Development of a Matlab Simulation Framework for 5G Cellular Ultra-Reliable and Low-Latency Communication

Master Thesis

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Introduction

Since 2010 the number of internet-connected devices keeps increasing and the number of so called IoT devices worldwide should reach 75B by 2025 [6]. To meet this growing demand the upcoming 5G will include IoT specific standards with notably URLLC for latency critical communication.

The first non-standalone New Radio specifications were frozen in Q1 2018 which means implementation of 5G’s digital baseband algorithms can start. The main objective of this thesis is to implement a Matlab 5G simulation framework, to be able to easily implement and test new algorithms. The secondary goal was to focus on URLLC constrains, which led to the implementation of a SSC list polar decoder.

Main Objectives

1. Matlab implementation of a simulation framework based on 5G specifications
2. Complexity estimation for a URLLC receiver
3. Implementation of a Simplified Successive Cancellation (SSC) polar list decoder

5G Matlab simulation framework

The implemented Matlab framework simulates an entire downlink transmission, along with the initial synchronization process. The SS/PCCH block used for the cell search is generated according to the 5G specifications and mapped to the time-frequency grid often used to represent OFDM systems. For every channel the payload is then generated, the correct CRC is appended if necessary, then the coding and rate matching are applied, if necessary. Finally the bits are transmitted and modulated and mapped to the time frequency grid. The cyclic prefix is added and an OQAM transmission is simulated by applying a channel model and other impairments such as channel frequency offset, time offset, sub-sample timing offset. Upon reception the cell ID is retrieved and those impairments are estimated and corrected before decoding the PDCCH (the control channel) and finally the PDSCH (the data channel). The global structure can be seen in Fig. 1.

Complexity estimation for an URLLC receiver

In a Matlab simulation, the latency is not considered, but in a real world application latency is important, especially for URLLC where the end to end round-trip time has to be 1 ms maximum. In this section we’ll focus on URLLC constrains.

According to [6] where mini-slots (that have a duration of 2 OFDM symbols) are considered, the processing time available for a round trip time of 6 mini-slots and a sub-carrier spacing of 30 kHz, is 4 symbols. This would mean that the processing time available for the UE is:

\[ t_{\text{UE}} = 4 \times t_{\text{sys}} = 4 \times \frac{1}{\text{symbol rate}} < \frac{1}{30 \text{kHz}} \]

The complexity estimation in terms of number of additions and multiplication can be seen in Tab. 1. It was based on a typical URLLC use-case [6]. We can see that decoding could be the bottleneck as it is the most computationally expensive step. We decided to focus on polar decoding which accounts for about 30% of all additions. This is due to the fact that several blind attempts at decoding the PDCCH must be performed. The target polar decoding time is \( t_{\text{dec}} = 0.3 \times t_{\text{sys}} = 4.5 \text{µs} \).

High Level Synthesis of a simplified successive cancellation (SSC) polar list decoder

As we saw in the previous section, polar decoding of the control channel might be the bottleneck for a URLLC receiver. For this reason a list polar decoder based on the simplified successive cancellation algorithm was implemented. The results for a block length of 1024, which is the maximum length allowed for 5G, along with a comparison with state of the art decoder, are shown in Tab. 1. For a fair comparison, results synthesized based on 90 nm technologies \([4]\) were scaled to a 65 nm technology. Frequency and area were respectively scaled by a factor (0.9/15) and (0.6/0.7).

Conclusions

As there are currently no URLLC-specific physical layer specifications the simulation framework can be used for any 5G simulation. The Matlab simulation framework a complete base station to UE transmission according to 5G specifications, is highly configurable and many different simulations can be performed: synchronization, PBCCH, PDCCH, PDSCH. Before being processed by the UE, the data to send is generated, encoded and OFDM-modulated before being sent OTA in a noisy channel environment emulated by different 3GPP channel profiles. Impairments such as channel frequency offset, sample based timing offset and time offset can be enabled to study how well they can be estimated and corrected, and their impact on decoding algorithms’ performances. A complexity estimation for a typical URLLC receiver was then performed. It showed that the decoding could be a bottleneck. For this reason a high level synthesis implementation of a SSC polar list decoder was performed, based on a non-list decoder. The decoding latency achieved for 5G’s largest block length, \( N=1024 \), and a half rate code is 3.29 µs with a clock frequency of frequency of 125 MHz and for a total area of 0.59 mm\(^2\), which meets URLLC’s estimated latency constraints.

References


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