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Novel Architectures and Networking Solutions for Intelligent Mobile Edge Computing Networks

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Doctor of Philosophy

under the supervision of Dr. Diep N. Nguyen, Dr. Dinh Thai Hoang, and Prof. Eryk Dutkiewicz

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I, YURIS MULYA SAPUTRA declare that this thesis, is submitted in fulfilment of the requirements for the award of DOCTOR OF PHILOSOPHY, in the Faculty of Engineering and Information Technology at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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ABSTRACT

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Mobile edge computing (MEC) has emerged as a highly-effective solution to address the proliferation of smart devices and growing demands for computationally-intensive applications. The key idea of MEC networks is to distribute computing resources closer to mobile users (MUs) by deploying servers at the "edge" of the networks, i.e., mobile edge nodes (MENs). Nonetheless, the development of MEC networks has been facing various challenges including the decentralized nature, small coverage, unreliable computing/communication resources, and limited storage capacity of the MENs. This thesis aims to address the above challenges through developing novel collaborative architectures and intelligent networking strategies for MEC networks.

Firstly, we introduce a novel MEC network architecture that leverages an optimal joint caching-delivering with horizontal cooperation among MENs. Particularly, we first formulate the content-access delay minimization problem by jointly optimizing content caching and delivering decisions under various network constraints, aiming at minimizing the total average delay for the MEC network. Then, we design centralized and distributed solutions to find the decisions of joint caching and delivering policy for the transformed problem.

As the second contribution, we propose a novel economic-efficiency framework for the MEC network to maximize the profits for MENs. Specifically, we first introduce a demand prediction method for MENs leveraging federated learning (FL) approaches. Based on the predicted demands, each MEN can reserve demands from the MEC

service provider (MSP) in advance to optimize its profit. Nonetheless, due to the competition among the MENs as well as unknown information from the MSP, we develop a multi-principal one-agent (MPOA) contract-based utility optimization under the MSP's constraints as well as other MENs' contracts. We then develop an iterative algorithm to find the optimal contracts for the MENs.

Finally, we propose a novel dynamic FL-based framework leveraging dynamic selection of MENs for the FL process in the MEC network. Particularly, the MSP first implements an MU selection method to determine a set of the best MUs for the FL process according to the location and information significance at each learning round. Then, each selected MU can collect information and offer a payment contract to the MSP based on its collected QoI. For that, we develop an MPOA contract-based policy to maximize the profits of the MSP and learning MUs under the MSP's limited payment budget and asymmetric information between the MSP and MUs.

Dedication

To my beloved wife, son, parents, parents-in-law, university, and country, Indonesia.

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List of Publications

Book Chapters

B-1. **Y. M. Saputra**, D. T. Hoang, D. N. Nguyen, E. Dutkiewicz, and D. Niyato, "Wireless Edge Caching for Mobile Social Networks," in *Wireless Edge Caching: Modelling, Analysis, and Optimization*, Cambridge University Press, Mar. 2021. `https://www.cambridge.org/au/academic/subjects/engineering/wireless-communications/wireless-edge-caching-modeling-analysis-and-optimization?format=HB`. (Partly corresponding to Chapter 1)

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J-1. **Y. M. Saputra**, D. T. Hoang, D. N. Nguyen, and E. Dutkiewicz, "A Novel Mobile Edge Network Architecture with Joint Caching-Delivering and Horizontal Cooperation," *IEEE Transactions on Mobile Computing*, vol. 20, no. 1, pp. 19-31, Jan. 2021. `https://ieeexplore.ieee.org/document/8821308`. (Corresponding to Chapter 2)

J-2. **Y. M. Saputra**, D. N. Nguyen, D. T. Hoang, T. X. Vu, E. Dutkiewicz, and S. Chatzinotas, "Federated Learning Meets Contract Theory: Economic-Efficiency Framework for Electric Vehicle Networks," Early Access, *IEEE Transactions on Mobile Computing*, Dec. 2020. `https://ieeexplore.ieee.org/document/9300192`. (Corresponding to Chapter 3)

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4)

C-5. **Y. M. Saputra**, D. N. Nguyen, D. T. Hoang, and E. Dutkiewicz, "Incentive Mechanism for AI-Based Mobile Applications with Coded Federated Learning," presented in *IEEE GLOBECOM*, Madrid, Spain, Dec. 2021.

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O-1. T. V. Khoa, **Y. M. Saputra**, D. T. Hoang, N. L. Trung, D. N. Nguyen, N. V. Ha, and E. Dutkiewicz, "Collaborative Learning Model for Cyberattack Detection Systems in IoT Industry 4.0," in *IEEE WCNC*, Seoul, South Korea, May 2020, pp. 1-6. `https://ieeexplore.ieee.org/document/9120761`.

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Abbreviation

5G	The fifth generation technology standard for cellular networks
AADF	Average Annual Daily Flow
AUD	Australian Dollar
BS	Base Station
CLS	Cloud Server
CN	Core Network
CS	Charging Station
CSP	Charging Station Provider
D2D	Device-to-Device
DFEL	Decentralized Federated Energy Learning
DNN	Deep Neural Network
ETSI	The European Telecommunications Standards Institute
EV	Electric Vehicle
FL	Federated Learning
FNN	Feedforward Neural Network
FoA	Frequency-of-Access
GAMS	General Algebraic Modeling Language
GB	Giga Bytes
GPS	Global Positioning System
HetNets	Heterogeneous Networks
iBBA	Improved Branch-and-Bound Algorithm
IC	Incentive Compatibility
IEEE	Institute of Electrical and Electronics Engineers
i.i.d	independent and identically distributed
IL	Inner Level

IPM	Interior-Point Method
IoT	Internet-of-Things
IoV	Internet-of-Vehicles
IR	Individual Rationality
JOCAD	Joint Cooperative Caching and Delivering
kNN	k-Nearest Neighbor
kWh	kilo Watt hours
MB	Mega Bytes
MEC	Mobile Edge Computing
MEN	Mobile Edge Node
MINLP	Mixed Integer Non Linear Programming
ML	Machine Learning
MPOA	Multi-Principal One-Agent
MSP	MEC Service Provider
MU	Mobile User
MWh	Mega Watt hours
NP	Non-deterministic Polynomial-time
OL	Outer Level
QoI	Quality-of-Information
RAM	Random Access Memory
RMSE	Root Mean Square Error
RP	Root Problem
SGP	Smart Grid Provider
SNN	Shallow Neural Network
SP	Subproblem
SV	Smart Vehicle
UK	United Kingdom
UPF	User Plane Function
VSP	Vehicle Service Provider
Wi-Fi	Wireless Fidelity