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Resource Optimization for Communication and Radar Sensing in Vehicular Networks

by

Ping Chu

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Certificate of Authorship/Originality

I, Ping Chu declare that this thesis, is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the School of Electrical and Data Engineering at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise reference or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis. This document has not been submitted for qualifications at any other academic institution.

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ABSTRACT

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With a great increasing volume of vehicles and population, transportation systems are facing many challenges such as congestion, air pollution, crashes and noise. Vehicular communication and radar sensing technology is promising for realizing intelligent, faster, safer transportation. The rapidly increasing amount and mobility of vehicles require frequent resource allocation, which can cause network congestion , large signalling and processing delay. In addition, due to the limited available bandwidth, wide deployment of radar sensors on automotive vehicles can potentially lead to a severe interference problem. Therefore, resource optimization for vehicular communication and automotive radars becomes a key issue in future autonomous vehicular networks, to meet their performance requirements and improve the spectral efficiency.

In this thesis, we investigate the resource optimization algorithm for communication and radar sensing in vehicular networks, addressing the following three issues:

1. The resource allocation and optimization scheme for vehicular communications based on traffic prediction, considering both critical latency requirement and spectral efficiency;

2. The mode selection scheme for vehicle-to-everything (V2X) communications to optimize energy consumption, considering resource reusing between vehicular users and conventional users;

3. The power optimization and interference characterization for automotive radars,

including the modeling of vehicle distribution, the consideration of different types of radars and the assumption of radar antenna directivity.

Regarding the first issue, we propose a novel semi-persistent resource allocation scheme based on a two-tier heterogeneous network architecture including a central macro base station (MBS) and multiple roadside units (RSU). Considering the predictability of vehicular flows, we combine the traffic prediction with this resource allocation scheme. In the proposed semi-persistent scheme, the MBS pre-allocates persistent resources to RSUs based on predicted traffic, and then allocates dynamic resources upon real-time requests from RSUs while vehicles simultaneously communicate using the pre-allocated resources. Based on this scheme, we mainly study two classes of optimization problems: 1) minimizing the relative latency with the constraint of total bandwidth; 2) minimizing the total bandwidth with the constraint of transmission latency. Different algorithms are developed to address the problems.

Towards the second issue, we investigate a two-tier heterogeneous cellular network where the macro tier and small cell tier operate according to a dynamic time-division duplex (TDD). Based on dynamic TDD which can adjust UL and DL time configurations to accommodate to the traffic asymmetry, we propose a vehicular device-to-device (V-D2D) mode selection scheme jointing time allocation, power control to minimize the energy consumption of the vehicles and the whole network. The problem is formulated as a convex optimization problem, and a geometrical interpretation is provided.

For the third issue, we firstly study the mean power of effective echo signals and interference, by considering both front- and side- mounted automotive radars equipped with directional antennas. We employ the stochastic geometry method to characterize the randomness of vehicular location and hence radars in both two-lane and multi-lane scenarios, and derive closed-form expressions for the mean interference by approximating the radiation pattern by Gaussian waveforms. Based on the interference analysis, we aim to minimize the total transmission power of each vehicle with constraints on the required signal to interference and noise ratio. An optimal solution is obtained based on linear programming techniques.

Dedication

To my parents Meizhen Zhu and Guanghe Chu

To my husband, Xuewei Pan

Thank you for your love and support

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List of Publications

0.1 Publications Related to This Thesis

Journal Papers

J-1. **P. Chu**, J. Andrew Zhang, X. Wang, Z. Fei, G. Fang and D. Wang, “Interference Characterization and Power Optimization for Automotive Radar with Directional Antenna," in *IEEE Trans. Veh. Technol.*, vol. 69, no. 4, pp. 3703-3716, 2020.

J-2. **P. Chu**, J. A. Zhang, X. Wang, G. Fang and D. Wang “Semi-Persistent Resource Allocation Based on Traffic Prediction for Vehicular Communications," in *IEEE Trans. Intell. Veh.*, vol. 5, no. 2, pp. 345-355, 2020.

Conference Papers

C-1. **P. Chu**, J. A. Zhang, X. Wang, G. Fang and D. Wang, “Semi-Persistent V2X Resource Allocation with Traffic Prediction in Two-Tier Cellular Networks," *in Proc. IEEE 89th Veh. Technol. Conf (VTC 2019-Spring)*, pp. 1-6, 28 April-1 May, 2019.

C-2. **P. Chu**, X. Wang, D. Wang and L. Yu, “A D2D Mode Selection Scheme with Energy Consumption Minimization Underlaying Two-tier Heterogeneous Cellular Networks," *in Proc. 28th Annu. Int. Symp. Pers., Indoor, Mobile Radio Commun. (PIMRC 2017)*, pp. 1-5, 8-13 Oct., 2017.

Contents

List of Figures

Abbreviation

3GPP - 3rd Generation Partnership Project

AWGN - Additive White Gaussian Noise

ANN - Artificial Neural Networks

ARIMA - Auto-Regressive-Integrated-Moving-Average

BS -Base Station

CDF - Cumulative Distribution Function

CRLB-Cramér-Rao Lower Bound

CSI - Channel State Information

CUEs -Cellular Users

D2D - Device-to-device

DS - Dynamic Resource Allocation Scheme

DSRC - Dedicated Short Range Communication

FMCW - Frequency Modulated Continuous Wave

FoVs - Field of Views

FR - Front-mounted Radar

ITS - Intelligent Transportation System

JCRS - Joint Communication and Radar Sensing

KKT - Karush-Kuhn-Tucker

kNN - k-Nearest Neighbour

LMMSE - Least Minimum Mean Square Error

LP - Linear Programming

LRR - Long Range Radar

LTE - Long-Term Evolution

LTE-V - Long-Term Evolution-Vehicle

MAPE - Mean Absolute Percent Error

MBS - Macro Base Station

MNAE - Mean Normalized Approximation Error

MIMO - Multi input multi output

MRR - Medium Range Radar

PPP - Poisson Point Process

PS - Persistent Resource Allocation Scheme

QoS - Quality-of-Service

RCS - Cross-Section Area

RSU - Roadside Unit

SINR - Signal-to-Interference-plus-Noise Ratio

SIR - signal-to-Interference Ratio

SNR - Signal-to-Noise Ratio

SPS - Semi-Persistent Resource Allocation Scheme

SR - Side-mounted Radar

SRR - Short Range Radar

TDD - Time Division Duplex

ULA - Uniform Linear Array

V2V - Vehicle-to-vehicle

V2I - Vehicle-to-everything

V2P - Vehicle-to-pedestrian

V2X - Vehicle-to-everything

V-D2D -Vehicular Device-to-device

VUEs -Vehicular Users

Nomenclature and Notation

Bold lower-case letters denote column vectors.

Bold Capital letters denote matrices.

$(\cdot)^\dagger$ denotes pseudo-inverse of a matrix.

$\overline{x}$ denotes the mean of x.

$\|\mathbf{x}\|$ denotes the norm of the vector $\mathbf{x}$.

$\mathbb{E}[\mathbf{x}]$ denotes the expectation of $\mathbf{x}$.