A Dissertation submitted in fulfillment of the requirements for the degree of Doctor of Philosophy

A Software Defined paradigm for mobile networks

A feasible SDN based architecture solution for 5G networks

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Certificate of Original Authorship

I, Khaled Alghamdi 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 at the University of Technology Sydney. This thesis is wholly my own work unless otherwise reference 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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Dedication

I dedicate this thesis to my lovely father, mother, sister, beloved wife and our children for their love and support.

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Journal Papers

These papers have been prepared and published during the course of my research.

J-1. Khaled Alghamdi, *Performance Benchmark for Handoff with the Software Defined Network in Cellular Networks: A Simulation Approach*, International Journal of Scientific & Engineering Research, Volume 10, Issue 8, August-2019, ISSN 2229-5518

J-2. Khaled Alghamdi, *Deploying Hand Off Mechanism with the Software Defined Network vs Mobile IP for 5GNetwork: A Feasibility Study*, International Journal of Scientific & Engineering Research, Volume 10, Issue 8, August-2019, ISSN 2229-5518

J-3. Khaled Alghamdi, Robin Braun, *Software Defined Network (SDN) and OpenFlow protocol in 5G Network*, Scientific Research Publishing, Communications and Network (CN) journal", Vol. 12 No. 1 of February issue,2020, ID: 6101747

Abstract

There is a sharp increase in mobile devices that access the Internet with the rollout of Third generation technology standard (3G) and subsequently Fourth generation technology standard (4G), Long-Term Evolution (LTE) technologies by the Mobile Network Operators (MNO). In the Asia-Pacific region, the 4G connections have grown up to ~1 billion as of January 2016. The inevitable increase in the Internet users' base and the mobile devices has led to Internet Protocol (IP) addresses to be run out soon where IPv6 will enable bringing more than ever Internet users. The LTE Advanced networks deployments can soon reach their lifetime where the preparation for the fifth generation technology standard (5G) network is also widespread and rolling out is already taking place. For example, Australian mobile network Telstra has already brought one-third of the population under 5G signal coverage. Currently, the solutions related to supporting IP mobility have various drawbacks including huge signalling overheads, handover inefficiency and service update effect time to name a few.

As the mobile networks evolve towards 5G, the infrastructure network will have the capability to handle operational complexities and support unforeseen services that are diverse and likely to grow with demand for applications that include M2M (machine-to-machine) modules, video surveillance, smart cities, mobile industrial automation, and vehicle connectivity [56]. These applications include requirements that are divergent and will trigger mobile network performance and capabilities requirements at their extremity with more scalability and flexibility to be included. SDN technology using cloud computing as a carrier will play a critical and enabling role in designing the 5G wireless networks for Quality of Experience (QoE), service performance and network resilience as parameters to give greater freedom for balanced operations in these networks.

In this thesis, an investigation was carried out with the Software-Defined Network (SDN) controllers architecture for addressing many of IP Mobility issues primarily focusing on handover optimisation case studies. It is demonstrated through handover network simulations that SDN can handle next-generation mobility handover situations with the help of proper SDN interfacing, control layout and control logic algorithms. The experiments conducted predominantly benefitted from the OpenFlow protocol based SDN control and data forwarding plane as a proof of concept for deploying into real-world devices for mobile network management. The simulations showed a definite and considerable performance gain when using SDN based

solution compared to the traditional Mobile IP for mobility management from the perspective of the user equipment.

To accomplish a realistic simulation goal, careful consideration was given while selecting a network emulation platform which is flexible and can be modified and extended easily by external simulation processing modules. Mininet-WiFi emulator was selected and by synthesising SDN architecture a number of functionalities were implemented for the emulator which allowed designing realistic mobile network mobility use case scenarios and also scenarios pertaining to 5G networks applications for the network simulations. All the simulations carried out were extensively substantiated by the mobile network and SDN literature studies and reviews which helped define simulation parameters appropriately.

Nomenclature

General

3G	Third generation technology standard for broadband cellular networks
3GPP	3rd Generation Partnership Project
4G	Fourth generation technology standard for broadband cellular networks
5G	Fifth generation technology standard for broadband cellular networks
5G-PPP	The 5G Infrastructure Public Private Partnership
ACL	Access-control lists
AN	Access network
ANDSF	Access Network Discovery and Selection Function
AP	Access point
API	Application programming interface
AR	Access Router
ARP	Address Resolution Protocol
BDDP	Broadcast Domain Discovery Protocol
BS	Base station / Cellular site
BSC	Base station controller
BTS	Base Transceiver Station
CAPWAP	Control And Provisioning of Wireless Access Points
CC	Component Carrier

CDP	Cisco Discovery Protocol
CLI	Command Line Interface
CN	Correspondence node
CNet	Core network
COA	Care of Address
CoMP	Coordinated Multipoint Transmission and Reception
CPU	Central processing unit
C-RAN	Cloud Radio Access Network / Centralised Radio Access Network
CSMA	Carrier-Sense Multiple Access
CSN	Circuit-Switched Network
DCA	Dynamic Controller Assignment
DHCP	Dynamic Host Configuration Protocol
DiffServ	Differentiated services
DMM	Distributed Mobility Management
DNS	Domain Name System
DoS	Denial-of-Service attack
DPI	Deep Packet Inspection
eBPF	extended Berkeley Packet Filter
EDP	Extreme Discovery Protocol
EMMA	Energy Management Monitoring Application
EMS	Element Management System
eNodeB	Evolved Node B
EPC	Evolved Packet Core
ESP	Encapsulating Security Payload
ETSI	European Telecommunications Standards Institute

FA	Foreign Agent
FBACK	Fast Binding Acknowledgement
FBU	Fast-Binding Update
FHMIP	Fast Handover Mobile IP
FN	Foreign network
FNA	Fast Neighbor Advertisement
gNodeB	Next Generation NodeB
GPRS	General Packet Radio Service
GPS	Global Positioning System
GPU	Graphics Processing Unit
GSM	Global System for Mobile Communications
GTP	GPRS Tunnelling Protocol
HA	Home Agent
HACK	Handover Acknowledgement
HDTV	High Definition Television
HetNet	Heterogeneous network
HI	Handover Initiation
HMIP	Hierarchical Mobile IP
HN	Home network
HSPA	High Speed Packet Access
HSS	Home Subscriber Server
IaaS	Infrastructure as a Service
ICMP	Internet Control Message Protocol
ICT	Information and Communications Technology
IDMP	Intra domain Mobility Management protocol

IETF	Internet Engineering Task Force
IMS	IP Multimedia Subsystem
IoT	Internet of things
IP	Internet Protocol
IPC	Inter-process communication
IP-IP	IP in IP
ISO	International Organization for Standardization
LAN	Local area network
LCoA	Local Care of Address
LLDP	Link Layer Discovery Protocol
LTE	Long-Term Evolution
M2M	Machine to machine
MAC	Media Access Control
MAG	Mobile Access Gateway
MAP	Mobility Anchor Point
MCN	Mobile Core Networks
MEC	Mobile Edge Computing
MIH	Media Independent Handover
MIP	Mobile IP
MME	Mobility Management Entity
MN	Mobile node
MNO	Mobile Network Operator
MPG	Mobile access gateway
MSC	Mobile Switching Center / Mobile Station Center
MTC	Machine Type Communication

MWG	Mobile Working Group
NAR	New access router
NDP	Nortel Discovery Protocol
Netconf	Network Configuration Protocol
NFV	Network Functions Virtualisation
NGMN	Next Generation Mobile Networks
NMS	Network Management System
NOS	Network operating system
NVF	Network functions virtualisation
OEP	Ongoing Exchange Protocol
OF	OpenFlow
OFDP	OpenFlow Discovery Protocol
OMAG	OpenFlow Mobile Access Gateway
ONF	Open Networking Foundation
ONOS	Open Network Operating System
OS	Operating system
OSI	Open Systems Interconnection model
OSS	Operations Support System
OTA	Over-the-air
OVS	Open vSwitch
OVSDB	Open vSwitch Database Management Protocol
PaaS	Platform as a Service
PAN	Personal area network
PAR	Previous access router
PCC	Primary Component Carrier

PCRF	Policy and Charging Rules Function
PDN	Packet Data Network
P-GW	Packet Data Network Gateway
PLMN	Public Land Mobile Network
PMIP	Proxy Mobile IP
PoA	Point of Attachment
PoP	Point of presence
PRA	Proxy Router Advertisement
PSN	Packet-switched network
PSTN	Public Switched Telephone Network
QoE	Quality of experience
QoS	Quality of service
RAM	Random-access memory
RAN	Radio Access Network
RAT	Radio Access Technology
RCoA	Regional Care of Address
REST	Representational state transfer
RFC	Request for Comments
RMA	Resource Management Application
RN	Relay node
RNC	Radio Network Controller
RRM	Radio resource management
RSP	Router Solicitation for Proxy
RSSI	Received Signal Strength Indicator
RTT	Round Trip Time

SaaS	Software as a Service
SCC	Secondary Component Carriers
SCTP	Stream Control Transmission Protocol
SDN	Software Defined Networking
SDO	Standard Development Organization
SDR	Software-defined radio
SDWN	Software-defined wireless network
S-GW	Serving gateway
SIP	Session Initiation Protocol
SLA	Service Level Agreements
SPOF	Single point of failure
SSID	Service set identifier
TCP	Transmission Control Protocol
TMN	Telecommunications Management Network
TTFB	Time to First Byte
UDP	User Datagram Protocol
UE	User equipment
UMTS	Universal Mobile Telecommunications Service
UTS	University of Technology Sydney
VLAN	Virtual LAN
VMs	Virtual Machines
VoIP	Voice over IP
VPN	Virtual Private Networking
WAN	Wide Area Network
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless LAN
WLC	Wireless LAN controller
WTN	Wireless Token Network

Units

GB	gigabyte
Gbit	gigabit
Gbps	gigabit per second
GBps	gigabyte per second
GHz	gigahertz
GB/s	gigabyte per second
m	metre
m/s	metre per second
MB	megabyte
Mbps	megabit per second
Kbps	kilobits per second
MBps	megabyte per second
ms	millisecond
sec	second
Tbps	terabit per second

Conventions

Square brackets [ ] in computer command refers to the section of the command which needs to be replaced.

Dollar sign $ represents a non-administrative user in the Linux Bash command prompt.

Italic text refers to an entity or a group of similar entities of a larger system.

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