CHAPTER 1

INTRODUCTION

1.1 Background

Internet of Things (IoT) era is predicted with massive scale constructions of future wireless networks. It is predicted by Ericsson that there will be around 28 billion connected devices by 2021, where more than 15 billion will be connected via machine-to-machine (M2M) communications [1]. This condition requires the capabilities of the fifth telecommunication generation (5G) wireless access to extend far beyond those of previous generations of mobile communications. As illustrated in Fig. 1.1, International Telecommunications Union-Recommendation (ITU-R) defines the challenges of 5G in 3 main challenges [2], i.e., (i) enhanced mobile broadband, (ii) massive machine-type communications, and (iii) ultra-reliable and low latency communications.

Enhanced mobile broadband requires data rate up to 20 Gigabits in a second. For broadband IoT, 5G should support data rates more than 10 Gbps in indoor and dense outdoor environments, 100 Mbps for urban and suburban environments, and at least 10 Mbps almost everywhere [3]. The research, for example, in [4, 5] has already addressed this challenge by using massive Multiple Input Multiple Output (MIMO) and millimeter-Wave (mmWave) to reach high data rates. Another 5G challenge is massive machine-type communications, the application of which is, for example, IoT.

Fig. 1.2 illustrates massive scale construction in IoT era, where the networks serve massive number of communications between devices and apps via the server and base station (BS). The authors in [6–8] proposed several coding schemes for IoT devices. Convolutional codes are

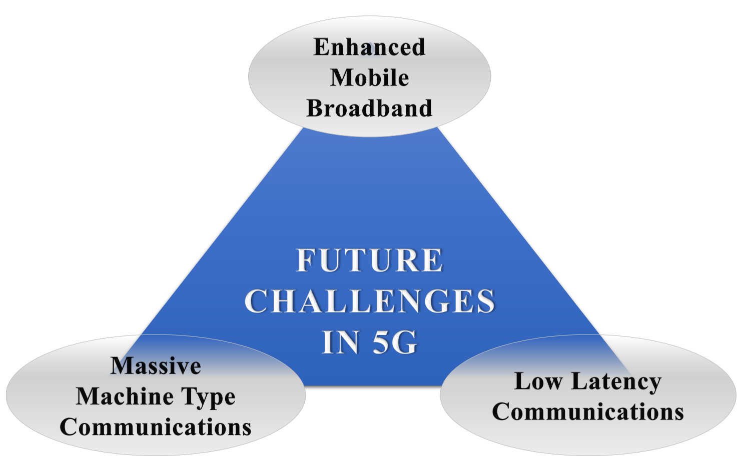

Fig. 1.1: Future challenges of 5G defined by ITU-R.

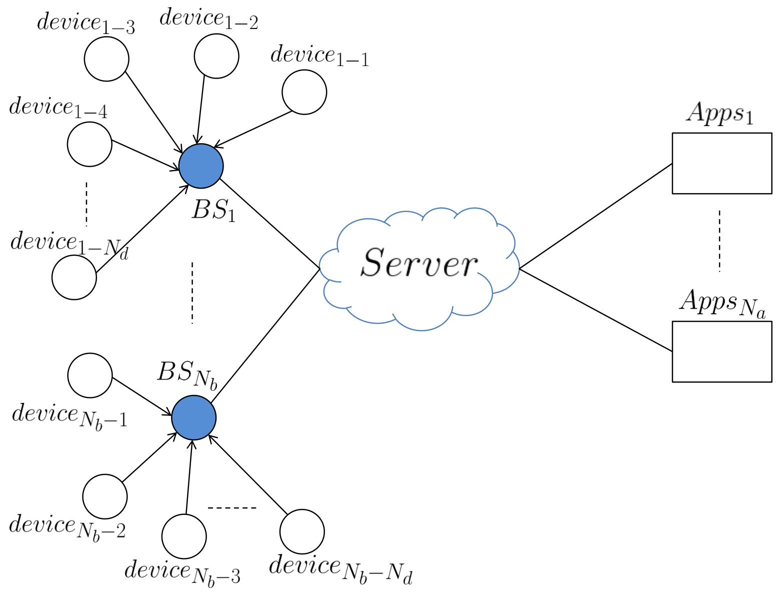

Fig. 1.2: IoT wireless networks serving massive number ($N_b \times N_d$) devices and N_a Apps.

proposed in [6] and [7]. A rate 1/3 tail biting convolutional code is used for error correction in M-physical downlink control channel (MPDCCH) to carry downlink control information (DCI) of enhanced machine type communication (eMTC). Meanwhile, authors in [7] utilizes a rate 1/3 convolutional codes used in Long-term evolution (LTE) [9] with 6 memory elements to evaluate the performance for M2M communications. Low density parity check (LDPC) codes, Turbo codes, and Polar codes are also discussed in [7] to be compared to convolutional codes for M2M communications. Moreover, the authors in [8] use Polar codes with list decoding plus cyclic redundancy check (CRC) and compare the performance with LDPC codes with short block-lengths.

Furthermore, massive access of IoT can be solved, for example, using Coded Slotted ALOHA [10] and Coded Random Access [11–14] presuming variable nodes as users for network coding, where the practical consideration has been investigated in [15], [16]. The throughput can be increased by using multiuser detection technique as in [12] and [13], with 2 packets/slot detection capability. Research in [14] solved more challenging problems by detecting simultaneously 3 until 4 users with general encoding (not only repetition codes, but the research includes maximum distance separable (MDS) codes) per slot leading to throughput of 10 times higher compared to the conventional Slotted ALOHA used by 3rd Generation Partnership Project (3GPP) Narrowband IoT (NB-IoT) [17] and 20 times higher compared to LoRA IoT.

However, the study in [10–14] assumes no precoding. Therefore, the error-floor probability due to stopping sets is still unsolved. The fact above provides us with insight about the necessity of precoder. In this thesis, we assume precode ensemble with modified fixed-rate Luby

Transform (LT) code to overcome the problem. We consider coding design for uplink communications between devices and BS as shown in Fig. 1.2. At this stage, downlink communications are out of the scope of this thesis.

This thesis proposes Raptor codes ensemble with low density generator matrix (LDGM) codes as the precode, called LDGM-based Raptor codes, having degree distributions suitable for broadband IoT communications with low complexity. As for the decoding process we use soft decision decoding in order to obtain higher performances compared to hard decoding. Extrinsic Information Transfer (EXIT) chart is used to analyze the design of coding scheme for the optimal performances approaching the Shannon Limit, under Additive White Gaussian Noise (AWGN) and multipath Rayleigh fading channels. Raptor codes analyzed in this thesis solely focus on the internal device (not for network coding). However, it has potential to be implemented later on error correction codes over the wireless IoT networks. Some parts of this thesis have been published in an International Conference on Signal and System (ICSigSys 2017) supported by IEEE [18] for the (sub)optimal degree obtained manually by carefully investigating the EXIT chart.

1.2 Research Contributions

This thesis proposes new design of LDGM-Raptor Codes for massive broadband IoT networks with the following contributions:

1. We propose precode in this thesis to solve error-floor problems remaining unsolved in [10–14]. Precode in Raptor codes are expected to have ability to overcome the problem.

2. Raptor codes [19] and LT codes [20] are designed originally as rateless codes. Meanwhile, our proposed LDGM-Raptor codes use modified fixed-rate LT codes devoted for uplink communications, devices as a channel coding scheme. The degree distributions proposed for LDGM-Raptor codes are for fixed-rate codes, which are mostly different compare to the degree distributions of rateless Raptor codes in [19].

3. In designing optimal degree distributions, we use EXIT analysis [21] in Binary Erasure (BEC), AWGN, and multipath Rayleigh fading channels which become one of our significant contributions in this thesis.

4. This thesis considers the fifth telecommunication (5G) New Radio (NR) modulations, which have been standardized in [22] especially for 64-QAM.

1.3 Problem Identification and Objective

High-dense communication networks are required by the future massive acces of IoT. The use of high computational complexity of coding techniques in each IoT device may result in a long time of encoding and decoding process contradicting to the requirement of future 5G networks. Devices supporting massive communications should use coding technique with low complexity but reliable in order to meet 5G requirement that provides long battery lifetime [2].

Raptor codes [19] consist of precodes and LT codes. LT codes can only decode the fraction of source symbols [20], which may still produce unrecovered symbols. As a consequence, if the coding technique for massive communication networks only use LT codes, there may be massive number of unrecovered users with the probability of $(1 - 1/b)^c$, which is upper bounded by $e^{-c/b} = 1 - R(1 + \epsilon)$ [19]. Notations b and ϵ refers to the encoded/intermediate bits and erasure probability, respectively. Meanwhile, c is output bit collected by the decoder expressed as [19]

$$c = -N \cdot \ln(1 - R(1 + \epsilon))/R, \tag{1.1}$$

with N and R being input bits and coding rate, respectively.

Raptor codes help to improve the performance of LT codes by introducing the precode to decode the remainder of the unrecovered source symbols. Our goal is to design LDGM-Raptor codes suitable for low latency communications with good performances. The use of LDGM as the precode in this thesis is to produce low complexity of coding technique through its simplicity. The simplicity of LDGM codes is due to the sparsity of generator matrix having lower density of bit ”1” [23], the generator matrix $\mathbf{G}$, of which is consisting identity matrix, resulting easy construction of parity check matrix $\mathbf{H}$. The problem is to find degree distributions best suit for LDGM-Raptor codes, where the codes are no longer having rateless property. With fixed-rate transmission, the best and optimal degree distribution should be carefully searched. Soft decoding is used for decoding of the proposed codes to obtain high performances.

This thesis designs LDGM-Raptor codes that provide high performances in terms of optimal degree distributions BER, and outage probability. We also evaluate the effectiveness of the proposed coding scheme compared to Shannon Limit under AWGN and multipath Rayleigh Fading Channels with finite block-length for broadband transmissions.

1.4 Scope of Work

To avoid complex description, this thesis assumes the following points:

1. The devices are assumed either fixed or mobile users with low mobility such that the chan-

nel can be modeled as block Rayleigh fading, where the fading channels do not change in one block. This model is realistic in practice because human or IoT devices practically do not move too fast affecting fast changes on channels during one block.

2. To easily manage the problem of broadband communications, we use cyclic prefixed Orthogonal Frequency Division Multiplexing (CP-OFDM) to avoid the necessity of complex channel equalization. However, in principle any other transmission schemes are applicable to the proposed LDGM-Raptor codes.

3. This thesis assumes perfect synchronization between the devices and the BS such that we do not need to evaluate the BER degradation due to failed synchronization.

4. To complete the EXIT analysis, this thesis uses BEC, AWGN and multipath Rayleigh fading channels. However, the real performances are evaluated using the real AWGN and multipath block Rayleigh fading channels rather than with BEC.

1.5 Research Method

This thesis is divided into 5 work packages (WP) to make efficient and high quality results.

1. WP 1: Study Literature

   In this WP, we study the literatures related to Raptor codes and tools to analyze the performance, i.e., EXIT charts. This WP also studies about the basic concepts of the related topics with the proposed coding technique.

2. WP 2: Optimal Degree Distributions

   There are two ways to obtain degree distribution: (i) manual and (ii) computer-based searching. We design (sub)optimal degree distribution manually by perceiving the intersection points of EXIT curves. However, the best degree distribution is the optimal degree distribution obtained by using computer-based searching.

3. WP 3: EXIT Analysis

   EXIT analysis is used to analyze the performance of the obtained degree distribution and also to evaluate the overall performance of the proposed coding technique.

4. WP 4: Decoding

   Decoding process utilized in this thesis is soft decision decoding by using the Log-likelihood Ratio (LLR) information exchange.

5. WP 5: Performance Evaluations

   We evaluate the performances of the proposed coding technique in terms of BER performance and outage probability under AWGN and multipath Rayleigh fading channels for 5G channel model developed in [24].

1.6 Structure of Thesis

Furthermore, this thesis is structured as follows:

CHAPTER 2: Basic Concept

This chapter describes the basic concept of the proposed codes including the general structure of Raptor codes, LDGM codes, LT codes, and general EXIT chart analysis.

CHAPTER 3: System Model of Broadband-IoT using LDGM-Raptor Codes

This chapter discusses about the system model of broadband-IoT using the proposed LDGM-based Raptor codes, starting with the general practical parameters followed by the transmitter and receiver structure, including the assumed channel models.

CHAPTER 4: The Proposed LDGM-based Raptor Codes

This chapter discusses the proposed degree distributions design of LDGM-Raptor codes followed by EXIT charts analysis. The proposed decoding analysis of the proposed codes is also discussed.

CHAPTER 5: Performance Evaluations

This chapter discusses the performance evaluations of the proposed LDGM-Raptor codes, begin with the validation of the systems, followed by the analysis of the performance parameters, i.e., (i) BER and (ii) Outage probability. We also provide the comparison of complexity between the proposed codes and other coding techniques.

CHAPTER 6: Conclusions and Future Works

This chapter concludes all the discussion and analysis in this thesis so that it can provide significant contribution to the future development of massive wireless IoT.