ENHANCEMENT ON 5G CELLULAR SYSTEM'S FRAMEWORK & ARCHITECTURE TO SUPPORT MISSION CRITICAL COMMUNICATIONS ENCOMPASSING MULTIMEDIA DATA AND VOICE COMMUNICATIONS

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ASIA e UNIVERSITY
2021

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NOREHAN YAHYA

A Thesis Submitted to Asia e University in
Fulfillment of the Requirements for the
Degree of Doctor Of Philosophy
(Information & Communication Technology)

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Abstract

Public Safety Networks (PSN) provide mission critical communications (MCC) to agencies providing emergency services like police, fire and ambulance. Most PSN Network Operators, including PMR A, utilize TETRA PSN systems for their voice communications, and cellular LTE for their broadband needs. To meet these purposes, they operate dual PSN hybrid network (LTE/TETRA), which are cost prohibitive and operationally inefficient. PMR A aspires to have a single PSN network using Cellular system that meets their MCC requirements provided that the technical gaps on the service offerings can be adequately addressed. PMR A characterized 'easy to use push to talk services with unlimited users for Groupcalls' as the most critical technical gap. To realize the single PSN MCC network aspiration, the opportunities made available from cutting edge mobile solutions delivered over telecommunication's new 5G Cellular Network Architecture will need to be fully exploited. Pursuant to this, the research objectives and methodology, were aimed at addressing gaps by providing 5G design recommendations to meet specific communication needs of MCC for multiple agencies over a single PSN network. The objectives and methodology are summarized as follows:

Objective 1: ***Identify*** MCPTT and MCC Performance Gap. Qualitative study and 5G Lab experiments were conducted to validate the 5G architecture technical gaps.

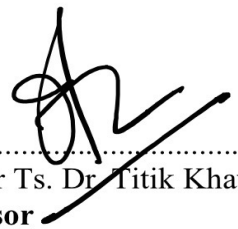
Objective 2: ***Develop*** 5G commercial network enhancements to support MCC. Qualitative study was used to develop and validate the 5G PSN architecture.

Objective 3: ***Improve*** the 5G PSN design using SDN to support multiple agency use. Qualitative study was used to develop and validate the 5G PSN architecture. The Theoretical Framework of this research was adapted from industry framework comprising of 5G Cellular system network elements (NE), inclusive of 5G Core, 5G Access Network, 5G QoS, 5G Applications and 5G Security. 'The Open Group Architecture Framework'

(TOGAF) approach was adopted for this qualitative research with 3GPP used as the standards benchmark. The most crucial research finding was, the 5G PSN network architecture support for ‘simple to use MCPTT with unlimited users for Group Calls’, was reflected as the ***deciding factor*** for migration from TETRA to 5G PSN network. To bridge this gap, and all the technical gaps acknowledged by industry experts, the research recommendations included enhancements to 5G NEs via implementation of ‘5G PSN Developmental Framework & Architecture’ that capitalizes on 3GPP’s ‘Group Communication System’, ‘evolved Multimedia Broadcast Multicast System’ and ‘User & Bearer Prioritization Tool’ architectures, incorporated with Network Slicing and Network Function Virtualization, delivered over Software Define Networks With this novelty, the research concluded that, migration towards a single 5G PSN deployment by PMR A, could be accelerated to meet evolving MCC needs.

APPROVAL

I certify that I have supervised / read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in quality and scope, as a thesis for the fulfillment of the requirements for the degree of Doctor of Philosophy.



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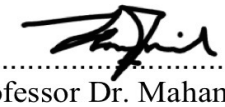

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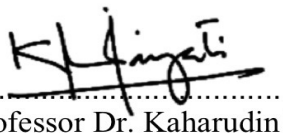

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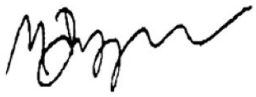

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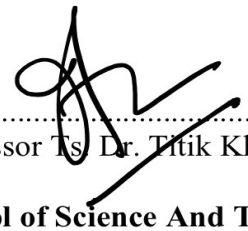

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DECLARATION

I hereby declare that the thesis submitted in fulfillment of the Doctor Of Philosophy (Information & Communication Technology) degree is my own work and that all contributions from any other persons or sources are properly and duly cited. I further declare that the material has not been submitted either in whole or in part, for a degree at this or any other university. In making this declaration, I understand and acknowledge any breaches in this declaration constitute academic misconduct, which may result in my expulsion from the programme and/or exclusion from the award of the degree.

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Signature of Candidate Date: July 2021

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List of Abbreviations

3GPP	3rd Generation Partnership Project
4G	4th Generation Mobile Systems (also known as LTE)
5G	5th Generation Mobile Systems
5G AN	5G Access Network
5GS	5G System
5G NR	5G New Radio
5G NSA	5G Non-Standalone
5G SA	5G Standalone
ADC	Application Detection and Control
AF	Application Function
AMBR	Aggregated Maximum Bitrate
AMF	Access and Mobility management Function
ARP	Allocation and Retention Priority
ASP	Application Service Provider
AUSF	Authentication Server Function
API	Application Programming Interface
APN	Access Point Name
CAPEX	Capital Expenditure
CDR	Charging Data Record
CN	Core Network
cRAN	Cloud Radio Access Network
CRM	Customer Relationship Management System
CSV	Coma Separated Values
D2D	Device to Device
DL	Downlink
DPI	Deep Packet Inspection
DC	Data Centre
DC	Dual Connectivity
DL	Downlink
DRX	Discontinuous Reception
EC-GSM	Extended-Coverage GSM
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
eMBMS	evolved Multimedia Broadcast/Multicast Service
eMBB	enhanced Mobile Broadband
eNB	eNodeB
gNB	gNodeB
eSIM	embedded Subscriber Identity Module
EPC	Evolved Packet Core
ePDG	evolved Packet Data Gateway
EPS	Evolved Packet System
eMBMS	Enhanced Multimedia Broadcast/Multicast Service
EPS	Evolved Packet System
FDD	Frequency-Division Duplexing
feICIC	Further Enhanced Inter-cell Interference Coordination
FR	First Responders
FMO	Future Mode Operations
GBR	Guaranteed Bit Rate

GCSE	Group Call System Enablers
GDP	Gross Domestic Product
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
GSMA	Global System for Mobile Communications Association
GTP	GPRS Tunneling Protocol
GBR	Guaranteed Bit Rate
GCSE	Group Call System Enablers
gNB	5G Node B
GSM-R	Global System for Mobile Communications – Railways
HA	High Availability
HeNB	Home eNodeB
HSPA	High Speed Packet Access
HTTP	Hypertext Transfer Protocol
IMS IP	Multimedia Subsystem
IOPS	Isolated LTE Operation for Public Safety
ITU-R	International Telecommunications Union, Radiocommunication sector
IaaS	Infrastructure as a Service
IDS	Intrusion Detection System
IMS	IP Multimedia Subsystem
IMT	International Mobile Telecommunications
I/O	Input/Output
IoT	Internet of Things
IPR	Intellectual Property Rights
IPX	Internetwork Packet Exchange
ITU	International Telecommunications Union
ITU-R	International Telecommunications Union, Radiocommunication sector
KPI	Key Performance Indicator
KQI	Key Quality Indicator
LAN	Local Area Network
LTE	Long Term Evolution
LTE-A	LTE Advanced
LMR	Land Mobile Radio (same as PMR)
LTE	Long Term Evolution
MC-PTT	Mission Critical Push to Talk
MCC	Mission Critical Communications
MCE	Multi-cell/Multicast Coordination Entity
MCS	Mission Critical Services
M2M	Machine to Machine
MBMS	Multimedia Broadcast / Multicast Service
MBSFN	MBMS over a Single Frequency Network
MBR	Maximum Bit Rate
MCMC	Malaysia Communication and Multimedia Commission
MEC	Mobile Edge Computing
MIMO	Multiple Input Multiple Output
MOCN	Multi-Operator Core Network
MMTC	massive Machine Type Communications
mmWave	Millimeter Wave
MPS	Multimedia Priority Service
MS	Mobile Station

MSC	Mobile Switching Centre
MT	Mobile Termination
MTC	Machine Type Communications
MU-MIMO	Multi-User MIMO
MVNE	Mobile Virtual Network Enabler
MVNO	Mobile Virtual Network Operator
NB-IoT	Narrow Band Internet of Things
NEF	Network Exposure Function
NFV	Network Function Virtualization
NGMN	Next Generation Mobile Networks
NNI	Network-Network Interface
NRF	Network Repository Function
NSA	Non Standalone
NSSF	Network Slice Selection Function
NSWO	Non-seamless Wi-Fi offload
OEM	Original Equipment Manufacturer
OPEX	Operating Expenditure
OSS	Operations Support Systems
OTT	Over the Top
PC	Personal Computer
PCF	Policy Control Function
PCRF	Policy and Charging Rules Function
PDCP	Packet Data Convergence Protocol
PDN	Packet Data Network
PLMN	Public Land Mobile Network
PMO	Present Mode Operations
P25	Project 25
PMR	Public Mobile Radio
PPDR	Public Protection and Disaster Relief
ProSe	Proximity Services
PSA	Public Safety Agency
PSMB	Public Safety Mobile Broadband
PTToC	Push to Talk over Cellular
PWS	Public Warning System
QCI	Quality Class Indicator
QFI	QoS Flow Identifier
RAN	Radio Access Network
RAT	Radio Access Technology
RCS	Rich Communication Services
RTP	Real Time Protocol
SDN :	Software-Defined Networking,
SIM	Subscriber Identity Module
SIP	Session Initiation Protocol
SMF	Session Management Function
TCCA	Tetra Critical Communications Association
TEA	Tiny Encryption Algorithm
TETRA	Terrestrial Trunked Radio
TM Forum	Telecommunications Management Forum
TRS	Trunked Radio Systems
UE	User Equipment

UPF	User Plane Function
UDM	Unified Data Management
URLCC	Ultra Reliable Low Latency Communications
vRAN	Virtual Radio Access Network
VoLTE	Voice over LTE
WAN	Wide Area Network
WRC	World Radio Conference

1. CHAPTER I: INTRODUCTION

1.1 Background of the Study

To prevent economic losses, maintain social order, and protect the well being of the citizens during public safety and crisis recovery situations, the efficient and effective delivery of time-critical information to first responders and victims play a key role (Bonde et. al., 2015). This delivery of time-critical information is referred to as Mission Critical Communications or MCC. The MCC is delivered using Public Safety Networks or 'PS Networks'. Despite the existence of more sophisticated Mobile Cellular Communications technology, Trunked Radio Systems still remain as the preferred technology for users particularly Public Safety Agencies or 'PSA' in the market as it offers a unique combination of cost-effectiveness, reliability and features that are not offered by other commercial Cellular Communications services (MCMC, 2009). Trunked Radio System is also able to serve a broad spectrum of users, including organisations with mostly mobile workers that require person-to-person and person-to-group radio communications to coordinate and facilitate their operations. Both the private and public sectors are amongst user groups of Trunked Radio Systems. Trunked radio users can be categorised into three distinct groups (MCMC, 2009):

a. Commercial and Light Industrial, such as hotels and transportation industry
b. Professional/Business Critical such as utilities, oil and gas industry and
c. Public Safety/Mission Critical used by first responders namely, police, ambulance and fire fighters.

Each group has their own needs and expectations from the systems and services

provided. The research is related to the Public Safety/Mission Critical Communications group of users. The selection of this research scope, is based on, the importance to the nation in terms of empowering our first responders to protect our communities better. And this can be achieved via improvements in situational awareness as well as life saving solution capabilities using next generation Public Safety Networks, potentially made available from cutting edge mobile solutions delivered over telecommunication's new 5G Cellular Network Architecture. Public Safety Networks (PSN) provide mission critical communications (MCC) to public safety agencies (PSA) offering emergency services such as police, fire and ambulance (Bonde et al., 2015).

As part of ensuring effective public safety support, Malaysia has deployed two PS Networks with nationwide radio coverage area using TETRA (referred as GIRN or Government Integrated Radio Network) and P25 (referred as RMPNet or Royal Malaysian Police Network) standards (MCMC, 2009). These legacy PS networks were built since 2008 and have been supporting first responders from various Malaysia PS Agencies namely Polis Diraja Malaysia (PDRM), Kementerian Kesihatan Malaysia (KKM), Jabatan Bomba & Penyelamat Malaysia (JBPM), Agensi Penguatkuasaan Maritim Malaysia (APMM), Jabatan Penjara Malaysia (JPM), Jabatan Imigresen Malaysia (JIM), Jabatan Sukarelawan Malaysia (RELA) and others. All the local Mobile Network Operators have not implemented any Public Safety Network over their commercial networks.

The PSN concept and ecosystem discussed in this Thesis covers various terminologies and associations as described in Figure 1.1. These terminologies, include, PSN (Public Safety Network), MCC (Mission Critical Communications), PSA (Public Safety Agencies), PMR (Private Mobile Radio), PMR networks (TETRA, P25), Cellular

Network (4G, 5G), PSN Standards (ETSI, APCO), PSN Cellular Standards (3GPP and ITU). Further details are discussed in Chapter 2.

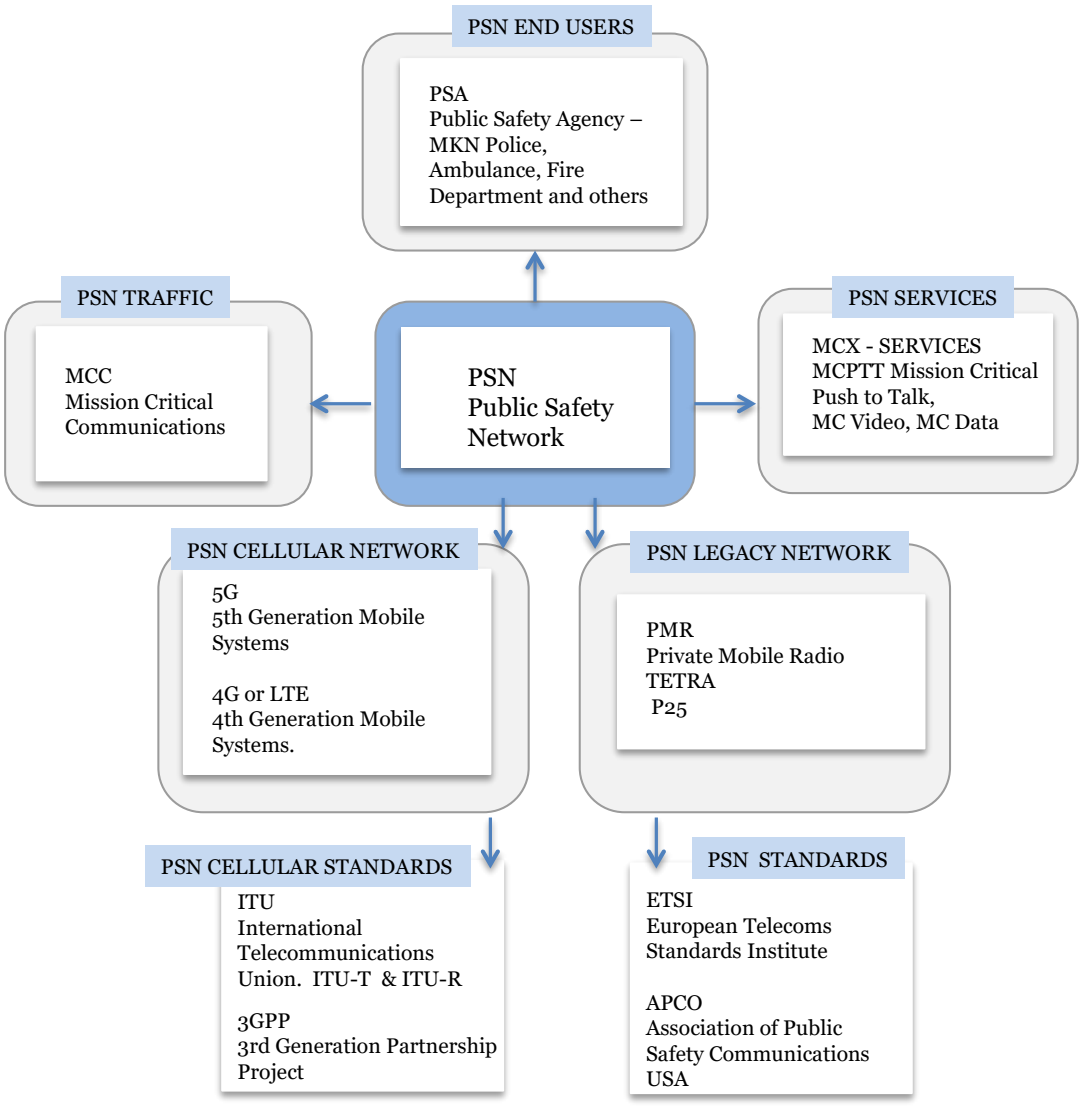

Figure 1.1: PSN and MCC Concept & Ecosystem used in Thesis

The PS Networks available in Malaysia namely P25 and TETRA as well as 4G Cellular Networks are described in the following sections:

1.1.1 P25 Standards Overview

P25 standard compliant technology has created the foundation for interoperable, digital, two-way wireless communications for public safety and emergency responders since

1989 and it has been deployed over two main phases, discussed as follows (ANSI, 2014) (P25, 2012):

a. **Phase 1:** Supports the following
    - IMBE voice codec.
    - operate in 12.5 kHz
    - FDMA access method.
    - 4 FSK modulation
    - 9.6 kbps total channel throughput.
b. **Phase 2:** Support the following
    - uses the AMBE+2 voice codec
    - aimed at improving spectral efficiency,
    - uses 2-slot TDMA scheme
    - 6 kbps for one voice channel.

    The P25 legacy PS Network in Malaysia is referred to as RMPNet and is exclusively used by PDRM (MCMC, 2009).

1.1.2 TETRA Standards Overview

Terrestrial Trunked Radio or 'TETRA' is known as Trans-European Trunked Radio. It is a European standard for a trunked radio system and was specifically designed to meet public safety requirements. The TETRA standards supports the following (TCCA, 2017):

a. TETRA Mobile Stations (MS) can communicate direct-mode operation (DMO). In emergency situations with no TETRA coverage, this feature allows direct communications between MS.

b. Status messages and short data services (SDS) are also offered.

c. TETRA provides for authentication of terminals, air interface encryption and end-to-end encryption as part of system security.

d. Group Calls of which a single button push will connect the user to the users in a selected call group and/or a dispatcher.

e. Access method : Time-Division Multiple Access (TDMA) with four user channels on one radio carrier and 25 kHz spacing between carriers.

1.1.3 LTE 4G 3GPP Standards Overview

The general trend in most countries reflects 4G LTE as the preferred Next Generation Public Safety network (TCCA, 2017).

However, is 4G LTE able to meet Mission Critical Communications requirements? According to Telecoms Academy LTE as a Public Safety Network does offer a lot of advanced communication features involving data, however the voice features are still being developed to meet PS expectations, and this architecture is reflected in Figure 1.2 and discussed as follows:

a. LTE specific enhancements for Public Safety communications
   - User friendly push to talk or 'walkie talkie' feature
   - Large scale push to talk group calls
   - Device to device or 'Direct Mode' voice communications
   - Network resilience

b. These capabilities are defined in LTE 3GPP Release 12 as well as 3GPP Release 13.

c. Voice over LTE or VoLTE requires major enhancements to meet PS requirements

d. Group Communications

- PTT and Group Communications is fundamental to most Public Safety Communications applications
- Group Communications (GC) are further defined at two levels GC System Enablers for LTE (R12) and Mission Critical Push To Talk or MCPTT (R13)
- The Group Communications System (GCS) Architecture is shown in Figure 1.2 and described in further detail in Appendix A (LTE Network Architecture)
- The GCS supports Unicast services as well as Multicast Broadcast

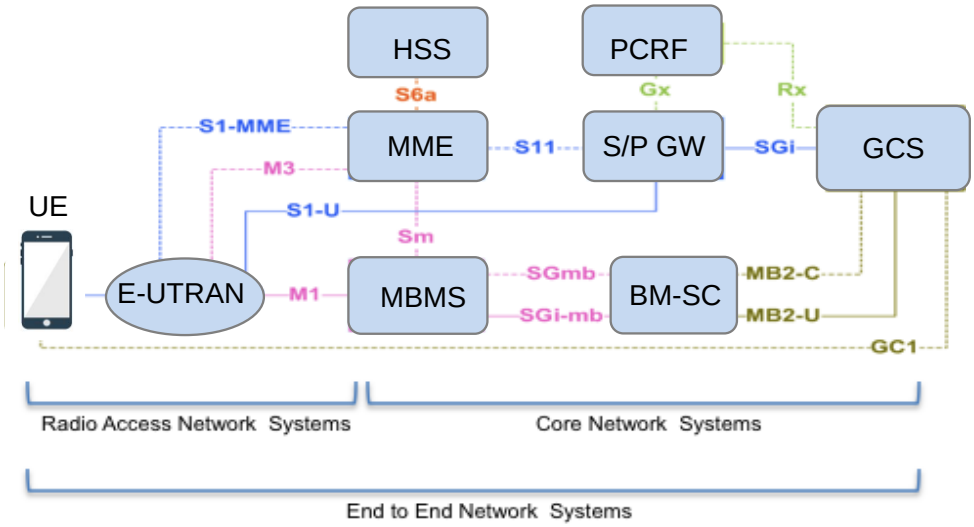

Figure 1.2: LTE as a Public Safety Communications network. Source: 3GPP, 2016

Considering voice features offered by 4G LTE are still being developed to meet PS expectations, Public Safety Agencies are still relying on PMR systems mainly P25 and TETRA for mission critical voice communications (TCCA, 2017). In summary, there will not be a 'one size fits all' solution. It's important to understand that current PS Network solutions such as TETRA and P25 will be still be required for the foreseeable future to deliver reliable mission critical voice and messaging services.