{\text{nodal}} = \frac{ƚ\,(1+\alpha)}{Ʀ} + \frac{\varphi}{\zeta} \tag{7}$$

2.1.3. Probability of packet loss

Another feature to be involved in the constraints of the objective function. Where the probability of packet loss ψ can be formed as a function of ꝑ transmission power utilized in sending packets over a link $\mathcal{L}$. As the packet loss is a ratio of received over sent values with exponent behavior; in this case, it's the transmission power ꝑ, subtracted from unity to measure the probability. We assumed that a packet is received error-free with Ʀ transmission rate and bandwidth ω over the link $\mathcal{L}$. Ɛ[H] represents the expected channel state that is fixed for each packet and is realized at the transmitter side [31], [32]:

$$\psi = 1 - e^{-G/ꝑ} \tag{8}$$

$$G = \frac{\sigma \times \omega}{Ɛ[H]} \times \left(2^{Ʀ/\omega} - 1\right) \tag{9}$$

2.2. Problem formulation

Now we formulate the optimum path multi-objective problem. We first define a variable that aims to maximize the bit rate and minimize the total network delay as well as packet loss. The prime objective function is bit rate maximization for$\mathcal{N}$ number of available paths in a network and can be expressed mathematically by:

$$\max \ \sum_{i=1}^{\mathcal{N}} Ʀ_i \tag{10}$$

That subject to the constraints of total delay minimization and packet loss minimization for each $\mathcal{N}$ paths and can be characterized by:

$$\min \sum_{i=1}^{\mathcal{N}} \delta_i + \min \sum_{i=1}^{\mathcal{N}} \psi_i \tag{11}$$

Utilizing the multi-objective approach to model this idea to get:

$$\max \sum_{i=1}^{\mathcal{N}} Ɽ_i - \min \sum_{i=1}^{\mathcal{N}} \delta_i - \min \sum_{i=1}^{\mathcal{N}} \psi_i \tag{12}$$

By applying the Lagrange optimization method to the model idea to ensure that the gradient of bit rate is proportional to the gradients of the total delay and packet loss. The proportionality variables are called Lagrange multipliers and are denoted by λ and μ. The Lagrange optimization function is expressed as:

$$\nabla \text{ bit rate} = \lambda \nabla \text{ total delay} + \mu \nabla \text{ packet loss} \tag{13}$$

$$\mathcal{L}.\mathcal{F} = \nabla \text{ bit rate} - \lambda \nabla \text{ total delay} - \mu \nabla \text{ packet loss} \tag{14}$$

The challenge is to find an equation formula for all three, the objective and constraints, that consist of common parameters. The reason behind that is because when taking partial derivative for equations with parameter in common will not result in a nil value, due to fact that derivatives of constants are zero. Those common ground parameters are the power (ꝑ) and bandwidth (ω).

From a mathematical perspective, the desired Lagrangian function is characterized as:

$$\mathcal{L}\ \mathcal{F}\ (ꝑ, \omega) = \sum_{i=1}^{\mathcal{N}} [Ɽ_i(ꝑ, \omega)] - \sum_{i=1}^{\mathcal{N}}[\lambda_i\ \delta_i(ꝑ, \omega)] - \sum_{i=1}^{\mathcal{N}}[\mu_i\ \psi_i(ꝑ, \omega)] \tag{15}$$

where Ɽ(ꝑ, ω) represent the gradients of a bit rate as a result of the first-order derivation concerning the power (ꝑ) and bandwidth (ω) respectively. Moreover, δ(ꝑ, ω) denotes the gradients of total delay by taking of the first-order derivative of total delay relative to the power (ꝑ) and bandwidth (ω) respectively. Furthermore, ψ(ꝑ, ω) represent the gradients of packet loss probability as a result of the first-order derivation concerning the power (ꝑ) and bandwidth (ω) respectively.

Now, setting up the Lagrange multipliers objective function. The first step is to construct the objective function by preparing the first derivatives for the main function (bit rate) and the constraints (total delay and packet loss probability) concerning ꝑ, and concerning ω as a second step.

$$\frac{\partial \mathcal{L}.\mathcal{F}}{\partial ꝑ} = \sum_{i=1}^{\mathcal{N}} \frac{\partial Ɽ_i}{\partial ꝑ} - \sum_{i=1}^{\mathcal{N}} \lambda_i \frac{\partial \delta_i}{\partial ꝑ} - \sum_{i=1}^{\mathcal{N}} \mu_i \frac{\partial \psi_i}{\partial ꝑ} \tag{15}$$

$$\frac{\partial \mathcal{L}.\mathcal{F}}{\partial \omega} = \sum_{i=1}^{\mathcal{N}} \frac{\partial Ɽ_i}{\partial \omega} - \sum_{i=1}^{\mathcal{N}} \lambda_i \frac{\partial \delta_i}{\partial \omega} - \sum_{i=1}^{\mathcal{N}} \mu_i \frac{\partial \psi_i}{\partial \omega} \tag{16}$$

2.2.1. Transmission rate

Assuming the equation in [29] finding the partial derivative of Ɽ concerning ꝑ, ω:

$$\frac{\partial Ɽ}{\partial ꝑ} = \frac{1}{\left(1+\left(\frac{ꝑ}{\sigma\times\omega}\right)\right)\times \sigma \times \mathrm{Ln}2} \tag{17}$$

$$\frac{\partial Ɽ}{\partial \omega} = \left(\frac{-\frac{ꝑ}{\sigma\times\omega}}{\left(1+\left(\frac{ꝑ}{\sigma\times\omega}\right)\right)\times \mathrm{Ln}\,2}\right)) + (\log_2\left(1 + \frac{ꝑ}{\sigma\times\omega}\right)) \tag{18}$$

2.2.2. Total nodal delay

Considering the equation in [30], Total delay is treated as the first constraint to the objective. The constraint should be equal to zero by moving parameters to the left-hand side of the equation as shown below:

$$\sum_{i=1}^{\mathcal{N}} \delta_i \leq \Delta_T \tag{19}$$

$$\sum_{i=1}^{\mathcal{N}} \delta_i - \Delta_T \leq 0 \tag{20}$$

$$\frac{\partial \delta}{\partial ꝑ} = \frac{\partial}{\partial ꝑ}\left[Ł\ (1+\alpha) \times \omega^{-1} \times \left(\log_2\left(1+\frac{ꝑ}{\sigma\times\omega}\right)\right)^{-1} + \frac{\varphi}{ȿ} - \Delta_T \right] \tag{21}$$

$$\frac{\partial \delta}{\partial \text{ꝑ}} = \frac{-\,\text{ł}\ (1+\alpha)}{\omega^2 \times \sigma \times \text{Ln}2 \times \left(1+\left(\frac{\text{ꝑ}}{\sigma\times\omega}\right)\right)\left(\log_2 1+\left(\frac{\text{ꝑ}}{\sigma\times\omega}\right)\right)^2} \tag{23}$$

$$\frac{\partial \delta}{\partial \omega} = \left[\left[\frac{\text{ꝑ} \times \text{ł} \times (1+\alpha)}{\sigma\times\omega^3\times\text{Ln}2\left(1+\frac{\text{ꝑ}}{\sigma\times\omega}\right)\left(\log_2\left(1+\frac{\text{ꝑ}}{\sigma\times\omega}\right)\right)^2}\right] - \left[\frac{\text{ł} \times (1+\alpha)}{\omega^2 \times \log_2\left(1+\frac{\text{ꝑ}}{\sigma\times\omega}\right)}\right]\right] \tag{22}$$

2.2.3. Probability of packet loss

Packet loss is handled as the second constraint to the bit rate maximization objective. The constraint should be equal to zero by moving parameters to the left-hand side of the equation as shown below:

$$\sum_{i=1}^{\mathcal{N}} \psi_i \quad \leq \psi_{\text{T}} \tag{25}$$

$$\sum_{i=1}^{\mathcal{N}} \psi_i \ - \psi_{\text{T}} \ \leq \ 0 \tag{26}$$

Considering the equation in [7], [32], Packet loss is handled as the second constraint to the bit rate maximization objective. The constraint should be equal to zero by moving parameters to the left-hand side of the equation as shown below:

$$\frac{\partial \psi}{\partial \text{ꝑ}} = \frac{\partial}{\partial \text{ꝑ}}\left[\ [1-\exp\left(\frac{-\sigma\times\omega}{\text{ꝑ}} \times 2^{\left(\log_2\left(1+\frac{\text{ꝑ}}{\sigma\times\omega}\right)\right)} + \frac{\sigma\times\omega}{\text{ꝑ}}\right)] - \psi_{\text{T}}\right] \tag{23}$$

$$\frac{\partial \psi}{\partial \text{ꝑ}} = \left[-\exp\left(\frac{-\sigma\times\omega}{\text{ꝑ}} \times 2^{\left(\log_2\left(1+\frac{\text{ꝑ}}{\sigma\times\omega}\right)\right)} + \frac{\sigma\times\omega}{\text{ꝑ}}\right)\right] \times \left[\frac{\left(\frac{\sigma\times\omega}{\text{ꝑ}} \times 2^{\left(\log_2\left(1+\frac{\text{ꝑ}}{\sigma\times\omega}\right)\right)}\right) - \left(\frac{\sigma\times\omega}{\text{ꝑ}}\right) - 1}{\text{ꝑ} + \left(\frac{\text{ꝑ}^2}{\sigma\times\omega}\right)}\right] \tag{24}$$

$$\frac{\partial \psi}{\partial \omega} = \frac{\partial}{\partial \omega}\left[[1-\exp\left(\frac{-\sigma\times\omega}{\text{ꝑ}} \times 2^{\left(\log_2\left(1+\frac{\text{ꝑ}}{\sigma\times\omega}\right)\right)} + \frac{\sigma\times\omega}{\text{ꝑ}}\right)] - \psi_{\text{T}}\right] \tag{25}$$

$$\frac{\partial \psi}{\partial \omega} = \left[-\exp\left(\frac{-\sigma\times\omega}{\text{ꝑ}} \times 2^{\left(\log_2\left(1+\frac{\text{ꝑ}}{\sigma\times\omega}\right)\right)} + \frac{\sigma\times\omega}{\text{ꝑ}}\right)\right] \times \left[\left(\frac{-\left(\sigma\times\omega\times 2^{\left(\log_2\left(1+\frac{\text{ꝑ}}{\sigma\times\omega}\right)\right)}\right) + (\sigma\times\omega) + \text{ꝑ}}{\left(\text{ꝑ}\times\omega + \frac{\text{ꝑ}^2}{\sigma}\right)}\right] \tag{26}$$

$$\begin{aligned}\frac{\partial\, \mathcal{L}\cdot\mathcal{F}}{\partial \omega} = {} & \sum\nolimits_{\text{i}} \left[\frac{-\frac{\text{ꝑ}}{\sigma\times\omega}}{\left(1+\left(\frac{\text{ꝑ}}{\sigma\times\omega}\right)\right)\times\text{Ln}2})) + (\log_2\left(1+\frac{\text{ꝑ}}{\sigma\times\omega}\right)\right]_{\text{i}} - \\ & \sum\nolimits_{\text{i}} \left[\lambda_{\text{i}} \left[\frac{\text{ꝑ} \times \text{ł} \times (1+\alpha)}{\sigma\times\omega^3\times\text{Ln}2\left(1+\frac{\text{ꝑ}}{\sigma\times\omega}\right)\left(\log_2\left(1+\frac{\text{ꝑ}}{\sigma\times\omega}\right)\right)^2}\right] - \left[\frac{\text{ł} \times (1+\alpha)}{\omega^2 \times \log_2\left(1+\frac{\text{ꝑ}}{\sigma\times\omega}\right)}\right]\right]_{\text{i}} + \\ & \sum\nolimits_{\text{i}} \left[\mu_{\text{i}} \left[\exp\left(\frac{-\sigma\times\omega}{\text{ꝑ}} \times 2^{\left(\log_2\left(1+\frac{\text{ꝑ}}{\sigma\times\omega}\right)\right)} + \frac{\sigma\times\omega}{\text{ꝑ}}\right)\right] \times \right. \\ & \left.\left[\left(\frac{-\left(\sigma\times\omega\times 2^{\left(\log_2\left(1+\frac{\text{ꝑ}}{\sigma\times\omega}\right)\right)}\right) + (\sigma\times\omega) + \text{ꝑ}}{\left(\text{ꝑ}\times\omega + \frac{\text{ꝑ}^2}{\sigma}\right)}\right]\right]_{\text{i}}\end{aligned} \tag{27}$$

The next step is to solve the system of Lagrange multipliers' objective function equations. That can be achieved by setting those equations equal to zero, then solve to find λ and μ in terms of all other parameters, and calculate those multipliers for each path i. Finally, evaluating μ and λ and then plugging those values back into the objective function and in our program.

2.3. LORDP algorithm

In this section, we provide an algorithm, named LORDP, to compute the optimal solution for the objective function, which is the best possible solution as the problem can be proved. Devoting the numerical evaluation of the performance of the Lagrangian optimization of rate, delay, and packet loss algorithm (LORDP) designed schemes as compared to ad-hoc on-demand distance vector (AODV). Figure 1 shows the flowchart of the LORDP algorithm.

3. RESULTS AND ANALYSIS

To test the obtained optimization formula on the practical side, a simulation examination is performed in terms of AODV as a conventional method and the proposed LORDP algorithm. For ease of reading, we consider case studies in implementing the underlying algorithms. We assumed a random node distribution of 9 nodes, then adopt the source and destination nodes and their dedicated path as shown in Figure 2 for case study 1 and Figure 3 for case study 2.

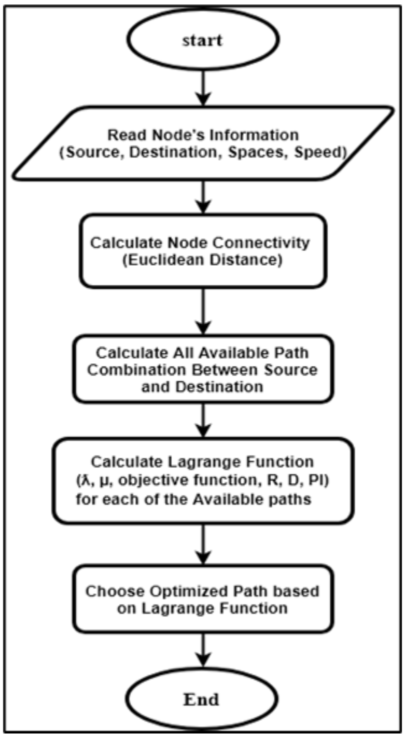

Figure 1. LORDP algorithm

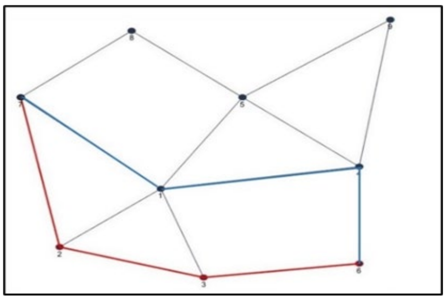

Figure 2. LORDP vs AODV selected path from source node7 to destination node6

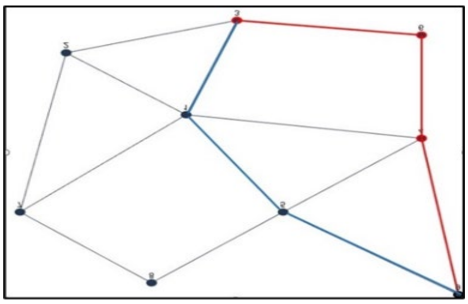

Figure 3. LORDP vs AODV selected path from source node3 to destination node9

3.1. Case study 1

Considering node7 as the source node while node6 as the destination node, with 5.5 meters each node apart. Figure 2 represents the optimal path selected by LORDP versus AODV's. This figure shows the distribution of nodes in addition to the selected path.

3.1.1. Transmission rate

The values of bit rate are measured per-hop and as average, as one can observe that the LORDP achieved a higher bit rate than those corresponding to AODV. This is proved in in Figures 4 and 5 that are represented as bar shapes. Such enhancement delivered by multi-objective optimization that assumed the bit rate as the main priority.

3.1.2. Total nodal delay

The values of total nodal delay are also measured per-hop and as average. One can see that the LORDP achieved less total nodal delay than those corresponding to AODV, as shown in Figures 6 and 7 that are represented as bar shape. Total nodal delay is assigned as the first constraint in this path optimization.

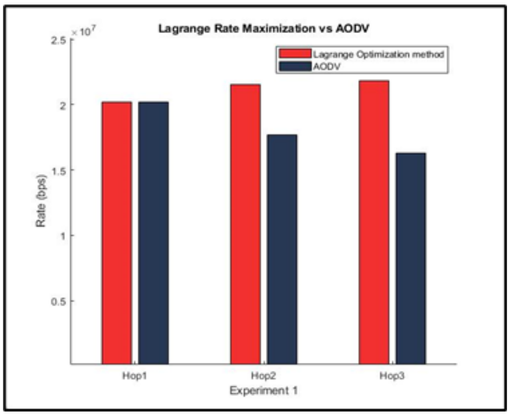

Figure 4. LORDP vs AODV Rate values per hop from source node7 to destination node6

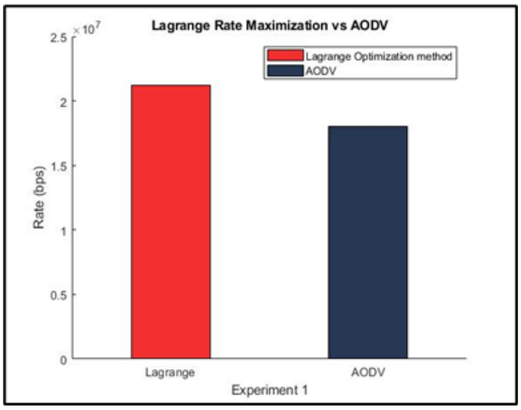

Figure 5. LORDP vs AODV average rate from source node7 to destination node6

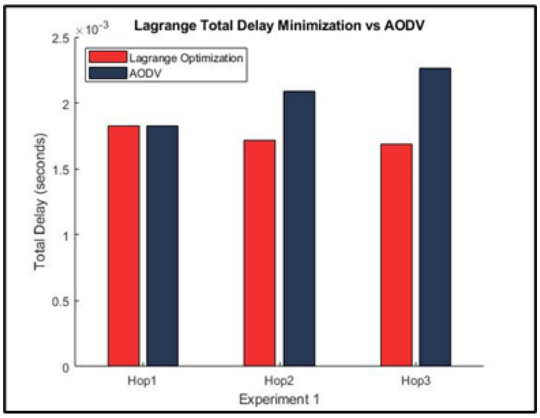

Figure 6. LORDP vs AODV total nodal delay from source node7 to destination node6

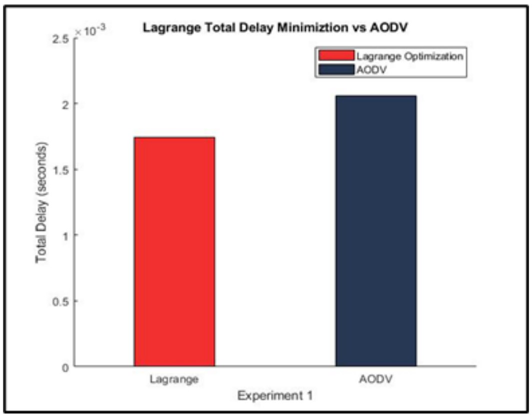

Figure 7. LORDP vs AODV average nodal delay from source node7 to destination node6

3.1.3. Probability of packet loss

Moreover, both algorithms; LORDP and AODV, have achieved the same value shown in Figure 8. The probability of packet loss is assigned as the second constraint in this path optimization. This is due to high importance of this parameter in selection of optimal path.

3.2. Case study 2

Considering node3 as the source node while node9 as the destination node, with 5.5 meters each node apart. Figure 3 represents the optimal path selected by LORDP versus AODV's. In addition, the distribution of nodes is also shown in this figure.

3.2.1. Transmission rate

The values of bit rate are measured per hop. As one can observe that the LORDP achieved a higher bit rate than those corresponding to AODV as shown in Figures 9 and 10. These figures are represented as bar shape to show the performance in clear way.

3.2.2. Total nodal delay

The values of total nodal delay are also measured per-hop and as average. It can be seen that the LORDP achieved less total nodal delay than those corresponding to AODV as shown in Figures 11 and 12. The total nodal delay improvement due to the first constraint in this path optimization.

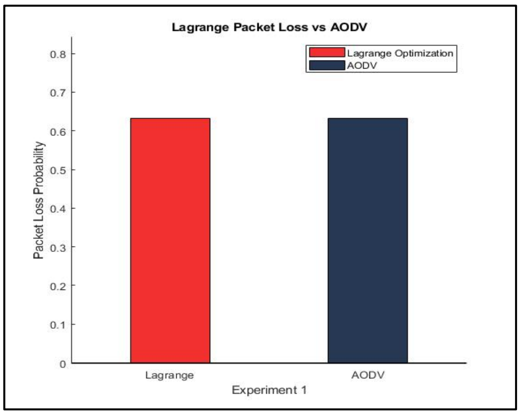

Figure 8. LORDP vs AODV probability of packet loss from source node7 to destination node6

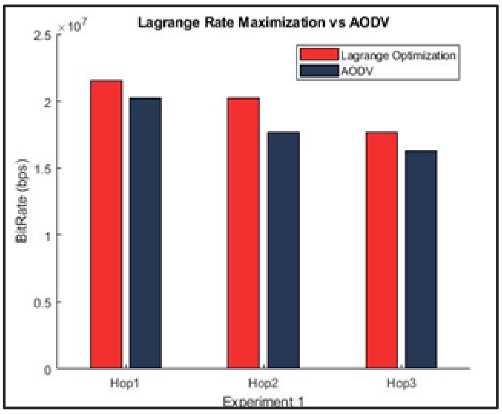

Figure 9. LORDP vs AODV Rate values per hop from source node3 to destination node9

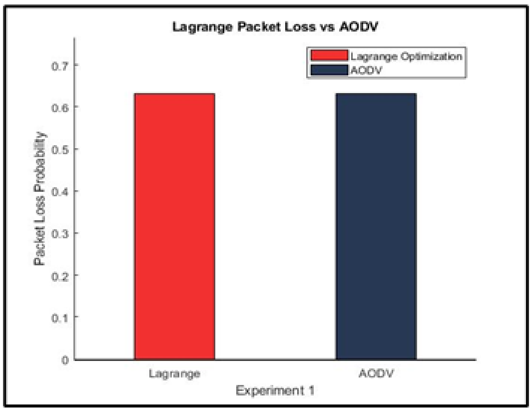

Figure 10. LORDP vs AODV average rate from source node3 to destination node9

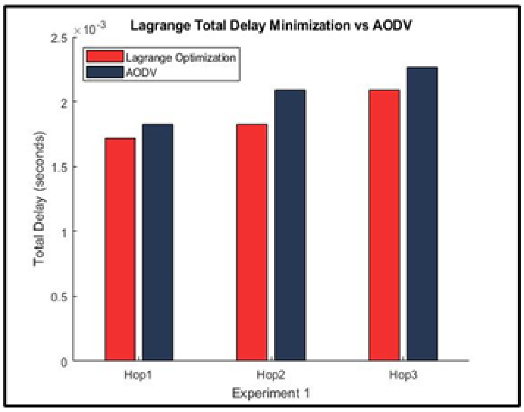

Figure 11. LORDP vs AODV total nodal delay from source node3 to destination node9

3.2.3. Probability of packet loss

On the other hand, both algorithms; LORDP and AODV, have achieved the same values measured in Figure 8 for case study 1. Where the probability of packet loss is assigned as the second constraint in this path optimization. The similar values are given to evaluate the other parameters and their effects on the optimization problem.

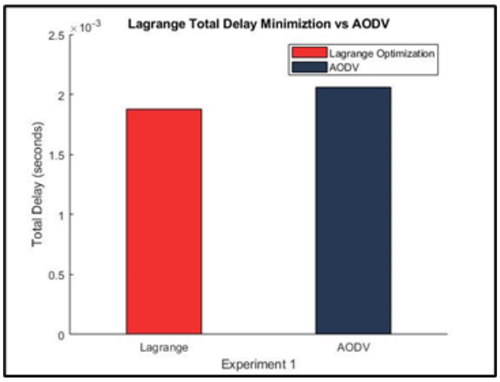

Figure 12. LORDP vs AODV average nodal delay from source node3 to destination node9

4. CONCLUSION

This paper addressed routing-efficient scheduling problems over ad hoc channels to maximize the bit rate under the total nodal delay and probability of packet loss constraints. we proposed an optimal routing algorithm that runs in between nodes to maximize the bit rate and minimize the nodal delay and packet loss probability starting from the source node and reaching the destination node using the Lagrange multiplier method. The optimal routing represented the best possible solution that verifies the objective function. We consider the case where each packet is sent over an additive white Gaussian noise channel. Simulation results manifest the efficiency of the proposed algorithms in maximization of the objective function.

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