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Optimized routing algorithm for maximizing transmission rate in D2D network

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ABSTRACT

Wireless devices have been equiping extensive services over recent years. Since most of these devices are randomly distributed, a fundamental trade-off to be addressed is the transmission rate, latency, and packet loss of the ad hoc route selection in device to device (D2D) networks. Therefore, this paper introduces a notion of weighted transmission rate and total delay, as well as the probability of packet loss. By designing optimal transmission algorithms, this proposed algorithm aims to select the best path for device-to-device communication that maximizes the transmission rate while maintaining minimum delay and packet loss. Using the Lagrange optimization method, the lagrangian optimization of rate, delay, and the probability of packet loss algorithm (LORDP) is modeled. For practical designation, we consider the fading effect of the wireless channels scenario. The proposed optimal algorithm is modeled to compute the optimal cost objective function and represents the best possible solution for the corresponding path. Moreover, a simulation for the optimized algorithm is presented based on optimal cost objective function. Simulation results establish the efficiency of the proposed LORDP algorithm.

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1. INTRODUCTION

MANET stands for mobile adhoc network that is a self-configured and infrastructure-free network based on ad-hoc communications, routing in mobile adhoc networks is very challenging due to the recurrent upgrade in topologies, and active routes may be disconnected as wireless mobile devices transference from one place to another [1]-[2]. The route selection protocol must be competent to adapt to these changes by continually monitoring the link qualities and route the data accordingly [3].

The concept of D2D communications has been introduced to allow local peer-to-peer transmission among mobile devices [4] by direct communication without the need for infrastructure (access points or base stations). Mobile users in today's cellular networks use high data rate services such as video sharing and gaming in which they could potentially be in range for direct communications (i.e., D2D). The advantages of D2D communications to increase spectral efficiency and improves throughput, energy efficiency, and delay.

Prior efforts in the research field were investigated to address the issue of the optimal route policies and methods using diverse objectives that minimize or maximize the duration, the energy consumption, and number of hops. A series of new technologies and techniques have been exploited in prior work [5]. The authors of [6] addressed direct end devices communication in restricted cellular connectivity due to emergencies.

In [7], introduced a novel QoS routing in MANETs using emergent intelligence. They divided MANET into clusters by static and mobile agents. Moreover, for data loss minimization, suggested energy-efficient multiple-path routing protocols for MANET and enhanced QoS and QoE metrics. An energy-efficient clustering was introduced using the PSO and fuzzy optimization approach that performed better in terms of nodes' reduced energy consumption. In terms of disaster response, the authors of [8] focused on direct device communications to extend the coverage. They used controlled assisted routing to increase the total end-to-end throughput to maximum using ant colony optimization that outperformed shortest-path based routing in terms of throughput and rates allocation. Moreover, for writers to enhance the capacity of offloading for cellular D2D relays, authors of [9] introduced a unified model to supported three D2D communication modes. They designed a radio architecture for the three D2D modes and suggested an algorithm for scheduling.

On the other hand, in [10] introduced a reliability aware AODV by awarding routes stability. The selected routes are restricted with a variables bandwidth and end-to-end delay and they also enhanced the reliability speed of intermediate nodes. Authors of [11] introduced a hybrid optimized link-state routing protocol v2 that is multipath energy and QoS-aware to solve the limitation of energy resources, nodes mobility, and traffic congestion in WSN based MANET for IoT networks. The researcher in [12] 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 enhanced a fuzzy-ant colony optimization routing algorithm and used a distributed fuzzy logic unit to identify and exclude misbehaved nodes from the routing procedure that performed better in the ratio packet delivery and end-to-end delay. In [13], introduced a trust-based and secure QoS routing method that depended on relieving nodes with various packet forwarding misbehavior and path discovery to guarantee reliable communication with QoS variables. Also, in [14] introduced an ant colony optimization routing method to improved mobility and energy. The method reduced the route discovery packets and speeded up the interchange of the routing algorithm using an offset value of the transition probability. In terms of optimal routes, the authors of [15] proposed a new on-demand routing protocol called performance routing. The route is selected by PRP as it satisfied throughput as well as hop number. The throughput condition means that the throughput of each link must achieve the minimum threshold with the highest throughput for the entire route.

A new concept of route availability was presented in [16] as a measurement of route no uniformity in a MANET as it represents the QoS or QoE of video streaming. They confirmed that RA had a linear correlation with the two QoS metrics and founded that RA is more affected by the video quality. More on videos over MANETs, authors of [17] streamed high definition videos. They designed a transmission system followed by a distortion system to evaluate packet loss rate and end-to-end delay. They utilized the available bandwidth in MANETs efficiently, minimized distortions, and improved quality of service QoS. The authors also used an error concealment to recover the lost/dropped video frames to improve QoE. An optimized routing method was proposed in [18] to enhance the performance of the network and overcome path destruction within a specific time. All possible paths are discovered and subjected to a three metric QoS that is: a maximum bit rate, minimum packet loss rate, and minimum delay. The decision of path selection relies on weighted sum optimization, weighted sum-genetic optimization and genetic algorithm-II with two crossover types. A D2D communication network assisted routing for in 5G was introduced in [19] to extend the coverage of base stations. NAR took into account that base stations manage D2D communications. NAR results were compared with the load balancing based selective multipath AODV algorithm. Eventually, authors of [20] modeled a D2D-QoS routing and proposed a distributed multi-agent routing algorithm. They assigned the QoS in terms of delay, bandwidth, and the rate of packet loss, and the routing path was allocated according to dynamic environments. A novel joint routing and wireless allocation in D2D communications was introduced in [21] that is based on the branch-and-cut method. Finally, authors of [22] composed cellular networks of D2D pair where relays arranged in clusters. They investigate D2D communication optimal and suboptimal routing in the interference presence. The optimal path was the one with the largest end-to-end SINR.

This paper presents a proposed optimal routing algorithm for D2D network, in which the bit-rate is maximized under the constraints of latency and packet loss. This algorithm is formulated based on the designed multi-objective optimization formula. This formula is solved using Lagrange multiplier method.

2. RESEARCH METHOD

In this section, we present the system model and algorithms of the proposed system.

2.1. System model

Presenting the mathematical modeling and formulation of the proposed system. We adopted an ad-hoc network consist of nodes $\mathcal{N}$ that are connected by links $\mathscr{L}$ and represents a device-to-device communication environment [23]. The main assignment of our presented algorithm is to identify the optimum path in a network that maximizes the bit rate and minimizes the total network latency as well as the packet loss. The main objective function is bit rate maximization [24]-[25] for$\mathcal{N}$ number of available paths in a network and can be expressed mathematically by;

$$\max \sum_{i=1}^{\mathcal{N}} \text{Ɽ}_{\mathrm{i}}$$

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

$$\min \sum_{i=1}^{\mathcal{N}} \delta_{\mathrm{i}} + \min \sum_{i=1}^{\mathcal{N}} \psi_{\mathrm{i}}$$

By utilizing the multi-objective approach to model this idea and applying the Lagrange Multipliers Optimization method to the above model, we construct the objective function as shown in the equation:

$$\mathcal{L}\,\mathcal{F} = \nabla \text{ bit rate} - \boldsymbol{\lambda}\ \nabla \text{ total delay} - \boldsymbol{\mu}\,\nabla \text{ packet loss}$$

In (1) and (2) shown below, represent the Lagrangian-objective function with respect to the transmission power.

$$\frac{\partial \mathcal{L}.\mathcal{F}}{\partial \square} = \sum_{i=1}^{\mathcal{N}} \frac{\partial \text{Ɽ}_i}{\partial \square} - \sum_{i=1}^{\mathcal{N}} \lambda_i \frac{\partial \delta_i}{\partial \square} - \sum_{i=1}^{\mathcal{N}} \mu_i \frac{\partial \psi_i}{\partial \square} \tag{1}$$

$$= \sum_{i=1}^{\mathcal{N}} \left[\frac{\omega \times H}{\left(1+\left(\frac{\square \times H}{\sigma}\right)\right) \times \sigma \times Ln2}\right]_i + \sum_{i=1}^{\mathcal{N}} \left[\lambda_i \frac{\text{Ł} \times H\,(1+\alpha)}{\omega \times \sigma \times Ln2 \times \left(1+\left(\frac{\square \times H}{\sigma}\right)\right)\left(log_2\left(1+\left(\frac{\square \times H}{\sigma}\right)\right)\right)^2}\right]_i + \sum_{i=1}^{\mathcal{N}} \left[\mu_i \left[exp\left(\frac{\sigma}{\square \times H} \times 2^{\left(log_2\left(1+\left(\frac{\square \times H}{\sigma}\right)\right)\right)} - \frac{\sigma}{\square \times H}\right)\right] \times \left[\frac{2^{\left(log_2\left(1+\left(\frac{\square \times H}{\sigma}\right)\right)\right)}}{\square\left(1+\left(\frac{\square \times H}{\sigma}\right)\right)} - \frac{\sigma \times 2^{\left(log_2\left(1+\left(\frac{\square \times H}{\sigma}\right)\right)\right)}}{\square^2 \times H} + \frac{\sigma}{\square^2 \times H}\right]\right]_i \tag{2}$$

While (3) and (4) represent the Lagrangian-objective function with respect to channel fade.

$$\frac{\partial \mathcal{L}\,\mathcal{F}}{\partial H} = \sum_{i=1}^{\mathcal{N}} \frac{\partial \text{Ɽ}_i}{\partial H} - \sum_{i=1}^{\mathcal{N}} \lambda_i \frac{\partial \delta_i}{\partial H} - \sum_{i=1}^{\mathcal{N}} \mu_i \frac{\partial \psi_i}{\partial H} \tag{3}$$

$$= \sum_{i=1}^{\mathcal{N}} \left[\frac{\omega \times \square}{\left(1+\left(\frac{\square \times H}{\sigma}\right)\right) \times \sigma \times Ln2}\right]_i + \sum_{i=1}^{\mathcal{N}} \left[\lambda_i \frac{\text{Ł} \times \square\,(1+\alpha)}{\omega \times \sigma \times Ln2 \times \left(1+\left(\frac{\square \times H}{\sigma}\right)\right)\left(log_2(1+\left(\frac{\square \times H}{\sigma}\right))\right)^2}\right]_i + \sum_{i=1}^{\mathcal{N}} \left[\mu_i \left[exp\left(\frac{\sigma}{\square \times H} \times 2^{\left(log_2\left(1+\left(\frac{\square \times H}{\sigma}\right)\right)\right)} - \frac{\sigma}{\square \times H}\right)\right] \times \left[\frac{2^{\left(log_2\left(1+\left(\frac{\square \times H}{\sigma}\right)\right)\right)}}{H\left(1+\left(\frac{\square \times H}{\sigma}\right)\right)} - \frac{\sigma \times 2^{\left(log_2\left(1+\left(\frac{\square \times H}{\sigma}\right)\right)\right)}}{H^2 \times \square} + \frac{\sigma}{H^2 \times \square}\right]\right]_i \tag{4}$$

By evaluating μ and λ from the previous equations and then plugging those values back into the objective function. This procedure is applied for every available node connection and eventually select the optimum path that maximize the objective function Table 1. Summarize a list of notations used in modeling equations and algorithms.

Table 1. List of notations

Symbol	Semantics
ꝑ	Power available for data transmission
ω	Bandwidth allocated for the network
σ	Noise generated by the channel
H	Random variable represent the channel fading
φ	Euclidean distance
$\mathcal{L}$	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
α	Packet average arrival rate
$\mathcal{N}$	Number of Nodes in the ad-hoc network

2.2. LORDP algorithm

Aiming to forward traffic between two nodes in a mobile ad-hoc network, a routing table must be issued. A route request/ reply procedure delivers such an assignment. Firstly, all available path connections from source end to destination end must be considered and a routing table is constructed accordingly. Algorithm 1 shows the building steps of the LORDP system.

This implies building up a table of all nodes connected to the source and leading to the destination. The cost of all available paths is calculated using a multi-objective optimization method. Algorithm 2 determines path connectivity. Finally, the optimum route for request and reply is selected according to the route with the highest objective that is being served. Algorithm 3 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
```

```
Algorithm 2 path connectivity
Input: distance spaces, packets, number of nodes
Output: line

identify global variables (distance spaces, packets, number of nodes)
for i = 1 to number of nodes
     for j = 1 to number of nodes
           if i = j then it’s the same node
           obf = 0
           connection matrix = 0
           continue
           end if
           Calculate Euclidean distance φ
           If    Euclidean distance φ < = distance spaces
           Plot a path line
           Store connection matrix = j
           End if
     end for
end for
```

2.3. Route request algorithm

After being supplied by the source and destination nodes’ identifications. A request procedure from the source side is emitted to explore the neighborhood. Algorithm 4 clarifies the Route Request procedure. This procedure is delivered in stages:

a) At the first stage, all linked neighbor nodes of the source are listed along with their corresponding objective functions.
b) While the second stage includes the linked neighbors from the first stage associated with all of their linked nodes and their corresponding objective functions and so on.
c) Lastly, the request list is conducted where a path to the destination is allocated.

If multiple paths are manifested, then the optimum request path is chosen based on the highest value of the objective function that satisfies bit rate maximization, latency, and packet loss minimization.

```
Algorithm 3 Lagrange Optimization Calculations
Input: nextNode, currentNode
Output: Optimum Lagrangian path

Identify global variables (packets, pktLength, avgArrvRate, w, p, No, dT, PL)
For i = 1 to number of paths to the destination
       If nextNode = currentNode then it's the same node
           Set Euclidean distance $\varphi$, Ɽ, $\delta$, $\psi$, and $\mathcal{LF}$ = 0
       Else
          Calculate bit rate Ɽ
          Calculate transmission, queuing, propagation delay, and total nodal delay $\delta$
          Calculate packet loss probability $\psi$
          Determine Lagrange Multipliers $\lambda$, $\mu$
         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 $\varphi$
Else
        Choose optimum path = max $\mathcal{L}.\mathcal{F}$
End if
```

```
Algorithm 4 Route Request
Input: SrcN, DestN
Output: obfNodesTable

Identify variables (packets, pktLength, avgArrvRate, w, p, No, dT, PL)
Starting node = 0
While route discovery request is true
          Starting node = starting node +1
          Get connection matrix (starting node)
          For i = repeated DestN entries
                For j = number of occurrences entries
                    Go to Lagrange Optimization algorithm
                    Delete repeated DestN entries but the optimum path
                End for
          End for
          For k = number of entries in the route discovery list
               Calculate Euclidean distance $\varphi$
               If Euclidean distance $\varphi$ = 0 then it's the same node
                  Set  Ɽ , $\delta$, $\psi$, and $\mathcal{LF}$ = 0
               Else
                 Calculate bit rate Ɽ
                 Calculate transmission, queuing, propagation delay, and total nodal delay $\delta$
                 Calculate packet loss probability $\psi$
                 Determine Lagrange Multipliers $\lambda$, $\mu$
                 Calculate the Lagrange objective function $\mathcal{LF}$
              End if
          End for
Set route discovery list (obfNodesTable)
End while
Go to RouteReply function and pass the DestN as the initial node
```

2.4. Route reply algorithm

The destination node identification is allocated as the initial node in the reply-objective list. A replying procedure from the destination side is exhibited in Algorithm 5.

a) The first stage is achieved by search and match for the destination name in the first stage of the request list. If no match occurs, then a reply-objective list is created and the destination name is added and all Ɽ, φ. δ. ψ. $\mathcal{L}\mathcal{F}$ is naught since it's the node itself.
b) Then proceeding to the second stage of the reply procedure, the second stage of the request procedure is now under consideration. Inspecting which nodes are linked to the destination name and add them to the reply-objective list along with their corresponding Ɽ, φ. δ. ψ. $\mathcal{L}\mathcal{F}$.
c) Continuing the preceding steps until the source name condition is met. Breaking off the reply procedure and passing back the reply-objective list to the request procedure to combine both lists and forming the

Objective-Route table based on the highest objective and achieve bit rate maximization, total delay, and packet loss minimization.

```
Algorithm 5 Route Reply
Input: SrcN, DestN
Output: replyObjTable

Set starting node = SrcN
Set dedicated reply destination of (starting node) in obfNodesTable = DestN
Setup calculation of replyObjTable (FromNode, ToNode, ObjectiveValue, NodesDistance,
Rate, Delay, packetLoss)
Add SrcN to replyObjTable
set $\mathrm{R}$, $\boldsymbol{\varphi}$. $\boldsymbol{\delta}$. $\boldsymbol{\psi}$.$\mathcal{LF}$ = zeros
While route reply is true
         Assign nextObvNode of (starting node) = obfNodesTable.FromNode
         If more than one element responded as reply destination, then
            go to Lagrange optimization function and choose accordingly
        End if
        Set values of replyObjTable (starting node)
        Insert $\mathrm{R}$, $\boldsymbol{\varphi}$. $\boldsymbol{\delta}$. $\boldsymbol{\psi}$.$\mathcal{LF}$ correspondingly
        Set starting node = nextObvNode
        If DestN = starting node
            Return to Route Request algorithm to form the obfRouteTable (request &
reply list)
        End for
End while
```

3. RESULTS AND ANALYSIS

It is very benefit to mention some of research so far that built a strong methodology for designing system, such as [26]-[32]. This section is dedicated to the network setup and numerical calculation of the routing table for the designed schemes. The node distribution shown in Figure 1 is based on the random waypoint model that is used to evaluate mobile ad hoc network routing protocols. Nodes connectivity is placed within a pre-defined communication range and a set of performance calculations is applied for each path. These calculations are implemented for all available paths. In our scenario, from the source node (1) to the destination node (6). Each path identifies four parameters, that is, the objective function value, the distance between end nodes, the transmission bit rate, and finally the total nodal delay. Moreover, the packet loss rate is assumed to be fixed in this stage at 0.1. Table 2 show all available paths between node (1) and node (6) and their corresponding calculations. By examining Table 2, one can notice that more than one path can lead to the same node. That's when path optimization and selection come in handy. Implementation of the path optimization procedure is based on choosing the path that achieves the maximum calculated objective function in terms of bit rate, total latency, and packet loss rate, and discarding all others. This procedure is performed in several stages for every path leading to the same node resulting in the final routing table as shown in Table 3.

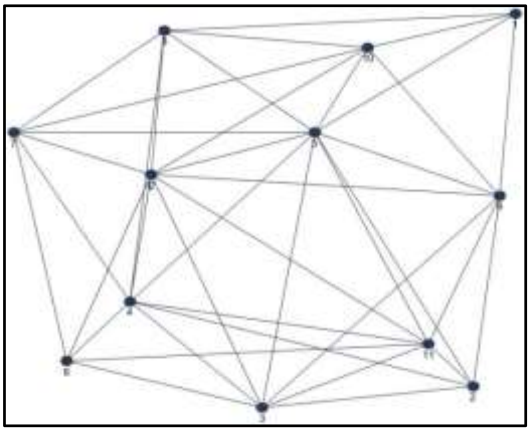

Figure 1. Node distribution

Table 2. All available paths between node (1) and node (6)

FromNode	ToNode	ObjectiveValue	NodesDistance	Rate (bps)	Delay (m)	PacketLossRate
1	5	-2.76E+24	4.720169488	1624199.788	0.011348373	0.1
1	8	-6.52E+06	6.662019213	1247222.759	0.014778457	0.1
1	9	-199609838.6	4.492215489	1305541.682	0.014118293	0.1
1	10	-1.34E+19	2.912043956	1553400.531	0.011865591	0.1
5	2	-1.23E+17	6.708203932	1520684.59	0.012120879	0.1
5	3	-1.98E+15	6.576473219	1488314.015	0.012384505	0.1
5	4	1104216.014	5.315072906	1107378.363	0.016644735	0.1
5	7	1103793.417	5.7	1097052.246	0.016801407	0.1
5	11	1.09E+06	5.905294235	1128247.94	0.016336854	0.1
5	12	-3.02098E+12	3.257299495	1428456.37	0.01290345	0.1
8	4	1104216.014	6.43292313	1107378.363	0.016644739	0.1
8	7	1103793.417	3.725922705	1097052.246	0.0168014	0.1
8	12	-3.02098E+12	3.409178787	1428456.37	0.012903451	0.1
9	2	-1.23E+17	4.527692569	1520684.59	0.012120872	0.1
9	3	-1.98E+15	6.103277808	1488314.015	0.012384504	0.1
9	4	1104216.014	6.5	1107378.363	0.016644739	0.1
9	11	1.09E+06	4.015283303	1128247.94	0.016336848	0.1
9	12	-3.02098E+12	5.622277119	1428456.37	0.012903458	0.1
10	7	1103793.417	6.992138443	1097052.246	0.016801411	0.1
10	12	-3.02098E+12	5.080354318	1428456.37	0.012903456	0.1

Table 3. Optimization of available paths between node (1) and node (6)

FromNode	ToNode	ObjectiveValue	NodesDistance (m)	Rate (bps) (bps)	Delay (sec)	PacketLossRate
1	5	-2.76E+24	4.720169488	1624199.788	0.011348373	0.1
1	8	-6517583.249	6.662019213	1247222.759	0.014778457	0.1
1	9	-199609838.6	4.492215489	1305541.682	0.014118293	0.1
1	10	-1.34E+19	2.912043956	1553400.531	0.011865591	0.1
5	4	1104216.014	5.315072906	1107378.363	0.016644735	0.1
8	7	1103793.417	3.725922705	1097052.246	0.0168014	0.1
9	2	-1.23E+17	4.527692569	1520684.59	0.012120872	0.1
9	3	-1.98E+15	6.103277808	1488314.015	0.012384504	0.1
9	11	1092404.98	4.015283303	1128247.94	0.016336848	0.1
9	12	-3.02098E+12	5.622277119	1428456.37	0.012903458	0.1
11	6	-7585928862	6.850729888	1358613.643	0.013566794	0.1

4. CONCLUSION

This paper addressed routing optimization problems over ad hoc connection that perform maximization of the bit rate under the total nodal delay and probability of packet loss constraints. we proposed an optimal routing procedure and their corresponding algorithms that are applied in between nodes to satisfy the designed objective starting from the source node and reaching the destination node using the Lagrange Multiplier optimization. The optimal path represented the best fit measurement that verifies the objective function over an additive white Gaussian noise channel. Results show the effectiveness of the proposed scheme in maximizing the objective function.

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