

Generation of 5G Waveforms using MATLAB 5G Toolset

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Abstract - With the rapid technological advancements in the field of cellular networks, the study of 5G and its features have become very important for the engineers as it is the future technology which is known for its significant speed and performance boosts to the user devices. Also these 5G cellular network has the limitations which are hazardous to both the human beings and the environment. Here in this project the 4G LTE throughput analysis is done and an attempt is made to improve the data transmission rate of the 4G LTE by enhancing the necessary specifications. So, this project explains on the study of 5G waveforms and also the Throughput analysis using MATLAB Toolset. This Analysis/study helps us in understanding that enhancing the existing 4G speed with the acceptable frequency would boost the speed and improves the performance of the user devices rather than migrating to the high frequency of 5G which is hazardous. In this Project, A study and analysis is done on the 5G waveforms for both uplink and downlink channels by using MATLAB code to generate respective waveforms in the MATLAB 5G toolset.

Key Words: 5G cellular network, 4G LTE, Throughput Analysis, 5G waveforms, MAT Lab toolset.

1. INTRODUCTION

Mobile technology is evolving rapidly over the years. Exponential growth in digital technologies has sprouted the growth in mobile technology from a digital beeper (pager) to cell phone, instant messaging client, and GPS navigation device. Technologists believe that the future of communication technology rests in wireless technology. Establishment of new standards, technologies aids enhancement of data communication speed along with the voice calling system. With periodic research in communication technology, various mobile technologies are evolved. The various generation of technology which are evolved over the

years in telecom industries are 1G 2G, 3G, 4G and 5G (under development).

1.1 Drivers Driving for Enhanced Wireless Networks:-

A need for improved wireless networks is driven by the main 3 Drivers. First, there is an exponential growth in users and the consumption of data on multiple devices. Post-2016, data is consumed more on mobile devices (smartphones) compared to desktops. The global survey indicates that there will be a seven times increase in the data consumption from 2016 till 2021. Owing to increased congestion in mobile communication traffic the current spectrum will be unable to meet the increasing demand of the customer

Secondly, the number of devices that are internet-connected such as consumer devices (e.g., smartwatches) and industrial devices (e.g., sensors which aid in preventive & predictive maintenance), are increasing. Per a global survey till 2018 there were around 16 billion connected devices, Out of which 7 billion are other devices (Example Industrial sensors) which enable users to use mobiles (smartphone) to supervise and organize activities, further thrusting requirement offset networks.

Final driver is, in day to day business activities and to evaluate strategic decisions businesses are counting on devices which are connected via internet. Industries use these devices to collect and access performance data. These devices are designated as IoT (Internet of Things). Sophisticated IoT devices such as self-driving cars, critical medical systems need networks that will offer services with minimal latency, highly persistent, and greater capacity to rapidly compile and compute and share the data. These are all the factors that present mobile networks cannot support consistently.

1.2 Evolution of Wireless Cellular Technology

Around 19th century, nature of communication was changed by telegraphy and telephony. Over the years, the information propagation had reached the speediness of light. Gradually much more revolution happened in communication, as communication via wire were freed by Radio wave. These waves possesses magical properties. Roaming through our atmosphere, they connect devices that couldn't be connected by other ways. It appears that radio signal propagate in a straight path from source to destination. However practically it moves spherically.

It propagates past obstructions via reflection and diffraction, so that the data it embeds is available throughout its coverage zone. As a result, thousands of users can access and share the same "broadcast" news and entertainment at a minimal cost. This characteristic of radio waves leads not only to broadcast but also allows us to reach a designated User "anytime, anywhere".

1.3 Objectives of Project

- A Study on 5G waveforms generation and its features using MATLAB 5G Toolset.
- A Study on Limitations due to 5G high frequency shorter range.
- Throughput Analysis of LTE using MATLAB LTE Toolset and attempt to increase the data transmission rate.
- To develop a code in Matlab tool to determine maximum input transmission data rate for increased channel bandwidth.

1.4 Problem Statement

5G is quantitatively and qualitatively different from its previous technologies. 5G is a vital technology that supports ultrafast speeds and improves people's lives around the continent by making their life much easier. Implementation of technology will have its own pros and cons. Apart from enhanced QoS, these technologies have an advert effect on Environment and costs for implementing.

In order to transmit the enormous amounts of data required for the IoT, 5G technology will use millimeter waves, which are poorly transmitted through solid material. Compare to preceding technologies where a single antenna is used to broadcasts over a wide area, 5G will need multiple antennas arranged in arrays, installed at 100 meters range that work together to emit steerable, focused, laser-like beams(EMF) that track each other. "Electromagnetic fields-EMF" which are recorded in hertz (Hz) are invisible prime sources of energy. Longer wavelengths with lowest frequencies are less powerful in terms of energy, while shorter wavelengths at higher frequencies are more powerful. When 5G radio wave penetrates the body it causes significant health effects over a longer period such as alteration of heart rhythm, alteration of metabolism, DNA Damage, etc., 5G is a unique technology, which requires a denser range of base stations to provide the required capacity. 5G would cost more to deploy than preceding mobile technologies. This expense is projected at around €400 billion by 2025 to meet the target, according to European Commission estimates.

Owing to high frequency, increase in bandwidth, corresponding effect of 5G waves on Environment and cost to implement the latest technology, we need to think of alternative to upgrade the existing technology with minimum modification to achieve increased QOS. One approach is expanding the bandwidth of current 4G system and correspondingly analyzing the throughput to achieve maximum transmission efficiency to realize the increase in data speed which is higher than current4G technology. Various theoretical toolsets are available to study and analyze the network communication. The consistent toolset which is being used is MATLAB LTE testing tool. Using the MATLAB LTE testing tool, we can generate the waveforms and analyse the throughput for each reference channel of 4G LTE. So analysing the throughput generated, the bandwidth and the resource blocks defined for the reference channel would be increased to reach the optimal peak throughput.

2. SYSTEM MODEL

2.1 Downlink Carrier Waveform Generation

This project work implements 5G new radio downlink carrier waveform generator with 5G toolset. To show the generation and parameterization of 5G new radio downlink waveform by considering parameters here. The generation of channels and signals are as follows.

- PDSCH
- PDCCH
- PBCH PSS and SSS
- CSI-RS

This example considered here helps the generation and parameterization of multiple SCS carriers and multiple BWP(Bandwidth parts). The PDSCH and PDCCH channel instances are generated over the different bandwidth parts. Mapping the PDCCHs, CORESETs sets were configured.

2.1.1 Waveform and carrier configuration

Here the SCS carrier bandwidths inside RBs, the cell ID and generated waveform length in sub frames is set. It is possible to imagine the generated resource grids by setting the display grids field to one. The parameters of channel frequency and bandwidth range are used to show the minimum guard bands of the single carrier subsequence carrier arrangement.

2.1.2 SS Burst

Here in this step SS burst parameters can be set. SS burst numerology can vary from other parts of the waveform. This is defined through the parameter of the block pattern as stated in REFERENCE [16]. In a 5ms half-frame burst, a bitmap is used to identify which block was being transmitted.

2.1.3 Bandwidth Parts

A Bandwidth Parts (BWP) are generated on the carrier by a collection of continuous resources being distributed a numerology. This example allows uses a

structure array to use different bandwidth components. Each entry in the array is BWP. Subcarrier spacing (SCS) must be defined for-BWP, the cyclic prefix (CP) length, and the bandwidth. The spacing factor for the Subcarrier maps the BWP to one of the earlier specified SCS specific carriers. The parameter RB offset influences the BWP 's location inside the carrier. That's represented in BWP numerology terminology. Different BWPs may overlies among themselves as shown in Figure 1

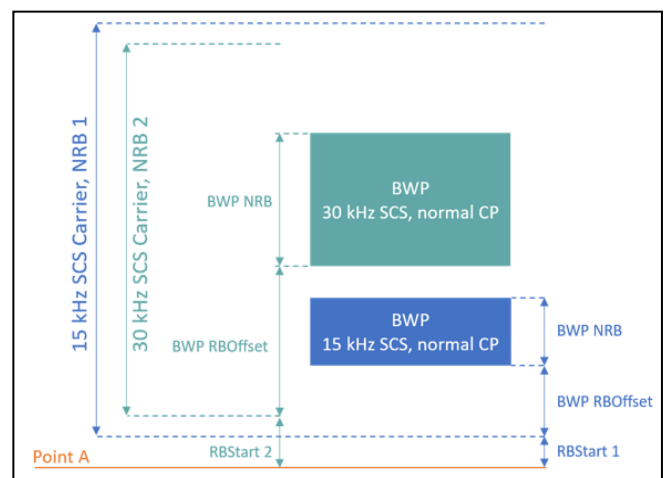


Figure 1: BWP

2.1.4 CORESET and Search Space Configuration

This might define the following parameters as shown in Figure 2.

- The OFDM symbols allocated are the first symbol of each CORESET monitoring opportunity inside a slot.
- Reserved slots defined by allocation duration and periodicity. If this is set to blank it does not mean a repetition
- Length of CORESET in symbols which would be 1 or 2 or 3.
- The CORESET assigned PRB indices. It should be noted that the allocation of CORESET frequencies is specified in blocks of 6 PRBs, consistent with the numbering of CRB relative to point A. allocated input PRB index selects all six PRBs in the block associated with the CRB that contain it.

- CCE may be 'interleaved' or 'non-interleaved' to REG mapping.
- REG (Resource Element Group) in the 'L' bundle size, either (2,6) or (3,6) based on CORESET time.
- The interleave size is 2 or 3, or 6.

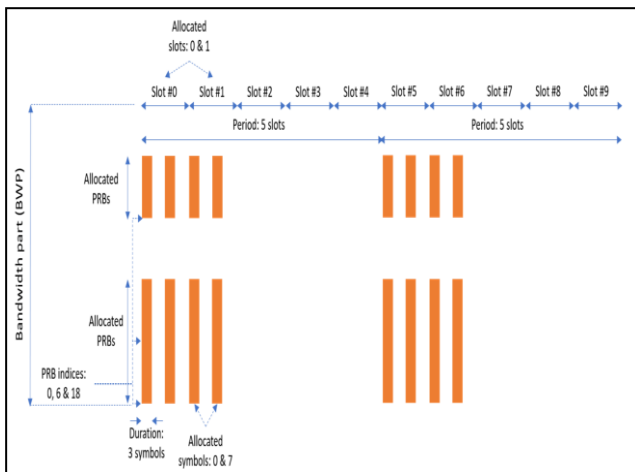


Figure 2: The CORESET parameters

2.1.5 PDCCH Instances Configuration

Here the parameters used for the set of PDCCH instance is specified within the waveform. Every element define a PDCCH sequence instance in structure array.

Can be set to the following parameters:

- Toggle the PDCCH series on / off
- Indicate the bandwidth parts carrying PDCCH
- PDCCH instance control, in dB
- DCI channel enable / disable encoding
- Check spaces reserved in the CORESET sequence;
- CORESET bears an instance PDCCH.
- If the allocation periodicity is set to zero, this does not mean a repeat.
- Control channel elements (CCEs) number in PDCCH.
- RNTI (Radio Network Temporary Identifier)
- Scale of payload DCI

- Source of data DCI post. After one regular PN sequence: PN9-ITU, PN9, PN11, PN15, PN23.

2.1.6 PDSCH Instances Configuration

In this set of PDSCH instances are specified into the waveform. Each one element defines a PDSCH sequence instance in the structure array. Here in this project two PDSCH sequence instances are defined.

Each PDSCH sequence instance must be set with the below parameters:

- Enable/disable PDSCH sequence.
- Identify the Bandwidth parts carrying the PDSCH.
- Power scaling represent in decibel
- Enable / disable coding of DL SCH transport channel
- Data source block conveyor. Each of the regular PN sequence is:-PN9-ITU, PN9, PN11, PN15, PN23.
- The target code rate is used to measure the block sizes of the transport.
- Parameter overhead, Rotation of symbols, number of layers and series of redundancy models.

2.1.7 Allocation

The Figure 3 describes the parameters used for the allocation to PDSCH. The parameters which are specified below can be place to control the PDSCH allocation. These parameters are related to Bandwidth parts.

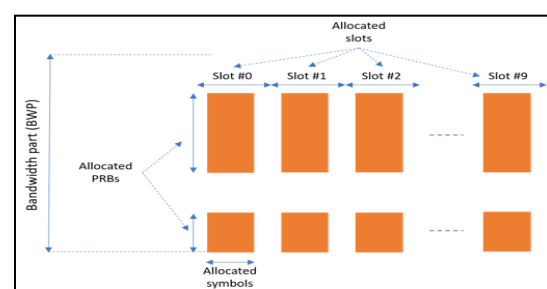


Figure 3: The PDSCH allocation

The below specified PDSCH allocation will avoid the locations use for the SS burst.

- Symbols inside the allocated slot to each of the PDSCH instance.
- Slots in a frame use for the PDSCH sequence.
- The period of the slot allocation. If the period is blank, it specify no repetition.
- The allocated PRBs are related to the Bandwidth parts.
- Radio Network Temporary Identifier is use to link the PDSCH to PDCCH instance.
- NID for scrambling PDSCH bits.

2.1.8 Waveform generation for Downlink channel

Waveform Generation block collects all the parameters into carrier configuration and generates the waveform.

2.2 Uplink Carrier waveform Generation

Here the steps and parameters are specified on how to generate and parameterize 5G NR uplink waveform. The following are the channels and signals that can be generated.

- PUSCH
- PUCCH
- SRS

The Multiple instance of PUCCH, PUSCH, SRS can be generated above the different Bandwidth parts. This allows to configure PUCCH, PUSCH and SRS for a particular UE categorized by RNTI and transmits only PUSCH for the particular RNTI when both PUSCH and PUCCH overlap in a slot.

2.2.1 Waveform and Carrier Configuration

Waveforms and Carrier Configuration sets the sub-carrier spacing definite carrier bandwidth in the resource block, length of the generated waveform in sub frames and physical layer cell identity N_{CellID} . It is possible to imagine generate resource grids by set the display grids field to 1. The channel bandwidth and

frequency range parameters are used to show the minimum guard bands of the SCS carrier alignment.

2.2.2 Bandwidth Parts

Bandwidth parts are created by a set of adjacent resources distribution of a numerology on SCS specific carrier which is given. It supports the usage of many bandwidth parts by means of a structure array. Every entry in the array represents BWP(Bandwidth parts).For each BWP, it is possible to specify the cyclic prefix length, subcarrier spacing (SCS) and the bandwidth. The SCS parameter maps the bandwidth parts to one of the SCS particular carriers that are previously defined. In carrier, the RB Offset parameter controls the place of the bandwidth parts as shown in Figure 4.5

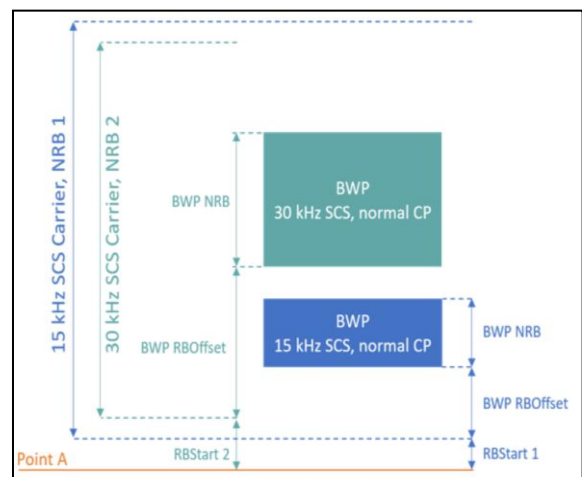


Figure 1: Bandwidth parts

2.3 PDSCH Throughput Analysis in Simulink

The example shown mainly demonstrate how to calculate PDSCH throughput presentation in Simulink using LTE toolbox for the following TM (Transmission Modes):

- Single antenna (Port 0) TM1
- Transmit diversity TM2
- Open loop codebook based on precoding: Cyclic Delay Diversity (CDD) TM3

The exemplar workings on a *subframe* by *subframe* foundation. For every subframe, the model

generates and OFDM modulates a populated resource grid to make transmission waveform. The generated waveform is then skilled a load fading channel. The receiver next performs channel estimation, equalization, demodulation, and decoding. The block CRC result by the channel decoder output is employed to determine the PDSCH throughput performance.

2.3.1 Structure of the Model

The model has four main parts:

Transmitter: Generates haphazard codewords and a settled resource grid, which is modulated by OFDM to create a transmit waveform.

Channel: In this transmitted waveform is filtered through a multipath Rayleigh fading channel with AWGN.

Receiver: Recovers the transmitted progression of bits by performing synchronization, channel estimation, equalization, demodulation and decoding.

Throughput analysis: Calculates the throughput presentation with the block CRC decoding consequences.

In conclusion, the Model parameters block enables to vary the most common parameters for the simulation, channel modeling, and channel estimation

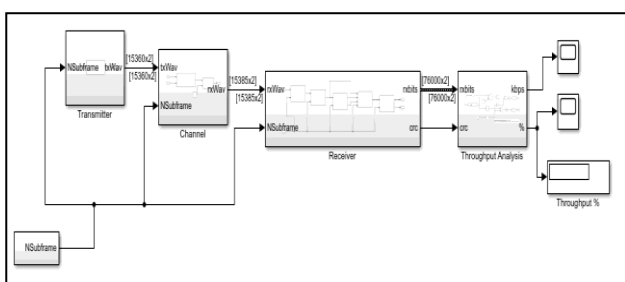


Figure 5: PDSCH Throughput Performance Model

Transmitter

The Transmitter block creates one or two random code words with information bits, counting on the transmission mode. Then the decision to the *lteRMCDL tool* function produces an OFDM modulated waveform

from the knowledge bits. This waveform contains the physical channels and signals. Since the model will not specify an RMC, all downlink sub frames are scheduled

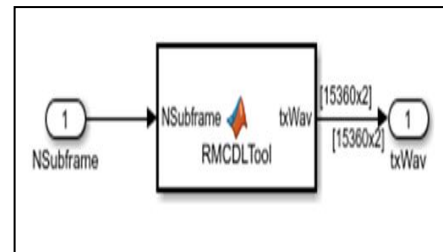


Figure 6: Transmitter Block

Channel

In the channel subsystem, the waveform is passed through a multipath Rayleigh fading channel and AWGN noise is then added. The noise power is restricted by varying the SNR parameter. The parameters of the fading process can be controlled from the Channel Parameters tab in the model parameters block.

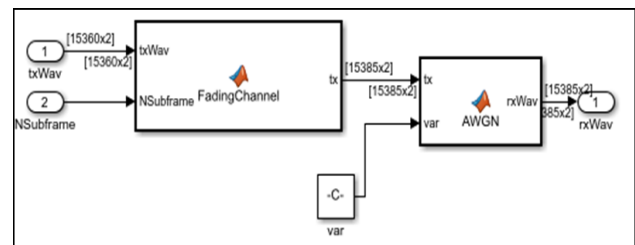


Figure 7: Channel Block

Receiver

The receiver recover the PDSCH information from the channel and computes the block CRC. This process consists of the following steps:

- **Synchronization:** The symbols which received are offset to account for a combination of both implementation and channel delay spread.
- **OFDM Demodulation:** Received symbols are demodulated by OFDM.

- **Channel Estimation:** The noise levels and channel response are get estimated. These are used to decode the PDSCH.
- **PDSCH Decoding:** The recovered PDSCH signs for every transmit antenna from the received grid, along side a channel approximation, are demodulated and descrambled to urge an approximation of the established code words.
- **DL SCH decoding and block CRC error computing:** The vector of soft bits which are decoded is passed to 'lteDLSCHDecode'. This function is used to decodes the codeword and returns the block CRC error used to find out the throughput of the system.

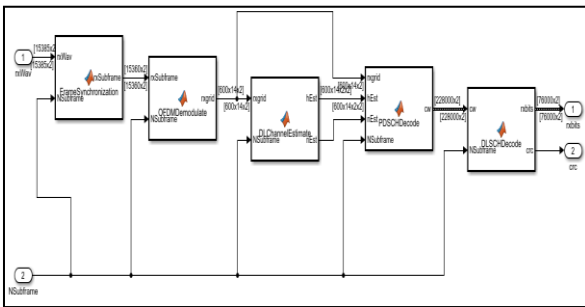


Figure 8: Receiver Block

Throughput Analysis

Throughput is the data packets transmitted per second. It is represented or measured in bits per second (bps). Throughput is an important factor that indicates the quality and performance of a network connection.

Here, LTE Toolbox offers standard compliant functions and software for designing, simulating and testing LTE, LTE Advanced communications systems. With the toolbox, end-to - end communications links can be designed , simulated, calculated and analyzed. There are many parameters which needs to be selected to generate the throughput.

3. RESULTS

3.1 Downlink carrier waveform generation

This project implements 5G new radio downlink carrier waveform generator using 5G toolbox.

Below are the waveforms generated for the Downlink using the MATLAB code.

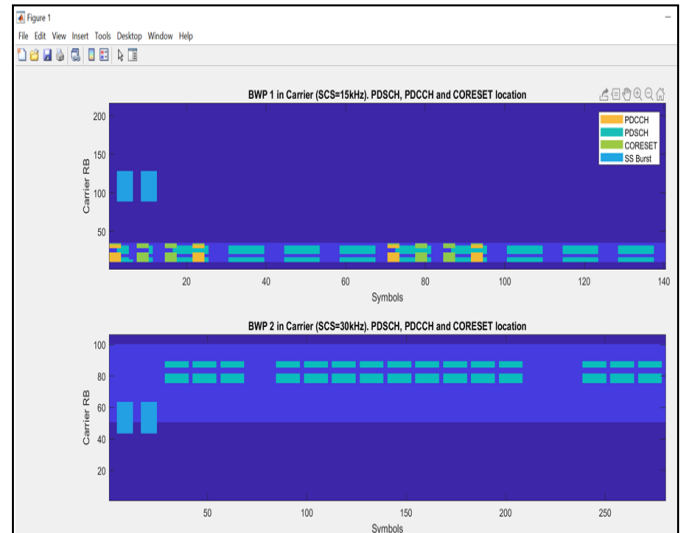


Figure 9: 5G NR downlink carrier waveform (Symbols, Carrier RB)

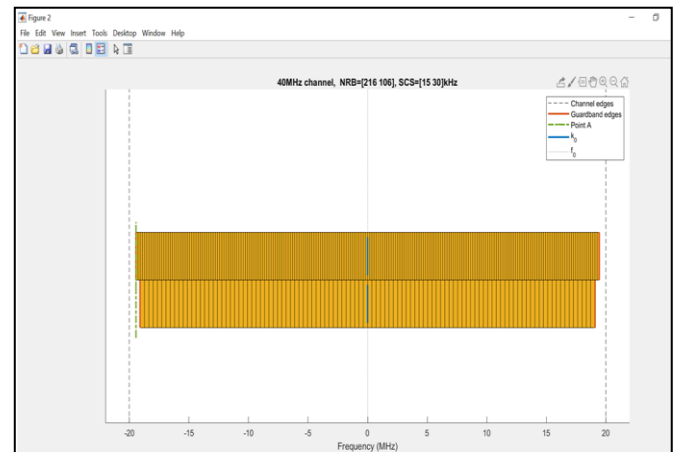


Figure 10: 5G NR downlink carrier waveform, 40MHz Channel

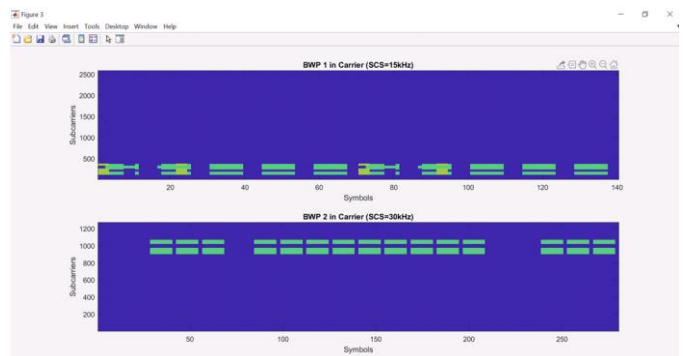


Figure 11: 5G NR downlink carrier waveform (Symbols, SubCarrier)

3.2 Uplink carrier waveform generation

This section implements 5G uplink carrier waveform generator using 5G Toolbox. Below are the waveforms generated for the Uplink Carrier waveform generation in the MATLAB 5G toolset using the MATLAB code.

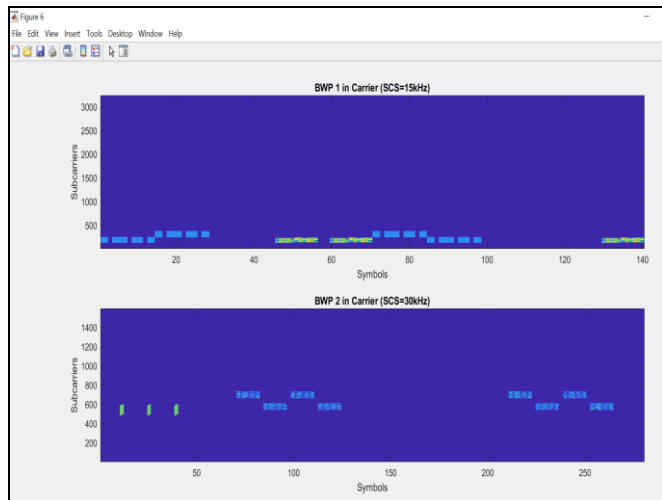


Figure 12: 5G NR uplink carrier waveform (Symbols, Carrier RB)

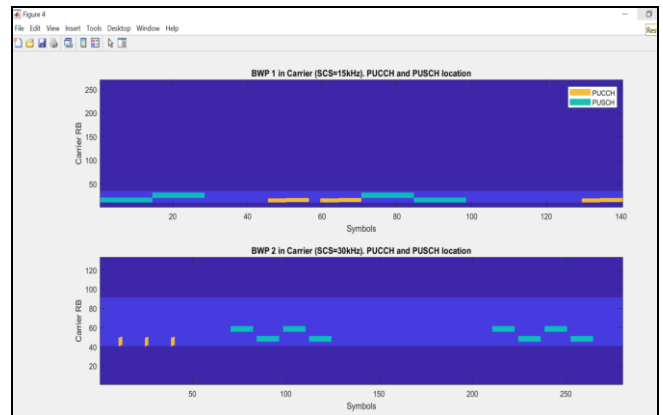


Figure 14: 5G NR uplink carrier waveform, (Symbols, SubCarrier)

Analysis of Throughput in LTE

Here the MATLAB LTE throughput Analyzer tool is used to analyze the throughput. As a first step the reference channels R.7,R.8,R.9 are considered and generated the throughput efficiency using a plot of Throughput versus SNR and Throughput versus Frame number. The theoretical calculations are done in order to find the peak throughput for each reference channel. The plot of Peak throughput versus frames is generated by using a code in MATLAB.

The Bandwidth (25MHz and 30 MHz) and the Resource blocks are enhanced in order to achieve the high data transmission rate.

Reference Channel - R.7 (Bandwidth: 10MHz)

Below is the Throughput generated for the R.7 Specifications.

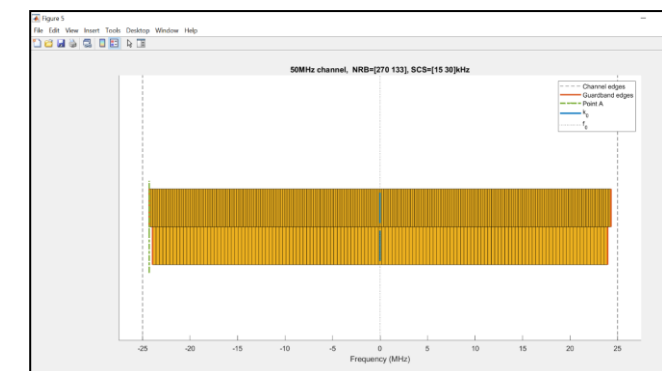


Figure 13: 5G NR uplink carrier waveform, 50MHz Channel

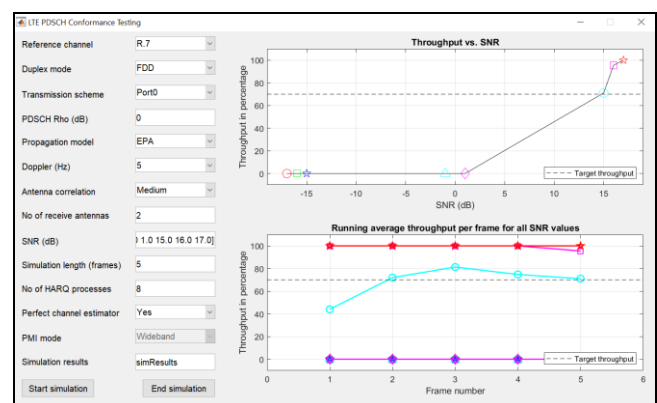


Figure 15: Throughput generation for 10MHz

Theoretical calculation to find the physical throughput for 10MHz(R7):

$$PRB = 2 \times RB = 12 \text{ SC} \times 14 \text{ OFDM}$$

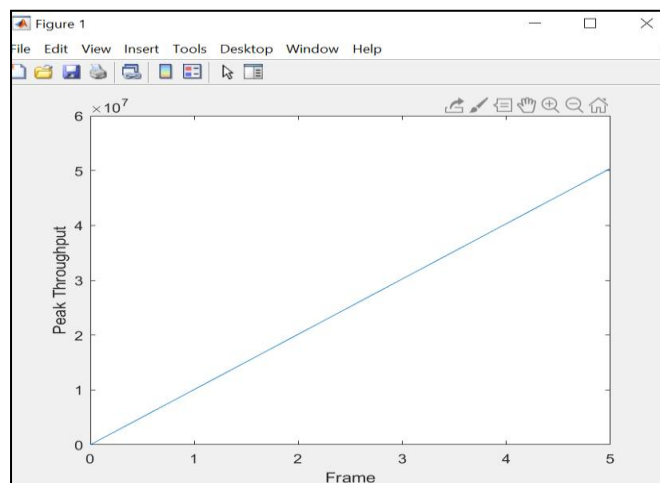
RB = 12 SC x 7 OFDM Symbols in Normal CP (0.5 ms = 1 Time Slot).

$$\text{One PRB} = 12 \times 7 \times 2 = 168 \text{ RE}$$

10MHz ==> 50 PRB ==> 50*168 per ms= 8400 per ms or 8400000 symbols per seconds.

Maximum Physical Throughput in LTE is (8400000) * (6bits) = 50.4 Mbps for 10MHz

Figure 16: peak throughput for 10 MHz using the code



Reference Channel - R.8 (Bandwidth: 15MHz)

Below is the Throughput generated for the R.8 specifications.

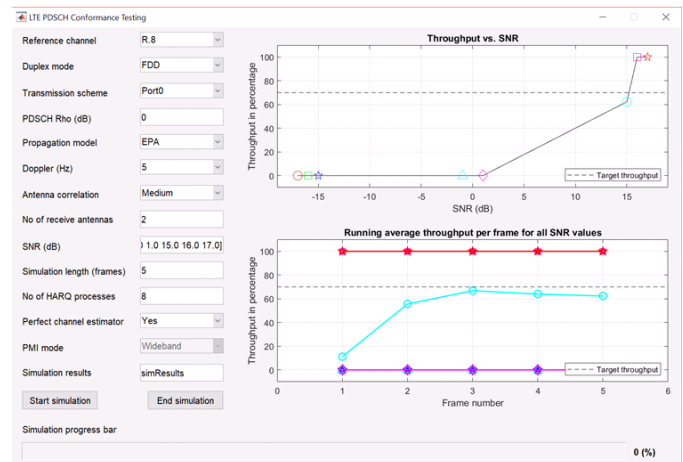


Figure 17: Throughput generation for 15MHz

Theoretical calculation to find the physical throughput for 15MHz(R8):

$$PRB = 12 \times 7 \times 2 = 168 \text{ RE}$$

15MHz ==> 75 PRB ==> 75*168 per ms = 12600000 symbols per second.

Maximum Physical Throughput in LTE is (12600000) * (6bits) = 75.6 Mbps for 15MHz

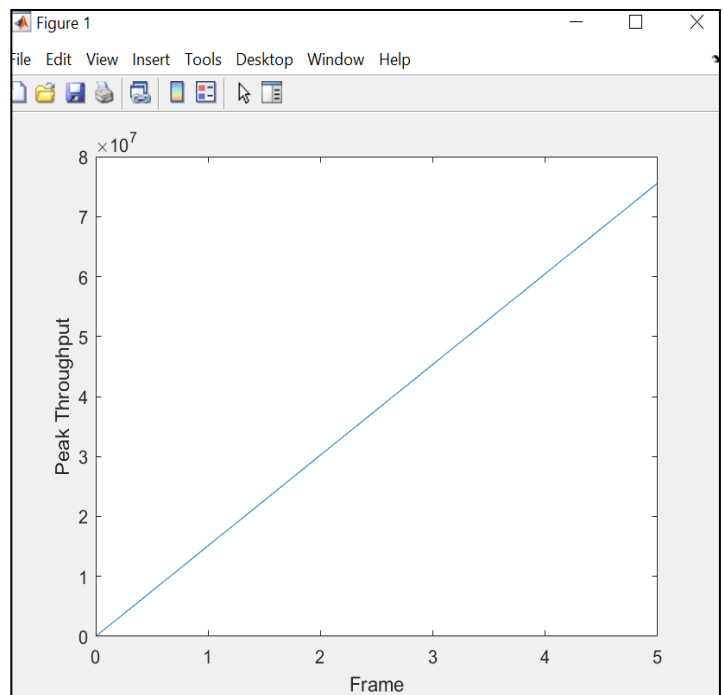


Figure 18: Code generated peak throughput for 15MHz

Reference Channel - R.9 (Bandwidth: 20MHz)

Below is the Throughput generated for the R.9 specifications.

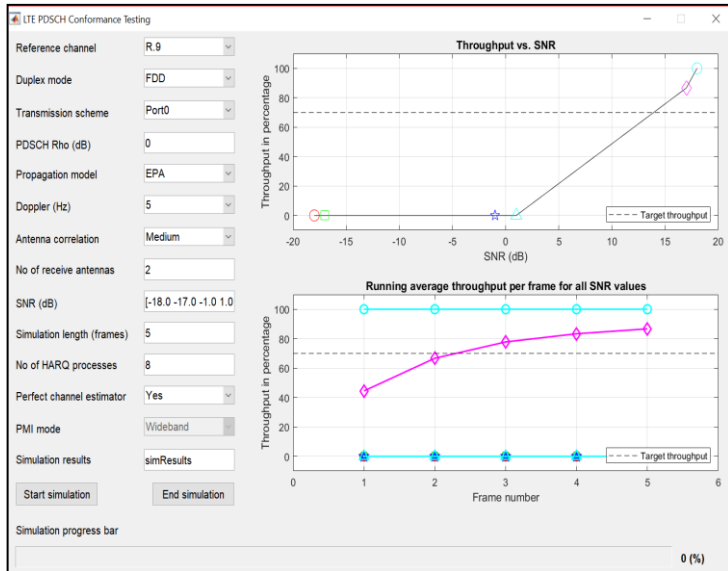


Figure 19: Throughput generation for 20MHz

Theoretical calculation to find the physical throughput for 20MHz (R9):

$$PRB = 12 \times 7 \times 2 = 168 \text{ RE}$$

20MHz ==> 100 PRB ==> 100*168 per ms = 16,800,000 symbols per second

Maximum physical throughput in LTE is (16800000) x (6bits) = 100.8 Mbps for 20MHz

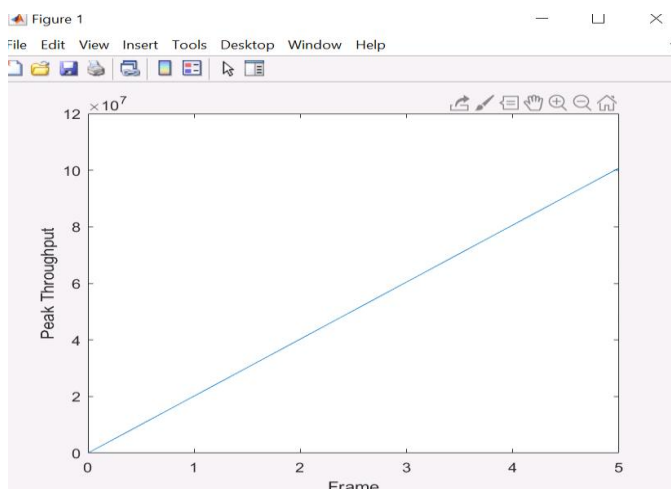


Figure 20: Code generated peak throughput for 20MHz

For 25MHz:

$$PRB = 12 \times 7 \times 2 = 168 \text{ RE}$$

25MHz ==> 125 PRB ==> 125*168 per ms = 21000000 RE Maximum physical throughput in LTE is

$$(21000000 \text{ RE}) \times (6\text{bits}) = 126 \text{ Mbps for 25MHz}$$

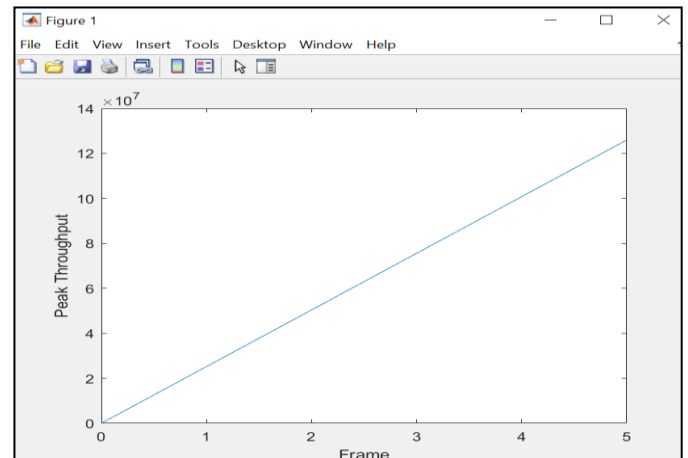


Figure 21: Code generated peak throughput for 25MHz

For 30MHz:

$$PRB = 12 \times 7 \times 2 = 168 \text{ RE}$$

30MHz ==> 150 PRB ==> 150*168 per ms = 25200000 RE

Maximum physical throughput in LTE is (25200000 RE) x (6bits) = 151.2 Mbps for 30MHz

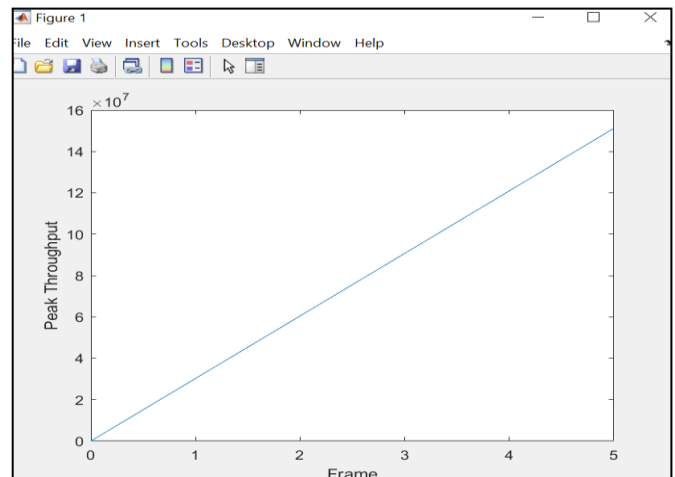


Figure 22: Code generated peak throughput for 30MHz

4. CONCLUSIONS

In this project, the study has been carried out on understanding the mobile network technologies starting from 1G to 5G. Each technology has its own standards specified. There is no common architecture for interconnecting various engineering standards. Technology enhancement is always associated with its own advantages and disadvantages. It is obvious that 5G is characterised with high speed data transmission rate because of its high bandwidth. These characteristics will have negative impact on the ecosystem and cost involved to migrate from existing technology to 5G. Here an attempt is made to counteract these limitations of 5G by using MATLAB LTE toolset to improve the data rate transmission beyond the 4G specifications.

The Project flow starts with the Generation of 5G waveforms using the MATLAB toolset. The MATLAB toolset provide standard compliant functions and references for the modelling, simulation and verification of communication system. It gives us more idea and understanding on the 5G technology as it is very important as whole world is waiting to experience this fastest technology which make the life of people much easier.

The Throughput analysis of the LTE gives us an understanding on how the Throughput varies for the data rate sent by changing the different parameters available in MATLAB LTE Testing tool.

By this Analysis we can have higher channel capacity having higher throughput with the Bandwidth selection for the channel higher than defined for the reference channels and lower than the 5G.

Using this Analysis, we can achieve the higher bit rate transmission designed with lower frequency bandwidth defined for 5G which will cause the environmental hazardous.

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