A Street-Centric QoS-OLSR Protocol for Urban Vehicular Ad Hoc Networks

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***Abstract*—In this paper, we address the problem of routing in urban Vehicular ad hoc networks (VANETs) using the proactive Optimized Link State Routing (OLSR) protocol. OLSR selects MultiPoint Relays (MPRs) according to neighbors' reachability index while Quality-of-Service OLSR (QoS-OLSR) for highway VANET considers bandwidth, velocity and distance for MPR selection. For urban VANET, several reactive and position-based protocols were proposed using mobility metrics such as velocity and distance. Both QoS-OLSR and urban VANET protocols depend on basic mobility metrics which rapidly change due to environment restrictions; intersections and street topology. Our proposed street-centric QoS-OLSR protocol for urban VANET is considered as the first attempt to use an urban-based QoS metric for OLSR MPR selection. Link and street centric parameters such as bandwidth, street and lane are utilized in the proposed protocol. Simulations are conducted using the modified NS3 OLSR's implementation to incorporate the QoS metric. Simulation results demonstrate that our proposed QoS-OLSR improves throughput, Packet Delivery Ratio (PDR), average hop count and end-to-end delay compared to OLSR in urban VANET.**

***Index Terms*—Urban, VANET, Proactive Routing, QoS-OLSR**

I. Introduction

With the emergence of Internet of Things (IoT), various elements such as vehicles are being connected to the Internet. Connected vehicles can be utilized to improve transport applications such as traffic light control, information dissemination, electronic payment and public transport management [1]. As the number of vehicles is in exponential growth, Vehicular Ad Hoc Networks (VANETS) surfaced to connect vehicles in an ad hoc manner through wireless links. In addition to the distributed nature of VANET, the urban environment characteristics such as street topology and intersections usually limit the network's connectivity.

Various efforts have attempted to improve network's connectivity through proper selection of relay node for urban VANET. The protocols proposed in [2]–[7] mostly utilize basic mobility metrics such as velocity and position. However, the rapid change in these metrics have been proven to lower their significance in the urban environment. While these proposals use reactive and position-based protocols, proactive OLSR was found to be more suitable for urban VANET [8], [9] because of its shorter delay, path length and routing overhead.

Proposals using OLSR and QoS-OLSR for highway VANET, such as the ones in [10]–[12], either use basic mobility metric or offline processing for MPR selection limiting their applicability in urban VANET as the latter requires online selection using urban-based metrics. The main challenge considered in this work is the use of the proactive OLSR protocol in the urban environment to handle the rapid change in the network topology.

In this paper, we propose the first effort in extending OLSR to a street-centric QoS-OLSR protocol for urban VANET. Our QoS metric incorporates both link and street centric parameters such as available bandwidth, lane and percentage of neighbors on other streets. This urban-based QoS is used replacing the reachability and uniqueness selection metric for MPRs in OLSR protocol. A vehicle's current street identifier is used to extract its $RealNeighbors$ which are neighbors residing on the same street. $RealNeighbors$ is introduced as neighbors on the same street have a higher probability of remaining neighbors than ones on adjacent streets due to their movement directions. Both QoS and current street identifier are appended to the periodically broadcasted HELLO messages for MPR selection.

Simulations are conducted using SUMO traffic simulator and NS3 network simulator to evaluate the performance against OLSR protocol. As NS3's OLSR protocol implementation does not include QoS and street identifier, a modification to the HELLO message implementation is done to append the extra metrics. Simulation results show that our QoS-OLSR for urban VANET outperforms OLSR in throughput, PDR, end-to-end delay and average hop count when deployed in an urban environment. The percentage of MPRs for our proposed protocol was found to be decreasing in contrast to that of OLSR.

In summary, the main contribution of this work is a street-centric QoS-OLSR protocol for urban VANET that:

- Extends the proactive OLSR protocol for urban VANET.
- Utilizes link and street centric parameters such as bandwidth, street and lane in an urban-based QoS MPR selection metric.
- Includes QoS and street identifier in the periodic HELLO messages of OLSR's NS3 implementation.
- Enhances connectivity and network performance among vehicles in an urban environment.

The paper is organized as follows. Section II presents a summary of existing VANET routing protocols; urban and proactive OLSR. Section III presents the proposed street-centric QoS-OLSR routing protocol. Section IV presents the simulation setup and results. Section V concludes the paper.

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II. LITERATURE REVIEW

This section presents a summary of the existing urban VANET routing protocols along with utilized parameters for relay selection. Proactive OLSR VANET protocols are presented. Limitations in existing protocols are highlighted.

A. Urban VANET Routing Protocols

In [2], a street connectivity metric was proposed to improve forwarding decisions at intersections where vehicles stopped at traffic lights were excluded. The protocol depends on the existence of vehicles without considering their link capabilities, packet drops and disconnection rates might increase. In addition, dependency of the protocol on externally acquired information limits its deployment scope.

In [3], signal fading and mobility pattern were incorporated in a link availability metric calculated between vehicle pairs to select paths with minimum failure cost. The protocol exchanges parameters such as velocity, position, and direction to calculate relative metrics as Expected Transmission Cost on Path (ETCoP) and number of path transmissions when the destination fails to receive a packet (F_c) for link availability calculation. However, requiring multiple relative selection metrics increases complexity and overhead in dense networks as many vehicles reside in the same transmission range.

In [4], buses were utilized, due to their low speed and high number, as a routing backbone in a link state protocol to minimize hop count. However, as cars can only relay data through buses, the protocol's deployment scope is limited creating disconnected street segments. Moreover, the existence of a link does not reflect of movement or its quality thus a packet may be forwarded to a bus moving away from the destination or with a weak link.

In [13], buses were used in a position-based protocol where the number of bus lines passing a street segment at a particular time represents its connectivity index. When the expected number of buses is not sufficient to provide complete connectivity, cars are used in routing decisions. A major drawback is the dependency on predetermined bus route which may not reflect the real time traffic. Additionally, vehicles are expected to continuously update bus routes to correctly determine the street segment's connectivity.

In [5], virtual applied forces were used to elect cluster heads. Vehicles accumulate charges according to their lane weight, following a predefined route, length, driver behavior and historical data. These charges are used to calculate the force between neighboring nodes to select the neighbor with highest positive force as cluster head. The metrics proposed do not consider the link conditions of a vehicle. Moreover, the force calculation between vehicle pairs introduces an overhead in dense areas.

In [6], a flow-oriented metric incorporating coverage, distance and velocity was proposed. This metric allows vehicles to elect cluster heads from their traffic flow to decrease cluster disconnection after an intersection. However, intersections cause rapid change in vehicles' velocity and distance making the cluster heads selection locally optimal given selection time.

In [7], the remaining time for a vehicle in a street is used to cluster vehicles together. The relative speed and number of vehicles with similar speeds are integrated in a selection metric for cluster head election. For data forwarding between clusters, a higher transmission power control channel is introduced. As simulations are conducted on a highway environment without considering the existence of intersections, the validity of the proposal in an urban environment is questionable.

B. OLSR VANET Routing Protocols

The proactive OLSR routing protocol [14] maintains and updates paths to nodes in the network even when no requests are sent to them. The protocol selects MPRs to maintain and update routing tables for shortest path calculation. Nodes in OLSR use periodic HELLO messages to find their neighbors and their link conditions. Next, reachability and uniqueness of neighbors are determined from received HELLO messages to use in MPR selection reducing the future network traffic. However, this protocol does not consider any urban challenges which limits its deployment for urban VANET.

In [10], OLSR parameters were optimized to result in an energy-aware OLSR protocol for urban VANET. The combinations of parameters to optimize are generated through the genetic algorithm and explored using parallel evolutionary algorithms. However, the optimized metrics are dependent on the offline processed traces. Thus, any change in the real time environment requires repeating the offline optimization which is impractical as urban environments are continuously changed.

In [11], OLSR protocol was extended to incorporate a QoS metric in MPR selection for highway VANET. The proposed QoS function combines bandwidth, distance and velocity to elect highest QoS neighbor as cluster head. Even though parameters used improve the performance in a highway environment, the urban environment characteristics are not considered even though they affect velocity and distance in addition to the driver's mobility pattern.

In [12], QoS-OLSR and intelligent water drop model were used for MPR selection in VANET routing. Similar to [11], the QoS parameters focus on distance and velocity which hold significant information in highway VANET but not in urban VANET due to the existence of intersections.

C. Limitations

In summary, most urban VANET routing protocols rely on basic vehicle mobility metrics such as velocity and distance which rapidly change due to external environment factors as intersections [15]. Additionally, protocols rely on external information or relative selection metric between vehicles which both introduces delay and routing overhead.

Various studies as in [8], [9] have proven that OLSR proactive protocol outperforms reactive Ad hoc On-Demand Vector (AODV) and position-based Greedy Perimeter Stateless Routing (GPSR) in urban environments which are used in most proposed urban VANET protocols. Moreover, existing protocols using proactive OLSR do not consider environment metrics where the QoS-OLSR protocol was proposed for highway based VANET and not urban VANET considered in this work.

III. Street-centric QoS-OLSR Protocol

In this section, the proposed street-centric QoS-OLSR protocol is presented; its parameters, QoS function and algorithm.

A. Selection Parameters

To properly select vehicles for packet relay, appropriate parameters are to be used. Selected parameters can be classified into two types: link centric and street centric.

1) Link Centric: Available Bandwidth (AB) represents the link capabilities of a vehicle and bandwidth resource it is willing to dedicate for the network. This is important as vehicles dedicate different percentages of their bandwidth for routing.

2) Street Centric: As connectivity is affected by the urban environment, the below parameters are used to incorporate the urban restrictions in QoS calculation.

- Lane Weight (LW) is used to favor the selection of MPRs from lanes that carry the majority of the traffic flow to increase their stability. Static weights are used to increase the QoS value for vehicles on the middle lane, middle 2 lanes for streets with even number of lanes, as it typically carries the majority of the traffic. Arbitrary weight values are used as shown in eq. 1.

$$LaneWeight(x) = \begin{cases} 3 : x \text{ is on middle lane} \\ 1 : \text{otherwise} \end{cases} \quad (1)$$

- Percentage of Neighbors on Other Street (PoNOS) replaces the typically used number of neighbors. This is as most vehicles on a street provide reachability to similar neighbors making the number of neighbors high but insignificant. However, as different streets introduce distinct neighbors street, the percentage of vehicles on other streets is used to present the level of neighbors' diversity. PoNOS is calculated as shown in eq. 2

$$PoNOS = 100 \times (1 - \tfrac{NiS}{N}) \quad (2)$$

  where NiS presents the neighbors in the same street as the node. N presents the total number of neighbors.

B. QoS Selection Metric

To select MPRs with higher performance in an urban environment, an urban-based QoS metric is introduced to the OLSR protocol. While OLSR focuses on the uniqueness of neighbors a node is capable of reaching, our proposed urban-based QoS metric incorporates the link centric and street centric parameters mentioned above. The QoS value is calculated according to eq. 3.

$$QoS = AB \times PoNOS \times LW \quad (3)$$

C. RealNeighbors Classification

As neighbors might belong to different streets with opposite movement directions, their neighboring interval would be considerably short. If an MPR is selected from the set of neighbors on other streets, the MPR might be lost shortly requiring MPR set recomputation. To increase the stability of selected MPRs, selection is limited to neighbors on the same street which are classified as $RealNeighbors$ (RN) since they are expected to have longer neighboring interval. Each node uses only nodes from its RN set which is a subset of its neighbor set for MPR selection.

D. Street-centric QoS-OLSR Protocol Algorithm

The street-centric QoS-OLSR protocol deployed at each node in the network can be divided into three periodic phases as shown in alg. 1; HELLO message construction, NeighborSet population and MPR selection. In the first phase, node i calculates its $QoS(i)$ metric using eq. 3 and determines its current $Street(i)$. $QoS(i)$ and $Street(i)$ are appended to the HELLO message broadcasted to the network. In NeighborSet population phase, each received HELLO message at i is processed where the sending node k is added to NeighborSet $N(i)$ along with its $QoS(i)$ and $Street(i)$ values. Additionally, $Street(k)$ is checked to determine whether k resides on $Street(i)$ to add it to $RN(i)$. In the third phase, $MPR(i)$ is selected as the neighbor with highest QoS value from nodes in $RN(i)$ set. The selected MPRs by nodes are later used for routing.

Algorithm 1 MPR Selection Algorithm

i is a node in the network where:
AB(i) = Available Bandwidth of i
LW(i) = Lane Weight of i
N(i) = Set of i Neighbors
NoN(i) = Number of Neighbors of i
NOSS(i) = Number of Neighbors on Same Street as i
PoNOS(i) = $1 - \frac{NOSS(i)}{NoN(i)}$
QoS(i) = $AB(i) \times LW(i) \times PoNOS(i)$
Street(i) = Identifier of i's current street
RN(i) = Set of neighbors on same street as i

Phase 1 – HELLO Message Construction

Calculate QoS(i)
Insert QoS(i) and Street(i) to HELLO message
Broadcast HELLO message to neighbors

Phase 2 – NeighborSet Population

for Each node i in the network **do**
    for Each HELLO message received from node k **do**
        N(i):= k
        if Street(k) == Street(i) **then**
            RN(i) := k
        end if
    end for
end for

Phase 3 – MPR Selection

for Each node $m \in RN(i)$ U i **do**
    if QoS(m) == $max_{j \in RN(i) U i}$ (QoS(j)) **then**
        MPR(i) = m
    end if
end for

E. Illustrative Example

To demonstrate how street-centric QoS-OLSR protocol for urban VANET works, the following network in Fig. 1 is used. Seven vehicles are distributed on four streets at different lanes. The black circle indicates transmission range used to extract parameters for the calculations.

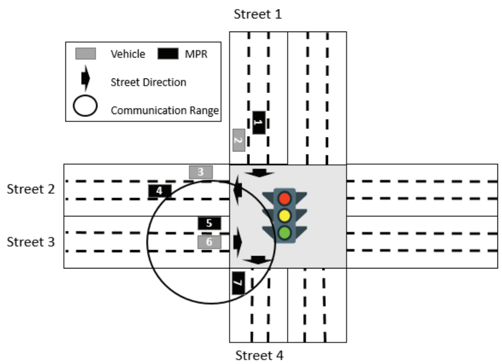

Figure 1: Illustrative Example Environment

Vehicle 6 randomly selects 35 Kbps as its available bandwidth value. Since it is on the middle lane of the street segment, its lane weight is assigned as 3. The vehicle has 2 neighbors in its communication range, vehicle 5 on street 3 and vehicle 7 on street 4, making the calculated PoNOS according to eq. 2 equal to 0.5. This makes QoS given the previous parameters and using eq. 3 equal to 52. The parameters for the rest of the vehicles and their calculated QoS values are presented in Table I where AB is randomly generated while LW and PoNOS are extracted from the environment in Fig. 1. The QoS and street identifier of vehicles are broadcasted to the network.

As vehicle 6 has 2 neighbors, it populates its NeighborSet with these vehicles' metrics. However, only vehicle 5 is added to $RN(6)$ set as it is on the same street.

For MPR selection, vehicle 6 considers itself and nodes in $RN(6)$. Vehicle 5 is selected as an MPR for vehicle 6 as it has the highest QoS value. Similarly, the calculated QoS and street identifiers are used in the selection of MPRs for remaining vehicles resulting in vehicles 1, 4, 5 and 7 being selected as MPRs in the network.

Table I: QoS Metric for Street-Aware QoS-OLSR urban VANET

Vehicle	**1**	**2**	**3**	**4**	**5**	**6**	**7**
AB	127	292	198	152	268	35	73
LW	3	1	1	3	1	3	1
PoNOS	0.5	0.5	0.66	0.66	0.6	0.5	1
QoS	190	146	132	304	161	52	73
Street	1	1	2	2	3	3	4
MPR Node	1	1	4	4	5	5	7

IV. Simulation Results

This section presents the simulation setup and environment used to run the proposed protocol. SUMO 0.25.0 [16] and NS3 3.19 [17] tools are used to generate the traffic and network traces. The simulation results are presented and compared to the original OLSR protocol.

A. Simulation Setup

As NS3 is considered one of the realistic network simulation software, it was used to evaluate the performance of the proposed model. However, the existing underlying OLSR protocol implementation for the proposed protocol does not include the QoS metric. Thus, we present the first attempt to modify the implementation to include QoS in the HELLO message used for MPR computation. This improves the validity of the proposed QoS-OLSR protocol network results and opens the door to other protocols which to be validated on NS3. Below are the performed modifications on NS3 to extend the OLSR protocol implementation to the QoS-OLSR protocol:

In node.h, the attributes mentioned in Table II are added to assist in the protocol operation as well as maintain high level features of the nodes.

Table II: Added Variables to node.h

Type	Name	Description
$uint16\_t$	QoSValue	the QoS value of local node
$uint8\_t$	Neighbor	the number of neighbors a node has
$uint8\_t$	lane	current lane a vehicle is on
$uint16\_t$	current street	identifier of vehicle's current street

In olsr-repositories.h file, NeighborTuple is modified to include the QoS value and street identifier. While in olsr-header.c, serialize, deserialize and getSize are modified to reflect the new HELLO message format.

In olsr-routing-protocol.c:

- $sendHello$ calculates the QoS value according to the protocol's parameters and includes it in the periodic HELLO messages along with current street identifier.
- $populateNeighborSet$ and $populateTwoHopNeighborSet$ save QoS in addition to the current street identifier in the Neighbor tuples.
- $MPRComputation$ selects MPRs according to neighbors' QoS and current street identifier.

In olsr-header.h, the original HELLO message packet format in Table III is altered to the format shown in Table. IV. The modified packet includes 4 additional bytes which increase routing overhead. However, as the urban environment is usually dense with multiple neighboring interfaces in the hello packet, the 4 bytes can be considered an insignificant addition to the packet.

Table III: Original HELLO Packet Format

<table>
<tr><td>0</td><td>8</td><td>16</td><td>24   32</td></tr>
<tr><td colspan="2">Reserved</td><td>Htime</td><td>Willingness</td></tr>
<tr><td>Link Code</td><td>Reserved</td><td colspan="2">Link Message Size</td></tr>
<tr><td colspan="4">Neighbor Interface Address</td></tr>
<tr><td colspan="4">Neighbor Interface Address</td></tr>
</table>

The environment shown in Fig. 2 is used to perform the simulations with 12 intersections connecting 17 streets of 500m length. Traffic lights are placed at intersections to regulate the flow of vehicles and make the environment more realistic. SUMO random trip generator is used to generate the mobility traces on the shown environment given the mobility parameters

Table IV: Modified HELLO Packet Format

0	8	16	24 32
Reserved		Htime	Willingness
QoS		**Street Identifier**	
Link Code	Reserved	Link Message Size	
Neighbor Interface Address			
Neighbor Interface Address			

mentioned in Table V. The generated traces are then exported to xml format which includes high level parameters; street name and lane, and tcl format which can be imported to NS3 for the mobility model of vehicles.

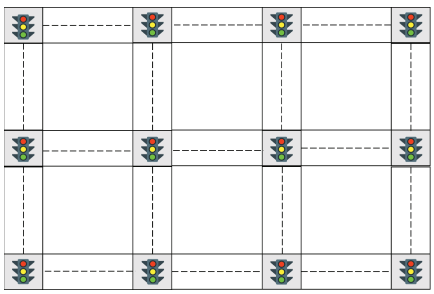

Figure 2: Simulation Environment

The network simulation parameters are also presented in Table V. To conduct simulations, 10% of the nodes are selected as source while another 10% are selected as destinations. Each pair of source and destination nodes is enabled for 10 seconds to evaluate its performance.

Parameter	Value
Mobility Model	Randomly generated traces
Velocity	up to 60 m/s
Number of Nodes	$150 - 350$
Transmission Range	$250m$
Packet Size	600 Bytes
Available Bandwidth	Random Value $[0 - 300]$ Kbps
Simulation Duration	10 seconds per connection
Number of Simulations	10 iterations

Table V: Simulation Parameters

B. *Simulation Results and Discussion*

Fig. 3 presents the percentage of selected MPRs in the network. The percentage of MPRs is higher for the proposed QoS-OLSR compared to OLSR due to the restriction imposed requiring MPRs being on the same street as their selecting vehicles. However, as the number of vehicles in the environment increases, the percentage of MPRs decreases as similar vehicles are selecting the same MPRs while the percentage in the case of OLSR increases. The higher percentage of MPR improves the connectivity of the network while not affecting its lifetime as vehicles are assumed to have infinite amount of energy.

Fig. 4 presents the measured throughput calculated according to the number of received packets by the destination per second. Our QoS-OLSR protocol increases the network throughput compared to OLSR in an urban environment. This is due to

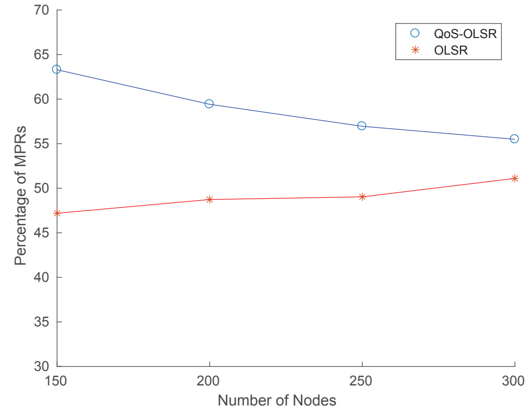

Figure 3: Percentage of Selected MPRs

the consideration of nodes' link quality to select MPRs with higher quality maximizing throughput.

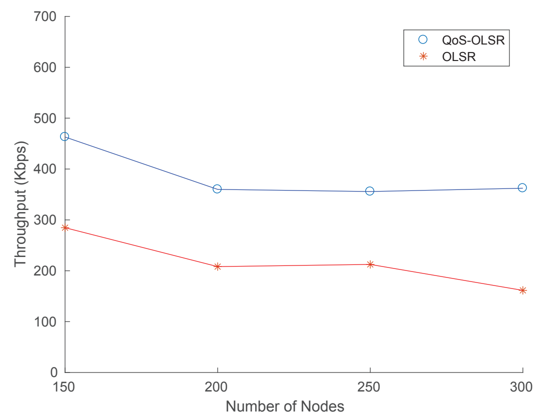

Figure 4: Throughput (Kbps)

Fig. 5 presents the packet delivery ratio obtained by dividing the number of received packets by the number of transmitted packets. The proposed QoS-OLSR protocol increases PDR compared to OLSR when deployed in an urban environment. This is as the node's QoS is considered in the MPR selection process to maximize the expected performance. However, the PDR value decreases with the increase in the number of nodes similar to OLSR due to the increased network traffic.

Fig. 6 and 7 represent the average hop count and end-end delay respectively. The hop count presents the number of nodes in the path between each pair of source and destination. A decrease in the hop count can be noticed when deploying our QoS-OLSR which in turn decreases the path's end-end delay.

In summary, for the scenario presented here the proposed QoS-OLSR protocol for urban VANET improves the network performance when considering throughput, PDR, average hop count and end-end delay with an average percentage of 58.6%, 62.5%, 45.3% and 23.1% respectively. This is as the selection of MPRs for routing utilizes the QoS of the node for higher

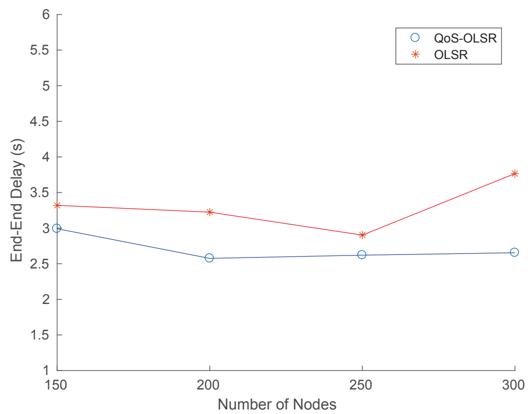

Figure 7: End-End Delay

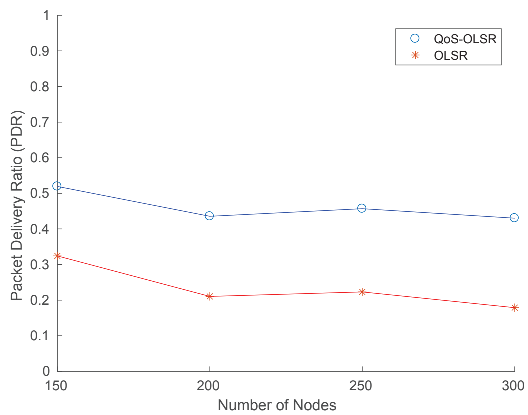

Figure 5: Packet Delivery Ratio

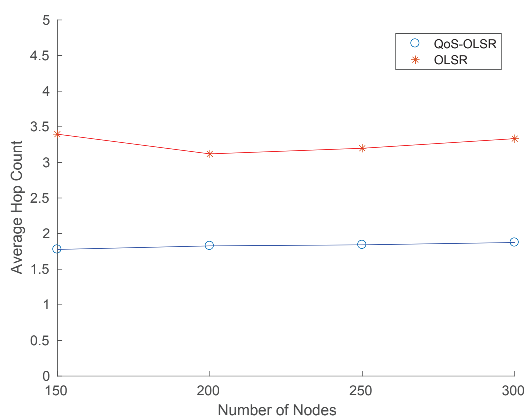

Figure 6: Average Hop Count

quality MPRs. Additionally, the proposel QoS-OLSR protocol decreases the percentage of MPRs in dense environments.

V. Conclusions

This paper presented the first effort in proposing a street-centric QoS-OLSR protocol for urban VANET which enhances throughput and connectivity. The proposed protocol uses link and street centric parameters such as available bandwidth, vehicle's lane and street to select MPRs. NS3's OLSR implementation was modified as our protocol requires including QoS and street identifier. The proposed protocol was evaluated against OLSR using NS3 resulting in an average improvement of 58.6% for throughput, 62.5% for PDR, 45.3% for average hop count and up to 23.1 % for end-end delay.

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