

A DISSERTATION SUBMITTED IN FULFILMENT OF THE
REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

Optimized Communication in 5G-Driven Vehicular Ad-hoc Networks (VANETs)

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Declaration Of Authorship

I, Ammara Anjum Khan, declare that this thesis titled, *Optimized Communication in 5G-Driven Vehicular Ad-hoc Networks (VANETs)*, is submitted in fulfilment of the requirements for the award of doctor of philosophy, in the Faculty of Engineering and Information Technology (FEIT), at the University of Technology Sydney.

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Dedication

I would like to dedicate this work to my beloved mother (Najma Khan) and my late beloved father (Salah Uddin Khan) whose dreams for me have resulted in this achievement. I thank my mother with all my heart for all her prayers and unconditional love and care that kept me flourishing throughout the journey of my PhD.

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List of Abbreviations

VANETs	Vehicular Ad-hoc Networks
VCNs	Vehicular Communication Networks
VCI	Vehicular Communication Infrastructure
HetVANETs	Heterogeneous Vehicular Ad-hoc Networks
5G	Fifth generation
IoT	Internet of-Things
SD-IoV	Software Defined Internet of Vehicles
ITS	Intelligent Transportation Systems
V2V	Vehicle to Vehicle
V2I	Vehicle to Infrastructure
RSU	Road Side Units
CPRI	Common Public Radio Interface
D2D	Device-to-Device
E2E	End-to-End
QoS	Quality-of-Service
LTE-A	Long Term Evolution Advanced
EGT	Evolutionary Game Theory
SDN	Software Defined Networking
NFV	Network Function Virtualization
C-RAN	Cloud-Radio Access Network
MEC	Mobile Edge Computing
BBU	Base Band Unit
RRH	Remote Radio Head
OTN	Optical Transmission Network

List Of Abbreviations

FC	Fog Computing
FC-ZCs	Fog Computing-Zone Controllers
FC-CHs	Fog Computing-Cluster-heads
FC-Vehicles	Fog Computing-Vehicles
FC-BBUCs	Fog Computing BBU Controllers
ZC	Zone Controller
D	Delay
T	Throughput
C	Cost
CN	Core Network
eNB	Evolved node B
GA	Genetic Algorithm
Min-BBUC	Minimise number of FC-BBUCs
Cap-LB	Capacity Load Balance
Min-Delay	Minimize Delay
FC-ZC-per-BBUC-Bal	FC-ZCs per BBUC Balance Algorithm
CTL	Constant Traffic Load
H-FLGA	Hybrid-Fuzzy Logic guided Genetic Algorithm
FIS	Fuzzy Inference System
ToS	Type of Service
EC	Edge Cloud
CN	Core Network Cloud
KPIs	key performance Indicators

List of Parameters

$G = \langle N, H, S, u_{C_h} \rangle$	EGT game
$S = \{C_h, M\}$	Strategy set for vehicular nodes
s_i	Current strategy of node i
$N = \{1, 2, \dots, n\}$	Set of vehicular nodes
$H = \{1, 2, \dots, j\}$ with $j \subset N$	Set of clusters
u_{C_h}	net utility of a cluster head
$p_i(s_i)$	Cost function
T_{TC}	Total throughput of cluster
c_1	link capacity between the cluster head and the RSU
$c_j, j \subset N$	link capacity between a member j within the cluster and CH
d_H	distance between the cluster head and the RSU
$d_{M,j}$	distance between a member j from the cluster head
γ	Speed to convergence
$\bar{U}(t)$	average payoff of the entire population of clusters
$u_{C_{h_i}}(t)$	payoff to become a cluster head
$p_{H_i}(t)$	proportion of vehicles choosing cluster H_i
T_{TC}	average total throughput capacity of a given cluster
n_e	Equilibrium point
$ZC = \{ZC_1, ZC_2, \dots, ZC_n\}$	set of Fog Computing Zone Controllers
n_{ZC}	Number of FC-ZCs
n_{BBUC}	Number of BBUCs
$Links = \{BBUC_i, ZC_j\}$	set of possible link pairs between FC-BBUCs and FC-ZCs
$Cost_{i,j}$	link cost for linking ZCs j and $BBUC_i$
D	average load demand across all BBUCs
D_i i^{th}	element indicating the total load demand in $BBUC_i$
N_i	i^{th} total number of FC-ZCs connected to $BBUC_i$
$(ToS) = \{D, T, C\}$	requirement of customers based Throughout, Delay and Cost

List Of Parameters

ω_1	Weight of Min-BBUC cost function
ω_2	Weight of Cap-LB cost function
ω_3	Weight of Min-Delay cost function
ω_4	Weight of FC-ZC-per-BBUC-Bal cost function
ω_5	Weight of CTL cost function
$d_{fronthaul}$	maximum front-haul distance
$v_{fronthaul}$	link propagation speed
δ_{RTT}	Round Trip Time
$\tau_{OWD}(ms)$	one way delay

Abstract

Next generation Vehicular Ad-hoc Networks will be dominated by heterogeneous data and additional massive diffusion of Internet of Things (IoT) traffic. To meet these objectives, a radical rethink of current VANET architecture is essentially required by turning it into a more flexible and programmable fabric.

This research endeavours to provide next generation 5G-driven VANET architecture, with solutions for efficient and optimized communication.

This thesis first introduces an innovative 5G-driven VANET architecture to provide flexible network management, control and high resource utilization, leveraging the concepts of SDN, C-RAN and Fog Computing. A new Fog Computing (FC) framework (comprising of zones and clusters) is proposed at the edge of the network to support vehicles and end users with prompt responses, and to avoid frequent handovers between vehicles and RSUs. The key results are improved throughput, reduced transmission delay and minimized control overhead on the controller.

Furthermore, a novel Evolutionary Game Theoretic (EGT) framework is presented to achieve stable and optimized clustering in the Fog Computing Framework. The solution of the game is presented to be an evolutionary equilibrium. The equilibrium point is also proven analytically and the existence of an evolutionary equilibrium is also verified using the Lyapunov function. The results are analysed for different number of clusters for different populations and speeds. An optimal cost is suggested that defines an optimum clustering thus reducing an overhead of frequent cluster reformation.

In addition, this thesis provides a Hybrid-Fuzzy Logic guided Genetic Algorithm (H-FLGA) approach for the SDN controller, to support diversified quality of service (QoS) demands and dynamic resource requirements of mobile users in 5G-driven VANET architecture. The proposed Fuzzy Inference System (FIS) is used to optimize weights of multi-objectives, depending on the Type of Service (ToS) requirements of customers. The results proved that the proposed hybrid H-FLGA performs better than GA. The results improve spectral efficiency and optimizes connections while minimizing E2E delay and further facilitates the service providers to implement a more flexible customer-centric network infrastructure.

Furthermore, an end-to-end (E2E) network slicing framework is proposed to support customized services by managing the cooperation of both the RAN and Core Network (CN), using SDN, NFV and Edge Computing technologies. A dynamic radio resource slice optimization scheme is proposed to slice the overall bandwidth resources for mission critical and non-mission critical demands. The results meet ultra reliability and E2E latency of mission-critical services.

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