UNIVERSITI PUTRA MALAYSIA

USER REQUIREMENT EVALUATION OF CHANNEL CODING SCHEMES FOR 5G MOBILE COMMUNICATION SYSTEM IN TRANSMITTING SHORT LENGTH MESSAGES

ZAHRAA RAAD MAYOOF HAJIYAT

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By

ZAHRAA RAAD MAYOOF HAJIYAT

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

January 2019

أَعُوذُ بِاللهِ مِنَ الشَّيْطَانِ الرَّجِيمِ

(وَقُلْ رَبِّ زِدْنِي عِلْمًا)

طه (114)

DEDICATIONS

To my Dear Parents
for their prayers, love, care and endless encouragement
To my brothers and my sister
for always being there for me
To all of them, I say
Thank you very much

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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January 2019

Chairman : Aduwati Sali, Prof. PhD. Ir.
Faculty : Engineering

The fifth-generation (5G) communication system begins in the year 2020. Based on different user requirements, the 5G setting includes three scenarios; Enhanced Mobile Broadband (eMBB), Ultra-Reliable Low-Latency Communication (URLLC), and massive Machine-Type Communication (mMTC). mMTC and URLLC scenarios, each having their requirements, are main categories of Machine-Type Communication (MTC) scenario. The channel coding scheme needed for the 5G MTC is yet to be chosen. Hence, this thesis contributes to filling knowledge and practical gaps in the area of finding the most appropriate channel coding for both 5G MTC scenarios. This thesis selects, investigates and assesses the following channel coding schemes: Low-Density Parity-Check (LDPC), turbo, polar, systematic convolutional and non-systematic convolutional codes, with their design parameters (some outlined design parameters) for both 5G MTC scenarios. The method of this thesis is to uses the 5G MTC user requirements to investigate different channel coding schemes for different short length message transmission ($64 \leq k \leq 1024$ bits) with different code rates (1/4, 1/3, 1/2) on an Additive white Gaussian noise (AWGN) channel with Binary Phase-Shift Keying (BPSK) modulation. Then, it evaluates the performance of different channel coding schemes in the 5G MTC user requirements. A comprehensive assessment of five-different channel coding schemes for both 5G MTC scenarios is included. Results of the study would include decoder computational complexity, encoding and decoding computational latency, and reliability. Finally, the results are expected to lead towards determining the most appropriate channel coding schemes for both 5G MTC scenarios. The evaluation of results shows that Systematic Convolutional Code (SCC) scheme is the most appropriate channel coding scheme for the 5G MTC scenarios in transmitting short length messages ($k \leq 1024$ bits). Both Non-Systematic Convolutional Code (NSCC) and SCC satisfy the 5G MTC user requirements. NSCC scheme has a lower decoder computational complexity (8192 1.311 $\times 10^5$) than SCC scheme, but the SCC scheme has high-reliability of 10^{-5} to 10^{-7} with 1 to 2 dB channel gain compared to

NSCC scheme at the cost of small decoding computational latency difference of 2.062 $\times 10^{-4}$ - 1.398$\times 10^{-3}$ second.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENILAIAN PERMINTAAN PENGGUNA OLEH SKIM SALURAN PENGEKODAN BAGI SISTEM KOMUNIKASI MUDAH ALIH 5G DALAM PENGHANTARAN MESEJ PENDEK

Oleh

ZAHRAA RAAD MAYOOF HAJIYAT

Januari 2019

Pengerusi : Aduwati Sali, Prof. PhD. Ir.
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Sistem Komunikasi Generasi kelima (5G) bermula pada tahun 2020. Berdasarkan kepada keperluan pengguna yang berbeza, tetapan 5G termasuk tiga senario; Internet Jalur Lebar Mudah Alih yang Dipertingkatkan (eMBB), Komunikasi Kependaman Rendah Ultra-Boleh Dipercayai (URLLC), dan Komunikasi Jenis-mesin Besar (mMTC). Scenario mMTC dan URLLC, masing-masing mempunyai permintaan mereka, adalah kategori utama scenario Kominikasi Jenis - Mesin (MTC). Skim saluran pengekodan diperlukan untuk 5G MTC masih belum dipilih. Oleh itu, tesis ini menyumbang kepada pengisian pengetahuan dan sebagai praktikal dalam jurang bidang mencari tempat pengekodan saluran yang paling sesuai untuk kedua-dua senario 5G MTC. Tesis ini memilih, menyiasat dan menilai saluran skim pengekodan berikut: Pemeriksaan Pariti Rendah-Ketumpatan (LDPC), turbo, kutub, konvolusi sistematik dan Kod konvolusi bukan sistematik, dengan parameter reka bentuk mereka (beberapa parameter reka bentuk yang dinyatakan) bagi kedua-dua senario 5G MTC. Kaedah tesis ini adalah untuk menggunakan permintaan pengguna 5G MTC untuk menyiasat saluran yang berbeza pengekodan skim untuk penghantaran mesej pendek yang berbeza ($64 \leq k \leq 1024$ bits) dengan kadar kod yang berbeza (1/4, 1/3, 1/2) atas saluran tambahan bunyi Gaussian putih (AWGN) dengan Binary Fasa-Peralihan-Penunjuk (BPSK) modulasi. Kemudian, ia menilai prestasi skim saluran pengekodan yang berbeza dalam keperluan pengguna 5G MTC. Satu penilaian komprehensif skim pengekodan lima saluran yang berbeza untuk kedua-dua senario 5G MTC disertakan. Hasil kajian itu termasuk decoder pengiraan kerumitan, pengekodan dan penyahkodan kependaman pengiraan, dan kebolehpercayaan. Akhirnya, keputusan dijangka akan membawa ke arah menentukan skim saluran pengekodan yang paling sesuai untuk kedua-dua senario 5G MTC. Penilaian Hasil kajian menunjukkan bahawa skim sistematik konvolusi Kod (SCC) adalah skim saluran pengekodan yang paling sesuai untuk senario 5G MTC dalam penghantaran mesej pendek ($k \leq 1024$ bits). Kedua-dua bukan - sistematik konvolusi Kod (NSCC) dan SCC memenuhi permintaan pengguna 5G MTC. Skim NSCC

mempunyai decoder pengiraan lebih-rendah-kerumitan (8192 - 1.311×10^{5}) daripada skim SCC, tetapi skim SCC mempunyai kebolehpercayaan 10^{-5} ke 10^{-7} yang tinggi untuk dengan 1 hingga 2 dB saluran lebih berbanding dengan skim NSCC pada kos penyahkodan kecil perbezaan kependaman pengiraan 2.062×10^{-4} - 1.398×10^{-3} saat.

ACKNOWLEDGEMENTS

Firstly, Alhamdu Allah for everything and all my thanks belong to Allah for helping me to achieve my academic journey.

I would like to give special thanks to my parents, who supported me emotionally and financially, my brothers and my sister, who encouraged me in my life and throughout writing of this thesis.

I would like to express my sincere gratitude to my supervisor Prof. Dr. Ir. Aduwati Sali for the continuous support of my research study, motivation, and huge knowledge. Her guidance helped me in the research and writing of this thesis.

I would like to thanks a lot my supervisor's committee: Dr. Makhfudzah Mokhtar and Dr. Fazirulhisyam Hashim for their useful comments and encouragement.

Last but not least, I would like to thanks my lab friends for all the stimulating discussions, and the fun that we had in the last two years.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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This is to confirm that:

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

1G	First Generation
2G	Second Generation
3G	Third Generation
3GPP	3rd Generation Partnership Project
4G	Fourth Generation
5G	Fifth Generation
6G	Sixth Generation
802.16e	Wireless Broadband Standards of Mobile WiMAX
802.11n	Wireless Networking Standard of Wi-Fi Allowing MIMO
ASIC	Application-Specific Integrated Circuit
ASIP	Application-Specific Instruction Set Processor
AWGN	Additional White Gaussian Noise
BCH	Bose-Chaudhuri-Hocquenghem
BCJR	Bahl, Cocke, Jelinek and Raviv
BER	Bit Error Ratio
BF	Bit-Flipping
BP	Belief Propagation
BLER	Block Error Rate
BPSK	Binary Phase-Shift Keying
BSC	Binary Symmetric Channel
CC	Convolutional Code
CDMA-2000	Code Division Multiple Access-2000
cMTC	critical Machine-Type Communication
CN	Check Nodes
CRC	Cyclic Redundancy Check
dB	Decibel
DSL	Digital Subscriber Loop
DVB	Digital Video Broadcasting
DVB-S2	Digital Video Broadcasting -Satellite Second Generation
Eb/N0	Energy Per Bit to Noise Power Spectral Density Ratio
eMBB	enhanced Mobile Broadband
FlexiChaP	Flexible Channel Coding Processor
FlexiTreP	Flexible Trellis Processor
IMT-Advanced	International Mobile Telecommunications-Advanced
ITU	International Telecommunication Union
LDPC	Low-Density Parity-Check
Log	Logarithm
Log-MAP	Logarithm-Maximum A Posteriori Probability
LTE	Long-Term Evolution
LTE-TBCC	Long-Term Evolution- Tail Biting Convolutional Codes
LTE-Turbo	Long-Term Evolution- Turbo
M2M	Machine-to-Machine Communication
MAP	Maximum A Posteriori Probability
Max-Log-MAP	Maximum-Logarithm-Maximum A Posteriori Probability
MIMO	Multiple-Input and Multiple-Output
ML	Maximum Likelihood

mMTC	massive Machine-Type Communication
MSP	Min-Sum Product
MTC	Machine-Type Communication
NA	Not Applicable
NR	New Radio
NSCC	Non-Systematic Convolutional Code
NSPC	Non-Systematic Polar Code
O	Big O notation is a mathematical notation that describes the limiting behaviour of a function when the argument tends towards a particular value or infinity
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase-Shift Keying
RAN	Radio Access Network
RSC	Recursive Systematic Convolutional Code
SC	Successive Cancellation
SCC	Systematic Convolutional Code
SCL	Successive Cancellation List
SCL + CRC	Successive Cancellation List + Cyclic Redundancy Check
SISO	Soft-In-Soft-Out
SNR	Signal to Noise Ratio
SOVA	Soft Output Viterbi Algorithm
SPA	Sum-Product Algorithm
SPC	Systematic Polar Code
TBCC	Tail Biting Convolutional Codes
uMTC	ultra-reliable low-latency Machine-Type Communication
UMTS	Universal Mobile Telecommunication
URLLC	Ultra-Reliable Low-Latency Communication
VA	Viterbi Algorithm
VLSI	Very-Large-Scale Integration
VN	Variable Nodes
Wi-Fi	Technology for Wireless Local Area Networking
WiMAX	Worldwide Interoperability for Microwave Access
WLL	Wireless Local Loop
XOR	Exclusive-OR Logic Gate

CHAPTER 1

INTRODUCTION

1.1 Background

The fifth-generation (5G) communication system begins in the year 2020 [1]. The International Telecommunication Union (ITU) define, which based on the different user requirements, the new radio access technology for 5G systems as three scenarios; Enhanced Mobile Broadband (eMBB), Ultra-Reliable Low-Latency Communications (URLLC), and massive Machine-Type Communication (mMTC) [2, 3]. eMBB is a legacy system from International Mobile Telecommunications-Advanced (IMT-Advanced), URLLC jointly demanding low latency and high reliability, and mMTC emphasising on high reliability that creates a considerable impact to the designs of 5G New Radio (NR) air interface [4, 5]. According to its usage, URLLC and mMTC are latency sensitive and highly reliable in communication, while the eMBB demands higher data rates and data capacities [3]. This thesis focuses on the user requirements of machine-type communication scenarios for the channel coding scheme for the 5G mobile communication system in transmitting short length messages.

The Machine-Type Communication (MTC) denotes the broad area of wireless communication with sensors, actuators, physical objectives and other devices that not directly operated by human [6]. The Machine-to-Machine communication (M2M) or MTC is an emerging application where either one or both of the end users of the communication session involve machines [7]. Recent developing 5G applications of MTC, such as metering, control system and monitoring, tracking, payment, and security and public safety [8] require a channel coding scheme that is suitable for short length message transmission. Two main classifications of MTC scenarios: massive MTC (mMTC), and critical MTC (cMTC) or URLLC, each having their requirements [9, 10].

The URLLC needs a channel coding scheme with high-reliability of 10^{-5} to 10^{-9} and a low latency [6]. Another requirement is the channel coding scheme with a low code rate (the code rate should be lower than 1/3) [1]. The mMTC needs a channel coding scheme that supports small information size (tens to hundreds of bytes [1]), low device cost, and long battery life [9]. As well, the mMTC needs a channel coding scheme with latency sensitive and high reliability in communication [3]. Although most of the mMTC applications transmit a small volume of data between end devices, it is foretold that a number of these new end-devices in the next few years will reach up to 50 billion [11]. The major challenge of mMTC is to support a massive number of low devices cost and low energy consumption devices [1]. The potential requirements for 5G mMTC scenario are the use of lower-order modulation schemes with shorter block size information to meet their low power requirements [1].

Figure 1.1 shows the three service categories of the 5G mobile communication system.

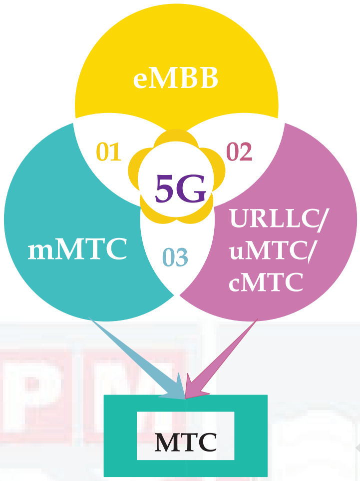

Figure 1.1: Three Service Categories of 5G Mobile Communication System

1.2 Problem Statement

The channel codes currently used in cellular networks are designed to approach the channel capacity for long packets [12]. Unfortunately, these coding techniques are not suitable for short packets, due to significantly low performance [12]. Thus, novel channel codes designed for short packet lengths are an essential requirement for 5G MTC [12]. Moreover, low-latency communications cannot use the classical coding methods that rely on long code words [8]. Instead, they need techniques for handling short packets using new coding methods designed for finite blocklength [8].

The 5G candidate channel coding schemes, which are the same as those identified in 3GPP, are turbo code, Low-Density Parity-Check (LDPC) code, convolutional code and polar code [1, 13, 14]. The channel coding scheme for URLLC and mMTC scenarios are not agreed yet [1]. Finding the channel coding scheme for reliability and latency requirement in URLLC is an open problem [1]. Therefore, the purpose of this study is to define a channel coding scheme for both 5G MTC scenarios; URLLC and mMTC scenarios. A full assessment of different channel coding schemes for both 5G MTC scenarios is investigated and evaluated. This full assessment will lead to determining the most appropriate channel coding scheme for both 5G MTC scenarios.

1.3 Aim and Objectives

The purpose of this research is to determine the most suitable channel coding scheme for the 5G mobile communication system in transmitting short length messages into both

MTC scenarios; URLLC and mMTC, which satisfies almost user requirements: reliability, latency, and complexity. The main objectives of this research are:

1. To design and select suitable design parameters of different channel coding schemes (low-density parity-check, turbo, polar, systematic convolutional, and non-systematic convolutional codes) for the 5G mobile communication system in transmitting short length messages to satisfy the user requirements in machine-type communication.
2. To investigate different channel coding schemes for the 5G mobile communication system of machine-type communication for different short length messages transmission ($64 \leq k \leq 1024$ bits) and different code rates (1/4, 1/3, 1/2) on an AWGN channel with BPSK modulation.
3. To evaluate the performance of different channel coding schemes for the 5G mobile communication system in transmitting short length messages based on the three user requirements of machine-type communication: complexity, latency and reliability.

1.4 Research Contribution

The channel coding scheme yet to be identified for 5G URLLC and mMTC scenarios [1]. This research contributes to filling a knowledge and practical gaps in the area of finding the most appropriate channel coding scheme for both 5G MTC scenarios. This research includes three 5G MTC user requirements; decoder computational complexity, encoding and decoding computational latency, and reliability, which makes the research unique by implementing these three user requirements with different design parameters of different channel coding schemes. It is the first time for systematic convolutional code scheme to investigate and evaluate for both 5G MTC scenarios compared to recent related works, such as [1, 13, 14, 15, 16]. A full evaluation of the decoder computational complexity of five-different channel coding scheme for both 5G MTC scenarios is considered. Furthermore, it is the first time to study the encoding computational latency, and decoding computational latency requirement for different channel coding schemes; LDPC, turbo, polar, systematic convolutional and non-systematic convolutional codes, for both 5G MTC scenarios that use unique methodology. Likewise, it is the first time to examine reliability requirement in term of Bit Error Ratio (BER) comparison for different channel coding schemes with different short length message transmission ($64 \leq k \leq 1024$ bits) and different code rates (1/4, 1/3, 1/2) that use unique methodology.

1.5 Research Scope

Figure 1.2 display a summary of the research scope. The bold line indicates the direction of the research area, while the dotted line shows the research areas that are out of the research scope of this thesis.

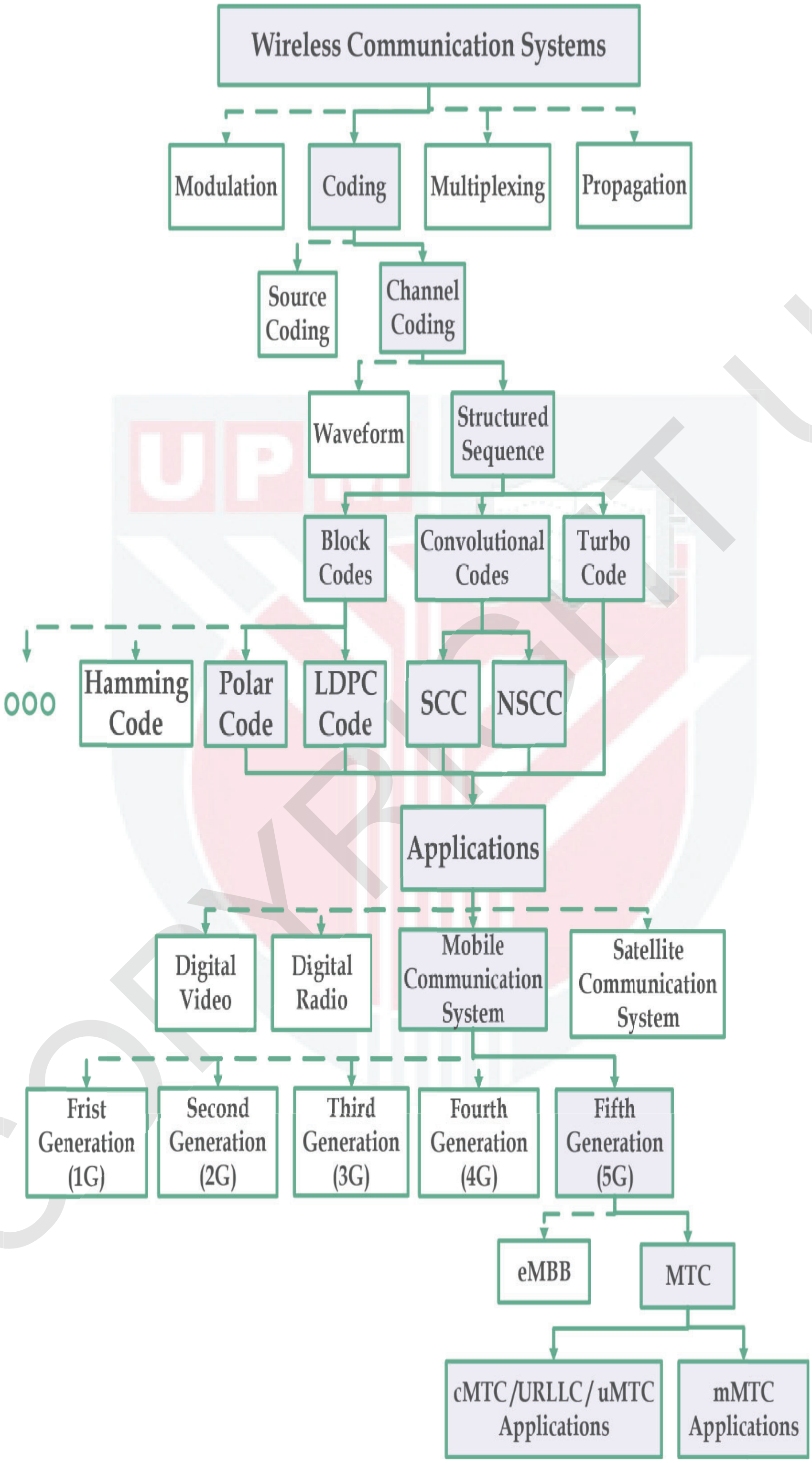

Figure 1.2: Study Module

1.6 Thesis Organization

The remaining of this thesis organization is as follows:

Chapter 2 provides a brief introduction about the 5G candidate channel coding schemes as follows: convolutional codes, turbo codes, LDPC codes, and polar codes. Moreover, a brief introduction about exiting channel coding schemes for both 5G MTC scenarios, and motivation to examine those specific channel coding schemes. Furthermore, a brief introduction about the classification of 5G MTC scenarios, and the MTC user requirements of the channel coding scheme for the 5G mobile communication system in transmitting short length messages as follows: flexibility, complexity, latency, and reliability.

In chapter 3, the suitable design parameters of five-different channel coding schemes for the 5G mobile communication system in transmitting short length messages is displayed. The evaluation methodology of three 5G MTC user requirements; complexity, latency, and reliability, is defined.

Chapter 4 focuses on presenting and discussing the evaluation of results of 5G MTC user requirements for different channel coding schemes in transmitting short length messages as follows: decoder computational complexity, encoding and decoding computational latency, and reliability.

Chapter 5 provides the conclusion that is obtained from this research area results as well as outline some areas for future research.

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PUBLICATION

Zahraa Raad Mayoof Hajiyat, Aduwati Sali, Makhfudzah Mokhtar and Fazirulhisyam Hashim, "Channel Coding Scheme for 5G Mobile Communication System for Short Length Message Transmission", Wireless Personal Communications, 106 (2): 377–400, 2019, Springer US, DOI: https://doi.org/10.1007/s11277-019-061 67-7. (Published).

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USER REQUIREMENT EVALUATION OF CHANNEL CODING SCHEMES FOR 5G MOBILE COMMUNICATION SYSTEM IN TRANSMITTING SHORT LENGTH MESSAGES

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