الجمهورية الجزائرية الديمقراطية الشعبية
République Algérienne Démocratique et Populaire
وزارة التعليم العالي والبحث العلمي
Ministère de l'Enseignement Supérieur et de la Recherche Scientifique
المدرسة الوطنية العليا للتكنولوجيا
Ecole Nationale Supérieure de Technologie

Département : Génie électrique Et Informatique Industrielle

Mémoire de Master en Télécommunication

Spécialité
Systèmes de Télécommunication et Réseaux

Study of QoS improvement mechanisms in vehicular networks

Réalisé par

Massinissa AHMAN
Aziz RECHACHE

Présent(e) et soutenue publiquement le : 06 Juillet 2022

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Année universitaire 2021 –2022

Study of QoS improvement Mechanisms in vehicular networks

Massinissa Ahman*, Aziz Rechache*, Abdellah Kaci†
* Département Génie Electrique et Informatique Industrielle, Ecole Nationale Supériere de Technologie (ENST), Algeria, m_ahmane@enst.dz, a_rechache@esnt.dz
† Laboratoire des Technologies Innovantes (LTI), Ecole Nationale Supérieure de Technologie (ENST), Algeria, ab_kaci@esi.dz

***Abstract*—The Internet of Vehicles (IoV) is a use case of the Internet of Things (IoT), where the urban vehicle fleet forms a worldwide network. Quality of Service (QoS) optimization in IoV is a challenging task, since vehicles are in continuous movement, which causes the network to be unstable and in continuous topology change, this creates a hostile environment with many variables that should be taken in consideration. Location based routing protocols have proven to be the most performing in such an environment, they offer high packet delivery with low delay, but they also encounter some issues such as routing loops and bandwidth overload. In the present paper, we study existing solutions and propose a novel optimal location based routing algorithm named Minimum Hops Routing (MHR). For experimental study, we compared the proposed MHR algorithm with existing solutions from the state of the art. The experimental results show that the proposed MHR solution is more efficient than existing solutions in terms of reliability enhancement and delay.**

***Index Terms*—Internet of Vehicles, Mobililty, Quality of Service**

I. Introduction

The Internet of Vehicles (IoV) is a distributed network of wireless communicating objects where the urban vehicle fleet forms a worldwide network, using V2X (Vehicle-to-Everything) [1]. In vehicle-to-human (V2H) communications, the data is shared between vehicle and people,while in vehicle-to-sensor (V2S) the vehicle is considered as a multi-sensory object. In vehicle-to-vehicle (V2V) the data is shared between connected vehicles using the IEEE Wireless Access in Vehicular Environments (WAVE). In vehicle-to-infrastructure (V2I) the car communicates with roadside units mainly using WiFi and 4G/5G. Finally the vehicle-to-cloud communications (V2C) the data is transmitted between the vehicles and the data centers [2]. The wireless nature of the V2X communications leads to new challenges, mainly in terms of security, mobility, and quality of services issues.

When transmitting packets from sources to destinations in a vehicular network, common routing protocols calculate the route or the next hop separately for each packet or set of packets according to algorithms specific to each protocol. This can create several problems, for example in a low mobility network, the same nodes will be reused each time for traffic forwarding, so this will consume the available bandwidth of the links formed between the nodes, on the other hand increasing the packet loss. This independent choice of routes for each packet considerably increases the number of used nodes. A regulation on the transfer of traffic between the network nodes is also necessary for a better exploitation of the bandwidth and to avoid congestion.

Geographical routing protocols have proven to be the most performing in VANET, they use position-based routing, where a node must know where its immediate neighbor is located [3], but they turned up to have the same problems mentioned before in this section. In the present work, we study existing solutions and propose a novel optimal location based routing algorithm named Minimum Hops Routing (MHR), inspired from Greedy Perimeter Stateless Routing (GPSR) [4] and Multi-paths SDN (Software Defined Networks) approaches [5] and [6]. The proposed MHR solution takes into consideration all the factors that influence on the effectiveness and reliability of communications. Indeed, the MHR solution uses location and mobility information to find the optimal path for routing information through a vehicular network that maximizes the reliability and minimizes the delay of communications. The main contributions of the paper are:

- The proposition of MHR, a new optimized routing protocol for IoV.
- The use of mobility information for selecting the most reliable nodes for routing information.
- The development of a simulator for comparing MHR with existing solutions from the state of the art.

The remainder of this paper is organized as follows. Section II presents the related work. Section III shows the system architecture, section IV describes the problem formulation, while Section V analyzes the performance evaluation of our proposed solution. Finally, Section VI concludes the paper.

II. Related work

QoS is essentially related to the routing mechanism used for communication. Routing in VANETs uses two strategies, Position and Topology based [7]. In topology-based routing, each node in the network shares its routing table with other nodes. This increases the packet overhead as well as end To end delay (E2E). Therefore, it has good performance in a small network. However, the Position-based routing protocol is appropriate for a dynamic and mobile network like VANET [7].

In the Position-based routing protocols, the routing table does not need to be shared with other vehicles, the main issues are maintaining the link reliability, network scalability, an appropriate selection of a relay node to forward the data and keeping the maximum data transfer rate. Position-based routing protocols are divided into three categories: Vehicular routing without junction node, Vehicular routing with the junction node and Vehicular routing using RSU and SDN-based network.

Karp et al in [4] proposed Greedy Perimeter Stateless Routing (GPSR) which is one of the famous Position-based protocols, it offers minimum E2E delay and reduces latency. GPSR selects the closest node to destination as the next hop to forward the data. However, this raises the chances of link failure during the data transfer since the selected node could leave the communication range.

Maxduration-Minangle GPSR (MMGPSR) [8] is an improved protocol based on GPSR proposed, it solved the issue of communication link breakage by selecting a neighboring vehicle which maintains the longest data communication with the source node. MMGPSR also eliminates the local optimum problem which occurs in the presence of communication void where the greedy forwarding fails, this by calculating the minimum angle between the source and neighboring vehicles, the neighbor node with minimum angle will be selected as the next hop.

To improve the greedy forwarding the proposed protocol add two parameters: the cumulative communication duration, named T, and the allowed communication area, named Q. When the source S tries to send packets to destination, S will find the nearest vehicle node to destination node from the neighbor vehicle nodes. The maximum allowed hop distance is calculated based on the distance between nearest vehicle node and destination. By comparing the cumulative communication duration and evaluating the communication stability between all the neighbor vehicle nodes of S, the most stable next hop node is selected.it determines the effective communication area in which it selects the next hop among the neighbors that are in this area. This zone is the intersection of a circle centered at S with a radius equivalent to the transmission range and the circle centered at D with a radius Dmax. We note that:

$$D_{max} = D_a + \alpha * D_b$$

such that Da and Db represent respectively the distance between D and the nearest neighbor of S of D called R, and between S and R,calculated respectively by the following :

$$D_a = \sqrt{(X_D - X_R)^2 + (Y_D - Y_R)^2}$$

$$D_b = \sqrt{(X_S - X_R)^2 + (Y_S - Y_R)^2}$$

As long as for α, it takes values between 0 and 1, generally taken equal to 0.3. Then the cumulative communication duration between the neighbor nodes in Q and the source node S, is calculated by:

$$T_i = T_{i-1} + t_i - t_{i-1}$$

T_i is the current cumulative communication duration, $T_{i-1}$is the last cumulative communication duration, t_i is the current time of receiving hello, t_{i-1} is the time of receiving the last hello.

The improved protocol takes the positional relationship between the neighbor nodes and the destination node into account to resolve the path redundancy in perimeter forwarding. By calculating the angle 0 formed by drawing a ray from S to D, and rays from S to any neighbor node of S. An optimal next hop of S will be selected by analyzing and comparing the corresponding 0 of all neighbor nodes of S.

Smiri et al [9] proposed Weight Aware GPSR WAGPSR protocol,is another improved protocol unlike the GPSR protocol that selects the closest node to destination as next hop, WAGPSR chooses the most convenient vehicle for the next hop based on additional constraints. This protocol considers multiple routing measures and assigns weights through additional features in order to offer a superior quality of service (QoS). First, it determines the reliable communication area in which it selects the next hop from the neighbors that are in this area, after that, it calculates the weight of each neighbor using the following formula:

$$weight_v = w_1 \times LLT_s + w_2 \times T_i + w_3 \times Density_v + w_4 \times \frac{1}{Mob_v}$$

Where:

- **LLTs:** is the link lifetime, which represents the remaining time until one of the nodes leaves the communication range.
- **Ti:** represents the cumulative communication time, it builds a stable path and avoids frequent rebuilding of routing due to changing node positions in greedy mode. Ti is calculated as follows:

  $$T_i = T_{i-1} + \delta T$$

  where $\delta T = t_i - t_{i-1}$
- $Density_v$**:** indicates the density of nodes around the source. The forward node having highest traffic density is chosen and computed as follow:

  $$Density_v = \frac{NumberOfNeighbors}{TransmissionRange}$$

- Mob_v indicates the speed difference between two nodes, the less it is, the longer they stay in each other's communication area. The mobility of node v and s is calculated as follows:

  $$Mob_v == |speed_s - speed_v|$$

- W1,w2,w3 and w3 are weighting constants, their sum is equal to 1.

Finally, the neighbor with the largest weight is selected as the next hop.

B.Suganthi and P.Ramamoorthy stated in [10] some state of the art protocols and their effect on the QoS in VANETs, This protocols allow to discover the routes in the communication network by maintaining the path between the source and

destination node, But it failed to maintain the unused data paths, which reduced the latency and available bandwidth, therefore reducing the overall QoS and network performance. In return they present their proposed solution to improve the QoS and establish the communication in vehicular network, the objective is to ensure successful communication in the network, they developed an efficient fitness based ad hoc on-demand distance vector (FBAODV) protocol with the computation of Received Signal Strength Indicator (RSSI), the reason for using this protocol is that it collects only a limited amount of information, it is divided on four stages: Network formation, Neighbor discovery, Fitness function estimation, routing process.

- Network formation: the various number of wireless nodes (vehicles) form the network, the access points and fixed gateways around the roadside ensure establishment of the connectivity between the mobile nodes, the movement of vehicles can change the network topology.
- Neighbor discovery: for initiating the route discovery the source node n broadcasts the route request (RREQ) on to the neighboring nodes. The node that receives the request is categorized into two types: destination nodes or intermediate nodes. When the intermediate node receives the request, it forwards the route response (RREP) to the source node. If it does not receive a hello message for a certain period, the above-involved link breakage can be detected.
- Fitness function estimation: the standard AODV protocol used designed the employment of the FBAODV protocol to route the packets in IOV. The route error message is forwarded to all networks' nodes, by following the position, the distance between the nodes could be determined, which is given by:

$$D_{(n1,n2)} = \sqrt{(X_{n2} - X_{n1})^2 + (Y_{n2} - Y_{n1})^2}$$

- Routing process: the routing process can be enabled after evaluating the QoS. Based on QoS measures the best routing paths available in the network are estimated, the maximum QoS establishes the data transmission.

Recently, with the exponential evolution of the SDN (Software defined Network), SDN based routing methods have got great attention to design an infrastructure-based routing protocol in VANET [11], since they perform very well in large network topology and help switching the data flow between wired and wireless networks.

[12] presented an improved channel access granting mechanism for data routing and scheduling via SVDN, the network topology is represented by a graph $G = (V, E)$, where V and E refer represent respectively the set of nodes (nodes include both OBUs and RSUs in the network), and edges connecting the nodes. $S \in V$ represents the set of sources and $D \in V$ their corresponding destinations. The main objective of this proposed solution is to maximize the number of delivered data packets with the least average service time, the total number of packets arrived at destinations *F(.)* can be modeled as follows:

$$F(.) = \sum_{t \in [t_s^p : t_e^p]} \sum_{p \in P} [\sum_{i \in N^V_{in,dP}} X^p_{i,d^p,t} + \sum_{i \in N^R_{in,dp}} Y^p_{i,d^p,t}]$$

Where, t_s^p and t_e^p represent the arrival time of the data packet *p* at the source node. *dp* refers to the destination of the packet *p*, meanwhile *X* and *Y* are binary variable set for different communication channels as X refers to V2V and Y for I2V communication. $X^p_{i,j,t}$ will be 1, if the *pth* packet is transmitted through the link *i,j* bteween node i and j at time step *t* via the V2V channel mode. The same goes for I2V mode referred to by $Y^p_{i,j,t}$. $N^V_{in,i}$ and $N^V_{out,i}$ are respectively the sets of neighboring vehicles with incoming links *in* to node *i* and outgoing links *out* from node *i*. Another objective function is the packet delay t_d^p that can be modeled by the following equation:

$$t_d^p = \sum_{t \in [t_s^p : t_e^p]} (t+1)[\sum_{i \in N^V_{in,dP}} X^p_{i,d^p,t} + \sum_{i \in N^R_{in,dp}} Y^p_{i,d^p,t}]$$

The global objective function is :

$$Minimize : C_T F(.) + \sum_{p \in P} (C^p L^p)$$

where C^p is a cost coefficient related to the packet delay, C_T is a large negative value and L^p is the delay of the *pth* packet and can be defined as:

$$L^p = t_d^p - t_s^p$$

The objective is to maximize packet delivery, this is why the first term of the equation is negative (C^T¡0), the second term of the equation aims to minimize the packet delay. This solution then provides a route and schedules the transmission of data packets by returning a set of time and path assigned packets, while avoiding any packet conflict, considering the link lifetime and packet deadline constraints [12].

In [13], chahal et al proposed an SDN based routing method that minimizes the link failure by using the roadside units (RSUs), which are connected with the SDN-based network. The RSU acts as a controller together with some selected special switches, which actually minimizes the latency.

In [14], the author proposed a new hierarchical 5G Next generation VANET architecture that integrates the centralization and flexibility of SDN and Cloud-RAN (CRAN), with 5G communication technologies, to allocate resources efficiently with a global network view. Furthermore, an edge fog computing framework has been proposed in order to avoid frequent handovers between RSUs and vehicles.

[15] proposed a novel SDN-based geographic routing (SDGR) protocol, where a central controller collects vehicles' information and has a global view of the network to compute the optimal routing paths, which will be inserted into the packet header and then the packet will be delivered to the next relay node according to this path.

SDNs have proven to be one of the best solutions in managing wired networks, this success has begun to extend

towards the wireless networks and several applications on VANETs showed great performance and solved many issues.

After taking a deep overview on the previously motioned routing protocols and QoS optimization methods, we've proposed a novel optimal location based routing algorithm that addresses most of the problems encountered by the aforementioned methods. Our solution allows to always find an existing routing path for a set of communicating nodes with minimal execution time, while avoiding any routing loops and assuring minimum delay by minimizing the number of hops, in the other hand, our algorithm reduces node usage, which minimizes the use of network resources, and also ensures load balancing by managing data traffic flows while considering the bandwidth of the formed link between nodes to avoid any overload.

III. System Overview

We propose the Minimum Hops Routing (MHR) protocol and a three level architecture formed of three levels: the Cloud, the Edge, and the vehicular adhoc network (VANET), as shown in Fig. 1. At the Cloud level we consider a Cloud service for IoV applications such as: vehicular tracking, road safety, and traffic management. At the Edge level, we place the resources of the Cloud service closer to its consumers thanks to the Tracking Authority (TA), which also could ensure security functions. Finally, at the VANET level, the vehicles forms an adhoc network in order to ensure connectivity and support mobility.

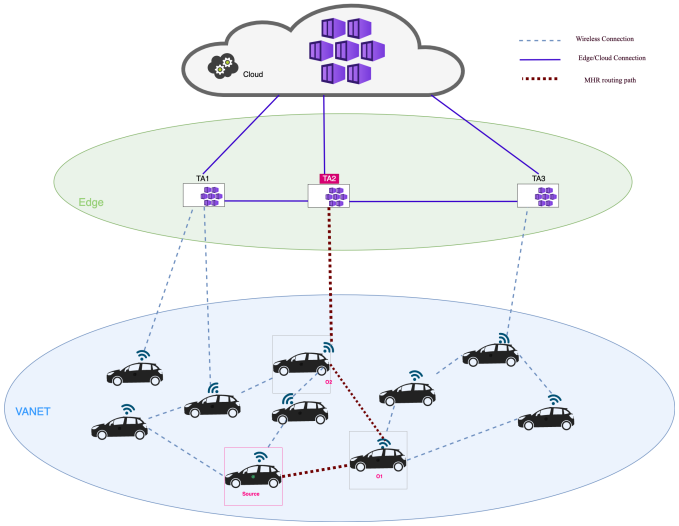


Fig. 1. System Overview

The consumers of the IoV service use the vehicular network to transmit the information from and to the Tracking Authority. We propose the MHR protocol first selects the neighbors of each node with consideration of the VANET topology and vehicles mobility. Then, MHR selects the optimal path from the information source to the tracking Authority using the model described in Section IV. The neighbors selection is done using MHR as shown in Fig. 2.

A vehicle (Source) detects a number of neighbors that are in its transmission range. We classify the neighbors into two categories: non-optimal neighbors and optimal neighbors. A non-optimal neighbor is a node that is within communication range of the source, but choosing it as a relay node or as a next hop can increase the hop count and route length during forwarding packets to the destination. The optimal Neighbor is a node that lies within the effective communication area Q, choosing it as the next hop will decrease the routing path length.

As shown in Fig. 2, let consider two circles Red and Green. The Green circle has the source S as center and R_s as radius. the Red circle has the destination D as center and d_{max} as radius. The effective communication area Q is defined as the area where minimizes this two circles overlap. This area is defined as the effective communication area where the next hop is chosen from.

The MHR protocol automatically selects the next hop from the efficient communication area Q, if no node is within this area, it finds another best neighbor that helps form a route towards the destination.

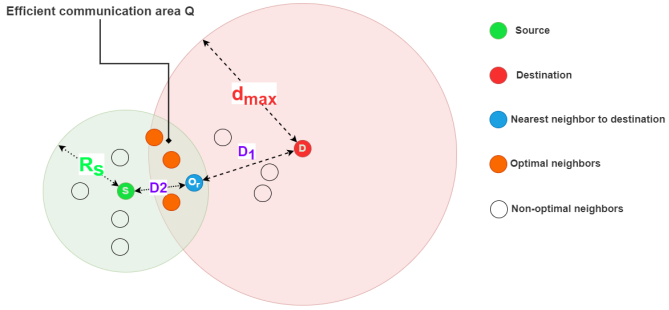


Fig. 2. optimal neighbor selection

To build the efficient communication area Q, the Source node will discover the nodes present in its coverage area: the green circle with the Source node S as center and the Radius R_s. The nodes present in the Source node's area are its neighbors. From these neighbors, we denote O_r (x_{O_r}, y_{O_r}) the nearest neighbor to the destination. Let D_1 the distance between the node O_r and the destination (the Tracking Authority), with coordinates (x_T, y_T). Let D_2 the distance between the source node S (x_S, y_S) and the node O_r. The distance D1 is given in the equation 1 and the distance D2 is given in the equation 2. We define d_{max} by the formula of equation 3, where $\lambda \in [0, 1]$.

$$D_1 = \sqrt{(x_D - x_{O_r})^2 + (y_D - y_{O_r})^2} \quad (1)$$

$$D_2 = \sqrt{(x_S - x_{O_r})^2 + (y_S - y_{O_r})^2} \quad (2)$$

$$d_{max} = D_1 + \lambda \times D_2 \quad (3)$$

In the above equation 3, λ controls the size of the area Q, when λ is closer to 1, Q gets bigger, therefore the selected next hop node could be closer to the source, this can increase the E2E delay. When λ is closer to 0, this reduces the size of Q, as a results, the next hop will be closer to destination, this reduces the E2E delay, but in the other hand increases the packet loss as the next hop could get out of the source's communication range. λ could be chosen in range [0.2,0.5] depending on road traffic density, transmission range,data sensitivity and if it is delay tolerant or not.

After obtaining the set of neighbors of each node, additional information such as the bandwidth available between the communicating nodes are used by the MHR algorithm to calculate the best path and allocate bandwidth for each traffic flow between sources and Traffic Authorities.

Given the mobility of the nodes forming the routing path, data transfer may be interrupted at any time. The lifetime of a routing path noted LLT (Link Life Time) can be estimated using information related to the position and speed of the nodes forming the route.

Let V_i and V_j the velocities of nodes i and j respectively, in this case we note that i is the source node and j is the next hop. The velocity and direction of the nodes are parameters that give an estimate of the communication duration between i and j noted *Link Connectivity* T_L , it can be calculated using the formula of equation 4, where $T_L(i,j)$ is the link connectivity between the source node i and the next hop j, R_s is the communication range of the node i, D_L is the distance between i and j, $V_{r_{i,j}}$ is the relative velocity between i and j and is computed according to equation 5, where θ is the angle between $\overrightarrow{\mathrm{V_i}}$ and $\overrightarrow{\mathrm{V_j}}$.

$$T_{L_{(i,j)}} = \frac{R_s - D_L}{V_r} \tag{4}$$

$$|\overrightarrow{\mathrm{V_{r_{i,j}}}}| = \sqrt{V_i^2 + V_j^2 - 2V_iV_j\cos\theta} \tag{5}$$

Let S, B, C and D a set of nodes. We assume that S sends a traffic flow to D using the following route $S \rightarrow B \rightarrow C \rightarrow D$. Let $T_{L_{(S,B)}}$, $T_{L_{(B,C)}}$ and $T_{L_{(C,D)}}$ be the link connectivity respectively between S and B, B and C and between C and D. The lifetime of this routing path is the minimum value of the mentioned link connectivities :

$$LLT = min(T_{L_{(S,B)}}, T_{L_{(B,C)}}, T_{L_{(C,D)}}) \tag{6}$$

IV. Problem Formulation

In what follows, we describe the optimization solution of MHR that minimizes the delay, maximizes the reliability, and takes into consideration resource constraints. The system is formed of a set the Source nodes S, the set of Tracking authorities T, and the set of other nodes from the VANET used for data transmission. For all u $\in S \cup O$ and v $\in O \cup T$, we define the following variables. For each Tracking Authority t $\in$ T, we define a matrix F^t of integer variables that represents the traffic generated and forwarded to that Tracking Authority. Each element $F^t_{i,j}$ represents the number of flows that shall be forwarded from i to j, whereby i $\in S \cup O$ and j $\in O \cup T$. The variables and notions used in MHR are summarized in Table I.

TABLE I
VARIABLE'S TABLE

variable	Description
S	the set of source vehicles sending data to the tracking authority.
O	the set of nodes in the network excluding the sources and Tracking authorities.
T	the set of Tracking Authorities in the network
O_r	The closest neighbor node to the destination
S_t	the set of the sources of the the tracking t $\in$ T.
$\lvert S_t \rvert$	the cardinality of S_t
G(V,E,W)	The graph that shows the network topology, where $V = S \cup O \cup T$, E denotes the set of edges,W denotes the bandwidth communication between different nodes in V and $w_{i,j} \in$ W denotes the bandwidth capacity between i, j $\in$ V .
Q	It is defined as the effective communication area containing the optimal neighbors
$X_{i,j}$	A decision boolean variable that shows if a node i selects j as parent to forward the traffic from S to T. $X_{i,j} = \begin{cases} 1 : \text{if i selects j as a parent to send it traffic} \\ 0 : \text{if not} \end{cases}$
$P_{i,j}$	A decision boolean variable that shows if a node j belongs to the efficient communication area Q. $P_{i,j} = \begin{cases} 1 : \text{if j belongs to Q} \\ 0 : \text{if not} \end{cases}$
$T_{i,j}$	A real number variable representing the amount of traffic that would be forwarded from i to j.
$\eta(u)$	A function that returns the neighbors of node u in graph G.
$\eta'(u)$	A function that returns the neighbors of node u that are in Q. $\forall u \in S \cup O \cup T, \forall j \in \eta(u) : \eta'(u) = P_{u,j} \times \eta(u)$
$F^t_{i,j}$	An integer variable that mimics packet flow generated from different sources towards T.
Y_i	Boolean decision variable that indicates whether a node $o \in O$ is selected or not to forward traffic: $y_i = \begin{cases} 1 : \text{if node i is chosen to forward traffic} \\ 0 : \text{if not} \end{cases}$
R_s	the range of the source vehicle

The proposed MHR protocol aims to minimizes the delay and maximizes the reliability. thereby, the proposed MHR solution selects the path from the data source to the tracking authority with the minimal length. So, the objective function of MHR minimizes the number of the nodes in the selected path connecting the source to the tracking authority. Considering a Boolean decision variable that indicates whether a node $o \in O$ is selected or not to forward traffic, the objective function is defined according to the equation 7.

- **Objective function:**

$$\min \sum_{\forall i \in O} y_i \tag{7}$$

- **Constraints:**

$$\forall i \in S \sum_{\forall j \in \eta'(i)} X_{i,j} = 1 \quad (8)$$

$$\forall i \in O, \forall j \in \eta(i) \cap (O \cup T) : X_{i,j} \leq y_i \quad (9)$$

$$\forall i \in O, \forall j \in \eta(i) \cap (O \cup S) : X_{j,i} \leq y_i \quad (10)$$

$$\forall i \in O : \sum_{j \in \eta'(i) \cap (S \cup O)} T_{j,i} = \sum_{j \in \eta'(i) \cap (O \cup T)} T_{i,j} \quad (11)$$

$$\forall i \in S \cup O, \forall j \in \eta'(i) \cap (O \cup T) : T_{i,j} \leq W_{i,j} \times X_{i,j} \quad (12)$$

$$\forall i \in T \sum_{\forall j \in \eta'(i)} F^i_{i,j} = |S_i| \quad (13)$$

$$\forall t \in T, \forall i \in S_t : \sum_{\forall j \in \eta'(i)} F^t_{i,j} = 1 \quad (14)$$

$$\forall i \in O, \forall t \in T : \sum_{j \in \eta'(i) \cap (S \cup O)} F^t_{j,i} = \sum_{j \in \eta'(i) \cap (O \cup T)} F^t_{i,j} \quad (15)$$

$$\forall i \in S \cup O, \forall j \in O \cup T : F^t_{i,j} \leq |S_t| \times X_{i,j} \quad (16)$$

The proposed MHR protocol takes into consideration network constraints formulated in equations 8-16. The constraints of equation 8 ensures that each source node should be connected to only one relay node. The constraints defined in equations 9 and 10 ensure that only vehicles equipped with a working transmission wireless device should participate in forwarding the traffic.

All traffic received by a node from its neighbors $\eta(i)$ or source must be equal to the output traffic by that said node.

The constraint given by equation 12 ensures that the traffic forwarded from a node (source or relay node) to another node(relay node or T) should not exceed the capacity of the link that interconnects these two nodes. For i ∈ S, the traffic generated from the client i should not exceed the link capacity between that source and the relay node.Likewise, for i ∈ O,the aggregated traffic forwarded from an relay node i to its successor j should not exceed the capacity of that link.

To avoid the presence of routing loops, we defined three constraints expressed through the equations 13, 14, and 15. The first constraint represented by the equation 13 ensures that the number of flows arriving at a given T equals to the number of sources' requests, while the second constraint defined by the equation 14 ensures that only one flow should be created between a source and T. The third constraint defined by the equation 15 ensures that the number of incoming flows to an node equals exactly to the number of out-coming flows. This constraint helps for ensuring the connectivity and preventing the creation of routing loops.

Finally, the MHR protocol forces the generated flow of a source vehicle to be routed only within the configured paths while avoiding loops. This is ensured thanks to the constraint defined by the equation given in equation 16.

V. Performance Evaluation

In this section, we evaluate the performance of the proposed MHR solution compared to two state of the art solutions using a Python simulator. This section is organized as follows, subsection V-A presents the experimental setup, followed by the simulation results in subsection V-B. Finally, the results are discussed in the subsection V-C.

A. Experimental setup

The simulation of vehicles was done in an area of 2500x2500m^2 using a realistic mobility model. The speed limit was set to 30m/s. We assume that each vehicle is equipped with an omnidirectional antenna, the communication range is set to 300m, meanwhile the channel data rate is set to 3Mbps. For the number of vehicles, we used 110 nodes. We've varied the number of source/destination (Tracking Authority) pairs each time in order to see the affect on the number of used nodes to forward the traffic. The used transport layer protocol is UDP (User Datagram Protocol), each packet has a size of 512bits. The total time for each simulation was set to 100 seconds.
Simulation parameters are summarized in Table II.

TABLE II
Simulation setup

Simulation time	100 seconds
Mobility model	realistic mobility model
Number of pairs source/Tracking Authority	2,4,6,8,10,12
Number of nodes	110
Transmission range	300m
Maximum speed	30m/s
Area size	2500x2500 m
Packet size	512 bit

B. Results

We compared the performance of the proposed MHR solution with the existing location based routing protocols GPSR and MMGPSR. To achieve that, we varied the number of communicating pairs source/destination, while considering the delay and the number of relay nodes used for traffic routing . The number of relay nodes represents the number of nodes that participated in the routing of the various packets transmitted in the network, excluding the sources and the destinations.

The end-to-end delay of each packet is the sum of the delays encountered at a sequence of intermediate nodes on the way to the destination. Each delay is the sum of two parts, a fixed part such as transmission delay and propagation delay and a variable part such as processing delay and queuing delay at nodes. For a packet p, the end-to-end delay is:

$$D_p = Ta_p - Te_p$$

D_p, T_a and T_e respectively represent the packet end-to-end delay for packet p, the packet transmission time by the source

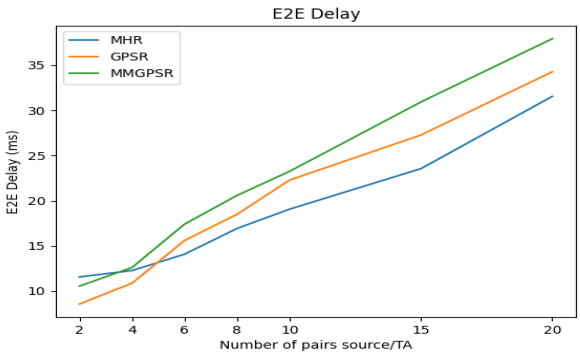


Fig. 3. Comparison of the communication delay

and the time of arrival at the destination. The average delay is the sum of each packet's delay, divided by the number of sent packets.

$$D = \frac{1}{N} \sum_{p=1}^{p=N} D_p$$

, where N represents the total number of packets. The results of the delay are presented in Fig. 3 and the results in terms of the number of relay nodes are presented in Fig. 4.

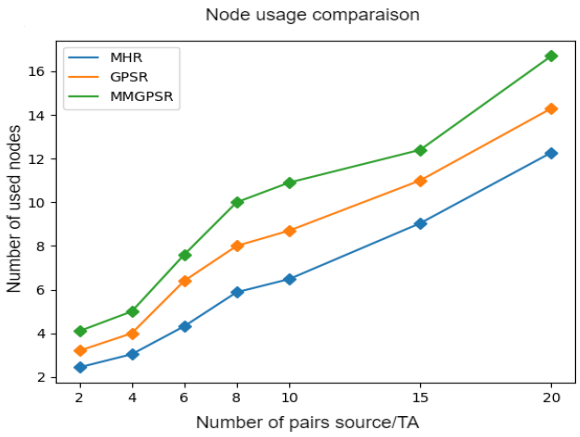


Fig. 4. Number of used nodes

To study the performance of the MHR algorithm, we varied the size of the VANET (number of total nodes in the network) and evaluated the execution time, the E2E delay and the number of activated relay nodes. The execution time is the time spent by the MHR algorithm to compute and select the optimal path. The results are shown in 5. The evolution of the E2E delay is shown by the Fig. 6, while the evolution of number the activated relay nodes is presented in Fig. 7.

C. Discussion

The figure3 shows the affect of varying the number of pairs source/TA on the performance of MHR,GPSR and MMGPSR in terms of E2E delay. With a low number of communicating entities, GPSR and MMGPSR show a slightly lower delay,

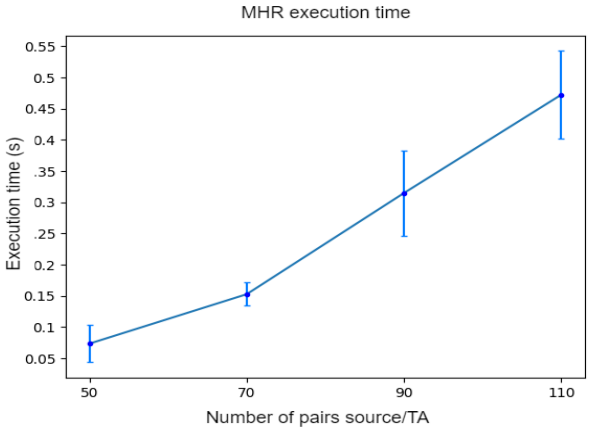


Fig. 5. Execution Time

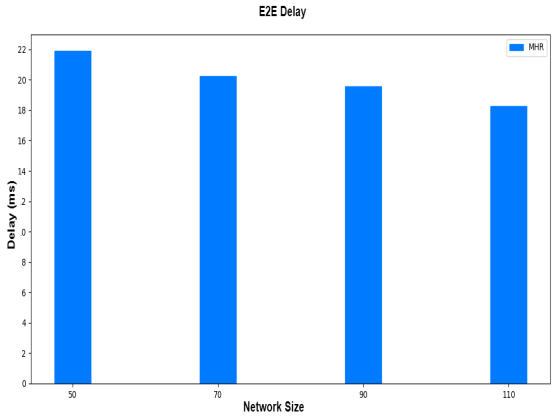


Fig. 6. E2E Delay1

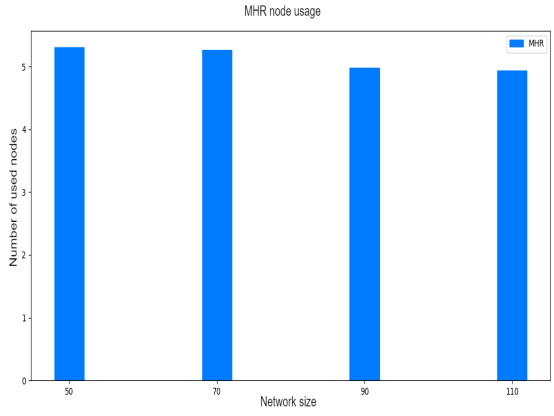


Fig. 7. Number of used nodes

but with a higher number of communicating pairs which is the case of VANET, MHR protocol shows better results, as it reduces the E2E delay unlike GPSR and MMGPSR. The figure4 shows the node usage of the evaluated protocols. We note that MHR is using less nodes to form the routing paths compared to the other two protocols, even when increasing the number of communicating entities, MHR's node usage stays minimal, unlike GPSR and MMGPSR in where we see that they tend to use more nodes for traffic forwarding. The figures 5,6 and 7 respectively present the performance evaluation of MHR while varying the network size. 5 shows a steady linear increase in the execution time, which confirms the influence of the number of nodes in the network on the execution of the MHR algorithm, since this increases the complexity of this algorithm and the search for an optimal solution will take more time. The figure6 indicates that when increasing the total number of nodes, the MHR algorithm performs better in terms of E2E Delay. From figure 7 we can see that the network size has no big influence on MHR's node usage.

VI. Conclusion

The extreme environment of Vehicular Ad hoc Networks makes routing design a very challenging task, in this paper, we proposed the MHR protocol that calculates routing paths with a minimum number of hops, avoiding routing loops, bandwidth overload and many problems encountered in VANET. Indeed, the MHR protocol calculates an optimal routing path for all the communicating entities in the network, results have shown that MHR performs very well in matter of reducing node usage compared to GPSR and MMGPSR, as it returns the best possible path with minimum hops, consequently, decreasing the E2E delay. The comparative study showed that the performance of MHR protocol outperforms both GPSR's and MMGPSR in regards to node usage and E2E delay.

References

[1] A. Kaci and A. Rachedi, "Named data networking architecture for internet of vehicles in the era of 5g," Annals of Telecommunications, vol. 76, no. 9, pp. 717–729, 2021.

[2] S. El Madani, S. Motahhir, and A. El Ghzizal, "Internet of vehicles: concept, process, security aspects and solutions," Multimedia Tools and Applications, pp. 1–25, 2022.

[3] M. N. Abdulleh and S. Yussof, "Performance analysis of aodv, olsr and gpsr manet routing protocols with respect to network size and density," Research Journal of Applied Sciences, Engineering and Technology, vol. 11, no. 4, pp. 400–406, 2015.

[4] B. Karp and H.-T. Kung, "Gpsr: Greedy perimeter stateless routing for wireless networks," in Proceedings of the 6th annual international conference on Mobile computing and networking, 2000, pp. 243–254.

[5] M. Bagaa, D. L. C. Dutra, T. Taleb, and K. Samdanis, "On sdn-driven network optimization and qos aware routing using multiple paths," IEEE Transactions on Wireless Communications, pp. 1–1, 2020.

[6] A. Nacef, A. Kaci, Y. Aklouf, and D. L. C. Dutra, "Machine learning based fast self optimized and life cycle management network," Computer Networks, vol. 209, p. 108895, 2022.

[7] A. Debnath, H. Basumatary, M. Dhar, B. K. Bhattacharyya, and M. K. Debbarma, "A routing technique for enhancing the quality of service in vanet," IETE Journal of Research, pp. 1–14, 2021.

[8] X. Yang, M. Li, Z. Qian, and T. Di, "Improvement of gpsr protocol in vehicular ad hoc network," IEEE Access, vol. 6, pp. 39 515–39 524, 2018.

[9] S. Smiri, A. B. Abbou, A. Boushaba, A. Zahi, and R. B. Abbou, "Wa-gpsr: Weight-aware gpsr-based routing protocol for vanet." International Journal of Interactive Mobile Technologies, vol. 15, no. 17, 2021.

[10] B. Suganthi and P. Ramamoorthy, "An advanced fitness based routing protocol for improving qos in vanet," Wireless Personal Communications, vol. 114, no. 1, pp. 241–263, 2020.

[11] M. Chahal, S. Harit, K. K. Mishra, A. K. Sangaiah, and Z. Zheng, "A survey on software-defined networking in vehicular ad hoc networks: Challenges, applications and use cases," Sustainable cities and society, vol. 35, pp. 830–840, 2017.

[12] K. L. K. Sudheera, M. Ma, and P. H. J. Chong, "Real-time cooperative data routing and scheduling in software defined vehicular networks," Computer Communications, vol. 181, pp. 203–214, 2022.

[13] M. Chahal and S. Harit, "Network selection and data dissemination in heterogeneous software-defined vehicular network," Computer Networks, vol. 161, pp. 32–44, 2019.

[14] A. A. Khan, M. Abolhasan, and W. Ni, "5g next generation vanets using sdn and fog computing framework," in 2018 15th IEEE Annual Consumer Communications Networking Conference (CCNC), 2018, pp. 1–6.

[15] X. Ji, H. Yu, G. Fan, and W. Fu, "Sdgr: An sdn-based geographic routing protocol for vanet," in 2016 IEEE International Conference on Internet of Things (iThings) and IEEE Green Computing and Communications (GreenCom) and IEEE Cyber, Physical and Social Computing (CPSCom) and IEEE Smart Data (SmartData), 2016, pp. 276–281.