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Improving dynamic and distributed congestion control in vehicular ad hoc networks

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ABSTRACT

To provide reliable communications in Vehicular Ad hoc Networks (VANets), it is vital to take into account Quality of Services (QoS). Delay and packet loss are two main QoS parameters considered by congestion control strategies. In this paper, a Multi-Objective Tabu Search (MOTabu) strategy is proposed to control congestion in VANets. The proposed strategy is dynamic and distributed; it consists of two components: congestion detection and congestion control. In the congestion detection component, congestion situation is detected by measuring the channel usage level. In congestion control component, a MOTabu algorithm is used to tune transmission range and rate for both safety and non-safety massages by minimizing delay and jitter. The performance of the proposed strategy is then evaluated with highway and urban scenarios using five performance metrics including the number of packet loss, packet loss ratio, number of retransmissions, average delay, and throughput. Simulation results show that MOTabu strategy significantly outperforms in comparison with other strategies like CSMA/CA, D-FPAV, CABS, and so on. Conducting congestion control using our strategy can help provide more reliable environments in VANets.

1. Introduction

Intelligent Transport Systems (ITSs) use Vehicular Ad hoc Networks (VANets) as wireless communications technology. Indeed, VANets are designed to provide a safe and efficient environment within transportation systems for reducing accidently dangers events for drivers, passengers and pedestrians in the roads. They are a new landscape of Mobile Ad-hoc Networks (MANets) that consider the vehicles as mobile nodes. VANets are equipped with two units that are called Road-Side Unit (RSU) and On-Board Unit (OBU). While the former is fixed on the roadside, the latter is carried on by vehicle. These units are used for carrying out wireless communications between vehicles (V2V communications) as well as between vehicles and roadside infrastructures (V2I communications) [1,2].

Dedicated Short Range Communication (DSRC) is a set of protocols and standards that are employed in VANets. Bandwidth utilization, which is one of main factors in DSRC, defines transmission range up to 1000 m and transmission rate ranging from 3 to 27 Mbps. DSRC employs Wireless Access in a Vehicular Environment (WAVE) to norm performance of V2V and V2I communications. WAVE is formed by IEEE802.11p and IEEE1609 standards in PHY and MAC layer, respectively. The above standards are applied for managing resources and network services for selecting channels, security, and so on.

VANets offer a large number of applications including safety applications (e.g., forward collision, traffic signal

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violation, and emergency brake lights) and service applications (e.g., traffic optimization, infotainment, and payment services). Safety applications utilize beacon and emergency messages that are transmitted by means of control channel, while service applications utilize non-safety massages transmitted over service channels [3,4]. VANets inherit the most behavior of MANets. However, they have different behaviors in comparison with MANets due to their special characteristics including high mobility of nodes, high rate of topology change, and high rate of node density. These unique characteristics in VANets raise new challenges related to data dissemination, scalability, security, and routing that lead to reduce performance of VANets [4,5].

To enhance performance of VANets, Quality of Services (QoS) strategies must be considered to guarantee reliability of safety and service applications. Packet loss and delay are two important parameters that can be used to quantify QoS and evaluate the performance of VANets. Congestion, which occurs due to the limitation of resources, leads to increase the number of packets loss and delay, and consequently to decrease the performance of VANets. Indeed, the channel bandwidth copes with congestion when the load of the network exceeds the capacity of the network nodes and links. Therefore, congestion control should be conducted for decreasing packet loss and delay to make a more reliable communication in VANets. Congestion control in VANets is a challenging task due to the special characteristics of the vehicular environment including sharing the wireless channel, frequently route break, dynamic topology, and so on. Thus, a dynamic and distributed strategy is required to handle congestion control [6–9].

Over the last decades, several strategies were proposed to address congestion problem in VANets. There are three main congestion control strategies for VANets: (1) controlling the transmission range that controls the range of transmission in channels, (2) controlling the transmission rate that controls the rate of packets transferring, and (3) scheduling messages in various channels based on their priorities [10]. Congestion control techniques can also be classified into end-to-end, and hop-by-hop techniques. The end-to-end techniques consider communication flows between senders and receivers, but they do not pay attention to intermediate nodes. The hop-by-hop techniques take into account the capacity of intermediate links [11]. However, using the existing strategies in practice revealed that there are a lot of problems associate with these congestion control strategies in VANets. Some of these problems include, but not limited to, high transmission delay, unfair resource usage, inefficient use of bandwidth, and communication overhead [8]. Therefore, a new strategy is needed to solve these problems, especially in emergency situations of VANets.

Tuning transmission range and rate to control congestion copes with computational overhead in VANets due to the large number of contributing parameters including size of messages, number of vehicles, number of lanes, vehicle velocity, and so on. Thus, the existing strategies conducting tuning transmission range and rate suffer from high delay and packet loss [10]. It will be shown that such a problem is NP-hard. Meta-heuristic techniques can be used to find near optimal solutions in a reasonable time for NP-hard problems [12].

In this paper, we propose a dynamic and distributed congestion control strategy to increase reliability of VANets. The remaining parts of this paper are structured as follow: Section 2 reviews the existing congestion control strategies in VANets. Section 3 proposes a congestion control strategy in VANets environments. Section 4 describes the Multi-Objective Tabu Search (MOTabu) algorithm for tuning transmission range and rate. Section 5 discusses the results obtained from applications of the proposed strategy in highway and urban scenarios.

2. Background and related works

Congestion control in modern wired/wireless communications plays an important role for providing reliable and fair environments. The main goals of a congestion control strategies are to obtain high bandwidth utilization, efficient fairness, high responsiveness, and fairly compatibility with protocols and standards. To increase efficiency of a congestion control, some metrics such as convergence speed, smoothness and responsiveness must be considered. The convergence speed is estimated by measuring the time spent to reach the equilibrium state. The smoothness, which depends on the size of fluctuation, is calculated using reflection of fluctuation intensity. Finally, the responsiveness is measured by Round Trip Time (RTT) to reach equilibrium [11].

The congestion control strategies are used to control channels loads and increase the performance of wireless channels. Generally, the congestion control strategies in VANets are classified into four categories: window-based, rate-based, single-rate, and multi-rate. Window-based category employs the congestion window in sender and receiver sides. The size of congestion window increases/decreases in states of with/without congestion. In rate-based category, transmission rate is adapted using some feedback-based algorithms. In single-rate category, the congestion is controlled using unicast protocols. Thus, sending rate must be adapted according to just one receiver. On the other hand, multi-rate category uses a layered multicast approach [11].

Torrent-Moreno et al. [13] proposed Distributed-Fair Power Adjustment for Vehicular environment (D-FPAV). This congestion control strategy dynamically controls transmission range of the safety messages (i.e., beacons and emergency messages). Beacon messages are periodically broadcasted between the vehicles that are composed of some information like speed, position, direction, and so on, while emergency messages are broadcasted when an event happens within VANets. In the congestion situation, D-FPAV shrinks the transmission range of the beacon messages. For reducing communication overhead, the value of transmission range is obtained based on the vehicle density. The main drawback of this strategy is that the probability of receiving beacons messages in far distance reduces by decreasing transmission range.

High beaconing frequency consumes a high amount of channel bandwidth when the number of vehicles