CHAPTER 1
INTRODUCTION

This chapter provides a brief overview of the research. Consist of six sections; the explanation starts with background, problem identification and objective, scope of work, research methodology, and structure of this thesis. A more detailed explanation will be later in the next chapter.

1.1 Background

Due to the swift advancements in manufacturing technology and cost reduction of unmanned aerial vehicles (UAVs), the utilization of UAVs in commercial applications has gained significant popularity in recent times. This is evident in initiatives such as Amazon's drone-delivery system. Following their exceptional mobility, rapid deployment capabilities, extensive coverage, and cost-effectiveness, UAVs-assisted wireless communications have gained widespread recognition as a vital component for the integration of space, air, and ground in sixth-generation (6G) mobile networks as illustrated in Fig. 1.1. UAVs have the capability to establish independent subnets that are not reliant on fixed networks such as terrestrial and satellite networks. By adjusting their altitudes and avoiding obstacles, UAVs can significantly increase the likelihood of line-of-sight (LoS) links, thereby enhancing connectivity [1].

UAVs are also capable of facilitating fundamental requirements including extremely reliable and low latency communications (ERLLC), further-enhanced mobile broadband (feMBB), and ultra-massive machine type communications (umMTC) [2]. They can be rapidly deployed to support emergency response efforts and ensure efficient communication during critical situations [3]. UAVs offer a cost-effective and flexible deployment solution to provide ubiquitous coverage and high-data-rate communications in specific areas, such as disaster relief scenarios. On the other hand, emergency management systems (EMSs) based on wireless communications in 6G networks gained increasing attention recently. Therefore, UAV technology become one of the key technologies for 6G communications. However, nowadays UAVs technology has not been completely standardized

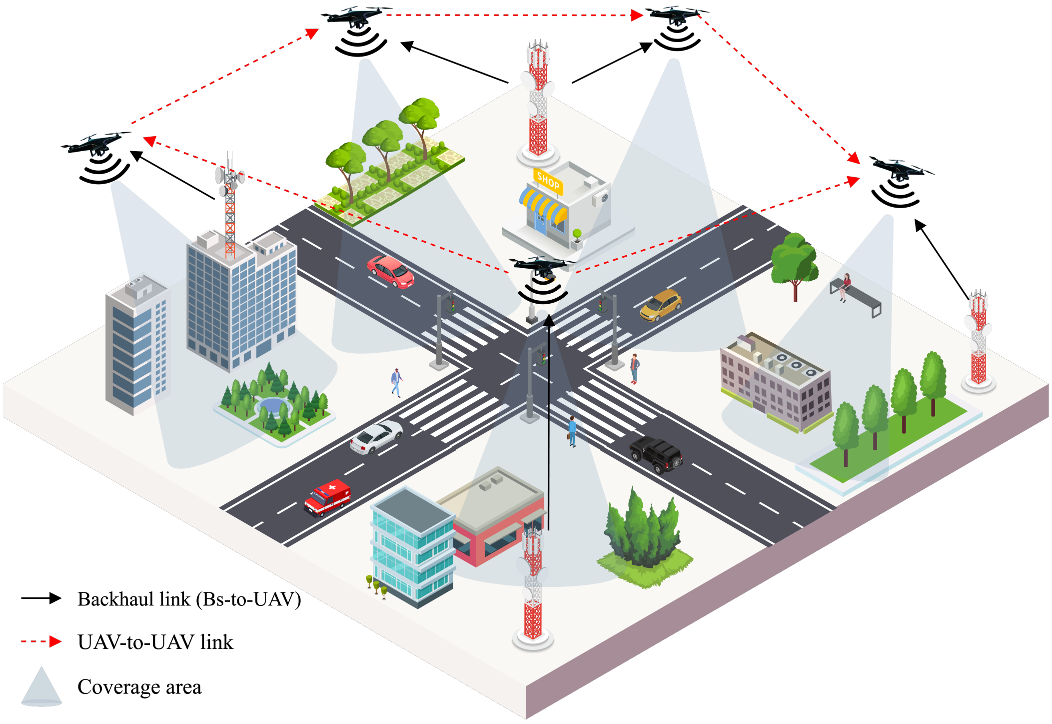

Fig. 1.1 UAV technology has become one of the key technologies for 6G communications.

and enhanced mature with the advent of 6G [4].

Disasters often strike suddenly and without warning, causing widespread casualties and severe damage to infrastructure. These catastrophic events can be natural, like earthquakes, tsunamis, and floods, or they can be human-caused, through terrorism, industrial accidents, or acts of war. In disaster relief scenarios, communication networks frequently break down during disasters, hampering rescue and recovery efforts. This lack of crucial communication is a common thread connecting all types of disasters, whether they are environmental, technological, or societal in origin. When disasters disrupt normal chan-

Fig. 1.2 The illustration of the affected area after a natural disaster.

nels of communication, emergency responders cannot coordinate aid, victims cannot call for help, and information cannot flow to guide decision-making as shown in Fig. 1.2.

The delays and errors in emergency response and disaster aid process, because of the partial or complete failure of fixed base station (BS) infrastructure lead to incapable preventable loss of life and damage to property [5, 6]. During critical times after a disaster, the deployment of terrestrial BS is economically feasible. Coordinated relief to the affected areas requires to be given as fast as possible to minimize further detrimental effects. Therefore, disaster-affected areas need an alternative BS that is easily deployed to help the recovery network process.

The mobile cognitive radio base station (MCRBS) is an alternative to temporary replace fixed BS to recover process during post-disaster time, however MCRBS can not reach disaster-affected areas if the road to the casualties is severely damaged or even disconnected [7–9]. Hence, temporary terrestrial BS requires additional BS on an airborne vehicle, i.e., unmanned aerial vehicle (UAV). In [10] and [11], the utilization of UAVs for disaster applications have been comprehensively studied.

UAVs can serve as aerial base stations (ABS) (see Fig. 1.1) where flying base stations can guarantee connectivity and serve users. These ABS can be deployed swiftly and positioned strategically to optimize coverage and support communication needs in disaster-affected areas or remote locations. By leveraging the mobility and flexibility of UAVs, ABS can effectively bridge the communication gap and provide essential services to users in challenging environments.

The dynamic movements of UAVs pose a significant challenge that cannot be overlooked when considering their role in providing wireless connectivity coverage. Unlike stationary base stations, UAVs are subject to various factors such as wind, turbulence, and maneuverability constraints, which can impact the stability and reliability of wireless communication links. Following some factors, the unstable position of UAVs changes the channel variations. Addressing these challenges and ensuring seamless connectivity in UAV-assisted wireless networks requires interference mitigation techniques (IMT) for the dynamic nature of UAV movements [12].

In [12], recent research has focused on exploring diverse techniques to mitigate interference in 5G UAV networks. These techniques encompass adaptive modulation and coding schemes, dynamic adjustment of antenna patterns, regulation of transmit power, and sub-channel scheduling. Furthermore, this thesis focuses on developing a new adaptive coding scheme using an intelligent approach to ensuring reliable and efficient communications for UAVs.

The fixed-rate channel coding technique is unsuitable for UAV communications due to its inability to adapt to changing channel conditions. These conditions can make the channel capacity smaller than the coding rate causing a large error, because it violates the Shannon channel coding theorem. This condition is called an outage, of which the probability is called the outage probability.

Low-density parity-check (LDPC) codes introduced by [13] have been standardized by the 3rd Generation Partnership Project (3GPP) for the New Radio (NR) specification [14,15]. LDPC codes offer a compelling combination of high error correction performance and low decoding complexity, making them well-suited for the demanding requirements of 5G and beyond networks. LDPC codes are designed to achieve near-optimal performance by approaching the Shannon capacity limit of the communication channel.

Adaptive coding schemes in wireless communication systems have been the subject of numerous studies. These schemes dynamically adjust coding parameters based on real-time channel conditions, providing a trade-off between data rate and error resilience to optimize system performance. The work in [16] analyzed the rateless capability of Polar accumulate tornado (PA-Tornado) codes using an extrinsic information transfer (EXIT) chart and revealed that the accumulator of PA-Tornado made a significant contribution in bringing the mutual information (MI) close to the (1,1) point. Moreover, density evolution (DE) analysis for 5G NR quasi-cyclic (QC)-LDPC codes was investigated in [17], where rateless capability with extended parity, effectively corrects errors even at higher rates.

Together with the development of channel coding, machine learning (ML) has also been applied in the context of wireless communications (see the survey paper [18]). A prior work [19] proposed the conventional belief propagation (BP) decoding algorithm as a partially connected neural network. The ML method in [20] is used to design error correction codes, and it has been shown that improved results can be achieved in the case of list decoding for polar codes by learning the parameters of an optimal code. The work [21] presented a neural network decoder (NND) for polar codes with short block lengths. ML for decoding of polar introduced in [22], where the objective is to learn frozen bit indices of a polar code as a binary vector, which can then be described as the trainable weights of a neural network.

ML for log-likelihood ratio (LLR) estimation with LDPC codes studied in [23] to reduced complexity solution and extended it to irregular LDPC codes, while the work [24] analyzed ML assisted LDPC coded adaptive modulation (AM) system using k-nearest neighbors (KNN) algorithm. The work in [25] proposed an application of Graph neural networks (GNNs) to the problem of LDPC and BCH codes in wireless communications. GNN in [25] replaces node and edge message updates with trainable functions. The hybrid deep learning approach based on polar-LDPC codes was designed in [26]. This thesis proposes reinforcement learning-based rateless coding scheme for UAV communications [27].

1.2 Problem Identification

The channel capacity is rapidly changing causing of dynamic movement of UAV. When UAV utilize channel coding techniques with fix-rated, the systems can not adapt to channel conditions. These conditions may make the channel capacity C smaller than the coding rate R causing a large error, because it violates the Shannon channel coding theorem, where $R \leq C$ should be satisfied. This condition is called an outage, of which the probability is called the outage probability.

The current solution for the outage performance is channel coding with a rateless scheme to adapt to the changes of the channel during transmissions. Rateless coding keeps rate R adaptable to the channel capacity C, hence $R \leq C$ is always satisfied. However, the current rateless coding scheme is based on the traditional way, where the decision of rate R is not based on intelligence decision causing high complexity in hardware.

1.3 Objective

The main goal of this thesis is to design a reinforcement learning-based rateless decoding scheme suitable for UAV communications that can decide correctly the appropriate coding rate R for a given channel capacity. The whole contributions of this thesis as described as follows:

1. This thesis studies a machine learning structure for box-plus operation, a crucial component of soft information processing, using a supervised learning approach.

2. *Transfer learning for rateless coding scheme*: this thesis proposes a novel TL approach to improve the performance of QC-LDPC decoders. By leveraging pretrained models, the proposed TL can significantly enhance the decoding performance of QC-LDPC codes, especially when additional EP is needed. The TL

framework enables efficient knowledge transfer from related coding tasks, leading to faster convergence and low computational complexity in terms of the training and testing stages, respectively.

3. *Reinforcement learning for rate determination*: this thesis develops a reinforcement learning-based Q-learning algorithm for dynamic rateless codes. The agent learns to adaptively choose the most suitable rate based on the channel conditions and performance requirements. By modeling the rate determination as a Markov decision process (MDP), the agent can make optimal decisions using its optimal policy to select the appropriate rate under a certain channel condition.

4. This thesis evaluates the proposed reinforcement learning-based rateless coding scheme in terms of BER and FER performances under Rayleigh fading channels.

1.4 Scope of Work

This thesis is only focusing on the following scopes:

1. The simulation that is carried out includes the process of generating information data, channel encoding, transmitting through the channels, demodulation, channel decoding, and retrieval of information data.

2. The generation of information data is carried out with the help of computer simulation by utilizing the random binary generator function. Changing information data into binary bits is not discussed in this thesis. It is assumed that information data has been converted into binary bits perfectly.

3. The results of computer simulation are presented in terms of error sign, MSE, BER, and FER performances.

4. This thesis is limited to AI especially using supervised learning and reinforcement learning.

5. This thesis assumes perfect channel state information, indicating that the receiver has the channel conditions perfectly known.

1.5 Research Methodology

This thesis is divided into four work packages (WP) to produce high-quality results.

- WP1: Study of Literature
  This thesis studies the basic concepts and theories related to general communications systems, channel coding techniques, rateless scheme, artificial intelligence, and reinforcement learning.

- WP2: Validation and Observation
  Validating the function, technique, and method of the neural network for soft information processing, and observing the characteristics of the neural network through the testing stage by analyzing the sign-error-rate performances to determine the best structure and activation function for establishing the baseline of the neural network decoder.

- WP3: Design Reinforcement Learning-based Rateless Coding Scheme Using BER Performances
  Designing a novel rateless coding scheme that leverages reinforcement learning techniques. Designing the state representation, action space, and reward function to enable the agents to learn an appropriate channel coding rate given the current channel capacity. Investigating different reinforcement learning algorithms, such as Q-learning and Sarsa, to find a suitable approach for this problem.

- WP4: Prove The BER and FER Performances
  This thesis evaluates the performances of the proposed reinforcement learning-based channel coding scheme using the performance metric of BER. This WP works on proving the BER performances under Rayleigh fading channels. This thesis designs rateless scheme of the channel coding to satisfy the channel coding theorem that coding rate R is less than capacity C during transmission proved in fading channels. In this step, this thesis performs simulation and analysis using a series of computer simulations.

1.6 Stucture of The Thesis

The rest of this thesis is organized as follows:

CHAPTER 2: BASIC CONCEPTS

This chapter provides basic concepts used in this thesis. The explanation focuses on general wireless communications, the basic concept of machine learning for physical layers especially machine learning-based decoding, and reinforcement learning for rate determination.

CHAPTER 3: SYSTEM MODEL

This chapter describes the system model, including parameters and variables used in the thesis, research methodology, and research design.

CHAPTER 4: PERFORMANCE EVALUATIONS

This chapter discusses the result of this thesis, starting from the validation and observation to the performance of the proposed design. This thesis provides performance metrics of sign error rate, accuracy, cumulative reward, FER, and BER to analyze the performance of the proposed reinforcement learning-based rateless coding.

CHAPTER 5: CONCLUSIONS

This chapter provides the conclusion of this thesis and notifies the future works.