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Integration of congestion and awareness control in vehicular networks

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ABSTRACT

Cooperative vehicular networks require the exchange of positioning and basic status information between neighboring nodes to support vehicular applications. The exchange of information is based on the periodic transmission/reception of 1-hop broadcast messages on the so called control channel. The dynamic adaptation of the transmission parameters when broadcasting such messages will be key for the reliable and efficient operation of vehicular networks. To this aim, vehicular networks utilize congestion control protocols to control the channel load, typically through the adaptation of the transmission parameters based on certain channel load metrics. Awareness control protocols are also required to adequately support cooperative vehicular applications. These protocols typically adapt the transmission parameters of periodic broadcast messages to ensure each vehicle's capacity to detect, and possibly communicate, with the relevant vehicles and infrastructure nodes present in its local neighborhood. To date, congestion and awareness control protocols have been normally designed and evaluated separately, although both will be required for the reliable and efficient operation of vehicular networks. In this context, this paper proposes and evaluates INTERN, a new control protocol that integrates two congestion and awareness control processes. The simulation results obtained for three different scenarios demonstrate that INTERN is able to satisfy the applications' requirements of all vehicles, while effectively controlling the channel load. The results obtained highlight the challenges ahead with emerging automated vehicles.

1. Introduction

Cooperative vehicular networks are being designed to improve traffic safety and efficiency thanks to the real time exchange of information between vehicles (V2V - Vehicle-to-Vehicle) and between vehicles and infrastructure units (V2I - Vehicle-to-Infrastructure). The exchange of information is based on the periodic transmission/reception of 1-hop broadcast packets on the so called control channel using the IEEE 802.11p radio access technology in the 5.9 GHz frequency band [1]. These packets are formally known as WSM (WAVE Short Messages) in the US or CAM (Cooperative Awareness Messages) in Europe, and are often referred to as beacons. Each packet includes positioning and basic status information of each vehicle, which is exploited by higher layer protocols and applications. For example, applications such as intersection collision warning or lane change assistance will exploit the position and speed information of nearby vehicles to detect potential road dangers with sufficient time for the driver to react. To effectively support vehicular safety applications, each vehicle needs to continuously receive updated information from all vehicles located within certain warning distance. The requirements of safety applications can be defined in terms of warning distance [2] and packet reception frequency (inverse of packet inter-reception

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time) [3]. Different applications can have different warning distance and packet reception frequency requirements [4], which can also depend on the context of the vehicles [5].

To adequately support cooperative vehicular applications, a number of awareness control protocols have been proposed in the literature [6]. These protocols are aimed at adapting the transmission parameters of beacons to ensure each vehicle's capacity to detect, and possibly communicate, with the relevant vehicles and infrastructure nodes present in its local neighborhood. In addition, all vehicles will periodically transmit their beacons on the control channel. This can lead to possible channel congestion, in particular under high traffic densities. The critical nature of the control channel has fostered significant efforts in the research and standardization communities to design congestion control protocols that ensure the scalability and adequate operation of vehicular networks by adapting the packet transmission frequency or power [6]. In fact, the ETSI communications architecture that future connected vehicles will implement includes a key Decentralized Congestion Control (DCC) module that is currently under development [7].

To date, congestion and awareness control protocols have been normally designed and evaluated separately, although both will be required for the reliable and efficient operation of vehicular networks. For example, in a highway scenario with a traffic jam in one direction of driving and free-flow conditions in the other direction, all vehicles might suffer channel congestion and would require the use of congestion control protocols to control the channel load. However, the requirements of the applications run by the vehicles in the traffic jam are notably lower from those of the applications run by the vehicles under free-flow conditions moving in the opposite direction with higher speeds and different inter-vehicle distances. In this scenario, a congestion control protocol would require the reduction of the transmission power and packet frequency to control the channel load, while an awareness control protocol would seek to increase the transmission parameters of vehicles under free-flow conditions due to their higher applications' requirements. In this context, an independent design (and disjoint operation) of congestion and awareness control techniques could create contradictory settings or conflicts that need to be solved [6]. To this aim, this paper proposes and evaluates INTERN (INTEgRatioN of congestion and awareness control), a new control protocol that integrates congestion and awareness control processes. INTERN dynamically adapts the transmission frequency and power of beacons of each vehicle to guarantee that its application's requirements are satisfied while controlling the channel load generated.

2. State of the art

To effectively support vehicular safety applications, each vehicle needs to continuously receive updated information from its relevant neighboring vehicles. To this aim, different awareness control protocols that adapt the transmission parameters of beacons have been proposed in the literature [6]. For example, the work in [8] proposes OPRAM, an awareness control protocol that adapts each vehicle's transmission parameters to reliably and efficiently exchange a message before reaching a critical safety area such as an intersection. The work in [9] proposes an awareness control strategy based on the random adaptation of the transmission power and a control process that adapts the packet transmission frequency. The random adaptation of the power provides different reliability levels at different distances, while mitigating correlated packet collisions by randomizing them in space. The packet transmission frequency adaptation can reuse freed channel resources by further increasing the beacon frequency. The protocol proposed in [10] dynamically selects the power and data rate required to successfully transmit a packet to a given vehicle, based on estimations of the average signal attenuation using previously received beacons. In other studies such as [11], the packet transmission frequency is adapted to bind the tracking errors of surrounding vehicles. Considering multi-hop beaconing, the work in [12] proposes a fully distributed algorithm that decides whether a vehicle has to forward a received beacon or not. Such decision is taken by the vehicle itself and its objective is to maximize the reliability of the beacon transmission. However, other studies such as [13] demonstrated that single-hop beaconing is in general more efficient than multi-hop beaconing.

The periodic transmission of beacons occupies a significant portion of the control channel, which can easily get congested. Different congestion control protocols have been proposed in the literature to control the channel load by adapting the transmission parameters of beacons. Two of the most relevant congestion protocols available in the literature are LIMERIC [14] and PULSAR [15]. Both protocols propose the adaptation of the packet transmission frequency based on the experienced channel load, and set the transmission power to a fixed value. Both protocols are able to maintain the channel load below certain target threshold independently of the vehicular traffic density. LIMERIC and PULSAR are currently being discussed at ETSI's Technical Committee on ITS to be part of the DCC set of standards [16,17]. Other congestion control approaches are also available in the literature. For example, the proposal in [18] computes the transmission power of each vehicle based on the number of detected neighboring vehicles and other metrics such as the estimated carrier sensing range. The objective of the protocol proposed in [19] is the efficient transmission of beacons as frequently as possible, while maintaining a congestion-free wireless channel. To this aim, in [19] the packet transmission frequency is adapted by taking into account the channel quality (estimated based on observed packet collisions, Signal-to-Noise ratio and number of neighboring vehicles) and the message utility. The work in [20] recently proposed the adaptation of the packet transmission frequency as a function of the channel load experienced, the target channel load and the number of neighboring vehicles. Other protocols such as the one proposed in [21] consider the adaptation of the contention window size of IEEE 802.11p. In particular, the work in [21] proposes the adaptation of the minimum contention window size based on local transmission statistics that estimate the channel load and differentiating traffic priorities. Other congestion control protocols propose sensing the wireless channel and reducing the transmission power when a channel load threshold is exceeded [22], or when the number of messages in the MAC queue is above certain maximum level [23].