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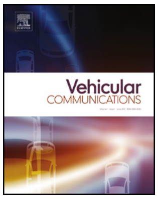

A Stackelberg game for street-centric QoS-OLSR protocol in urban Vehicular Ad Hoc Networks

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ABSTRACT

In this paper, we address the problem of routing in urban Vehicular Ad Hoc Networks (VANETs) using proactive Optimized Link State Routing (OLSR) protocol in the presence of passive malicious nodes. OLSR protocol routes through MultiPoint Relays (MPRs) that are selected according to neighbors' reachability and uniqueness. However, in urban VANETs, other parameters such as node's mobility and street topology are also of significance. These parameters can also be taken into consideration to improve the quality of selected MPRs. However, an MPR can adopt a passive malicious behavior by not cooperating with other nodes unless rewarded. As a solution, we propose a multi-leader multi-follower Stackelberg game model that motivates nodes to act cooperatively, being MPRs, by increasing their reputation. Collected reputation increments are used to determine the set of nodes (followers) that an MPR (leader) will route for based on nodes' reputation. Simulations conducted using NS3 demonstrate that the proposed Stackelberg game model improves the network performance in terms of stability of MPRs, throughput, and average hop count compared to OLSR and the street-centric QoS-OLSR protocol in urban VANET. Additionally, the proposed protocol presents a similar percentage of selected MPRs and end-to-end delay compared to the benchmarks.

1. Introduction

Background. Vehicular Ad Hoc Networks (VANETs) emerged as an enabler for information exchange in Intelligent Transport Systems (ITS) applications such as traffic light control, electronic payment, and public transport management [1]. It utilizes vehicles to route information instead of the Internet infrastructure which is not scalable considering the exponential growth in the number of connected vehicles. However, the network performance remains governed by the deployed routing protocol at each vehicle.

For urban VANET routing, the environment characteristics such as street topology and intersections impact the network performance. When considering distributed VANET, routing is further influenced by the willingness of nodes to share their resources with other nodes. This is as a node's resource would be consumed and when no incentive is provided, the node might adopt a passive malicious behavior of dropping packets to conserve its resources.

Motivation. Urban VANET routing protocols such as [2–5] enhance network connectivity and performance through improving relay selection for the urban environment. While they provide adequate network performance, they mostly utilize mobility metrics such as velocity and position which rapidly change in the urban environment making these metrics of lower significance.

These protocols depend on reactive and position-based protocols where a reactive protocol constructs routes when required using link information while position-based utilizes the position of a node in route selection. However, the proactive Optimized Link State Routing (OLSR) protocol [6] was found to be the most suited for urban VANET [7,8] because of its shorter delay, path length and routing overhead.

Multiple protocols have been proposed extending OLSR for VANET such as [9–12]. In OLSR, MultiPoint Relays (MPRs) are selected for network routing based on neighbors' reachability and uniqueness. Proposed protocols replace OLSR's selection metrics with more significant metrics in VANET such as node's mobility and environment metrics such as current street and lane weight. However, most of these protocols are proposed for highway VANET or use offline optimization. In the street-centric Quality-of-Service (*QoS*)-OLSR protocol [12], link and street-centric parameters are aggregated in a QoS for MPR selection. However, MPRs might adopt a passive malicious behavior of dropping received packets when overwhelmed by requests from nodes without a reward.

Game theory is a mathematical approach to analyze nodes' strategies and determine a node's final strategy accordingly. In ur-

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ban VANET, game theory has been introduced [13–17] for power allocation, coalition construction and securing data routes. However, it has not been used in the selection of relay nodes given nodes' preferences and capabilities.

In summary, limitations in surveyed urban VANET and OLSR routing protocols include:

- Dependency on frequently changing mobility metrics in relay selection which lowers their stability and performance [18].
- Lack of a win–win mechanism for both relays and nodes.
- Lack of an efficient motivation model to overcome passive maliciousness behavior.

Contributions. The main contribution of this work is a multi-leader multi-follower Stackelberg game model, which leverages OLSR's MPR selection in urban VANET and improves the network performance in terms of MPRs' percentage and stability, throughput, delay and hop count. Stackelberg game has two types of players, leaders and followers, which are classified by nodes' capabilities. Leaders (Possible MPRs) in our game are identified based on their *QoS* and reputation metrics. *QoS* from [12] is used to represent the quality of a node while reputation indicates its reliability in VANET given the previous game iterations.

The main objective of our game is to motivate nodes, acting as MPRs, in urban VANETs to cooperate by increasing their reputation and hence maximize the profit of all players. Nodes determine the profit of possible MPRs (leaders) based on their *QoS* and reputation where incentives in the form of reputation are given. Possible MPRs (leaders) receive and aggregate these reputation increments to determine the set of nodes that they accept to relay for. The game is continuously played to maintain a set of MPRs that provides adequate routing performance.

In summary, the main contribution of this work is a multi-leader multi-follower Stackelberg game model for urban VANET that can:

- Identify MPRs (leaders) according to their *QoS* and reputation metrics.
- Maximize the profit of MPRs (leaders) in terms of reputation and nodes (followers) in terms of *QoS*.
- Motivate the cooperation of MPRs' by increasing their reputation.
- Improve the network performance compared to OLSR and street-centric QoS-OLSR.

Simulations are conducted using Simulator of Urban MObility *(SUMO)* [19] and Network Simulator 3 *(NS3)* [20] to evaluate the performance against OLSR and the street-centric QoS-OLSR protocol for urban VANET [12]. Modifications were introduced to OLSR's implementation in *NS3* to accommodate the Stackelberg game model with its additional messages and timers. Simulation results show that the Stackelberg game model outperforms OLSR and the street-centric QoS-OLSR protocol in the percentage of stability, throughput, and average hop count while maintaining comparable results for the percentage of MPRs and end-to-end delay when deployed in an urban environment.

Organization. This paper is organized as follows. Section 2 presents the background and related work. Section 3 presents the architecture of the proposed game model. Section 4 presents the game model and its analysis. Section 5 describes the new messages and timers added to the proposed game model. Section 6 presents a running example for the model. Section 7 presents the simulation results to validate the performance of the proposed model. Section 8 concludes the paper and summarizes its results.

2. Related work

This section includes a survey for routing protocols and game theoretic approaches which tackle the problem of routing in urban VANET. First, evaluation criteria for surveyed efforts are presented. Second, a summary of surveyed protocols is presented. Third, limitations in surveyed protocols are highlighted.

2.1. Evaluation criteria

The evaluation criteria stated is used to compare the surveyed protocols. It takes into consideration the deployment environment to identify efforts targeting urban VANET, relay selection parameters to determine their implication on the proposed model, and game model to identify the currently used game model.

- **Environment**: indicates the intended environment for the protocol.
- **Link (L)**: represents consideration of a link characteristic such as signal fading or bandwidth.
- **Neighbors (N)**: reflects considering the neighbors surrounding a node.
- **Velocity (V)**: represents utilizing the vehicle's velocity/speed to predict vehicles' neighboring interval.
- **Position (P)**: denotes using the vehicle's geographical or relative position in the network to determine proximity between vehicles and which street they belong to.
- **Street Lane (SL)**: implies utilization of the vehicle's current lane. This is as each lane allows at least one movement direction at intersections making some lanes more stable when they abide to the direction of the majority of the street lanes.
- **Vehicle Type (VT)**: represents prioritized vehicle types in relay selection such as taxis and buses.
- **Game Model**: denotes considered game model in the protocol.

2.2. VANET routing protocols

This section presents a summary of urban VANET and OLSR-based routing protocols. OLSR-based protocols are considered due to the superiority of OLSR [6] in urban VANET in terms of delay, path length and routing overhead when compared to reactive Ad hoc On-Demand Vector (AODV) and position-based Greedy Perimeter Stateless Routing (GPSR) [7,8].

In [2], a protocol to improve forwarding decisions at intersections was proposed. It calculates a street's connectivity probability while excluding vehicles clustered at a red traffic light. The probability is calculated using historical and/or external information which do not reflect real-time traffic or may not be available, hence, misleading the relay selection. Additionally, the protocol neglects the link quality of existing vehicles on the street which may lead to high packet drops and disconnections due to insufficient bandwidth at vehicles even when enough vehicles exist to construct a connected street segment.

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 movement 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 used in routing decisions. Requiring multiple relative selection metrics increases complexity and overhead in dense networks where many vehicles are within the same transmission range and the metrics are to be calculated for each pair of neighboring nodes.

In [4], buses were utilized as a routing backbone in a link state protocol for the urban environment to minimize hop count. Buses'

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