D2D MULTI-OBJECTIVE ROUTE OPTIMIZATION IN MANET ENVIRONMENT

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Abstract- **Over the past decades, wireless networks and devices have experienced intensive growth. Route discovery and selection from device to device (D2D) that are randomly distributed came across services trade-offs. This paper presents an optimal routing technique for the MANET environment-based D2D network. The optimization method considers the Lagrange Multiplier approach to maximize bit rate along with constraints minimization of the latency and packet loss. This method is executed for D2D nodes by active route election for links. An intensive simulation is applied, and the obtained simulation results manifest the effectiveness of the presented Lagrange Optimization of Rate, Delay, and Packet loss algorithm (LORDP) in the optimal routing as compared to the Particle Swarm Optimization (PSO) and Genetic Algorithm (GA).**

I. Introduction

Mobile Ad-hoc Networks (MANET) is an infrastructure-free network configured on its own that relies on ad-hoc communications. MANET routing is very demanding due to the persistent updates in topologies where routes are changed and get disconnected due to wireless device mobility [1]. These wireless nodes are implemented as routers and as hosts for internal transmissions. Therefore, each node participates in the routing procedure to transfer packets to their destination. Resource shortage, mobility, power consumption, topology changes are all non-centralized characteristics of the MANET environment. Such properties motivate designing routing protocols that achieve some terms. The path selection protocol must adapt to variations and maintain continuous monitoring of the link status and apply routes accordingly [2]. Many researchers investigated different features in the research area and in such a thriving network business that needs continuous improvements and enhancement in terms of Quality of Service (QoS) and Quality of Experience (QoE). The process of transferring data packets from the source node to the destination node that is subject to resource constraints such as energy, bit rate, delay, packet loss rate, and cost should include the use of optimization methods in the routing process. In prior works, research efforts investigated diverse issues for different objectives to achieve optimal route criteria, e.g., maximizing the battery lifetime and minimizing the duration or number of hops. An Emergent Intelligence QoS routing was introduced in ad hoc networks [3]. A suggested energy-aware multipath routing scheme with Particle Swarm Optimization (PSO) technique that utilized a recurrent neural network to find the optimal paths in a Manet with measured transmission cost, energy factor, and the optimal traffic ratio [4]. An enhanced Cuckoo algorithm was proposed to select the QoS path based on the hop count, routing load, and residual energy [5]. Also, quality of experience routing was presented for wireless multi-hop networks with time constraints [6]. The OLSR routing algorithm was suggested to build a multi-hop Device-to-Device (D2D) communications platform based on smartphones and measured coverage, energy consumption, and latency [7]. The Ad-hoc On-Demand Distance Vector (AODV) protocol was suggested with reliability based on the stability of routes with

restricted end-to-end delay and bandwidth [8]. A D2D communications were used for disaster response to extend the coverage and utilized controller routing to maximize the throughput using ant colony optimization [9]. The optimization process is to select routes with the highest values utilizing the shortest route, maximum residual energy, and less data traffic. The genetic algorithm was applied to enhance the latency, packet delivery ratio, and energy consumption of the system, and the best path is selected depending on the best fitness value [10]. An AODV imitation to demonstrate a basic routing idea with a meaningful method for visual learning [11]. A Virtual Ad hoc Routing Protocol was proposed to increase security and scalability and lower consumed power [12]. Lastly, an improved energy and mobility ant colony optimization routing method was introduced to reduce the route discovery packets [13]. A combined PSO with a bacteria foraging algorithm was used to enhance the convergence speed to supply a QoS routing [14]. Also, a compact genetic algorithm-based one shortest path selection was used to enhance delay and improve the shortest path computation and selection using objective function values, population, throughput, and packet delivery ratio [15]. Moreover, The PSO algorithm was utilized to select the appropriate value of factors for the AODV routing protocol to enhance the QoS in MANET by using the highest objective to identify the best locations of the agents and used it to enhance AODV performance [16]. An Optimized PSO integrated into the LAR protocol to enhance performance metrics (end-to-end delay, overhead, energy consumption, packet delivery ratio) [17]. Also, a Genetic Algorithm fitness function was presented to select the optimized route prepared by the Ad hoc On-demand Multipath Distance Vector routing protocol [18]. Lastly, an optimal path method was proposed for MANET considering maximizing bit rate and under the constraints of minimizing latency and fixed packet loss [19]. Several ad-hoc model routing algorithms have been proposed in the literature, and they differ in how new routes are discovered and the limitations of these connections. Mostly applied metrics like energy consumption, throughput, bandwidth, end-to-end delay, fixed packet loss probability, and packet delivery ratio. On the other hand, users always desire to communicate fast, in the shortest amount of time possible, while retaining packet quality. Thus, in this paper, a method is introduced based on Lagrange optimization that selects the optimal route from one device to another device in a MANET to satisfy the desired objective function based on accompanying routing requirements. The 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 along the path while minimizing the total latency and packet loss rate in wireless data transmission. The paper is organized as follows. In Section II, the proposed method, as well as problem formulation and proposed algorithm, are described in detail. In Section III, the analysis of the proposed method and results are shown in figures. Then finally, in Section IV, conclude and sum up the results.

II. PROPOSED METHOD AND SYSTEM MODELING

In this section, the method behind modeling the system is presented as well as the process of problem formulation.

A. System Model

An environment of an ad-hoc network that consists of N nodes is considered. These nodes represent device-to-device communication via available links L. Each source node transmits a flow to the destination node using one of the available paths in the routing table. Frequent topology updates in the network require improvement in the routing methods and

should be optimized accordingly. Adopting the assumption that the source node performs data transmission with ρ watt power over an ω bandwidth and is subject to σ watt of transmission noise. Then include a fading factor h to reflect the effect of channel fading, at which the transmitting node routes data packets to the receiving node. Each of the nodes N is assigned a procedure that surf all available links L attached to that corresponding node. This process addresses parameters to inspect each connected link's significance to that hop. The process of surveying implies calculations for the bit rate of transmission $\Re$, the consumed total delay δ, and the rate of packet loss Ψ undertaken by the specified link. Moreover, an objective function $L \cdot F$ computation is attained for each of these connected links that mirror the prominence of a source with the resource allocation. According to these computations, each source node is qualified to select the optimal path that guides to the destination node. The path selection decision is conducted about the maximum objective function value, and its correlated links are nominated. Table I clarifies the main notations used and their corresponding definition throughout the paper.

TABLE I
List of symbols

Symbol	Semantics
ρ	Power to transmit data
ω	Bandwidth of the network
σ	Noise power of the channel
h	Channel fading random variable
L	Available links
L . F	Lagrangian objective function
$\Re$	Transmission bit rate
δ	All types of delay
ψ	Packets loss rate
λ , μ	Lagrange multipliers (weights)
t	Length of the packet of in bits
φ	Length of the physical medium
ζ	The propagation speed of the medium
ε	Average arrival rate of packets
N	Nodes number

The primary challenge is to identify a required equation formula for all three (the objective function and the two constraints) that embrace common parameters. The reason behind this challenge is that when taking partial derivatives for these formulas with no common parameter it will yield a nil value since derivatives of constants are zero. The building formulas for the objective function as well as the two constraints that are utilized are shown below.

1) Transmission Rate

The power used for transmission denotes ρ over a bandwidth ω of the link L, and let h reflect fading factor, whereas σ is the noise power. The transmission rate $\Re$ can be expressed in Eq. 1 below [20]:

$$\Re = \omega \, log_2(1 + \frac{\rho \, h}{\sigma}) \tag{1}$$

2) Total Nodal Delay

Now the delay property is involved to reflect as a constraint in the objective function. As packets start their journey from the source through a multi-hop reaching the destination. Whereas at each node, packets encounter a nodal delay that consists of several types of delays along the path. The transmission delay, propagation delay, and queuing delay are the most influential, and all together accumulate the total nodal delay [21]. Delay is an effective design consideration in real-time applications. The total nodal delay δ over a link L is expressed in Eq. 2 as [21]:

$$\delta_{L_{nodal}} = \delta_{L_{transmission}} + \delta_{L_{propagation}} + \delta_{L_{queue}} \tag{2}$$

Whereas the amount of required period to push all of the bits of the packets into the link L represents the latency of transmission. It depends on the length of the packet of t bits at a transmission rate $\Re$ of the link as shown in Eq. 3 below [21]:

$$\delta_{transmission} = \frac{t}{\Re} \tag{3}$$

The time is imposed to spread from the beginning of the link 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 L. The propagation delay is written in Eq. 4 as [21]:

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

As packets suffer output buffer queuing delay which is the period of waiting to be transmitted onto the link 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 simultaneously to an empty queue, the first packet endures zero lineup delays, while the later packet is stuck with queuing delay as it waits for the earlier packets to be transmitted. Therefore, an average queuing delay is considered. It is expressed by the length of the packet of t bits and the average rate at which packets arrive at the queue α at a $\Re$ transmission rate in Eq. 5 as follows [21]:

$$\delta_{queue} = \frac{t \times \varepsilon}{\Re} \tag{5}$$

Therefore, the total delay represents the sum of all as shown in Eq. 6 and Eq. 7 below [21]:

$$\delta_{nodal} = \frac{t}{\Re} + \frac{\varphi}{\zeta} + \frac{t * \varepsilon}{\Re} \tag{6}$$

$$\delta_{nodal} = \frac{t(1 + \varepsilon)}{\Re} + \frac{\varphi}{\zeta} \tag{7}$$

3) Packet Loss Rate

Another feature is consigned in the constraints of the objective function. The rate of packet loss ψ is modeled by a function of transmission power used in sending packets. As the packet loss ψ can be formed as a function of Signal-to-Noise Ratio (SNR) utilized in transmitting packets over a link L is expressed in Eq. 8 [22]:

$$\psi = \alpha\, t\, \exp(-\beta\frac{\rho \times H}{\sigma}) \tag{8}$$

B. Problem Formulation

To present the mathematical formulation and modeling of the presented method, an ad-hoc network is embraced and it consists of N nodes that are bonded by L links and symbolize a device-to-device communication medium. The primary task of the suggested algorithm is to clarify the optimum path of the network that provides bit rate maximization on one hand and the network total latency as well as the network packet loss rate minimization on the other. Firstly, the essential target function is the maximization of bit rate for N paths of the network, and its exhibited mathematically in Eq. 9 as:

$$max \sum_{i=1}^{N} \Re_i \tag{9}$$

That obeyed minimization constraints of the total delay and packet loss rate for all N paths and it's expressed in Eq. 10 as:

$$min \sum_{i=1}^{N} \delta_i + min \sum_{i=1}^{N} \Psi_i \tag{10}$$

To model this idea, employment of the multi-objective method combined along with the Lagrange Multipliers Optimization method to the above approach, then the aggregated objective function is constructed as presented in Eq. 11 and Eq. 12:

$$LF = \bigtriangledown transmission\,bit\,rate - \lambda \bigtriangledown total\,delay\,consumed - \mu \bigtriangledown loss\,rate\,of\,packets \tag{11}$$

$$LF = \bigtriangledown \left[\omega \log_2 \left(1 + \frac{p \times H}{\sigma} \right) \right] - \lambda \bigtriangledown \left[\frac{t}{\Re} + \frac{\varphi}{\zeta} + [\frac{t * \varepsilon}{\Re}] \right] - \mu \bigtriangledown \left[\alpha\, t\, exp \left(-\beta \frac{(p \times H)}{\sigma} \right) \right] \tag{12}$$

Eq. 13 and Eq. 14 expressed below, clarify the Lagrangian multi-objective form with respect to the transmission bandwidth ω.

$$\frac{\partial L \cdot F}{\partial \omega} = \sum_{i=1}^{N} \frac{\partial \Re_i}{\partial \omega} - \sum_{i=1}^{N} \lambda_i \frac{\partial \delta_i}{\partial \omega} - \sum_{i=1}^{N} \mu_i \frac{\partial \psi_i}{\partial \omega} \tag{13}$$

$$= \sum_{i=1}^{N} \left[\log_2 \left(1 + \left(\frac{p \times H}{\sigma} \right) \right) \right]_i + \sum_{i=1}^{N} \left[\lambda_i \frac{t \times (1 + \alpha)}{\omega^2 \times \left(\log_2 \left(1 + \left(\frac{p \times H}{\sigma} \right) \right) \right)} \right]_i + \sum_{i=1}^{N} [\mu_i[zero]]_i \tag{14}$$

Meanwhile, Eq. 15 and Eq. 16 show the Lagrangian-objective function with respect to the length of the packet of in bits t.

$$\frac{\partial LF}{\partial t} = \sum_{i=1}^{N} \frac{\partial \Re_i}{\partial t} - \sum_{i=1}^{N} \lambda_i \frac{\partial \delta_i}{\partial t} - \sum_{i=1}^{N} \mu_i \frac{\partial \psi_i}{\partial t} \tag{15}$$

$$= \sum_{i=1}^{N} [zero]_i + \sum_{i=1}^{N} \left[\lambda_i \frac{(1 + \alpha)}{\omega^2 \times \left(\log_2(1 + \left(\frac{p \times H}{\sigma} \right)) \right)} \right]_i + \sum_{i=1}^{N} \left[\mu_i \left[\alpha\, exp(-\beta \frac{(p \times H)}{\sigma}) \right] \right]_i \tag{16}$$

To continue the solution procedure, the evaluation of μ and λ in the previous equations by setting them equal to zero and then plugging back these entity values into the objective function formula. These proceedings are applied for every available node link to form a routing table with cost measures and ultimately nominate the optimum path that achieves the goal of maximizing the objective function.

C. LORDP Algorithm

In this section, the Lagrangian Optimization of Rate, Delay, and Packet loss algorithm (LORDP), named LORDP, is provided to compute the optimal solution for the designed objective function. The objective formula manifests the best possible fit solution and can be proved in the problem. The goal is to route and forward nodes' traffic over a mobile ad-hoc network and it's fulfilled by releasing a routing table. The discovery request for route and its reply processes deliver such a mission [23]. The first step is to determine path connectivity where all possible links from the transmitter to the receiver are attained. Later on, constructing the routing list accordingly by building up a list of all nodes connected to the transmitter and guiding it to the receiver. Then the cost value estimation of all paths possible is enumerated by utilizing the Lagrange Multiplier and multi-objective optimization methods. The final step is where the request-reply process with the optimum route is selected based on the route with the highest score of the designed objective formula. Algorithm 1 represents the procedure of the LORDP system while Algorithm 2 details Lagrange Optimization Calculations.

Algorithm 1 LORDP
Input: SrcN, DestN
Output: the optimum path from SrcN to DestN

Read Node's Information (SrcN, DestN, node spacing, node speed)
determine path connectivity using Euclidean distance φ
go to **route request** algorithm to acquire routing list
go to **route reply** algorithm to fulfill routing table
go to **Lagrange Optimization Calculations** algorithm to optimize routing table

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Algorithm 2 Lagrange Optimization Calculations
Input: nextNode, currentNode
Output: Optimum Lagrangian path

Identify global variables (packets, pktLength, avgArrvRate, w, p, No, dT, PL)
For $\underline{i}$ = 1 to number of paths to the destination
    If nextNode = currentNode then it's the same node
      Set Euclidean distance φ, R, δ, ψ, and $\mathcal{LF} = 0$
    Else
      Calculate bit rate R
      Calculate transmission, queuing, propagation delay, and total nodal delay δ
      Calculate packet loss probability ψ
      Determine Lagrange Multipliers λ, μ
      Calculate the Lagrange objective function $\mathcal{LF}$
    End if
End for
If values of Lagrange objective function $\mathcal{LF}$ are the same
    Choose optimum path = min φ
Else
    Choose optimum path = max $\mathcal{L}, \mathcal{F}$
End if

III. Results and Analysis

In this section, the network regulation and the routing table calculation of the designed schemes are presented. To inspect the proposed route optimization formula, the effectiveness of the Lagrangian Optimization of Rate, Delay, and Packet loss algorithm (LORDP) designed method is compared with the Genetic Algorithm (GA) [18] as well as the PSO [16]. The random waypoint approach is utilized in the node distribution that is used in the assessment of mobile ad hoc network routing methods as shown in Fig. 1. Node's connection links are confined in a pre-determined connection domain and a combination of performance computation is placed for each link. Those computations are executed for all obtainable path compositions. Using MATLAB R2019a, an intensive simulation of 200 trials is executed for 100 randomly distributed nodes in a 200 m2 coverage area underlying the SNR ranging from 0 to 25 dB. The selection of the source and destination nodes are arbitrarily executed, and the route discovery process is applied for all potential path combinations. Then utilize the best path selection approach of each algorithm accordingly. By observing the condensed simulation for nodes computations, it can be noticed that as the SNR value increases. The LORDP bit rate acquires the highest value over the bit rate of traditional algorithms of GA and PSO shown in Fig. 2. The increment in bit rate is because the LORDP function's primary objective is to select the path with the highest bit rate as compared to traditional GA and PSO. Meanwhile, Fig. 3 illustrates the total delay caused by node transmission, queuing, and propagation delays. The decreasing curves of the total delay mirror the fact that the designed method consumes less time to send packets over the selected path as compared to the paths taken by the GA and PSO paths. This is based on the inversely proportional relation in (7) between transmission and queuing delay on one hand and the bit rate on the other, meaning that the higher rate the less latency. Since LORDP has selected a path that scored higher in bit rate than the path of comparable parties, it achieved a better result in the delay accordingly. Regarding the rate of packet loss, Fig. 4 represents the calculated values in the degrading curve projecting the fact that the LORDP path manifests the path with the least registered packet loss rate of selected paths between the other two (GA and PSO). This behavior is due to the LORDP's ability to choose the path with the least fading effect that is projected over the packet loss values. Finally, the total length of a path elected by LOPRP represents the shortest path and shows its advancement over the other two methods as can be noticed in Fig. 5.
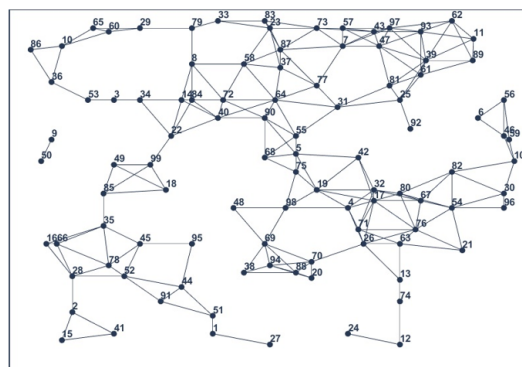

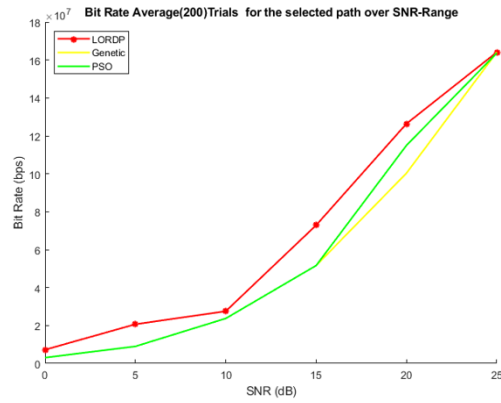Figure 1: Node distribution in the ad-hoc networks

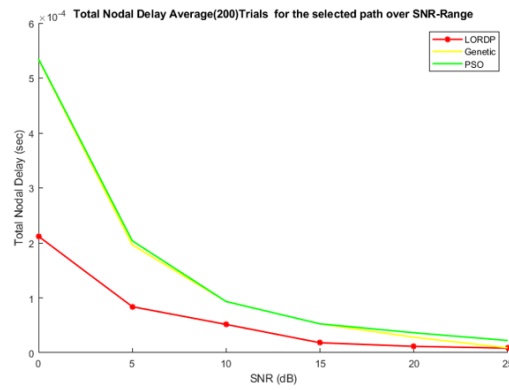Figure 2: Bit rate for LORDP, GA, and PSO
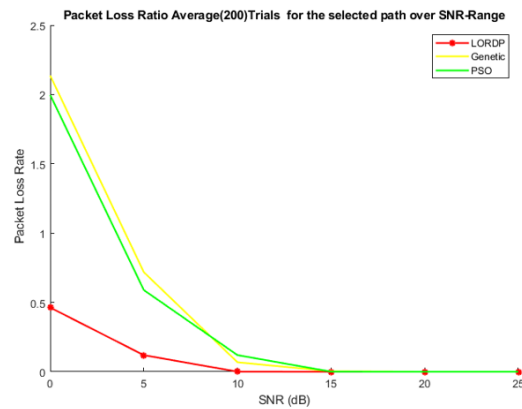

Figure 3: Total nodal delay for LORDP, GA, and PSO
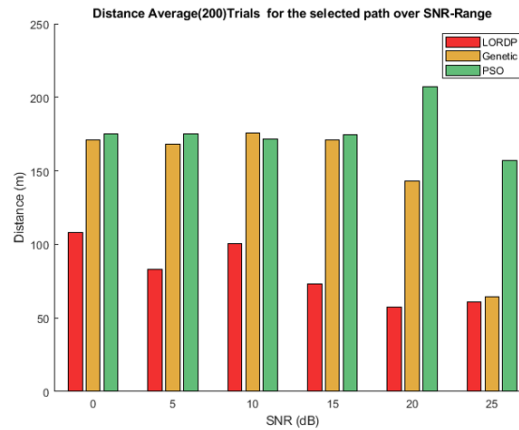

Figure 4: Rate of packet loss for LORDP, GA, and PSO

Figure 5: Path length of LORDP, GA, and PSO

IV. CONCLUSION

This paper handles optimization in routing matters under ad-hoc circumstances to maximize the transmission rate while maintaining some constraints. These constraints imply the three types of delay as well as the rate of packet loss. An optimal routing approach is proposed along with their designed algorithms at which placed between nodes to fulfill the modeled objective method starting from the point of transmission and reaching the point of destination by utilizing the multi-objective optimization the Lagrange Multiplier optimization. The best fit solution represents the optimal path that satisfies the objective function over a Rayleigh channel. Results acquired manifest the validation of the proposed scheme in maximizing the objective function in comparison with traditional ones like GA and PSO. As future work, the Lagrange optimization method can be combined with the AI technique to produce a more efficient routing method in D2D networks.

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