Modeling the Medium Access Control Layer Performance of Cellular Vehicle-to-Everything Mode 4 and IEEE 802.11p

Wijesiri Narayana Badal Arachchige Geeth Priyankara

(188008U)

Thesis submitted in partial fulfillment of the requirements for the degree
Doctor of Philosophy

Department of Electronic and Telecommunication Engineering

University of Moratuwa
Sri Lanka

December 2021

Declaration

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Signature: Dr. Tharaka Samarasinghe Date: 16th February 2023

Abstract

The capability of vehicle-to-everything (V2X) communication to wirelessly exchange information on speed and location of vehicles over an ad hoc network envisions promise substantially reducing vehicle collisions, congestion, fuel usage and pollution. V2X communication plays a pivotal role in intelligent transport systems (ITS), with IEEE 802.11p and cellular V2X (C-V2X) being the two competing enabling technologies. This thesis focuses on discrete-time Markov chain (DTMC) based modeling of the medium access control (MAC)-layer performance of the two enabling technologies for evaluation, comparison and enhancement. Firstly, DTMC-based models for the MAC layer operations of IEEE 802.11p and C-V2X Mode 4 are developed, considering periodic and event-driven messages. The results show that IEEE 802.11p is superior in average delay, whereas C-V2X Mode 4 excels in collision resolution, which leads to its higher throughput. Then, the models are extended to support the parallel operation of four multi-priority data streams, which are crucial for quality of service (QoS). Results show that IEEE 802.11p is superior in maintaining fairness among multi-priority data streams. It is also shown that the higher delay values in C-V2X lead to unfavorable packet delays in the low priority streams. The thesis studies the allocation of multiple candidate single-subframe resources (CSRs) per vehicle as a solution. It proposes a methodology to determine the number of CSRs for each vehicle based on the number of total vehicles, and to assign the multiple data streams for simultaneous transmission. The numerical results highlight the achievable delay gains of the proposed approach and its negligible impact on packet collisions.

Index terms— C-V2X Mode 4, discrete-time Markov chain, IEEE 802.11p, medium access control, multi-priority data streams.

Acknowledgements

First and foremost, I would like to thank my supervisor, Dr. Tharaka Samarasinghe, for offering me an opportunity to pursue my Ph.D. in the Department of Electronic and Telecommunication Engineering, University of Moratuwa (UoM). I am deeply grateful to him for the guidance, immense support, confidence, and invaluable encouragement during my Ph.D. research. He has always emphasized the importance of quality in research, which has helped me in my achievements in the past years. I am also grateful to my co-supervisor, Adjunct Professor Dr. Jussi Haapola from the Centre for Wireless Communication (CWC), University of Oulu, Finland, for the guidance provided to me during my doctoral studies. His comments and the opportunity provided to me to visit CWC contributed immensely to the scientific quality of my research. I wish to express my sincere gratitude to Professor Premanandana Rajatheva at the University of Oulu, Finland, and Professor Dileeka Dias at the UoM, Sri Lanka, for the guidance, support, inspiration, encouragement they have provided, and the confidence shown in me throughout my research career.

I want to thank the UoM, Sri Lanka, for providing me with excellent facilities, and a good work environment to conduct my research. My gratitude also goes to the CWC, University of Oulu, Finland, who provided me financial support and offered me an opportunity to pursue my Ph.D. at a top-notch research unit. I would also like to thank my university, the University of Ruhuna (UoR), Sri Lanka, where I am currently working as a lecturer and did my undergraduate degree, for providing me financial support during my Ph.D., and a sound technical foundation to carry out post-graduate studies and research.

In addition to my supervisors, it is a pleasure to also thank the following members of my Ph.D. progress review panel for their advice and support - Prof. Ruwan Udayanga, Prof. Frank Yong Li, and Dr. Prathapasinghe Dharmawansa. Special thanks go to Professor Frank Yong Li, University of Agder, Norway, who was my master thesis supervisor, for providing me encouragement and guidance throughout my Ph.D. I would also like to thank the Faculty of Graduate Studies,

Postgraduate Studies Division, and the administrative staff at the department of Electronic and Telecommunication Engineering of the UoM, who helped me in various administrative activities related to my Ph.D.

I also wish to extend my gratitude to all the academic and non-academic staff of the Faculty of Engineering, UoR. Special thanks go to Dr. Keerthi Gunawickrama, Dr. Rajitha Udawalpola, Dr, Anuradha Indika and Mr. Eranda Jayathunge at the Faculty of Engineering, UoR.

I want to express my unreserved gratitude to my mother Mallika De Silva and father Rathnasiri Wijesiri for their love, kindness, support, and encouragement provided throughout my life. The dedications you have made during my life are priceless. I am also grateful to my parents-in-law for their blessings. I also wish to extend my thanks to my cousin, Mr. Aruna Buddika, and brother-in-law Dr. Lalindra Ranaweera, for their continuous support. Then, to my sweet little three sons Kuvindu, Jeniru, and Yumeth thank you for bringing happiness to my life and that crucial motivation required to get things done. Finally, I would like to express my deepest gratitude to my loving wife, Isuru. Without your love, concern, understanding, encouragement, and support, none of this would have been possible.

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List of Abbreviations

Abbreviation	Description
3GPP	Third generation partnership project
AC	Access category
AIFS	Arbitrary inter-frame space
C-V2X	Cellular vehicle-to-everything
CAM	Cooperative awareness messages
CCH	Control channel
CSMA/CA	Carrier sense multiple access with collision avoidance
CSR	Candidate single-subframe resources
CTMC	Continuous time Markov chains
CTS	Clear to send
CW	Contention window
D2D	Device-to-device
DCC	Decentralized congestion control
DENM	Decentralized environmental notification messages
DSRC	Dedicated short-range communication
DTMC	Discrete-time Markov chain
ETSI	European telecommunications standards institute
GPS	Global positioning system
HPD	High priority DENM
ICT	Information communication technology
ITS	Intelligent transport systems
LTE	Long-term evolution
MAC	Medium access control
MHD	Multi-hop DENM
OSI	Open system interconnection
PHY	Physical
QoS	Quality of service
RC	Reselection counter
RTS	Request to send
SC-FDMA	Single-carrier frequency-division multiple access
SCI	Sidelink control information
SPS	Semi-persistent scheduling
TB	Transport block
TRC	Transmit rate control
TTI	Transmission time interval
URLLC	Ultra-reliable low-latency communication
WHO	World health organization