

UNIVERSITY OF TECHNOLOGY SYDNEY
Faculty of Engineering and Information Technology

**Resource Optimization for Communication and
Radar Sensing in Vehicular Networks**

by

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A THESIS SUBMITTED
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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.

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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 Underlying 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

Certificate	ii
Abstract	iii
Dedication	v
Acknowledgments	vi
List of Publications	viii
0.1 Publications Related to This Thesis	viii
List of Figures	xiii
Abbreviation	xvii
Notation	xix
1 Introduction	1
1.1 Research Background	1
1.2 Motivation and Objectives	3
1.2.1 Critical Delay and Reliability of Vehicular Communications . .	3
1.2.2 Limited Resources for Vehicular Networks and Predictability of Traffic Flow	4
1.2.3 Green Transportation Systems	4
1.3 Approach and Contribution	5
1.4 Thesis Organization	6
2 Literature Review	8
2.1 Communication and Radar Sensing in Vehicular Networks	8

2.2	Resource Optimization for Vehicular Communications	10
2.2.1	Resource Management for Cellular V2X Communications	11
2.2.2	Prediction for Vehicular Traffic Flow	15
2.3	Resource Optimization for Automotive Radars	15
3	Semi-Persistent Resource Allocation Based on Traffic Prediction for Vehicular Communication	19
3.1	Bandwidth-Constrained Semi-persistent Resource Allocation Scheme in Two-tier Cellular Networks	20
3.1.1	System Model for Semi-persistent Resource Allocation	20
3.1.2	Vehicular Traffic Prediction Based on kNN	27
3.1.3	Minimization of Average Relative Latency	33
3.1.4	Simulation Results	36
3.2	Latency-Constrained Semi-persistent Resource Allocation Scheme in Two-tier Cellular Networks	46
3.2.1	System Model and Problem Formulation	46
3.2.2	LMMSE Predictor for Network Traffic and Optimization of Cost Function	49
3.2.3	Simulation Results	52
3.3	Summary	56
4	V-D2D Mode Selection Underlying Two-tier Cellular Networks	59
4.1	System Overview and Problem Formulation	60
4.2	Optimal Mode Selection with Energy Minimization	63
4.2.1	Energy Minimization based on Macro Cellular Mode	64

4.2.2	Energy Minimization based on V-D2D Mode	66
4.2.3	Energy Minimization based on RSU Mode	67
4.2.4	Mode Selection Scheme	68
4.3	Analysis and Simulation Results	69
4.3.1	Simulation Setup	69
4.3.2	Results	70
4.4	Summary	73
5	Interference Characterization and Power Optimization for Automotive Radar with Directional Antenna	74
5.1	System and Signal Models	75
5.1.1	Geometrical Model	75
5.1.2	Radar Reception	77
5.2	Interference Characterization	80
5.2.1	Interference Characterization in Two-line Scenarios	81
5.2.2	Extension to Multiple-lane Scenarios	85
5.3	Minimization of Radar Transmission Power	88
5.3.1	Optimization in Two-lane Scenarios	88
5.3.2	Optimization in Multiple-lane Scenarios	91
5.4	Simulation Results and Discussion	94
5.4.1	Simulation Setup	94
5.4.2	Radar Mean Interference	95
5.4.3	Power Minimization Results	100
5.5	Summary	103
6	Conclusions	107

6.1 Summary	107
6.2 Future Work	108
Bibliography	111

List of Figures

2.1	An illustration of vehicular networks on an urban road.	9
3.1	RSU-cellular architecture and the segmented road model.	21
3.2	Illustration of latency for each timeslot in the n -th segment for the period $(t, t + 1)T_s$. Each period contains tens to hundreds of such timeslots.	25
3.3	Processing flow of the ST-kNN algorithm.	29
3.4	Illustration of traffic correlation and the windowing concept.	31
3.5	Illustration of the BC-WFA water-filling for dynamic resource allocation.	35
3.6	The traffic volume during off-peak and peak time period, respectively.	39
3.7	Prediction results with different k and q values in Segment 5.	40
3.8	Predicted and real traffic flow in a day in Segment 5 using (a) ST-kNN and (b) LMMSE algorithm. Time interval between the plotted samples is 5 minutes. The average MAPE values for ST-kNN and LMMSE are 0.098 and 0.1063, respectively.	40
3.9	Average relative latency versus θ for DS and SPS during off-peak and peak time. For PS, the averaged latencies are 1.1650 and 1.1404, respectively. Signalling latency is $t^s = 15\text{ms}$ and $a = 0.9$	42
3.10	Bandwidth efficiency versus θ for DS and SPS during off-peak and peak time. The averaged bandwidth efficiencies for PS are 85.45% and 87.91%, respectively.	43

3.11	Optimal θ values for different total bandwidth $B = aE_t(\sum_n B_n^{\text{req}}(t))$ for SPS.	44
3.12	Variation of average relative latency with the total bandwidth. Signalling delay is set as 15 ms.	45
3.13	The average relative time with varying relative signalling delay for three resource allocation schemes, where $\theta = 1.06$ and $\theta = 0.98$ for off-peak and peak time, respectively.	46
3.14	Two-tier cellular architecture and the segmented road model.	47
3.15	Minimum total bandwidth versus θ for dynamic and semi-persistent schemes; MAPE=5.63%; $t^s = 15\text{ms}$	53
3.16	Achieved total bandwidth versus signalling latency t^s for DS and SPS.	54
3.17	Optimal θ with varying signalling latency t^s	55
3.18	Prediction results with different M and L values in segment 5.	56
3.19	Total bandwidth versus θ for DS and SPS using real vehicle density data; MAPE=9.15%; $t^s = 15\text{ms}$	57
3.20	Total bandwidth versus signalling latency t^s for DS and SPS with the real vehicle density data; $\theta = 0.89$	58
3.21	Optimal θ versus signalling latency t^s	58
4.1	System model for V-D2D communication underlying two-tier heterogeneous cellular network with dynamic TDD scheme. V-UE ₁ communicates with V-UE ₂ via MBS, RSU or through a direct link.	61
4.2	V-D2D mode and RSU mode optimality area when minimizing the vehicles energy cost.	71
4.3	V-D2D mode and RSU mode optimality area when minimizing the overall network energy cost.	72

4.4	Percentage of energy saved in V-D2D mode compared with Mode A and Mode C.	72
5.1	The interference between automotive radars. (Red vehicles stand the interfering ones.)	76
5.2	Illustration of the signal strength and interference between automotive radars in different directions.	80
5.3	Illustration of the interference in multiple lanes.	86
5.4	Illustration of the optimal solution.	89
5.5	Analytical and simulated mean interference power at SR and FR, where $\sigma_f = 0.1112, \theta_f = 15^\circ$, and $\sigma_s = 0.5929, \theta_s = 80^\circ; \xi = 4\%$	96
5.6	MNAE between ULA and its Gaussian approximation for FR (left subfigure) and SR (right subfigure), with various beamwidth values.	97
5.7	Radiation pattern of a ULA and its Gaussian approximation for FR, where $\sigma_f = 0.1156, \theta_f = 15.6^\circ$ and SR, where $\sigma_s = 0.4373, \theta_s = 59^\circ$. In this specific example, the ULA has 10 and 3 antennas for the FR and SR, respectively.	98
5.8	Ratio $\overline{I^{ff}}/\overline{I^f}$ of FR (left sub-figure) and $\overline{I^{ss}}/\overline{I^s}$ of SR (right sub-figure), $\rho = 1/50$	99
5.9	Analytical and simulated results for the mean interference power at FR with varying beamwidth. In the right sub-figure, $\rho = 1/20; \xi = 4\%$	100
5.10	Variation of the SIR for FR with beamwidth, where $R_f = 30\text{m}$, $\theta_s = 60^\circ$ (left) and $\theta_f = 10^\circ$ (right), $\rho = 1/50; \xi = 4\%$	101
5.11	Analytical and simulated results for the mean interference power of SR with varying beamwidth. In the right sub-figure, $\rho = 1/20; \xi = 4\%$	102
5.12	Total minimized transmission power with a Gaussian beam for varying vehicle densities in a two-lane scenario.	103

5.13	Optimal total transmission power based on simulated results in two-lane case, where $\theta_f = 15^\circ$, $\theta_s = 60^\circ$, $\xi = 4\%$ and $\rho = 0.02$	104
5.14	Minimum transmission power with varying θ_f and θ_s in a two-lane scenario, where $\rho = 1/50$ and $\xi = 4\%$, $\theta_s = 60^\circ$ (left), and $\theta_f = 15^\circ$ (right).	105
5.15	Variation of minimum transmission power with vehicle density in a multi-lane scenario, where $\xi = 4\%$	106
5.16	Minimum transmission power with varying θ_f and θ_s , where $\theta_s = \theta_{s_1} = \theta_{s_2}$, $\rho = 1/50$ and $\xi = 4\%$. In the left subfigure, $\theta_{s_1} = \theta_{s_2} = 60^\circ$, and in the right sub-figure, $\theta_f = 15^\circ$	106

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.

\bar{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} .