CHAPTER 1
INTRODUCTION

1.1 Background

Mobile cellular network has been successful in facilitating the process of sending and receiving information based on human-to-human communication. Recently, fifth generation technology (5G) of mobile cellular network is being designed to meet technological requirements on various field of applications, such as machine-to-machine and vehicle-to-vehicle communication system. In general, 5G mobile cellular network requirements has been summarized by international telecommunication union (ITU) [1], i.e, (i) enhanced mobile broadband (EMBB) with throughput up to 20 giga bytes per second (GBps), (ii) ultra reliable and low latency communication (URLLC) systems with bit-error rate (BER) performances lower than 10^{-6} and system latency lower than 1 ms, and (iii) massive machine type communication (MMTC) to accommodate billions of connected devices and various type of communications.

URLLC systems are essential for the implementation of autonomous car and factory automation, because of, for example, dangerous accidents on factory automation or accidental collisions on autonomous car due to errors and/or delay on communication systems. Low density parity check (LDPC) codes are suitable to address the ultra reliable communication systems requirement, due to error correction performances close to Shannon limit and low complexity [2–4]. The design of LDPC codes has been exploited to achieve further good error correction. Progressive edge growth (PEG) is the most popular method to design LDPC codes [2] to achieve lower bounds on the girth and on the minimum distance of codes. Moreover, authors in [2] provide enhanced progressive edge growth (ePEG) algorithm to construct LDPC codes that eliminate short cycle that causing error-floor. Shortest cycle on LDPC codes ,girth, define independent iteration, where the error rate decreases exponentially with the number of independent iterations. Recently, scalable quasi cyclic (QC) LDPC (QC-LDPC) codes are proposed to reduce complexity for large block length. Author on ref [3] propose circular PEG (CPEG) to design QC-LDPC codes based on base graph (BG). Nowadays, rateless LDPC codes are designed to support (IR) hybrid automatic repeat request (HARQ) systems. Another design of QC-LDPC codes to support IR-HARQ scheme, author on ref [5] propose simple extension on punctured QC-LDPC codes, such that the codes can be made rateless.

Recently, protograph-based raptor like (PBRL) LDPC codes has been standardized as up-link/down-link shared channel codes for 5G new radio (NR) communications as described in technical specification (TS) 38.212, called 5G NR QC-LDPC codes. 5G NR QC-LDPC codes has a very good performance close to Shannon limit across family of code rates. 5G NR QC-LDPC codes has rate compatible (RC) codes, where the puncturing pattern are carefully design to ensure good BER performance across family of code rates. 5G NR QC-LDPC codes is low complexity iterative decoding and scalable parity check matrices. 5G NR QC-LDPC codes is low complexity [6] by constructing parity check matrix $\mathbf{H}$ based on small base graph (BG). Moreover, 5G NR QC-LDPC codes parity check matrix has scalable characteristics, by lifting the size of BG using permutative circulant matrix (PCM) algorithm. 5G NR QC-LDPC codes consist of concatenated QC-LDPC codes with adjustable extended parity (EP). Adjustable EP allows 5G NR QC-LDPC codes to maintain optimum code rates below channel capacity $R \leq C$ [7] that suitable for IR-HARQ scheme.

5G NR QC-LDPC codes has performances close to Shannon limit as described in [8]. Author on Ref. [8] has observe the use of EP, such that 5G NR QC-LDPC codes compatible with IR-HARQ scheme. IR-HARQ performed a packet re-transmission to solve time-varying channel model to support ultra reliable communication applications. However, packet re-transmission from IR-HARQ scheme will shift the time slot of current packet to be transmitted, which is lead to additional latency to the systems. Therefore, this thesis propose IR-HARQ with packet combining scheme, called superposed IR-HARQ (SIR-HARQ) for 5G NR communication systems to maximize data re-transmission such that number of slot can be minimized for URLLC systems.

1.2 Problem Identification

Conventional IR-HARQ does not minimize required time-slots to support low latency communication systems, which is important in 5G and beyond supporting critical applications. The failure of providing low latency may cause dangerous effect especially when the applications involve human or animal in the networks. Similar effect also applies for applications of industrial automation, where the process is highly depending on the speed of processing relying on the both latency and reliability of the networks.

1.3 Objective and Contributions

The objective of this thesis is to propose superposed transmission on IR-HARQ scheme transmitting two packets using one time-slot, such that minimum time-slot is required to support both URLLC and EMBB applications. The whole contributions of this thesis are summarized as follows:

1. This thesis provides 5G NR QC-LDPC codes EXIT chart analysis based on BG-1.
2. This thesis provides 5G NR complex BPSK (CBPSK) BER performance on Additive White Gaussian Noise (AWGN) channel.
3. This thesis proposes IR-HARQ with packet combining scheme for 5G NR communications.
4. This thesis design soft decoding of SIR-HARQ scheme based on sum product algorithm (SPA).
5. This thesis evaluates EXIT chart analysis of SIR-HARQ as well as EXIT chart derivation the codes.
6. This thesis evaluates BER performances of SIR-HARQ scheme under AWGN, Slow Rayleigh and Fast Rayleigh fading channels with 5G CBPSK modulation.

1.4 Scope of Work

To keep simple in description, this thesis assumes several assumptions as follow:

1. The channels are assumed to be AWGN, slow Rayleigh and fast Rayleigh fading channels. this thesis also consider complex binary phase shift keying (C-BPSK) modulation, of which, higher order of modulation are rather straight forward.
2. The transmission is assumed to be narrow-band and single carrier transmission, such that, at this stage, equalization is not required.

1.5 Research Methodology

This thesis is divided into 4 work packages (WP) for efficient high quality results.

1. Decoding behavior of 5G NR QC-LDPC codes based on BG-1. EXIT chart analysis is performed in this thesis to evaluates the decoding behavior of 5G NR QC-LDPC codes without EP and with full EPs transmission, i.e., (i) optimal iteration pattern, (ii) turbo-cliff and optimality of the codes. We also validate EXIT curve with EXIT trajectory based on computer simulations.

2. Result validation of 5G NR QC-LDPC codes. The EXIT analysis are then validated using BER performances under AWGN channel for a transmission without EP and with full EPs.

3. Decoding behavior and result validations of SIR-HARQ based on 5G NR QC-LDPC codes. This thesis also performs EXIT chart analysis to evaluates the decoding behavior of the proposed SIR-HARQ, i.e., (i) optimal iteration pattern, (ii) turbo-cliff and optimality of the codes. This thesis also validate EXIT curve with EXIT trajectory based on computer simulations. The EXIT analysis of SIR-HARQ are then validated using BER performances under AWGN channel.

4. BER performances analysis of SIR-HARQ forward error-correction (FEC) coding (SIR-HARQ and IR-HARQ) is addressed to solve time-varying channel. Such that this thesis performs and evaluates BER performances of SIR-HARQ and under slow and fast Rayleigh fading channels.

1.6 Organization of The Thesis

The rest of this thesis is organized as follows:

- Chapter 2: Basic Theory
  This chapter describe basic concept of digital communications including the modulator-demodulator, encoder-decoder, channel capacity, and forward error correction(HARQ). This chapter also describe useful tools to evaluates decoding behavior of the codes, such as EXIT chart for AWGN channel and theoretical BER performances.

- Chapter 3: System Model and The Proposed Superposed Codes
  This chapter describe transmitter, channel, and receiver system model of 5G NR QC-LDPC codes based on BG-1. This chapter also describe the design of proposed SIR-HARQ, i.e., SIR-HARQ soft-decoding algorithm, SIR-HARQ degree distributions, and EXIT chart calculation of SIR-HARQ.

- Chapter 4: Performance Evaluations

  This chapter discuss the obtained result of 5G NR QC-LDPC codes and SIR-HARQ scheme, i.e., iteration pattern for 5G NR QC-LDPC codes, EXIT of 5G NR QC-LDPC codes, BER performances of SIR-HARQ, EXIT chart of SIR-HARQ, and BER performances of SIR-HARQ.

- Chapter 5: Conclusion and Future Work

  This chapter concludes this thesis with some concluding remarks, so that it can contribute significant contributions to the development of 5G NR communications and beyond.