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.

I confirm that:

- This thesis is wholly my own work unless otherwise referenced or acknowledged
- The work is done solely while in candidature for a research degree at this University.
- All information sources and literature used are indicated in the thesis.
- This document has not been submitted/published for qualifications at any other academic institution.
- This research is supported by the Australian Government Research Training Program (RTP).

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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 $i$ |
| $N = \{1, 2, ...., n\}$ | Set of vehicular nodes |
| $H = \{1, 2, ......, j\}$ 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 |
| $\gamma$ | 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 |
| $ZC = \{ZC_1, ZC_2, ..., ZC_n\}$ | 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

| | |
|---|---|
| $\omega_1$ | Weight of Min-BBUC cost function |
| $\omega_2$ | Weight of Cap-LB cost function |
| $\omega_3$ | Weight of Min-Delay cost function |
| $\omega_4$ | Weight of FC-ZC-per-BBUC-Bal cost function |
| $\omega_5$ | Weight of CTL cost function |
| $d_{fronthaul}$ | maximum front-haul distance |
| $\upsilon_{fronthaul}$ | link propagation speed |
| $\delta_{RTT}$ | 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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