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# Thesis abstract

# Cooperative vehicle-to-everything communications for intelligent transportation system applications

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Of vehicle-to-everything (V2X) communications, vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) are the two technological innovations proposed to satisfy the stringent requirements of delay, service continuity and throughput in Intelligent Transportation Systems (ITS) applications, e.g. autonomous vehicle operation and stolen vehicle alert. However, in the stand-alone V2I networks, the sparse deployment and small coverage range of infrastructure units, e.g. road side units (RSUs), cause frequent service disruptions at requesting vehicles. Meanwhile, stand-alone V2V communications are intermittent and unreliable under high mobility and low vehicle density. Therefore, solutions that effectively combine V2I with V2V communications to meet the ITS application requirements, i.e. low service disruption and high achieved throughput, are called for. Additionally, the number of V2I and V2V links grows considerably when hundreds of vehicles request services at the same time. This leads to the question of how to allocate limited radio resources efficiently to a large number of links in ITS applications. In this study, we develop and evaluate a dynamic cooperative strategy and two scheduling schemes for V2I and V2V communications. The proposed approaches improve network connectivity in the scenarios where only one vehicle or many vehicles request the services simultaneously.

To maintain service continuity at a single requesting vehicle, we propose a dynamic forwarder selection to generate an adaptive multi-hop V2I and V2V path between the vehicle and the RSU that it has just passed by. Through an analytical model and extensive simulations using the practical settings of wireless channel and vehicular mobility, we show that: (i) The proposed scheme is a better choice than existing cooperation solutions in the sparse RSU scenarios; and (ii) A high vehicle density, more assistance willingness by the forwarders and larger buffer size at the requesting vehicle are shown to be beneficial for the proposed dynamic cooperation scheme.

To address the issue of insufficient radio resources, we design a frequency scheduling and power control scheme for when multiple vehicles download data via single-hop V2I and V2V communications in an RSU's coverage range. Mapping the V2I and V2V links to tuple-links, including multiple channel allocation, we formulate a mixed-integer nonlinear programming (MINLP) problem to maximize the number of concurrent tuple-links. To solve the problem, we apply the delayed column generation (DCG) method to propose an algorithm. Our main findings are: (i) This design minimizes

service disruptions compared to baseline scheduling approaches; and (ii) The proposed scheme not only improves average achieved throughput but also maintains throughput fairness among the requesting vehicles.

As the vehicles receive their requested data through multi-hop V2I and V2V paths in the area uncovered by any RSUs, we develop a frequency scheduling and power control scheme for multi-hop communications. Using the specific constraints of multi-hop transmission, we formulate a non-deterministic polynomial-time hard (NP-hard) problem to achieve the maximum number of active tuple-links within a sub-slot duration. Each tuple-link consists of multiple sub-slot and multiple channel allocations. After we design a DCG-based solution to the problem, our main findings are: (i) The proposed solution improves multi-hop network connectivity more than existing schemes when RSUs are deployed sparsely; and (ii) The efficiency of the proposed scheme can be further significantly enhanced by providing more available channels and equipping the requesting vehicles with a larger buffer size.

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