UTS UNIVERSITY OF TECHNOLOGY SYDNEY

Mobile Edge Computing: From Task Load Balancing to Real-World Mobile Sensing Applications

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Thesis submitted in fulfilment of the requirements for the degree of

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under the supervision of Professor Xiangjian He

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Certificate of Authorship/Originality

I, Xiaochen Fan, declare that this thesis is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the School of Electrical and Data Engineering, 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.

This document has not been submitted for qualifications at any other academic institution.

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List of Publications

This thesis is based on the following publications [1–4]:

- **Chapter 3**

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- **Chapter 4**

  Shuang Lai, **Xiaochen Fan***, Qianwen Ye, Zhiyuan Tan, Yuanfang Zhang, Xiangjian He, Priyadarsi Nanda, FairEdge: A Fairness-Oriented Task Offloading Scheme for IoT Applications in Mobile Cloudlet Networks, *in* 'IEEE Access' 8 (2020): 13516-13526 (**Co-first Author and Corresponding author**).

- **Chapter 5**

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- **Chapter 6**

  Xiaochen Fan, Chaocan Xiang, Chao Chen, Xudong Song, Panlong Yang, Liangyi Gong, Priyadarsi Nanda, Xiangjiang He, BuildSenSys: Reusing Building Sensing Data for Traffic Prediction with Cross-domain Learning, *in* 'IEEE Transactions on Mobile Computing' (Tier A*) (2020) Early Access, DOI identifier 10.1109/TMC.2020.2976936.

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- Liangyi Gong, Chaocan Xiang, **Xiaochen Fan**, Tao Wu, Chao Chen, Miao Yu, Wu Yang, Device-free near-field human sensing using WiFi signals, *in* 'Springer Personal and Ubiquitous Computing' (2020): 1-14

- Chaocan Xiang, Zhao Zhang, Yuben Qu, Dongyu Lu, **Xiaochen Fan**, Panlong Yang, Fan Wu, Edge Computing-Empowered Large-scale Traffic Data Recovery Leveraging Low-rank Theory, *in* 'IEEE Transactions on Network Science and Engineering' (2020).

- Jiabin Li, Ming Liu, Zhi Xue, **Xiaochen Fan**, Xiangjian He, RTVD: A Real-Time Volumetric Detection Scheme for DDoS in the Internet of Things, *in* 'IEEE Access' (2020) 8: 36191-36201.

- **Xiaochen Fan**, Chaocan Xiang, Liangyi Gong, Xin He, Yuben Qu, Saeed Amirgholipour, Yue Xi, Priyadarsi Nanda, Xiangjian He, Deep Learning for Intelligent Traffic Sensing and Prediction: Recent Advances and Future Challenges, *in* 'CCF Transactions on Pervasive Computing and Interaction' (2020).

- **Xiaochen Fan**, Chaocan Xiang, Liangyi Gong, Xiangjian He, Chao Chen, Xiang Huang, UrbanEdge: deep learning empowered edge computing for urban IoT time series prediction, *in* 'Proceedings of the ACM Turing Celebration Conference-China' (2019): 1-6.

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- Xudong Song, **Xiaochen Fan**, Chaocan Xiang, Qianwen Ye, Leyu Liu, Zumin Wang, Xiangjian He, Ning Yang, Gengfa Fang, A Novel Convolutional Neural Network Based Indoor Localization Framework With WiFi Fingerprinting, *in* 'IEEE Access' 7 (2019): 110698-110709.

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- Yue Xi, Wenjing Jia, Jiangbin Zheng, **Xiaochen Fan**, Xiaoshui Huang, Jinchang Ren, Zhiyuan Tan, Xiangjian He, Simultaneous Recovery to Classify: Dual-Stream Representation Learning GAN for Low-Resolution Image Classification, *in* 'IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing': vol.14, pp. 1705-1716 (2021).

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Abbreviation

IoT - Internet of Things
MEC - Mobile Edge Computing
RAN - Radio Access Network
ISG - Industry Specification Group
ETSI - European Telecommunications Standards Institute
AR - Augmented Reality
C-V2X - Cellular Vehicle-to-Everything
IoV - Internet of Vehicles
VEC - Vehicular Edge Computing
MVC - Mobile Vehicular Cloudlet
CND - Content Delivery Network
AP - Access Point
RMSE - Root Means Square error
QoS - Quality of Service
QoE - Quality of Experience
DRL - Deep Reinforcement Learning
RSS - Radio Signal Strength
MCS - Mobile Crowd Sensing
SVT - Singular Value Thresholding
RNN - Recurrent Neural Network
LSTM - Long Short-Term Memory
MAE - Mean Absolute Error
MAPE - Mean Absolute Percentage Error
Seq2Seq - Sequence to Sequence

Dedication

To my parents Jian Fan and Chunlan Shi

To my wife Lu Lu

ABSTRACT

MOBILE EDGE COMPUTING: FROM TASK LOAD BALANCING TO REAL-WORLD MOBILE SENSING APPLICATIONS

by

Xiaochen Fan

With the rapid development of mobile computing technologies and the Internet of Things, there has been an increasing rise of capable and affordable edge devices that can provide in-proximity computing services for mobile users. Moreover, a massive amount of mobile edge computing (MEC) systems have been developed to enhance various aspects of people's daily life, including big mobile data, healthcare, intelligent transportation, connected vehicles, smart building control, indoor localization, and many others.

Although MEC systems can provide mobile users with swift computing services and conserve devices' energy by processing their tasks, we confront significant research challenges in several perspectives, including resource management, task scheduling, service placement, application development, *etc.* For instance, computation offloading in MEC would significantly benefit mobile users and bring new challenges for service providers. Unbalance and inefficiency are the two challenging issues when making decisions on computation offloading among MEC servers. On the other hand, it is unprecedented to design and implement novel and practical applications for edge-assisted mobile computing and mobile sensing. The power of mobile edge computing has not been fully unleashed yet from theoretical and practical perspectives.

In this thesis, to address the above challenges from both theoretical and practical perspectives, we present four research studies within the scope of MEC, including load balancing of computation task loading, fairness in workload scheduling, edge-

assisted wireless sensing, and cross-domain learning for real-world edge sensing. The thesis consists of two major parts as follows.

In the first part of this thesis, we investigate load balancing issues of computation offloading in MEC. First, we present a novel collaborative computation offloading mechanism for balanced mobile cloudlet networks. Then, a fairness-oriented task offloading scheme for IoT applications of MEC is further devised. The proposed computation offloading mechanisms incorporate algorithmic theories with the random mobility and opportunistic encounters of edge servers, thereby processing computation offloading for load balancing in a distributed manner. Through rigorous theoretical analyses and extensive simulations with real-world trace datasets, the proposed methods have demonstrated desirable results of significantly balanced computation offloading, showing great potential to be applied in practice.

In the second part of this thesis, beyond theoretical perspectives, we further investigate two novel implementations with mobile edge computing, including edge-assisted wireless crowdsensing for outdoor RSS maps, and urban traffic prediction with cross-domain learning. We implement our ideas with the iMap system and the BuildSenSys system, and further demonstrate demos with real-world datasets to show the effectiveness of proposed applications.

We believe that the above algorithms and applications hold great promise for future technological advancement in mobile edge computing.

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