

**MODELING THE MEDIUM ACCESS CONTROL LAYER  
PERFORMANCE OF CELLULAR  
VEHICLE-TO-EVERYTHING MODE 4 AND IEEE  
802.11P**

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## Declaration

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## 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.

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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