Mitigating interference challenges in integrated 5G New Radio and Narrowband Internet of Things networks

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DECLARATION

I, LEBOHANG CASWEL TLAKE, identity number: ______________ and student number _________ do hereby declare that this study submitted to the Central University of Technology, Free State for the Master of Engineering in Electrical Engineering, is my own independent work; and complies with the Code of Academic Integrity, as well as other relevant policies, procedures, rules and regulations of the Central University of Technology, Free State; and has not been submitted before to any institution by myself of any other person in fulfilment (or partial fulfilment) of the requirements for the attainment of any qualification.

_______________________ **20/10/2023**

STUDENT SIGNATURE DATE

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ABSTRACT

This study focuses on mitigating Narrowband Interference (NBI) that results from Fifth Generation New Radio (5GNR) and Narrowband Internet-of-Things (NB-IoT) coexisting on the same spectrum. As NB-IoT reuses the same spectrum as the 5GNR, the coexistence of these two frequency bands results in an unwanted interference referred to as a Narrowband Interference (NBI). The main aim of the coexistence of these two bands is to enable frequency reuse which is important to maximise spectrum utilisation as spectrum is very scarce.

This study describes 5GNR specifications and how devices and network infrastructure transmit/receive data to/from each other by the reuse of electromagnetic radio waves. As 5GNR uses some of the frequencies up to 6GHz of the spectrum, referred to as sub-6 spectrum, interference tends to occur because of the spectrum being occupied by other cellular radio technologies including but not limited to Machine-Type Communication (LTE-M), Long-Term Evolution (LTE) and NB-IoT. Although 5GNR has an advantage of using a technology called Dynamic Spectrum Sharing (DSS) which allows spectrum sharing as the LTE, LTE-M and NB-IoT, the challenge of reduced spectral efficiency, user and network performance still exists.

The principal objective of this study is therefore to effectively analyse the coexistence of the 5GNR and NB-IoT and develop a protocol to reduce the current spectral efficiency limitation with the further aim of increasing overall user and network performance in a smart network. Firstly, analysis of the characteristics of 5GNR and NB-IoT was performed using MATLAB based on their bandwidth and modulation schemes and then which problem was addressed by experiments in MATLAB.

The characteristics of these waves on the spectrum analyser were investigated. The frequencies used in 5GNR and NB-IoT were of the most importance as

frequency and bandwidth have a relationship, and again the relationship of bandwidth and wavelength were among the considerations. Various modulation schemes were considered, and it was concluded that for this study, the highest order modulation scheme which is 256 Quadrature Amplitude Modulation (256QAM) be used as it is a better modulation scheme compared to other modulations schemes based on more information capacity than 64-QAM and 16-QAM and has 256 number of message points which is higher than the 64-QAM and 16-QAM.

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Among the key results of the study, it is shown that lower frequencies are required to be used to mitigate interference. Another advantage of using lower frequencies is that of having higher wavelength which are good for penetration of larger distances especially in South Africa where recently there are still not enough towers with 5GNR.

From the results of the MATLAB experiments in this study it was concluded that lower frequencies are used in either of the two technologies coexisting on the same spectrum to mitigate interference. As 256QAM is the modulation scheme used for 5GNR, the interferer gain is kept as low as possible. The key result from this study is the improved Signal to Interference and Noise Ratio (SINR).

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ABBREVIATIONS

3GPP	Third Generation Partnership Program
4G	Fourth Generation
5G	Fifth Generation
AI	Artificial Intelligence
AP	Access Point
ASK	Amplitude Shift Keying
BSBL	Block Sparse Bayesian Learning
BSS	Basic Service Sets
CIR	Channel Impulse Response
CMMOE	Constraint Minimum Mean Output Energy
C-V2X	Cellular-to-vehicle-to-everything
DL	Downlink
DoF	Degree of Freedom
EM	Expectation Maximisation
eMBB	enhanced Mobile Broadband
FSK	Frequency Shift Keying
FTE	Frequency Threshold Excision
GFSK	Gaussian Frequency Shift Keying
GMSK	Gaussian Minimum Shift Keying
IM	Interference Management
IoT	Internet of Things
IS	Interference Steering
LMMSE	Linear Minimum Mean Square Error
LTE	Long-Term Evolution
LTE-A	LTE Advanced
MATLAB	Math's Laboratory
ML	Maximum Likelihood
MIMO	Multiple Input Multiple Output
mMTC	massive Machine Type Communication
MSK	Minimum Shift Keying

NBI	Narrowband Interference
NB-IoT	Narrowband Internet of Things
NR	New Radio
PEF	Prediction Error Filter
PSK	Phase Shift Keying
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RIP	Restricted Isometry Property
RX	Receiver
SAR	Synthetic Aperture Radar
SBL	Sparse Bayesian Learning
SCEM	Sparse Cross-entropy Minimisation
SINR	Signal to Interference and Noise Ratio
SNR	Signal to Noise Ratio
S-SCEM	Simultaneous SCEM
UL	Uplink
WLAN	Wireless Local Area Networks
ICASA	Independent Communications Authority of South Africa
IMT	International Mobile Telecommunications
HAPS	High Altitude Platform Station
NGSO	Non-Geostationary Orbit

CHAPTER 1
INTRODUCTION

1.1 BACKGROUND

There is a steep rise in the demand for 5th Generation (5G) technology as 4th Generation (4G) is gradually waning. There is also a consensus among users that 5G will address more challenges not currently being addressed by 4G. These include but are not limited to increased data rate and capacity, latency, increasing connectivity of devices and general issues of quality [1].

The transition to 5G will have a huge advantage in our lives, economy, jobs, and our industries. Smart devices such as wearables like smart watches, are also evolving, to become independent mobile computing device. Technology in vehicles such as Cellular-Vehicle-To-Everything (C-V2X) is anticipated to save lives and increase transportation efficiency. Artificial Intelligence (AI), robots, drones, and healthcare services like remote monitoring and telemedicine are highly anticipated 5G technologies [2]. Globally the preparation to enable 5G is a task in hand, this includes spectrum allocation standardization, and implementation. The key to the success of 5G is the efficiency of spectrum utilisation due to its scarcity [3].

Based on the 3rd Generation Partnership Project (3GPP) standards, 5G is named New Radio (NR) and it enables technology capabilities such as Massive Machine Type Communication (mMTC), enhanced Mobile Broadband (eMBB), and Ultra-Reliable Low Latency Communication (URLLC). The wireless (IoT) Internet of Things connectivity is provided by mMTC [4]. The scarcity of spectrum which fits best for wireless electromagnetic transmission results in old and new communication systems being positioned close to each other. In some instances, it overlaps, and this inexorably results in rigorous interference. For example, LTE and NB-IoT coexist in the allocated spectrum when they are operating in an in-band mode. NB-IoT technology is developing in a promising way to support the expectancy of MTC in 5GNR with the capacity to interconnect large numbers of nodes with a very low consumption of power and narrowband bandwidth [13].

The narrowband interference that results from 5GNR and NB-IoT should be properly mitigated to permit smooth evolution of 4G to 5G. The mitigation or elimination of the NBI which exists between these three technologies: NR, LTE and NB-IoT is still an open topic because it does not have sufficient literature which has been investigated.

There are two scenarios of coexistence that have been carried out by 3GPP. These are co-carrier sharing and adjacent carrier sharing. The scenario of Co-carrier sharing is made up of two cases. The first case an uplink (UL) carrier is shared by both 5GNR and LTE and the second case a downlink (DL) is shared by both 5GNR and LTE respectively. These cases are known as UL and DL spectrum sharing [3]. 5GNR is deployed on Standalone and non-standalone whereby on non-standalone is coexisting with NB-IoT and LTE and there are interference challenges due to them coexisting on the same frequency band [3]. There are different types of techniques which are suggested to mitigate co-channel interference, but they need to be enhanced further.

The authors in [5] emphasized that the NB-IoT carrier deployment within carriers of 5GNR results in a different type of interference challenge which is not the same as that of a legacy network. However, with the NR and NB-IoT coexisting, the network capacity and data rate must be considered to improve coverage expansion as well as the improvement in robustness of the communication through frequency reuse process. The interference challenges may obstruct the NB-IoT devices channel estimation which incapacitate the energy performance which can be achieved including but not limited to the efficiency of the spectrum. Therefore, this means a scheme to mitigate interference is an essential strategy to curb the addressed challenge. This dissertation highlights the challenges of interference on the integrated 5GNR and NB-IoT networks. The existing narrowband mitigation schemes have been identified. This paper also highlights the research gaps and the comparison aspect of the identified narrowband interference mitigation schemes.

1.2 PROBLEM STATEMENT

5G New Radio (5GNR) and Narrowband IoT (NB-IoT) are two mobile technologies that use the same frequency spectrum. The coexistence in the 700, 600, 900, 1800, 2100, 1700 and 850 bands (results in an unwanted interference referred to as Narrowband Interference (NBI). Although frequency reuse maximises spectrum utilisation, it limits spectral efficiency, user performance and network performance.

1.3 OBJECTIVE OF THE STUDY

The research aim is to establish a protocol to mitigate NBI between 5GNR and NB-IoT with little or no harmful interference.

The objectives are to:

1. Effectively analyse the coexistence of the 5GNR and NB-IoT.
2. Develop a protocol to reduce the current spectral efficiency limitation.
3. Increase overall user and network performance in the smart network.

1.4 RESEARCH METHODOLOGY

The research and the protocol to mitigate NBI between 5GNR and NB-IoT is developed using the steps below:

1. Generation of 5GNR and NB-IoT on the same frequency band and analysis.

This is done using 5GNR toolbox to generate 5GNR and LTE toolbox to generate NB-IoT signals in MATLAB and combining both simulations on Simulink.

The following MATLAB tools are used:

A. 5GNR toolbox.
B. LTE toolbox.
C. Simulink.

2. Simulation and development of a protocol to mitigate NBI between 5GNR and NB-IoT and effectively analyse the network and user performance improvement in both 5GNR and NB-IoT networks. The approach below is used.

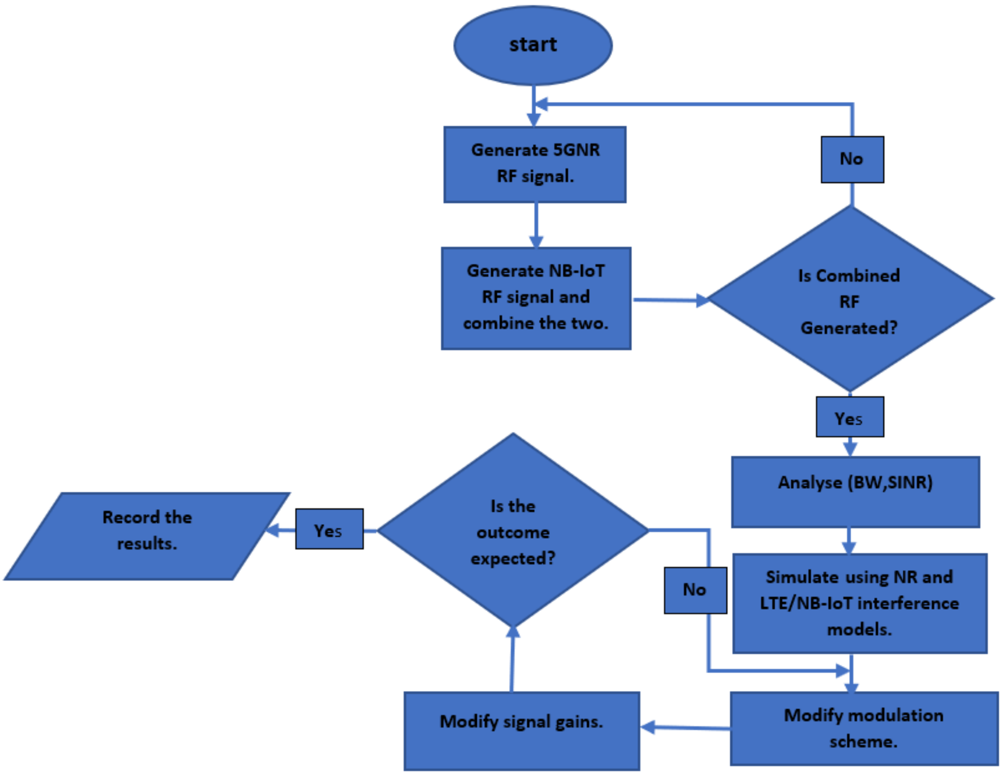

Figure 1: Proposed approached for NBI Mitigation protocol.

In Figure 1, the approach is to firstly generate the RF signal which in this case is 5GNR signal using the 5G toolbox in MATLAB tool. Once this is generated, it is analysed thoroughly. The analysis is based on the following key characteristics: bandwidth, frequencies and SINR. The NB-IoT signal is also generated separately using the LTE toolbox and analysed based on the bandwidth, frequencies used and the SINR. This part is important to have an idea of the expected output. The simulation of the deployment of NB-IoT to 5GNR is analysed using the modelling and testing an NR Receiver with LTE interference model and analysed using the above-mentioned characteristics of a signal. The result is simulated with varying modulation schemes, filter types and frequencies to achieve mitigated interference signal.

3. The last step to the suggested method is to come up with a plan during the simulation to balance the above-mentioned proposed method while optimizing the spectral efficiency. The proposed method is to combine this using massive MIMO antennas and embed this to the proposed setup and simulate the results.

1.5 HYPOTHESIS

Narrowband Interference is an important research gap which has potential to unlock the maximum capabilities of 5G. The analysis of interference shows exactly this interference when both technologies are simulated on the same spectrum. After the simulation, the possible mitigation protocol is investigated, which is the main aim of this study.

1.6 LIMITATION OF THE STUDY

The study is only focused on the NBI mitigation protocol using MATLAB. Any other 5G or technology aspect which is not mentioned in the methodology and objectives of this study is not part of this study. Using MATLAB there are different tools which are used for this study, for a start Wireless toolbox that contains 5G toolbox and LTE toolbox were used. 5G toolbox is used for generation of 5G frequency on a 5G spectrum which coexist with LTE and NB-IoT. Both LTE and NB-IoT use LTE toolbox and in this case NB-IoT frequency is also generated on the same spectrum. These frequencies are simulated together using Simulink so that they can clearly show how they interfere with each other. During the simulations, different technology components such as the resource grid which shows the 5G simulated resources, channel view, and the spectrum analyser are analysed for both the technologies. These components provide a clear view of the spectral efficiency which is the benefit of the NBI mitigation. This study, however, is not focused on the use of 5GNR or NB-IoT signals other than just NBI mitigation.

1.7 SCOPE OF DISSERTATION

This dissertation focuses on a model used to mitigate interference between 5GNR and NB-IoT signals which coexist in the same spectrum. The coexistence of 5GNR and NB-IoT interference mitigation is researched in the below sequence model:

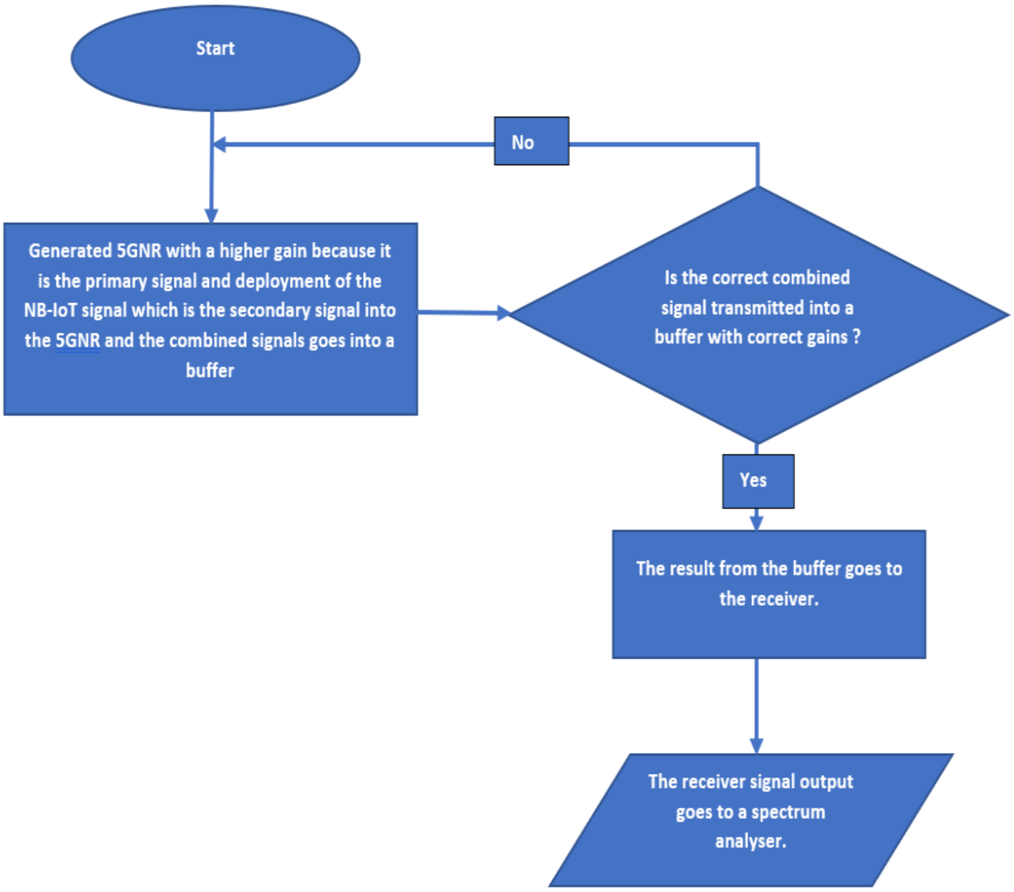

Figure 2: Interference Mitigation research sequence model.

Figure 2 shows the research sequence model that was followed to mitigate interference as the 5GNR was generated with a higher gain and NB-IoT with a lower gain. The resulting signal was fed to a buffer and then the receiver and the output signal were analysed from the spectrum analyser as the output.

1.8 OUTPUTS OF THE RESEARCH

Outputs that resulted from this research are as follows:

1. Tlake, L.C., Markus, E.D. and Abu-Mahfouz, A.M., 2021. A review of interference challenges on integrated 5GNR and NB-IoT networks. 2021 IEEE AFRICON, pp.1-6.

2. Tlake, L.C., Markus, E.D. and Abu-Mahfouz, A.M., 2021. Mitigation of Interference Challenges on Integrated 5GNR and NB-IoT Networks. 2023 (Presented at the IEEE 2023 International Conference on Data, Information, Knowledge and Wisdom (DIKW 2023) Melbourne Australia)

1.9 OUTLINE OF THE DISSERTATION

Chapter 1 provided a discussion of the background, intention of study and the breakdown of the context.

Chapter 2 is the literature review of the study. It provides an overview of the narrowband interference mitigation methods, benchmarking from different articles, results, drawbacks, and gaps. This chapter highlights and compares various mitigating methods and their advantages which gives the purpose of this study.

Chapter 3 discusses the approach used for a Narrowband Interference mitigation protocol using MATLAB. This includes the generation of the New Radio Signal as well as the interfering signal merged to display the interference on a spectrum analyser using a MATLAB model. The Interference is then analysed and investigated with different properties on a model to mitigate the interference observed.

Chapter 4 provides a discussion of the simulations performed in this study. The details of the model used and the parameters to mitigate NBI are also explained.

This chapter discusses all the advantages and disadvantages of having different technologies on the same spectrum band and the limitations of the study.

Chapter 5 is the final chapter of the dissertation. It presents a summary of the study and provides future perspective of the research area.

CHAPTER 2
LITERATURE REVIEW

2.1 INTRODUCTION

A review of the literature was conducted to comprehensively analyse interference challenges between the integrated 5GNR and the NB-IoT as well as the different narrowband interference mitigation techniques between NB-IoT and 5GNR used in various literature. As we know 5G is not yet popular in South Africa, but it is the next big technological concept, and it will unlock more and more communication channels and enhance NB-IoT on a much larger scale, but it will be more efficient if there is no interference challenge reviewed on [26, 55 - 64]. After many reviews from different articles, the gaps of improvement were identified [65 - 83]. These gaps include accuracy and spectrum reuse. It can be deduced that from an extensive review of literature in [12 - 15, 65 - 79] that this has not gained much attention from the researchers.

There are several reviewed solutions in this review chapter for the elimination of the Narrowband Interference mitigation, but it is still an open issue. For determination and relevance of this research project, this section is of importance for the definition of the general research question, to analyse proposed methods of NBI mitigation, the advantages, disadvantages, drawbacks, and possible improvement. The review of different narrowband interference mitigating methods are also included in this chapter, examination of articles, results, and more observations.

2.2 BACKGROUND KNOWLEDGE OF NBI MITIGATION METHODS

There are number of different proposed solutions for elimination of the narrowband interference (NBI). For instance, different curbing schemes such as the Sparse Cross-entropy Minimisation (SCEM) and other methods like Sparse Bayesian Learning (SBL), Block Sparse Bayesian Learning (BSBL) were proposed in [13]. This is a further improvement of SBL as addressed in [14] and Interference Steering (IS) in [15].

Sparse cross-entropy minimisation is proposed using the method of iteratively learning to the support distribution [45]. This method is an efficient and more accurate way for the recovery of NBI in which the coexistence of NR/LTE and NB-IoT is supported. Sparse machine learning framework is a form of recovery and elimination of NB-IoT to LTE/NR interference that operates in systems with more spectral efficiency and able to have good accuracy of recovery than other approaches [46]. This approach exploits the property of NBI sparsity.

A major concern with this approach is the difficulty in practical observation design which has adequate Restricted Isometry Property (RIP) which is a property that provides the necessary and sufficient requirements for the compressive sensing. In this context is required by the CS-based methods as a result when the noise background conditions, or the level of sparsity are unideal the performance is limited. The possible improvement is the extension of the proposed framework to (MIMO) Multiple-input Multiple-output systems to enable utilisation of the correlation of sparsity of the NBI at multi-antennas with what is called (S-SCEM) Simultaneous SCEM is formulated. The S-SCEM combines these contributions of multiple antennas and common support of the NBI is recovered simultaneously to improve the spectral efficiency and accuracy further [13].

Sparse Bayesian Learning (SBL) method's aim is to solve the block sparse recovery problems. The major concern of this method was prior information of the block partition and the impracticality of the NBI constant assumptions [49]. Dissimilar from the previous mentioned schemes, the powerful machine learning theory and techniques which are coming up are recently getting much attention in research and they can inspire greatly, and this can lead to a reliable and efficient NBI recovery method to be discovered.

Block Sparse Bayesian Learning method in [47 - 54] aims to improve the accuracy of the SBL. This further improves the SBL method, and its principal advantage is that the blockage of partitions prior estimation is not required. Expectation Maximisation (EM) is the recovery method in which it first blocks the partition estimation in terms of threshold power and followed by NBI recovery. According to the existing comprehensive literature survey, the NBI recovery based on the BSBL research does not exist yet and this recovery theory which is based on the BSBL is still a gap to be filled.

The proposed Interference Management (IM) method in [16] is called Interference Steering (IS). This is the approach of this method: a signal named steering signal is generated, then the originating interference found on the receiver is steered to the relevant direction with respect to the signal which is desired, and this leads to a signal with no interference to be achieved. Additional advantage of this method is that it consumes less power, but it requires some degree of freedom at the interfered Receiver (Rx). The application of IS in Wireless Local Area Network (WLAN) and Internet of Things (IoT) leads to the reuse of the same band of frequency used by the adjacent Basic Service Sets (BSS) with areas that are overlapping. IS allows simultaneous transmission of data from multi nearby Access Points (APs) on the same channel of their mobile stations and this enhances the reuse of spectrum.

2.3 CLASSIFICATION OF NBI MITIGATION METHODS

A comprehensive literature review was conducted on the different techniques used by the researchers to mitigate the narrowband interference between NB-IoT and 5GNR due to their coexistence, but Narrowband Interference mitigation is still an open issue. The narrowband interference recovery is an open issue regardless of the effectiveness of the reviewed method in [13] to cancel the Narrowband Internet of things interference in the long-term evolution advanced systems, but not proven in 5GNR.

The following NBI mitigating methods are analysed and are compared:

- Sparse cross-entropy Minimisation (SCEM)
- Sparse Bayesian Learning (SBL)
- Block Sparse Bayesian Learning (BSBL)

- Interference Steering (IS)
- Prediction-error filter (PEF)
- Constraint Minimum mean-output energy (CMMOE)
- Linear Minimum Mean Square Error (LMMSE)
- Frequency Threshold Excision (FTE)
- Maximum Likelihood (ML)
- Synthetic Aperture Radar (SAR) Image Formation

2.3.1 Sparse cross-entropy Minimisation

Sparse cross-entropy minimisation is proposed using the method of iteratively learning the support distribution. The authors in [13, 45 - 51] fully explained this method as the efficient and more accurate way for the recovery of NBI in which the coexistence of NR/LTE and NB-IoT is supported. In [13] the authors have reviewed the sparse machine learning framework as a form of recovery and elimination of NB-IoT to LTE/NR interference that operates in systems with more spectral efficiency and able to have good accuracy of recovery than other approaches. This approach exploits the property of NBI sparsity. A major concern with this approach is the difficulty in practical observation design which has adequate (RIP) Restricted Isometry Property which the CS-based methods require as a result when the noise background conditions, or the level of sparsity are unideal the performance is limited.

The possible improvement is the extension of the proposed framework to MIMO systems to enable utilisation of the correlation of sparsity of the NBI at multi-antennas with this called (S-SCEM) Simultaneous SCEM which is formulated. The S-SCEM combines these contributions of multiple antennas and common support of the NBI is recovered for simultaneous improvement of accuracy and spectral efficiency further [13].

2.3.2 Sparse Bayesian Learning

Sparse Bayesian Learning method's aim is to solve the block sparse problems of recovery. The major concern of this method was prior information of the block partition and the impracticality of the NBI constant assumptions [14]. Dissimilar from the previous mentioned schemes, the powerful machine learning theory and techniques which are coming up are recently getting much attention in research and they can inspire greatly, and this can lead to a reliable and efficient NBI recovery method to be discovered [45 - 47].

2.3.3 Block Sparse Bayesian Learning

Block Sparse Bayesian Learning is proposed in [48,49, 51,52,53] to further improve the accuracy. This further improves the SBL method, and its principal advantage is that the blockage of partition's prior estimation is not required. The simulated and reported results for this method shows the effectiveness in cancellation of the NBI in the LTE-A systems [15] but it is not proven in 5GNR.

In [15] EM recovery method used in this approach firstly blocks the partition estimation in terms of thresholding power and then followed by the recovery of the NBI. According to the existing comprehensive literature survey, the NBI recovery based on the BSBL research does not exist, yet and this recovery theory which is based on the BSBL is still a gap to be filled.

2.3.4 Interference Steering

According to the review in [16], the proposed (IM) Interference Management method called (IS) Interference Steering. This is the approach of this method: a signal named steering signal is generated, then the originating interference found on the RX is steered to the relevant direction respective to the signal which is desired, and this leads to a signal with no interference to be achieved. Additional advantage of this method is that it consumes less power, but it requires DoF at the interfered Receiver (Rx).

The application of IS (WLAN) Wireless Local Area Network IoT based leads to the reuse of the same band of frequency used by the adjacent (BSS) Basic Service Sets with areas that are overlapping. IS allows simultaneous transmission of data from multi nearby (APs) Access Points on the same channel of their mobile stations and this enhances the reuse of spectrum. The simulated results on [4] shows the significant improvement of the network because of IS over existing interference management schemes.

2.3.5 Prediction Error Filter

Prediction Error Filter (PEF) is the method in the time-domain to remove interference. It does this by keeping away from the spectral leakage that results after demodulation [21,39]. There is a property in PEF which is used for removal of the corelation between samples and thereby resulting in the whitening of the spectrum. The drawback of this method is that the uncongenial error floor that results from the subcarriers of data which are cut out, limits the performance.

2.3.6 Constraint Minimum Mean Output Energy.

Constraint Minimum Mean Output Energy (CMMOE) method in [22,40] uses the approach of suppressing the NBI. The receiver is used to minimise the output energy and keeping the symbol, which is desired, then cancel the inter-carrier frequency. The drawback to this method is that prior knowledge of the interference statistics is needed.

2.3.7 Linear Minimum Mean Square Error

Linear minimum mean square error technique in [22,41] is used as an estimation tool for the whole NBI signal. Just like the CMMOE, this technique also has a drawback of the prior knowledge of the interference statistics needed.

2.3.8 Frequency Threshold Excision

Frequency threshold excision approach uses subcarrier powers higher than the threshold which are detected and then excluded to reduce the impact of the subcarriers of the useful data. Some of the subcarriers which are virtual are kept for the detection of NBI. Irrespective of this, virtual subcarriers should be close to the spectral positions of the NBI accuracy and the (CIR) Channel Impulse Response has the exact assumption to be known at the receiver which in practice may be unrealistic [23,42]. The drawback to this approach is that any error in the estimation of one sub-carrier propagates to the sub-carriers which follows. The below Figure 3 explains this approach better.

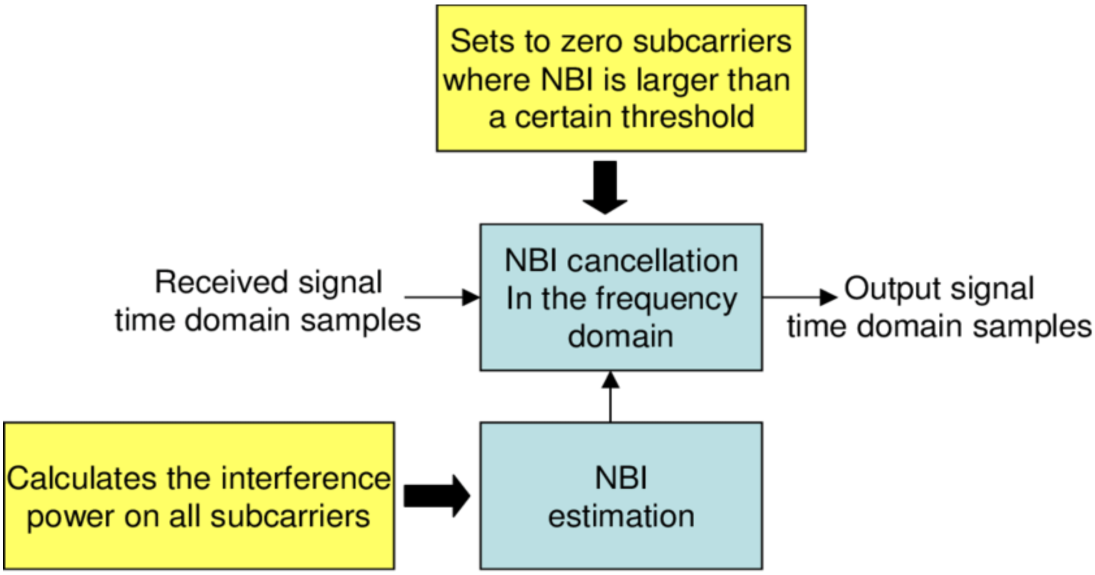

Figure 3: Frequency Threshold Excision approach [23]

2.3.9 Maximum Likelihood

Maximum Likelihood (ML) approach estimates NBI and then cancels it from the signal received. This approach is based on the sparsity property of the NBI. This approach has the popular drawback of estimation of the NBI like the previous mentioned approaches and therefore this is still the gap in the rese3].

2.3.10 Synthetic Aperture Radar (SAR) Image Formation

The main aim for NBI mitigation for (SAR) Synthetic Aperture Radar is to manage the removal of NBI and achieve the clear SAR imagery. Figure 4 shows the flowchart of this approach.

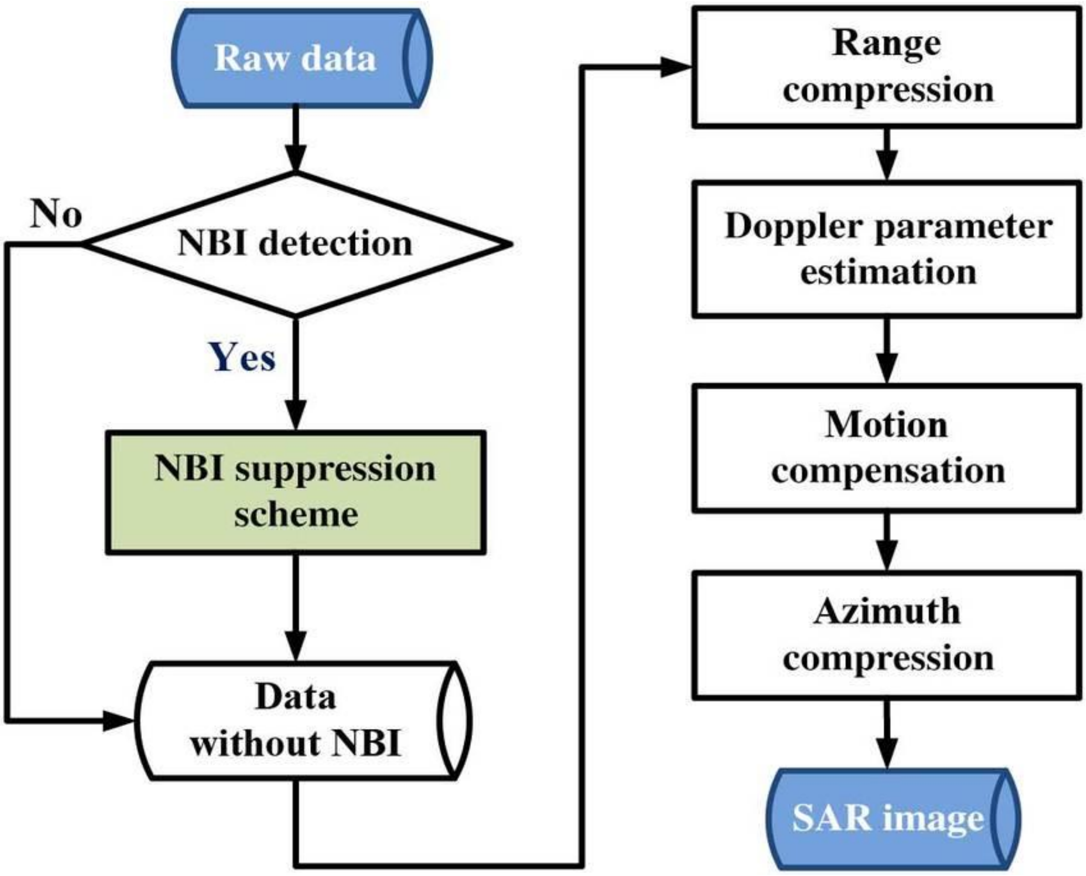

Figure 4: Synthetic Aperture Radar Image formation flowchart [24]

The suppression scheme is performed by each pulse and thus pushes the whole process faster to save the computation time.

2.3.11 A review of current existing NBI mitigating methods.

A review of different papers with different NBI mitigating techniques was done and these methods were compared with reference to the below as on Table 2.1:

- Problem Statement
- Objectives
- Strength of method (Proposed or Used)
- Findings
- Possible improvement and drawbacks

Table 2.1: BRIEF SUMMARY OF INTERFERENCE MITIGATION APPROACHES

REF	TYPE OF NBI MITIGATION METHOD	APPROACH	KEY OBJECTIVE	STRENGTH OF APPROACH	GAP/FUTURE WORK
[13]	SCEM	Exploitation of the sparsity property of the NBI	Recovery of NBI in NR, LTE and NB-IoT coexistence supported systems	Accuracy and efficiency.	Extension to the MIMO systems.
[12]	SBL	Sparse approximation.	Solving block sparse recovery problems.	N/A	To enable efficiency without the requirement of prior estimation of block partition
[14]	BSBL	The block partition is estimated in terms of the power thresholding and then the NBI is recovered through EM	To further improve the accuracy than the SBL method	There is no requirement of the prior estimation of the block partition.	The recovery theory based on BSBL
[16]	IS	A signal named steering signal is generated then the originating interference found on the RX is then steered to the	Achieving the interference-free transmission.	Less consumption of power.	N/A

		relevant direction respective to the signal which is desired.			
[21]	PEF	It keeps away from the spectral leakage which results post demodulation	Whitening the spectrum	Removes the interference in the time-domain	Improve the limitation of performance.
[22]	CMMOE	Suppression of the NBI by minimising the output energy while it keeps the symbol which is desired and then cancel the inter-carrier frequency	Suppression of the NBI	N/A	Operation without the prior knowledge of the interference statistics.
[22]	LMMSE	Estimation the NBI	Estimation of the whole NBI	Estimation of the NBI	Operation without the prior knowledge of the interference statistics.
[23]	FTE	Detection, usage, and exclusion of the sub-carrier powers higher than the	N/A	N/A	Estimation error of one sub-carrier propagates to the other sub-carriers.

		thresholding powers.			
[25]	ML	Estimates the NBI and then cancels is from the received signals	Cancellation of the NBI from the received signal	Estimation of the NBI	Error in the estimation propagates to the other sub-carriers
[24]	SAR Image formation	Detection and suppression of the NBI to achieve clear SAR imagery	Removal of the NBI	N/A	Estimation error improvement

Table 2.2 TECHNIQUE CONTRIBUTIONS

REF	TYPE OF NBI MITIGATION METHOD	CANCELLING	RECOVERY AND ELIMINATION	ACCURACY LEVEL	SPECTRUM REUSE
[13]	SCEM.		✓		
[12]	SBL.		✓		
[14]	BSBL			✓	
[16]	IS	✓			
[21]	PEF				✓

[22]	CMMOE				✓
[22]	LMMSE				✓
[23]	FTE	✓			
[25]	ML	✓			
[24]	SAR Image forma	✓			

2.4 DISCUSSION OF FINDINGS

A literature review was conducted on different techniques used by the researchers to mitigate the narrowband interference between NB-IoT and 5GNR due to their coexistence. Thus Table 2.1 shows the summary of these mitigation techniques in [12 - 14, 16, 39 - 43, 47 - 49, 51- 53]. There are still future work/gaps and the NBI mitigation remains an open problem. From [14, 41,42] the authors have addressed the NBI recovery as an open issue regardless of the effectiveness of this method in cancellation of the NB-IoT interference in the LTE advanced systems but not proven in 5GNR.
The authors mostly used the sparse learning techniques as a method of NBI cancellation, recovery, and elimination method, for example, the sparse cross-entropy minimisation method, its key objective is the recovery of NBI in NR, LTE and NB-IoT coexistence supported systems, while other methods do the bits and pieces to this problem like solving the parse recovery problem as the SBL in [41] does. These techniques are declared to be effective, and others are more effective than others but with drawbacks.

In [42] the authors proposed the SBL technique in which its approach uses a sparse approximation and solves the block sparse recovery problem, but the major drawback of this technique as mentioned in [43] is the need for prior information of the block partition and unknown signal statistics. The authors in [54] proposed the BSBL technique which is more effective than the SBL technique in [41] but the drawback to this technique is that there is no recovery theory to it, so there is still future work to be done here. The interference steering technique was another proposed technique in [16] which its advantage is that it consumes less power.

With NB-IoT devices and the future of technology power is the most important element because imagine having a very useful device and having to charge it time and time again, that is not an ideal scenario, so this technique is very useful in terms of power consumption. Another important advantage with this approach is that the spectrum reuse is enhanced which is good, but the problem is that it is limited by the requirement of the DoFs. In [21] the authors reviewed a PEF method which whitens the spectrum, but this whitening of the spectral results in performance limitation in which that is a drawback to that approach.

The authors in [22] reviewed two methods which is CMMOE and LMMSE. Both methods have a similar drawback; the prior knowledge of the interference statistics is needed. The CMMOE method uses suppression of the NBI by minimising the energy resultant which keeps the desired symbol at the same time while it cancels the inter-carrier frequency, while the LMMSE method is used for the estimation of the NBI. Different authors reviewed different approaches of the NBI estimation methods which have an impact in NBI mitigation, but all these methods have a drawback in which there is no literature yet to solve it. The authors in [23 - 25] reviewed FTE, ML and SAR imagery formation methods respectively, for FTE and SAR imagery formation the approach is to detect and suppress the NBI and for ML the approach is to estimate the NBI and cancel it from the signal which is received, but the drawback to these three mentioned approaches is that only one error in the estimation process may propagate to the other sub-carriers.

2.5 CONCLUSION

An NBI mitigation technique needs to be sufficient in covering all mentioned drawbacks. It is supposed to do the cancelling, recovering and elimination, it is supposed to do all the above mentioned with the systems with higher spectral efficiency, it is supposed to be accurate and allow spectrum reuse. Much work still needs to be done to fill these gaps.

CHAPTER 3
METHODOLOGY

3.1 INTRODUCTION

The principal objective of this chapter is to discuss the approach to a Narrowband interference mitigation protocol using MATLAB. MATLAB integrates all the tools needed for this study as it features all the Simulink capabilities of different RF and Interference analysis. The MATLAB tools in this dissertation are used for generation of 5GNR and deployment of NB-IoT signal for measurement and analysis of NBI. This chapter has dealt with analysis of these network components as compared to each other and how significant they are.

3.2 DATA COLLECTION METHODS AND TOOLS

The simulations form an important part of this study, as most of the research for this study is done via simulations. The simulation tool used in this study is MATLAB as it contains everything needed for this study. The focus is based on 5G and NB-IoT waveforms including their coexistence in the spectrum. The 5GNR waveform on a spectrum analyser is analysed with all its properties and characteristics when there is no interfering signal i.e., without interference. This is not the case in real-life scenarios where there is always some form of interference.

The most important characteristics that we analyse is the bandwidth, interference, wavelength of these signal with and without interfering signal. In MATLAB there are certain toolboxes and models used for this analysis which are discussed in section 3.2. such as the 5GNR toolbox, LTE toolbox which is used for the NB-IoT analysis and the modelling of the signals with interference. The uplink and downlink effect of the signals is also most important. Every tool has its properties which are unique, and they are used accordingly in this study.

3.3 DESCRIPTION OF MATLAB TOOLS USED

In this study the main tools used are the 5GNR toolbox and LTE Toolbox. The 5GNR toolbox provides a reference example for the modelling, simulation and verifies the NR communication systems. This toolbox allows the user to simulate, configure, measure, and analyse end to end 5GNR communications. It also allows modification and customisation of the toolbox functions to be used as reference models towards implementation of the 5G systems and devices [25]. For this study, this toolbox is used to provide functions which references the characteristics of the uplink and downlink specifications of the baseband and simulations of the effects of RF designs as well as sources of interference on system performances [25]. Table 3.1 gives more clarity.

The LTE toolbox allows the configuration, simulation, measurements, and analysis of the end-to-end communication links [26]. On this study the LTE toolbox is used with the RF capabilities to model and analyse the RF capabilities of the NB-IoT communication links and configuration to analyse interference source and possible improvement. The main reason LTE toolbox is used in this study is because NB-IoT elements and configurations are found in the LTE toolbox.

Table 3.1: Comparison of 5GNR and LTE Network Components [2]

	LTE (Based on 3GPP Rel-15)	**New Radio (Based on 3GPP Rel-15)**
Frequency Band	Sub- 6GHz	FR1, FR2
Maximum Bandwidth (CC)	20 MHz	FR1: 5,10, 15, 20, 25, 30, 40, 50, 60, 80, 100 MHz FR2: 50, 100, 200, 400 MHz
Max CC	5(Rel-10)/ 32(Rel-12), 5 current implementations	8

Subcarrier Spacing	15KHz	2^n x 15KHz
Waveform	SC-FDMA for UL; CP-OFDM for DL	CP-OFDM and DFT-s-OFDM (UL); CP-OFDM(DL)
Modulation	Up to 64 QAM UL; Up to 256 QAM DL (Moving to 1024 QAM);	Up to 256 QAM UL & DL
Max Number of subcarriers	1200	3276
Subframe Length	1ms (moving to 0.5ms)	1ms
Latency (Air interface)	10ms (moving to 5ms)	1ms
Slot Length	7 symbols in 500µs	14 Symbols (duration depends on SC Spacing) 2, 4 and 7 symbols for mini slots.
Channel Coding	TBCC (control); Turbo code (data)	Polar Codes (control); LDPC (data)
Initial Access	No beamforming	Beamforming
MIMO	Up to 8x8	Up to 8x8
Reference Signals	UE Specific DMRS and Cell Specific RS	Front-loaded DMRS (UE-Specific)
Duplexing	Static TDD; FDD	Dynamic TDD; FDD, Static TDD,

3.4 GENERATION OF 5GNR

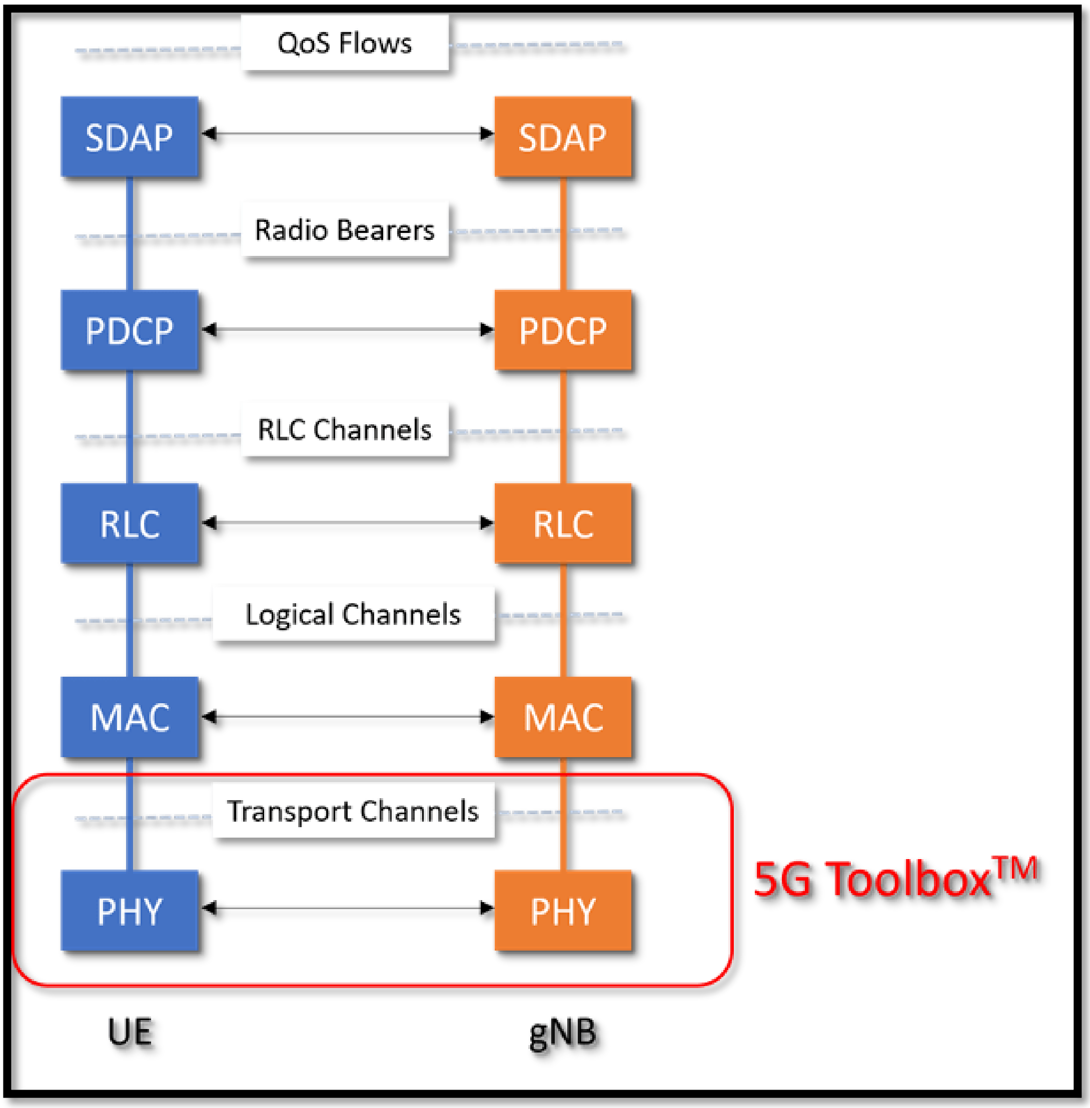

Figure5: 5G Protocol Stack [2]

Figure 5 addresses the 5G protocol stack, which is based on 5 layers, namely: Physical layer, MAC sublayer, transport layer, Radio Resource Control layer (RRC) and Management entity (ME) sublayer. The MAC sublayer is responsible for providing bit-level multiplexing for different logic flows, the transport layer includes user plane (U-Plane) and Control Plane (C-Plane). The RRC provides the signalling between e-NodeB (eNB) and User Equipment (UE) regarding system information, current transmission parameters such as data rates and signatures of various UEs that are currently connected to the eNB and messages related to the mobility of the UE. The ME sublayer handles various procedures such as authentication and authorisation between remote devices or networks [2].

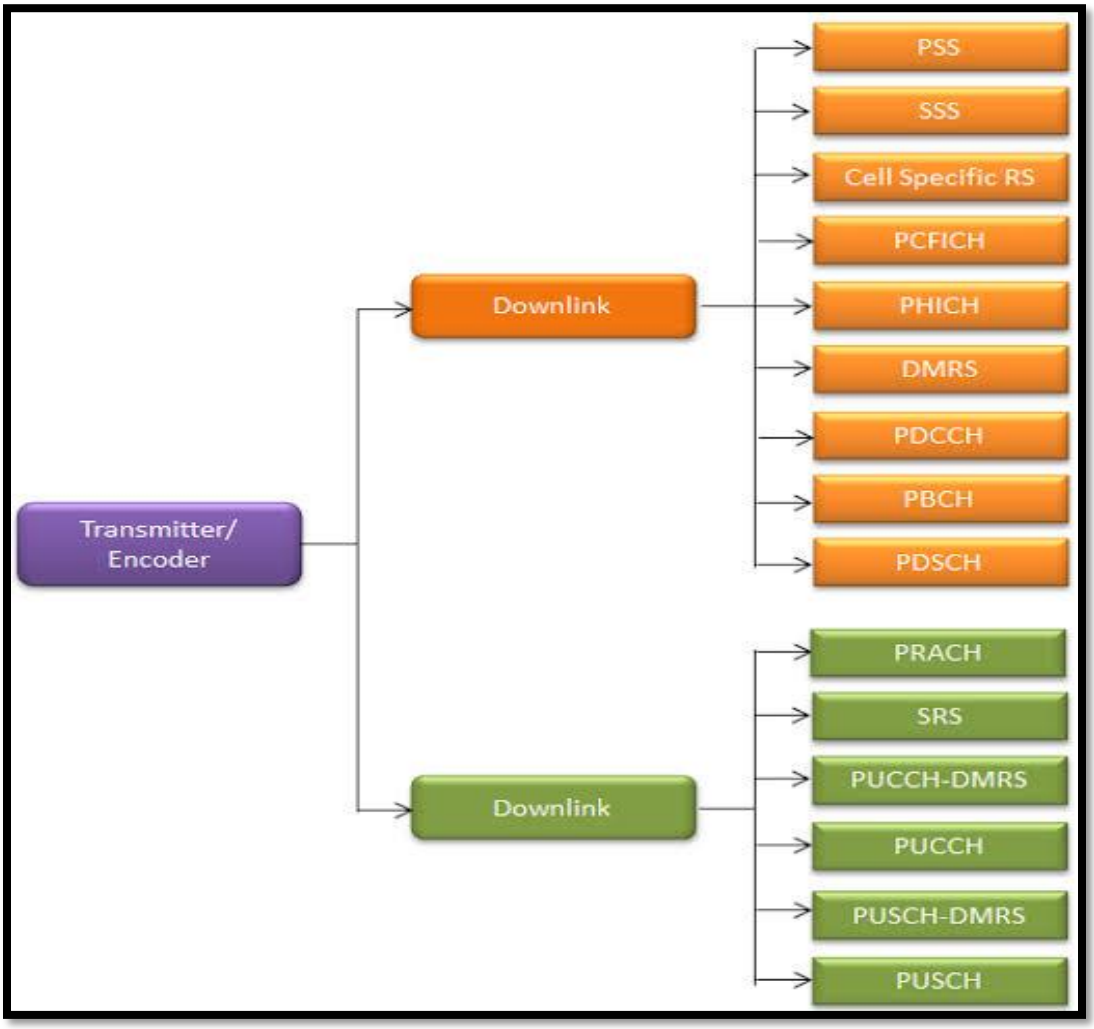

Figure 6: 5G Communications Channels [2]

Figure 6 addresses the 5GNR downlink physical channels. The Physical Downlink Shared Channel (PDSCH) carries the capacity to share data based on time and frequency. It carries a variety of data items as it uses an adaptive modulation that depends on the conditions of the uplink for example: SINR. The Physical Downlink Control Channel (PDCCH) carries downlink data control and functions to schedule the downlink transmissions on the PDSCH and the transmissions on the Physical Uplink Shared Channel (PUSCH). The Physical

Broadcast Channel (PBCH) is part of the synchronisation block that functions to provide UEs with the Master Information Block (MIB) and it also supports the synchronisation of frequency and time, this assists with the cell acquisition, selection, and re-selection. The Physical Random-Access Channel (PRACH) is used for channel access. PUSCH is the counterpart of the PDSCH and carries data from the from the Uplink Shared Channel (UL-SCH) and its channels which are higher mapped on a time and frequency-shared basis. The Physical Uplink Control Channel (PUCCH) carries uplink control data.

To generate the 5GNR signal using the 5G toolbox the downlink frequency components of 5G were considered. These components include the frequency range, channel bandwidth, Cell identity, subframes and sample rate. The 5GNR frequency resources are assigned in units of resources referred to as Resource Blocks (RBs) [4]. The 5GNR frames duration is 10ms which are divided into 10 subframes where each subframe is 1ms long [4]. The bandwidth of the 5GNR can either be FR1 or FR2 in which FR1: 5,10, 15, 20, 25, 30, 40, 50, 60, 80, 100 MHz and FR2: 50, 100, 200, 400 MHz’s. Below is the 5GNR toolbox that is used for generating a 5GNR with all the elements required.

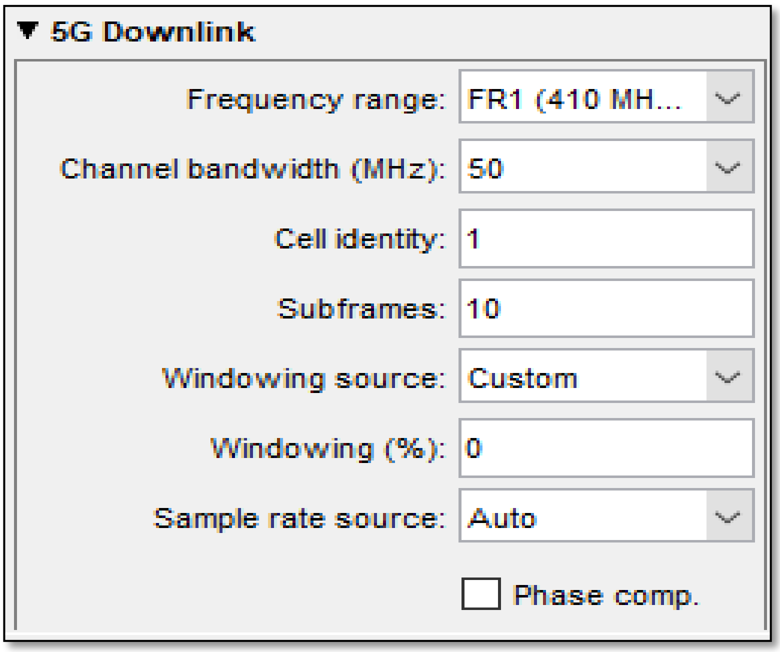

Figure 7: 5GNR DL Frequency components

Figure 7 shows the components used for generation of 5GNR in MATLAB in which the frequency range used is FR1 with a bandwidth of 50Mhz, cell Identity of 1 and 10 subframes.

The most important element that is considered when choosing the 5GNR elements is the throughput. Throughput of the 5GNR depends on the frequency range and the direction, number of layers, modulation scheme, numerology, number of RBs and the scaling factor.

$$data\ rate\ (in\ Mbps) = 10^{-6} \sum_{j=1}^{j} (v_{Layers}^{(j)} \cdot Q_m^{(j)} x f^{(j)} . R_{max} . \frac{N_{PRB}^{BW(j).u}.12}{T_s^u} . (1 - OH^{(j)})) \quad (1)$$

Below are all the elements in the above formula explained:

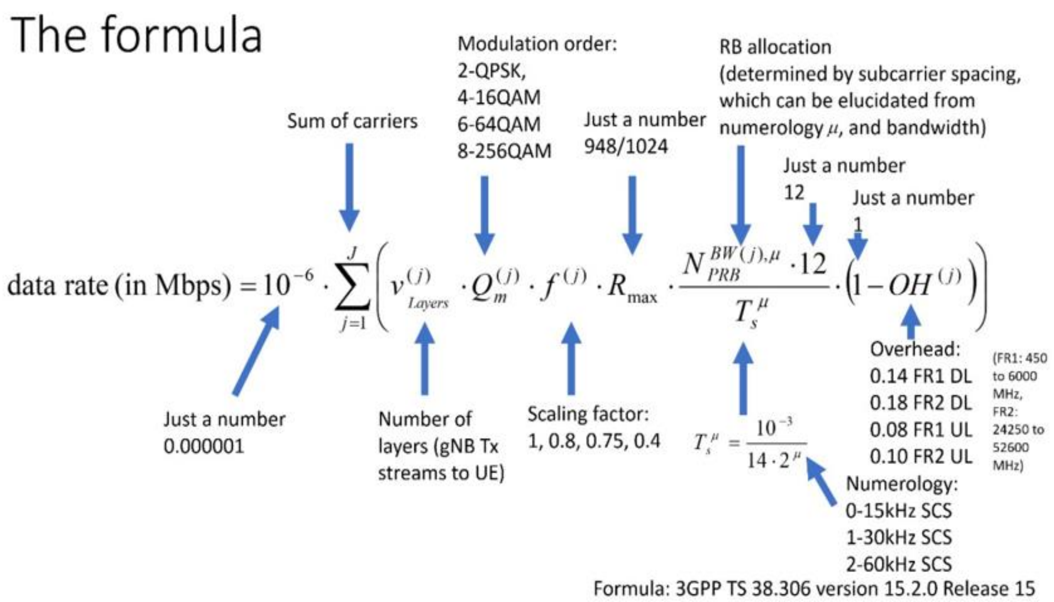

Figure8: 5GNR throughput calculation formula [6]

Figure 8 highlights the elements used in a formula to calculate throughput which is the most important element in 5GNR networks. The SCS carriers of the 5GNR were entered on a toolbox to be as below.

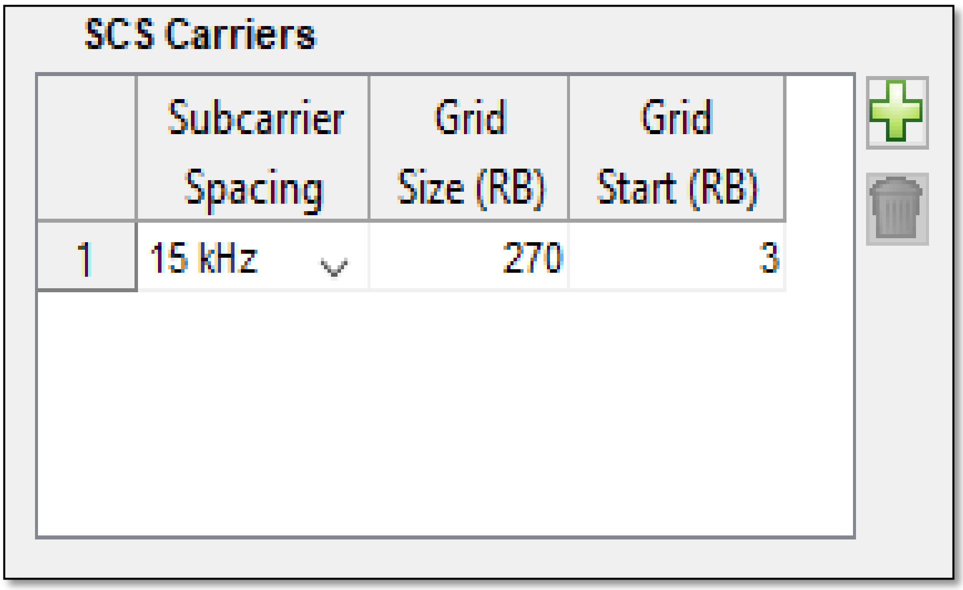

Figure 9: SCS Carriers of the 5GNR

The subcarrier spacing which was used for the generation of 5GNR is 15KHz as shown in Figure 9.

The bandwidth parts taking into consideration the subcarrier spacing were entered as below on the toolbox in Figure 10.

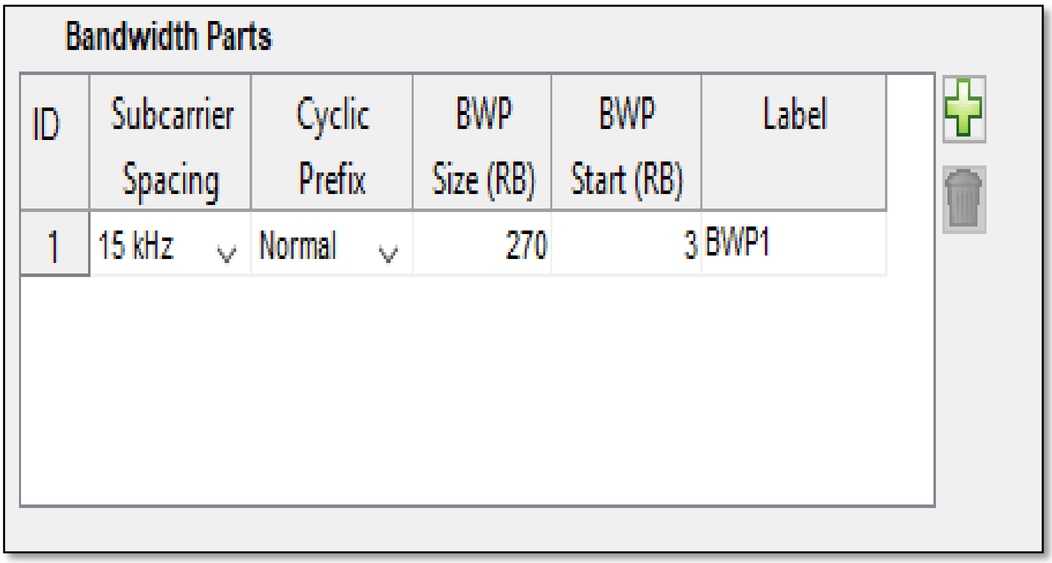

Figure 10: Bandwidth parts of the 5GNR

	Enable	Power (dB)	BWP ID	Modulation	Num Layers	Mapping Type	Start Symbol	Symbol Length	Slot Alloc.	Period	PRB Set	n_{ID}	RNTI	Coding	Target Code Rate	Enable PT-RS
1	☑	0	1	QPSK	1	A	0	14	[0:9]	10	[0:269]	1	1	☑	0.5137	☐

Figure 11: PDSCH Table

PDSCH uses the QPSK modulation scheme as part of the generation of the 5GNR. As shown in Figure 11, all elements and properties were populated including the PRB settings as from 0:269.

	Enable	Power (dB)	BWP ID	Search Space ID	Aggregation Level	Candidate	Allocated Slots	Period	Coding	Payload Size	Data Source	RNTI	DMRS Scrambling ID	DMRS Power (dB)	Label
1	☑	0	1	1	8	1	0	1	☑	20	PN9-I	1	2	0	PDCCH1

Figure 12: PDCCH Table

Figure 12 addresses all the PDCCH elements.

With reference to the above tables and properties, the resulting resource grid is as below. The resource grid represents the subframe that is two slots and a whole bandwidth. Figure 13 is the resulting resource grid for the 15KHz subcarrier spacing for the generation of the 5GNR signal generated.

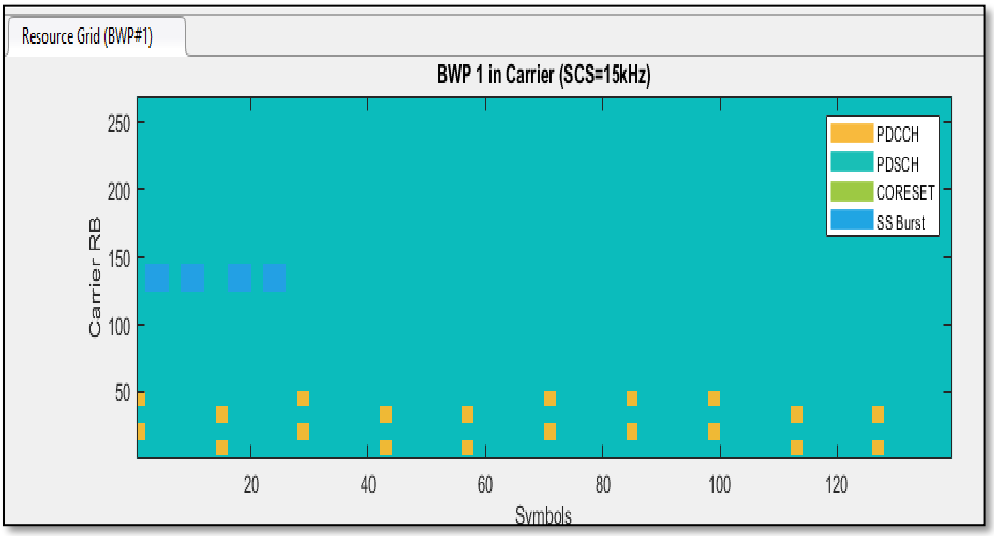

Figure 13: Resource Grid

Figure 14 is the resulting signal after the Generation of the 5GNR. From this figure, it is clearly visible that there is no interference observed as there are no spikes greater than the amplitude of the signal occurring.

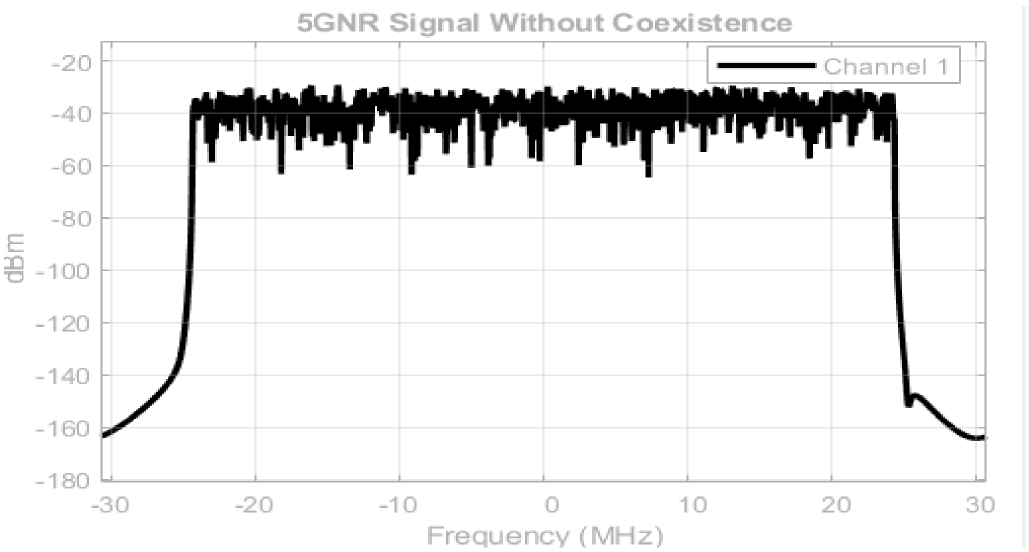

Figure 14: Resulting signal on the spectrum analyser for a 50MHzbandwidth.

3.5 GENERATION OF THE NB-IOT SIGNAL ON MATLAB

NB-IoT signal is generated using the LTE toolbox. In the LTE toolbox a test model is used with the desired bandwidth. As in Table 1, the maximum bandwidth that can be achieved on the LTE or NB-IoT is 20MHz. The FDD mode was used with 10 subframes on this test model as below.

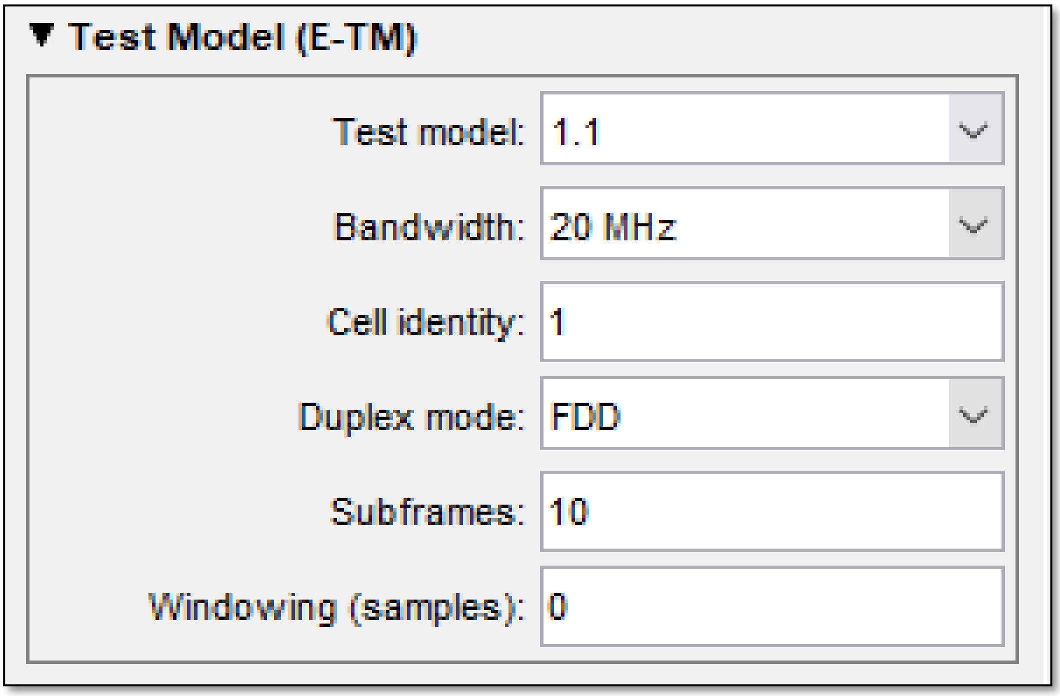

Figure 15: LTE Test model

In Figure 15, a test model that shows a feature or app in MATLAB is used to generate an RF signal. It was used to generate an NB-IoT signal using the LTE toolbox with the bandwidth of 20MHz, Cell Identity of 1 and duplex mode of Frequency Division Duplexing (FDD) for 10 subframes. The above test model using the LTE toolbox the below NB-IoT /LTE Resource grid resulted in Figure 16.

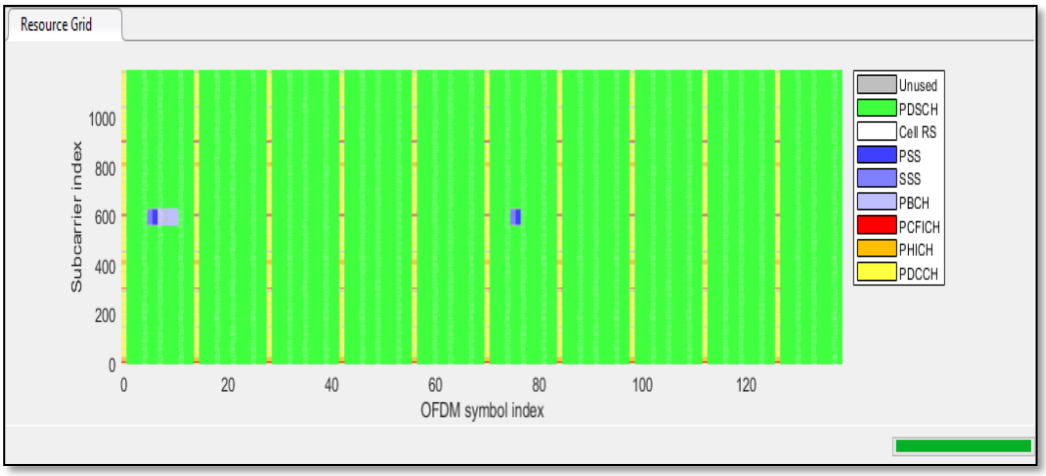

Figure 16: Resulting resource grid.

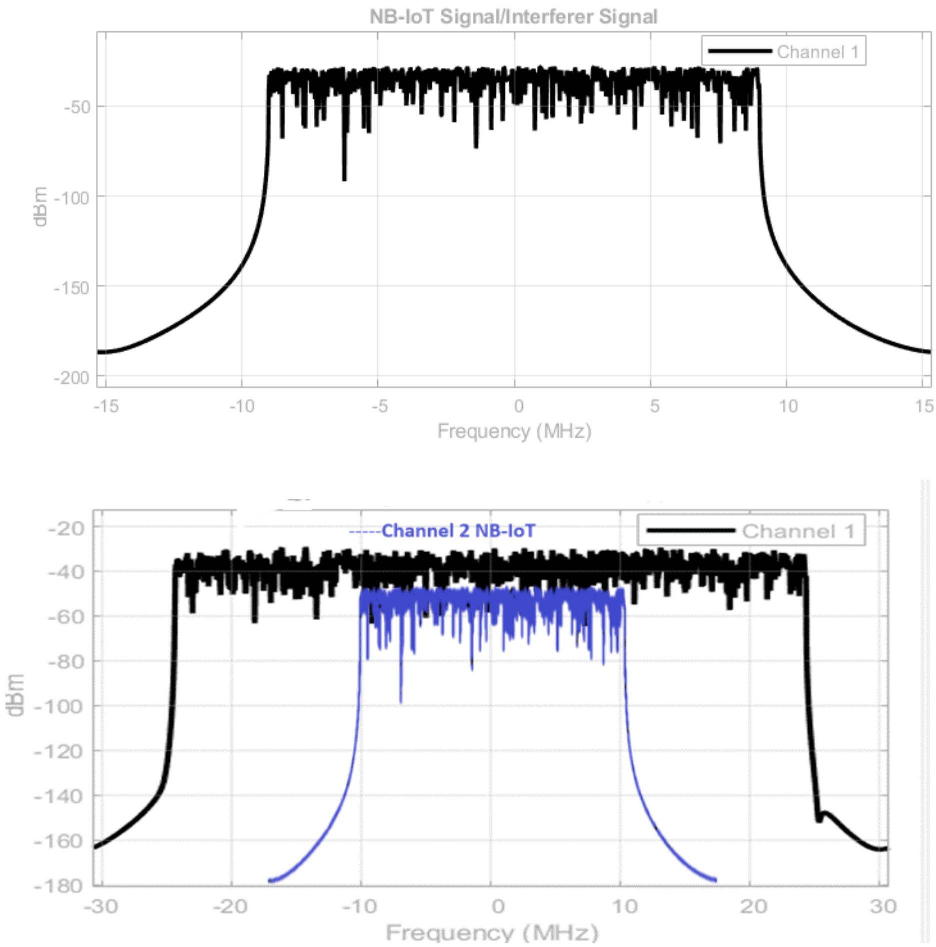

Figure 17: Resulting coexisting NB-IoT/LTE

The above figure is the resulting signal after the Generation of the NB-IoT signal. Figure 17 shows how NB-IoT coexists with the 5GNR with resultant interference.

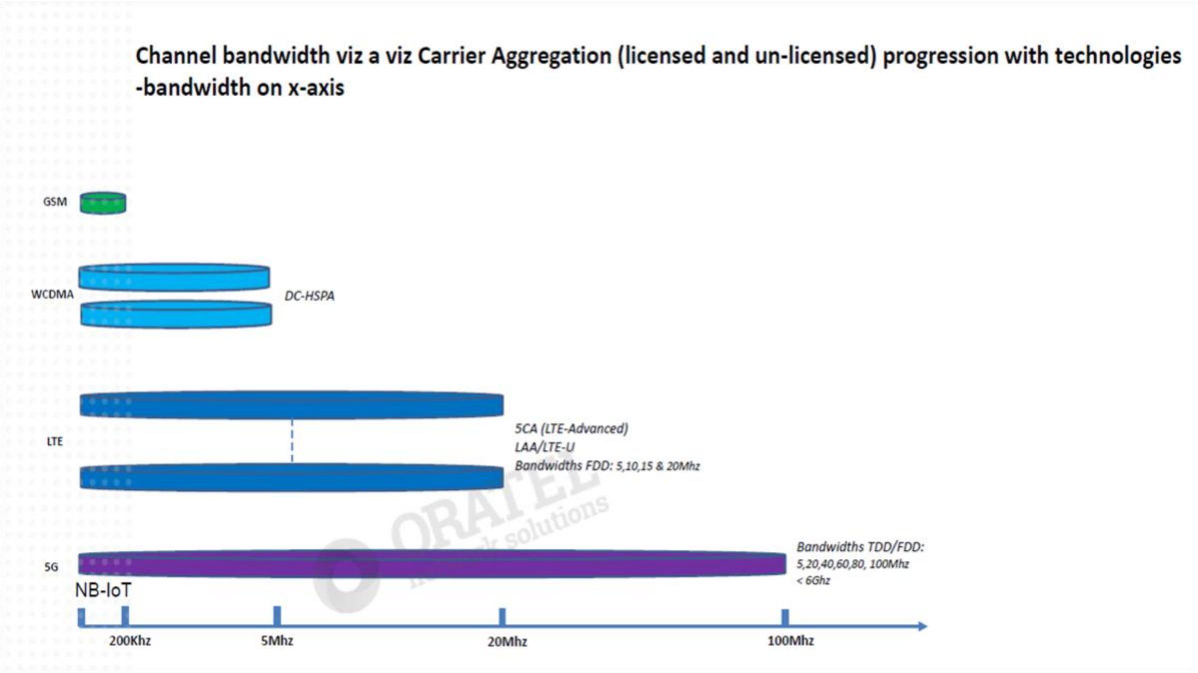

Figure 18: Bandwidth occupancy [38]

From Figure 18 it was noted that NB-IoT only occupies 200KHz of the spectrum shared by both 5G and LTE.

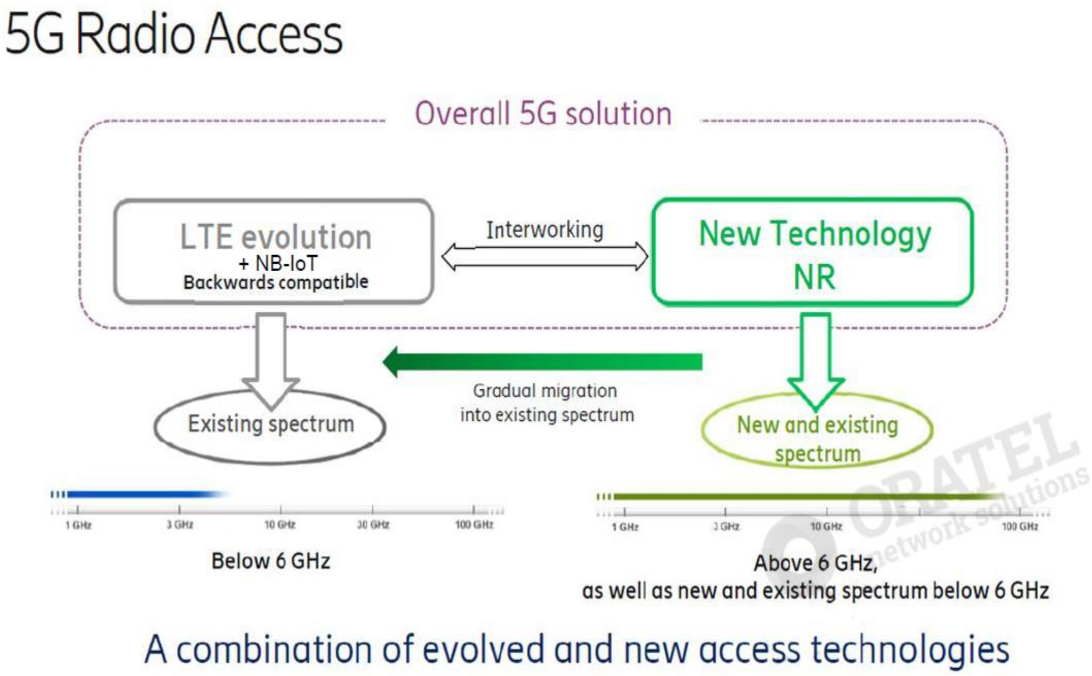

Figure 19: Spectrum Sharing [38]

Figure 19 addresses the existence of 5GNR coexisting with the LTE and NB-IoT due to it being rolled out in non-standalone mode. This figure explains the frequencies of 5GNR, NB-IoT and how they are interworking.

3.6 MERGING OF THE 5GNR AND NB-IOT ON THE SAME SPECTRUM USING MATLAB MODELLING

The two signals which are generated, 5GNR and the NB-IoT/LTE signal are merged for an interference view to show where they interfere as part of the study's objective. The method used the modelling and testing of an RF NR receiver with LTE interference as NB-IoT is part of the LTE. The below commands were used to open a modelling test in MATLAB:

```
modelName= 'NewRadioRFReceiverWithLTEInterferencemodel';
open_system(modelName);
```

From the above commands the below model on Figure 20 from MATLAB was developed to focus on the desired output.

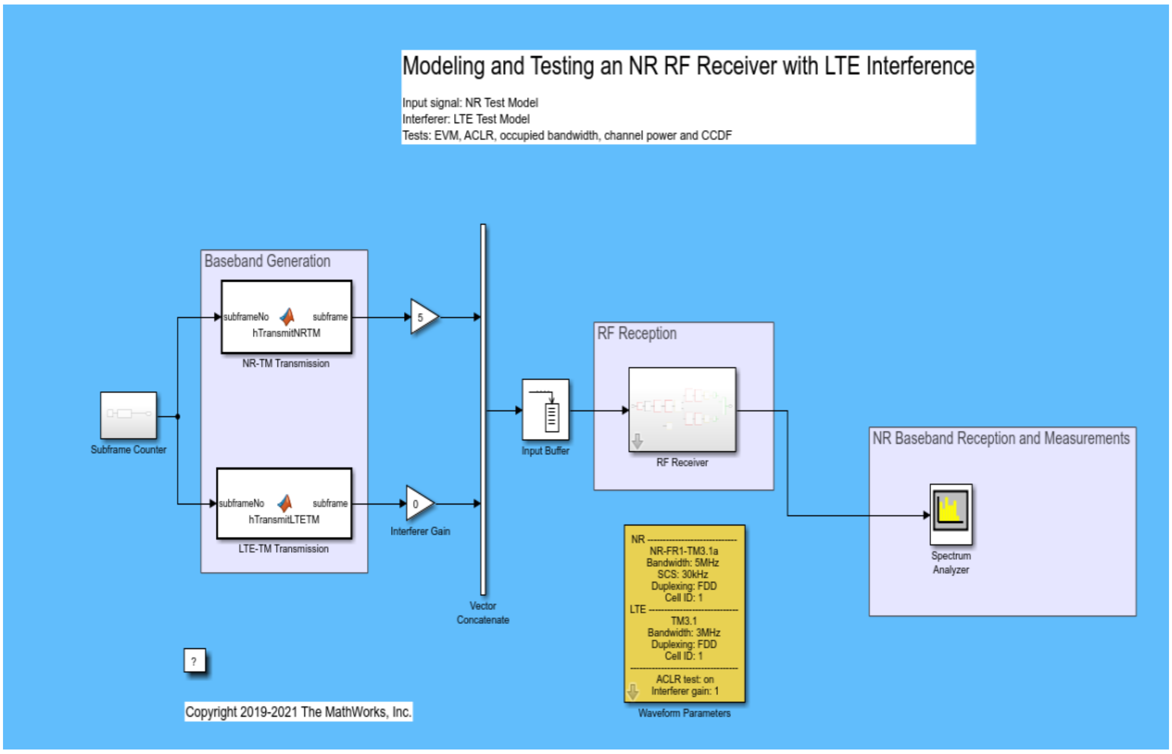

Figure 20: Modelling and Testing an RF Receiver with LTE interference

The baseband generation is the part where 5GNR and NB-IoT/LTE is generated and then transmitted. The interferer gain was set as zero because it is supposed to be as low as possible as this is the unwanted signal as the aim of the study was to mitigate interference. The 5GNR is the primary user of the band/spectrum. For the NB-IoT devices to use this band, they need to register with the 5G system and then for them to send/receive data to/from the IoT Application Server (AS), they can request to establish a data connection which is based upon unstructured, Ethernet and IP. The two signals do not have the same rights to the spectrum as NB-IoT deployment in the 5GNR/LTE spectrum in the in-band or guard mode only uses part and not all the spectrum i.e., 200KHz of the spectrum. Setting the gain to zero for NB-IoT protects the primary user which is the 5GNR in this case i.e., the interferer gain. The buffer was used because the two type of signal with different characteristics were merged and transmitted to the RF Receiver. The main aim of the buffer was to isolate an input from output. It was used to mirror the output state with the input state. The buffer's input impedance is high so as a result its small current is drawn to avoid disturbing the input circuit. Buffers prevent too much current being taken from the input circuit. After this stage, the signal was passed to the RF Receiver stage. The Receiver model resulted as below.

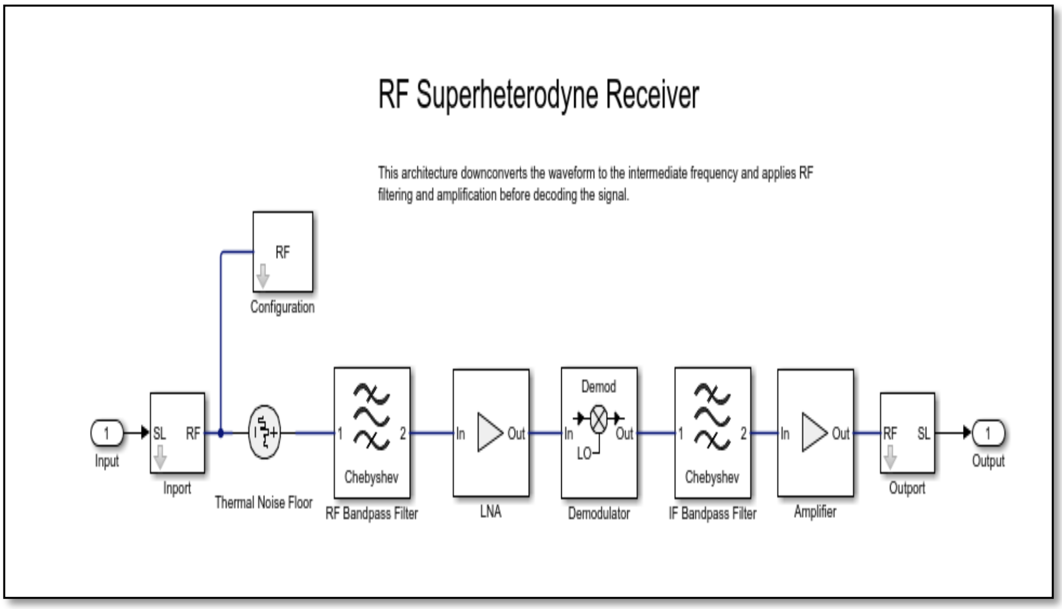

Figure 21: RF Superheterodyne Receiver

The main aim of the superheterodyne receiver on Figure 21 in this study was to offer a superior sensitivity, a frequency stability and selectivity. This was achieved by rejecting unwanted signals. This receiver also helps with a discrimination against image frequency signals and IF signals. The incoming signals is taken and then mixed with a variable frequency signal which was then locally generated to convert it down to a frequency where it was enabled to pass through a high fixed frequency filter before it can be demodulated to extract a required signal or modulation. In this stage, the choice of the filter was the most important part. The RF Filter that was chosen for this study is the band-pass filter using Chebyshev method [11]. The reason behind this choice is because the intension of the study was to only allow 5GNR and NB-IoT frequencies to pass and the reason behind the choice of the Chebyshev filter is because the intension was to separate one band of the frequency from another. In this study the aim was to separate 5GNR band from the NB-IoT band. An advantage of the Chebyshev filter that makes it perfect for this study is that it produces smaller absolute errors, higher execution speeds, and has a sharper transition speed between the passband and the stopband [11]. The below Chebyshev filter characteristics were looked at for selection of this study:

- Sharper roll-off than Butterworth filters
- Minimisation of peak error in the passband

The below (Figure 22) was selected to be the block parameters of the RF bandpass filter.

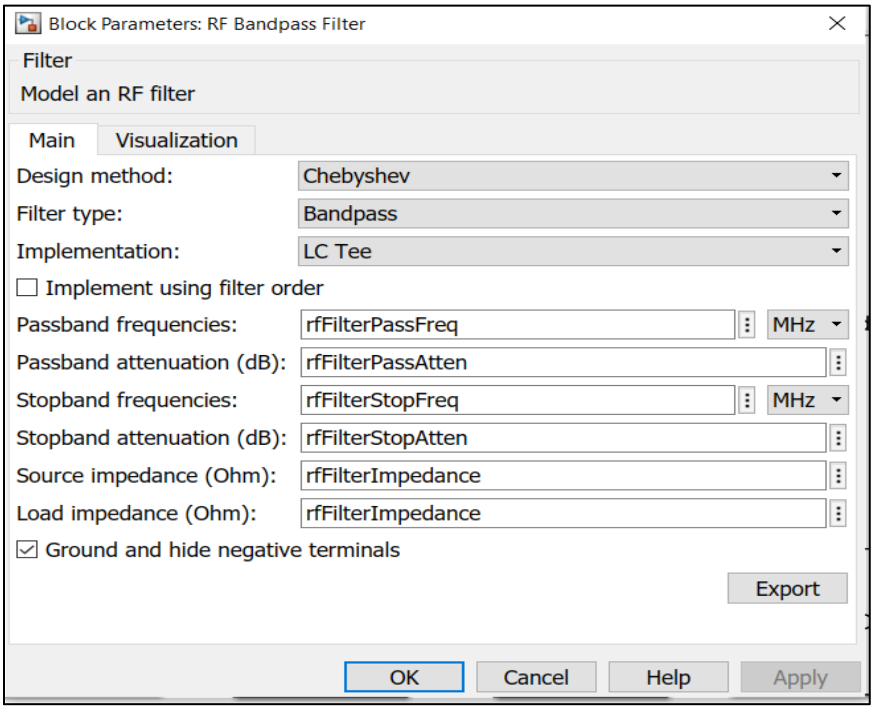

Figure 22: RF Bandpass filter block parameters

The NR Waveform parameters were defined to be as follows, this taking into consideration the formula used on (1) to get higher throughput the 256QAM modulation scheme was used. With the FR1 (40MHz) bandwidth was used.

3.7 THE CHOICE OF THE MODULATION SCHEME

Digital Modulation schemes makes a large contribution in telecommunications in terms of increasing capacity, speed, and the quality of a wireless network

[36]. Without an appropriate modulation scheme, an expected throughput will not be achieved [36]. Digital modulation has a preference over analogue modulation due to the error-free capability [36]. Digital modulation schemes also provide more capacity to carry information, data security, RF spectrum sharing to accommodate more services and better-quality communication [36] in which in this study the main aim of using the digital modulation is for RF spectrum sharing.

Digital Modulation provides increased immunity to noise at the cost of larger bandwidth required [36]. In data, video and audio, bandwidth is a serious problem, so in this case existing modulation schemes needs modification to accommodate both the situations of noise and bandwidth. Below are the different basic types of digital modulation schemes used in telecommunications systems:

- Amplitude Shift Keying (ASK)
- Frequency Shift Keying (FSK)
- Phase Shift Keying (PSK)

The implementation of ASK has a limitation to deliverance of reduced power and achievement of transmission data rates [36]. The PSK possess a steady envelope but discontinuous transition from symbol to symbol. In this study the focus was more on the Orthogonal Frequency Division Multiplexing (OFDM) as a result the consideration of the modulation schemes was more on the digital modulation schemes which can be used in the OFDM are: Binary Phase Shift Keying (BPSK), Eight – Phase Shift Keying (8PSK), Quadrature Phase Shift Keying (QPSK), Sixteen - Phase Shift Keying (16PSK), These are the types of M-ary modulation schemes [36].

Quadrature Amplitude Modulation (QAM) is a modulation scheme which allows amplitude to vary with phase, this technique can be observed as a combination of ASK and PSK [36]. A lot of digital communication applications uses QAM because of its ability to achieve a greater distance between the adjacent points in the I-Q plane by method of distribution of points and also data errors are reduced. The QAM modulation is a useful modulation and better than others.

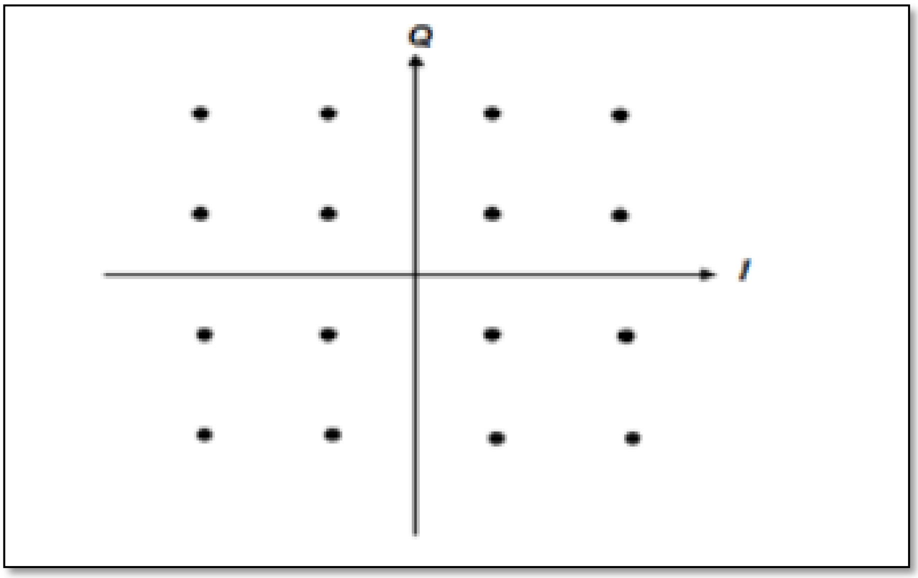

Figure 23: Constellation diagram of 16-QAM [36]

As illustrated in Figure 23, 16-QAM uses a four different magnitude level. This denotes that the combined stream is 4x4=16 whereby each symbol represents 4 bits.

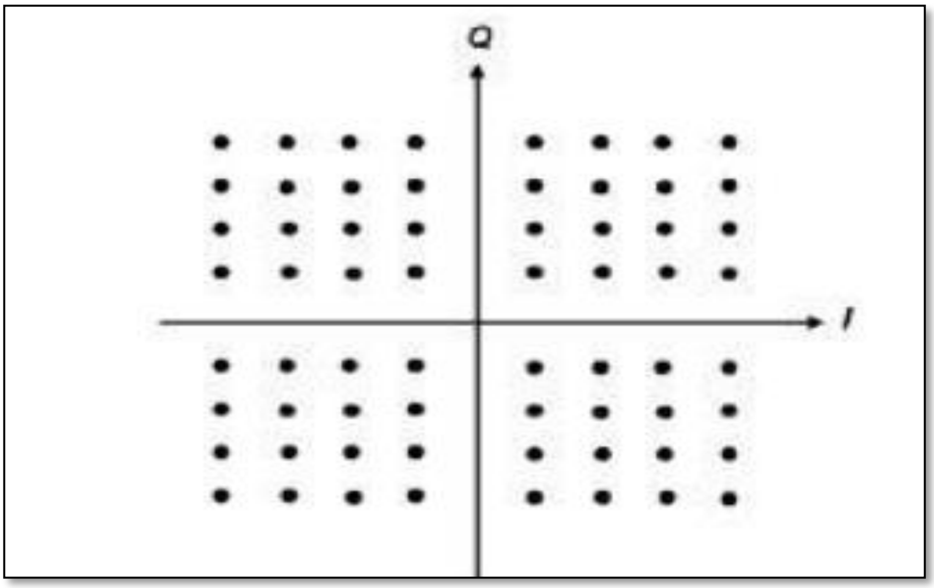

Figure 24: Constellation diagram of 64-QAM [36]

This is the same as 16-QAM but in this case it has 64 states where each symbol represents six bits as shown in Figure 24.

Table 3.2 Typical Applications of different modulations schemes

Modulation Scheme	Application
BPSK	Deep space telemetry, Cable modems
FSK, GFSK	public safety, Paging, land mobile
MSK, GMSK	Global System for Mobile
QPSK	cable modems, TFTS, Satellite, CDMA
8-PSK	telemetry pilots for monitoring broadband video systems, Satellite, aircraft
16-QAM	Microwave digital radio, Modems
32-QAM	Terrestrial microwave
64-QAM	Broadband set-top boxes
256-QAM	Modems, MMDS, Modems, Digital Video (US)

In Table 3.2 typical applications of different modulations schemes are presented. The table is the most important because it denotes that the selection of a modulation scheme or technique that is exclusively dependent on the type of the specific application as applications differs. Many applications require more data, while other applications require more bandwidth and other applications requires more power [36]. The Quality of Service (QoS) that is provided by the Wireless communication system is greatly enhanced by the selection of the correct modulation scheme [36]. The below table helps to choose the correct modulation scheme as a comparison towards another.

Table 3.3 Digital modulation schemes compared [36]

In Table 3.3, it is shown that a 256 QAM is a better modulation scheme

Digital Modulation Scheme	No. of Symbols	Types of Envelope	No. of message Points	Information Capacity	Symbol Shaping
BASK	01	Not Constant	01	Poor	Not Required
BFSK	01	Constant	01	Better than BASK	Not Required
BPSK	02	Constant	02	Double to BFSK	Not Required
DPSK	02	Constant	01	Same as BPSK	Not Required
QPSK	04	Constant	04 Expressed in terms of symbol Energy/Symbol	Double of BPSK	Required Rectangular Pulse
MSK	04	Constant	04 Expressed in terms of signal Energy/Bit	Same as QPSK	Required Half Co-sinusoidal Pulse
GMSK	04	Constant	04	Same as MSK	Required Gaussian Pulse
16-QAM	16	Not Constant	16	Higher than above	Better than Above schemes
64-QAM	64	Not Constant	64		

compared to all other modulations schemes as it has more information capacity than 64-QAM and 16-QAM and has 256 number of message points which is higher than the 64-QAM and 16-QAM.

From the literature review methods BSBL the measurements used was the SNR to measure results

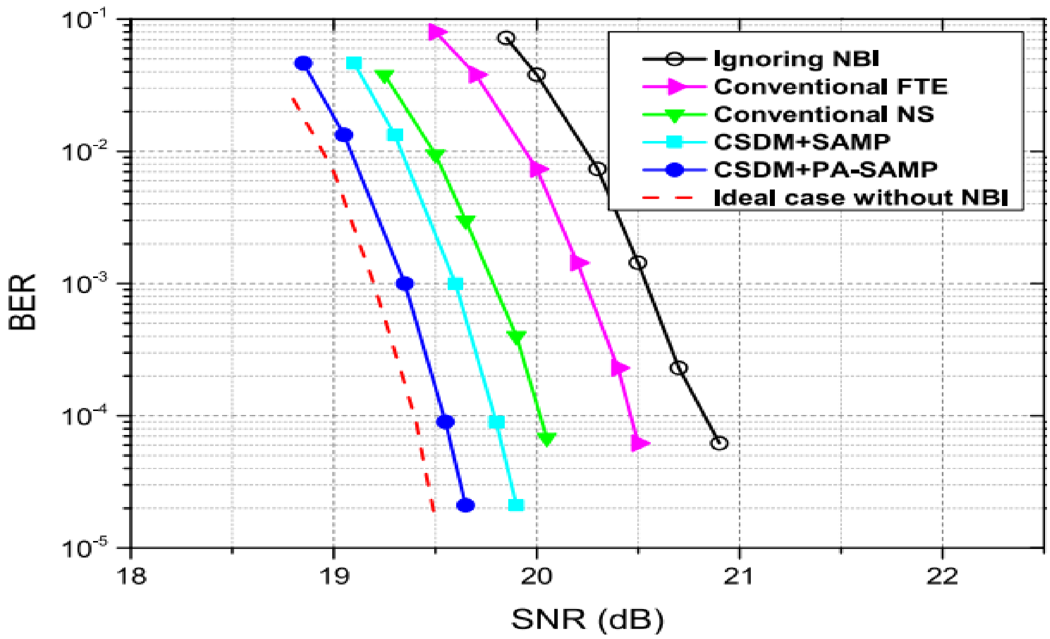

Figure 25: BSBL method simulation result

Figure 25 shows SNR result of the BSBL method which was reviewed. From the figure is clearly visible the SNR after the BSBL method is applied and the ideal case that is without the NBI.

3.8 CONCLUSION

The methods which are used for the simulations and all the tools used for this study are explained in this study. This chapter also provides the insights behind the reasoning of why certain parameters, elements and measures were taken. It makes it clear why the modulation scheme used for this study was selected as well as the filters used in this study by providing the theory behind the different filters and modulations schemes. The next chapter provides the results obtained using MATLAB simulations whereby the methodology in this chapter was used to mitigate interference challenges between 5GNR and NB-IoT Networks.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter confers the simulation results of mitigation of interference challenges in 5GNR and NB-IoT networks using MATLAB as discussed in the previous chapter. The first part of this chapter discusses the results obtained pre-optimisation using the tool discussed in the previous chapter. The second part of the chapter discusses the results after optimisation where the correct modulations schemes and the correct filter is used for simulations is discussed in the previous chapter.

4.2 RESULTS PRE-OPTIMISATION

Modelling and testing of the NR Receiver with the LTE Interference was simulated as on 3.7 on Chapter 3. On this model, there was no optimisation done the effect of the Filters was still investigated. The effect of the modulation schemes was also still investigated. The two signals 5GNR and NB-IoT which operates on the LTE bands were simulated using the model and the method on the previous chapter was followed and yielded the below results. At this stage, the filter used was a band-pass filter because we only want bands in which 5GNR and NB-IoT coexist.

The modulation scheme is the most important part of the study in which if it was not correctly selected the desired results could not be achieved. In this case the proper modulation scheme was not selected as it was investigated through the modelling simulation. The below results were achieved whereby the interference was still clearly observed as below on the spectrum analyser. The Interferer gain was not modelled to be 0 in this instance.

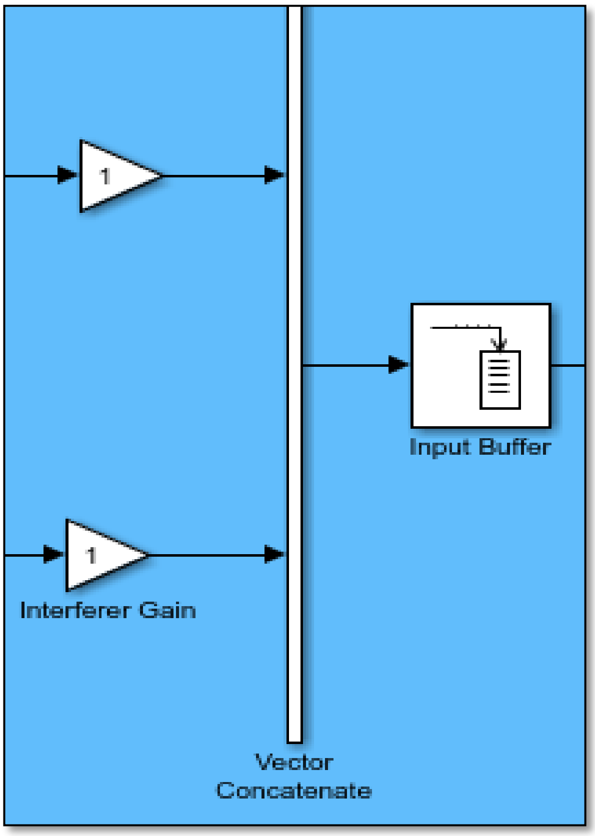

Figure 26. Interferer gain Pre-Optimisation

Figure 26 shows the pre-changes and optimisation of the interferer gain set to 1.

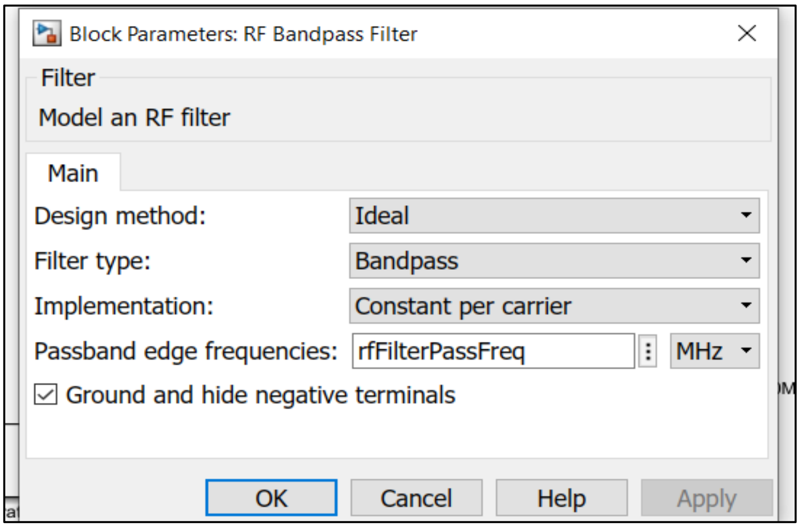

Figure 27: Band pass Filter Pre-Optimisation

The original filter that was used on the RF before optimisation as in Figure 27 was an Ideal Bandpass filter as a default and it was simulated to analyse its impact and the outcome.

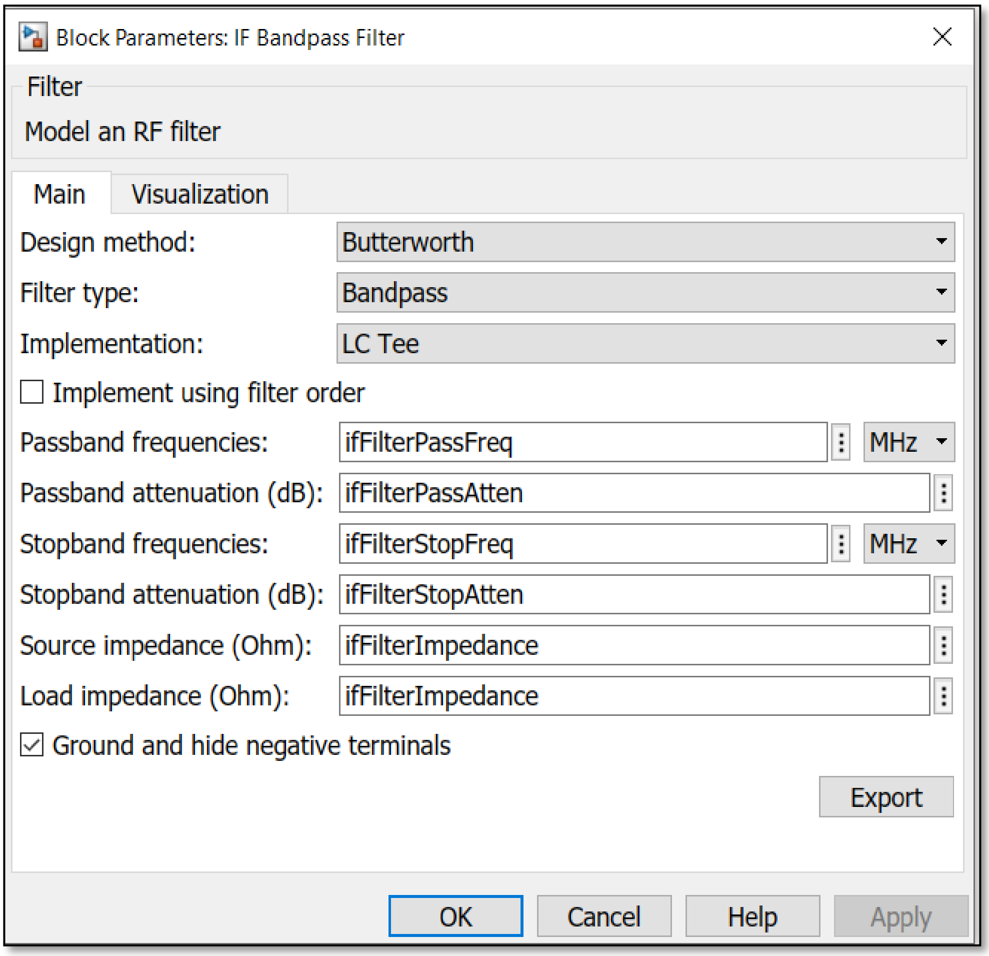

Figure 28: Filter Used Pre final Optimisation

The original filter that was used on the IF before optimisation as in Figure 28 was a butterworth Bandpass filter as a default and it was simulated to analyse its impact and the outcome.

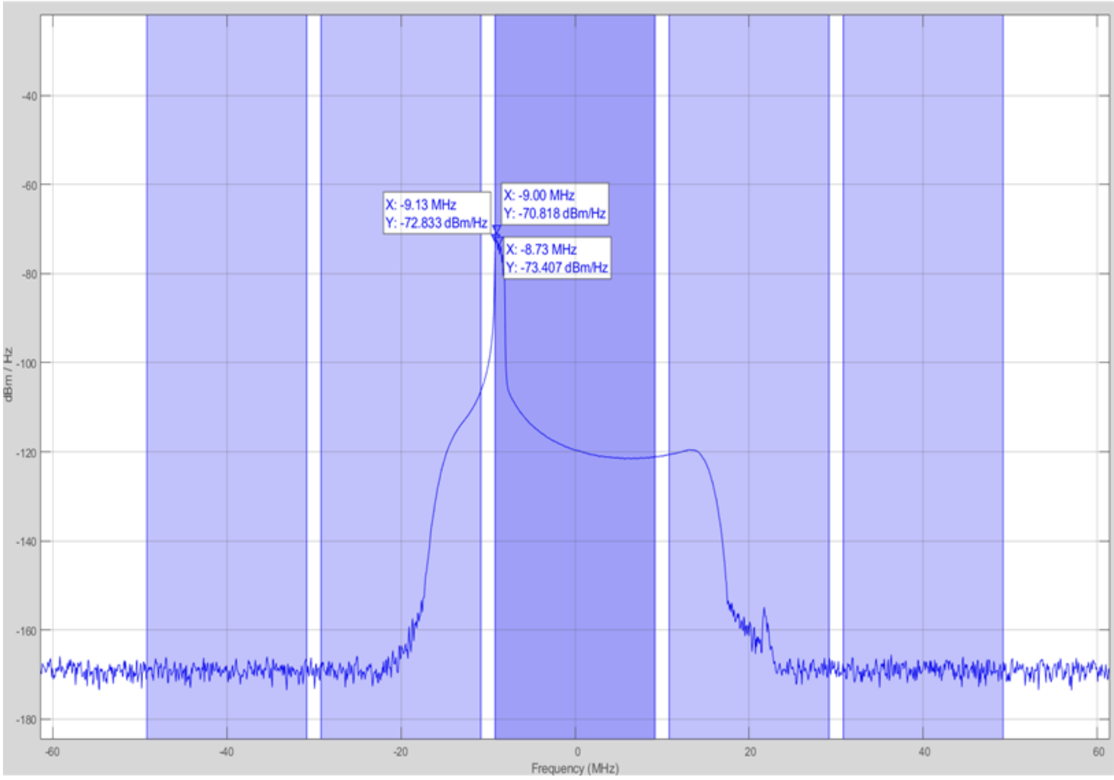

Figure 29: Resulting signal with interference pre-optimisation.

In Figure 29, the interference can clearly be seen on 9MHz as we transmitted NR on 40MHz and NB-IoT on 20MHz.

This was done before choosing the right modulation scheme and the right filter. After thorough investigation of the effect of filters in Chapter 3 and the modulation scheme to be used, the process was repeated to be the below parameter block. On this block it was also discovered that transmitting on lower frequencies mitigates interference.

4.3 RESULTS POST OPTIMISATION

The effect of Filters was tested and concluded that the right filter to use is the Chebyshev band-pass filter as discussed in Chapter 3. The effect of mitigation schemes was also tested and simulated, and it was discovered that the right mitigation scheme to use is the 256-QAM as discussed in Chapter 3.

The effect of frequencies and bandwidth was also of great importance as discussed in Chapter 3. It was discovered that it is necessary to transmit in lower frequencies for better penetration which enhances quality of services in wireless communication. With the above statement the block parameters used in this simulation for the study were as shown on Figure 30.

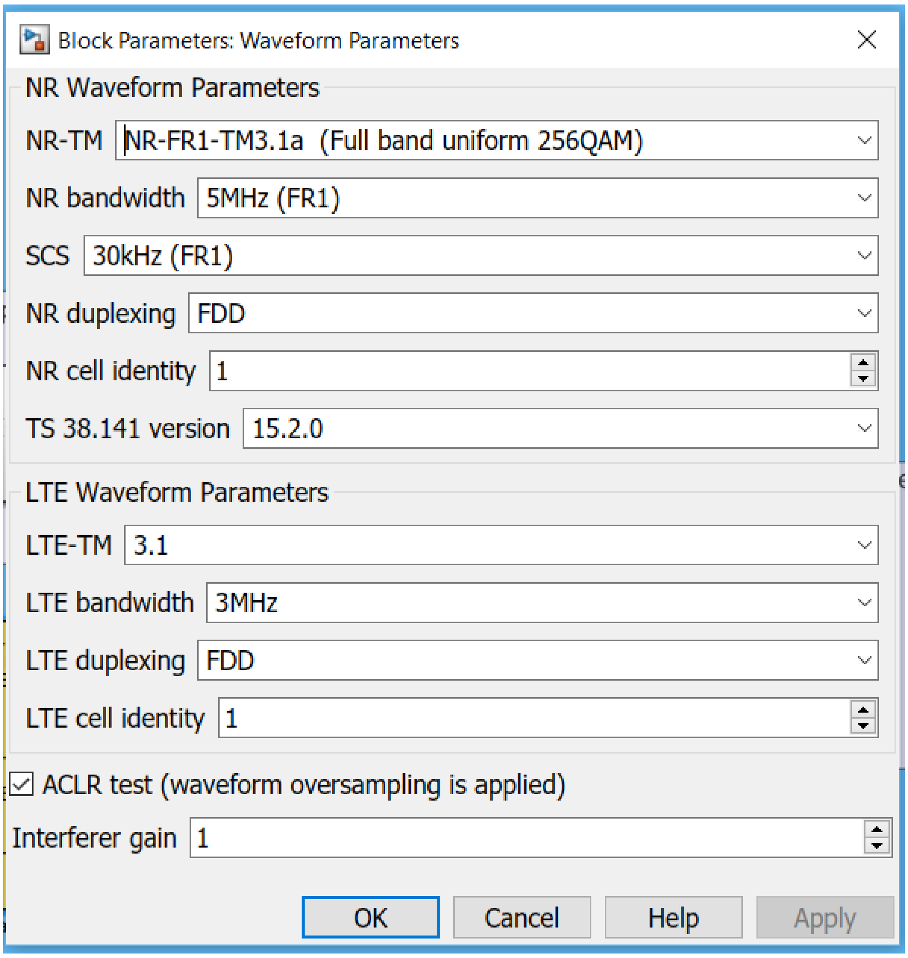

Figure 30: Optimised Waveform parameters

On the results the Interferer gain was reduced to 0 as the aim was to mitigate interference. Hence, 0 was input on the block as per Figure 31 below.

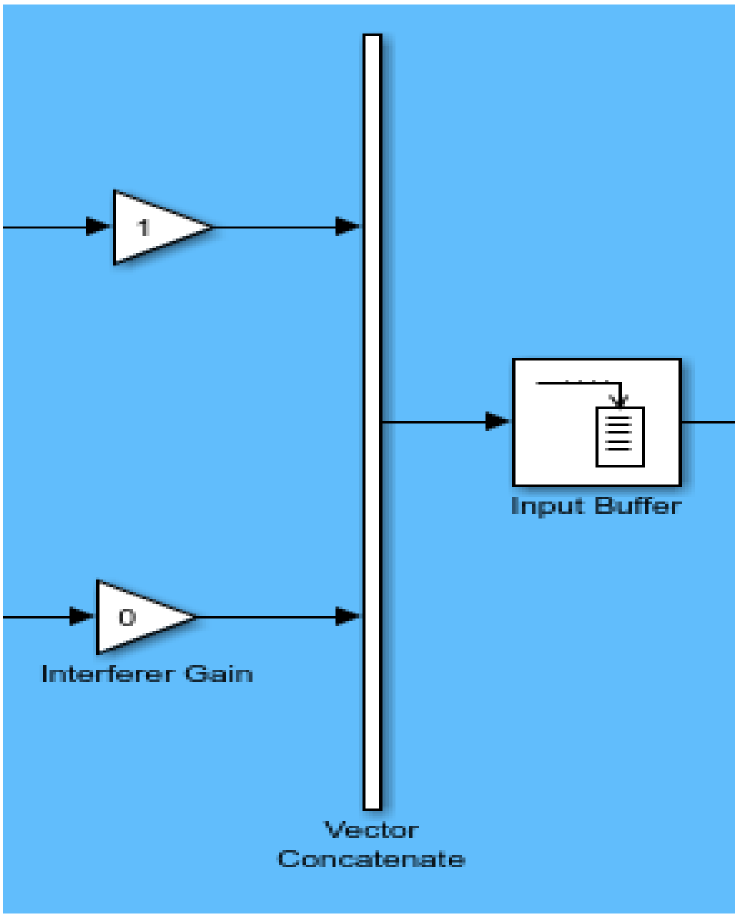

Figure 31: Final Interferer gain

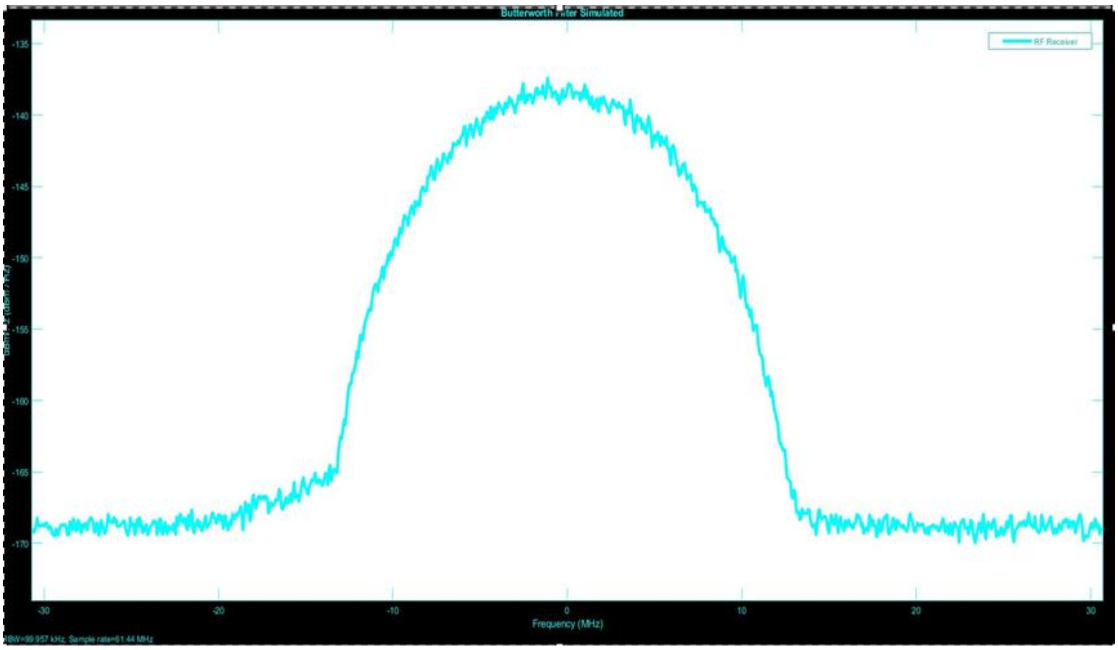

Figure 32: The Effect of the Butterworth Filter

In Figure 32 the Butterworth Filter was simulated and tested. However, the results are not satisfactory as seen in the figure.

The correct Filter was selected to be Chebyshev bandpass filter as discussed in Chapter 3 and the below block on Figure 33 was then simulated accordingly.

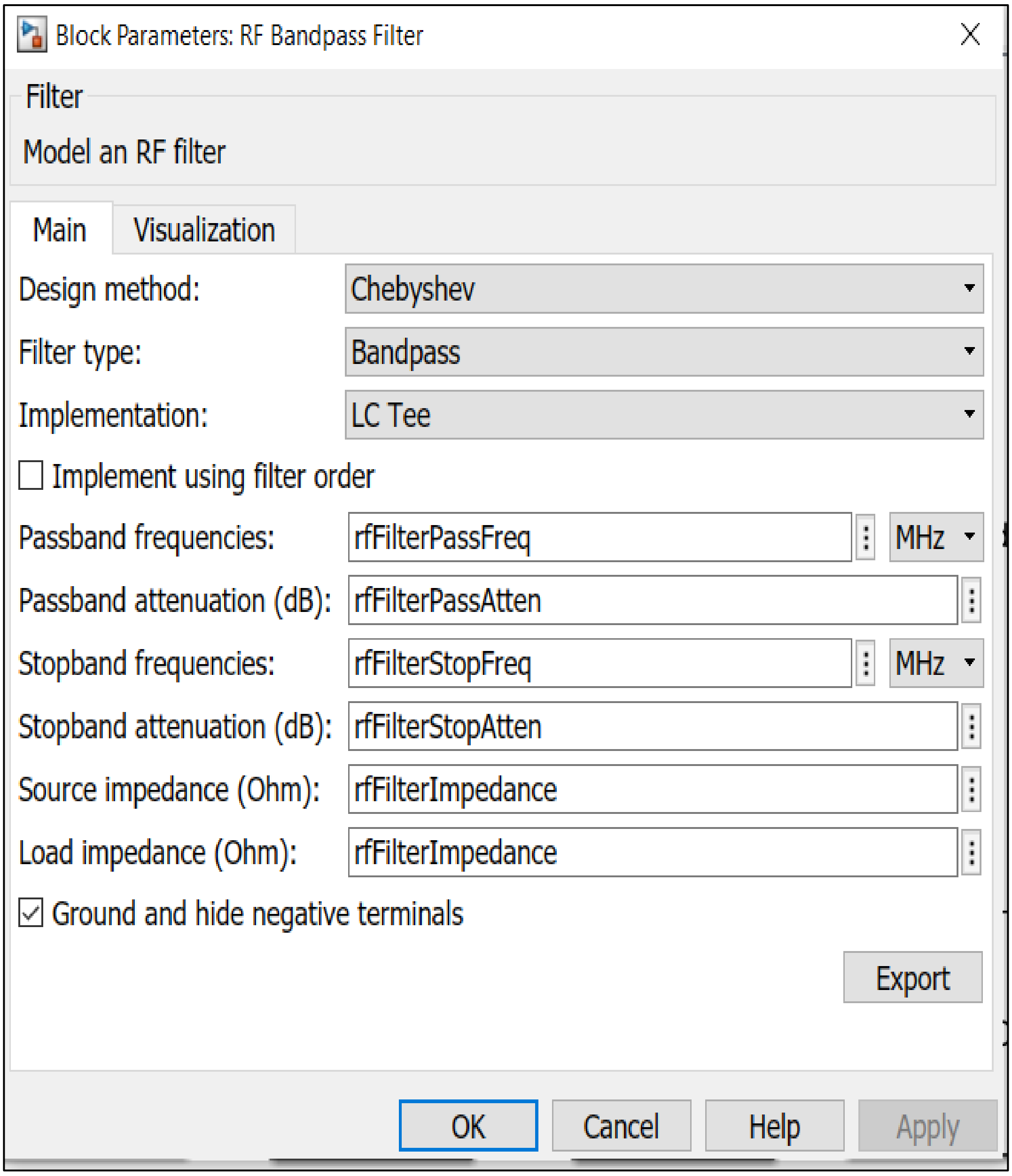

Figure 33: Final filter selection

In this study, SINR was the key element, and the investigation was based on the below formula given by Shannon Theorem:

$$C = Blog_2(1 + \frac{S}{N}) \tag{9}$$

C = capacity (in bit/s)

B = Bandwidth of a channel (Hz)

N= Noise power (in W)

S = Signal power (in W)

$$\frac{S}{N} = \frac{2H}{h} \tag{10}$$

All of the above was investigated taking into account that the spectrum is limited and it has been re-used or re-farmed for various technologies and systems, for example:

- Re -use of GSM900/DCS1800 for LTE roll-out in the 900/1800 MHz bands
- Re-use of DTV 700Mhz band for LTE APT700

With the above optimisation of the modulation scheme explained, the interfering gain, the selection of the correct band pass filter and transmission on the lower frequency, The below final desired result was achieved.

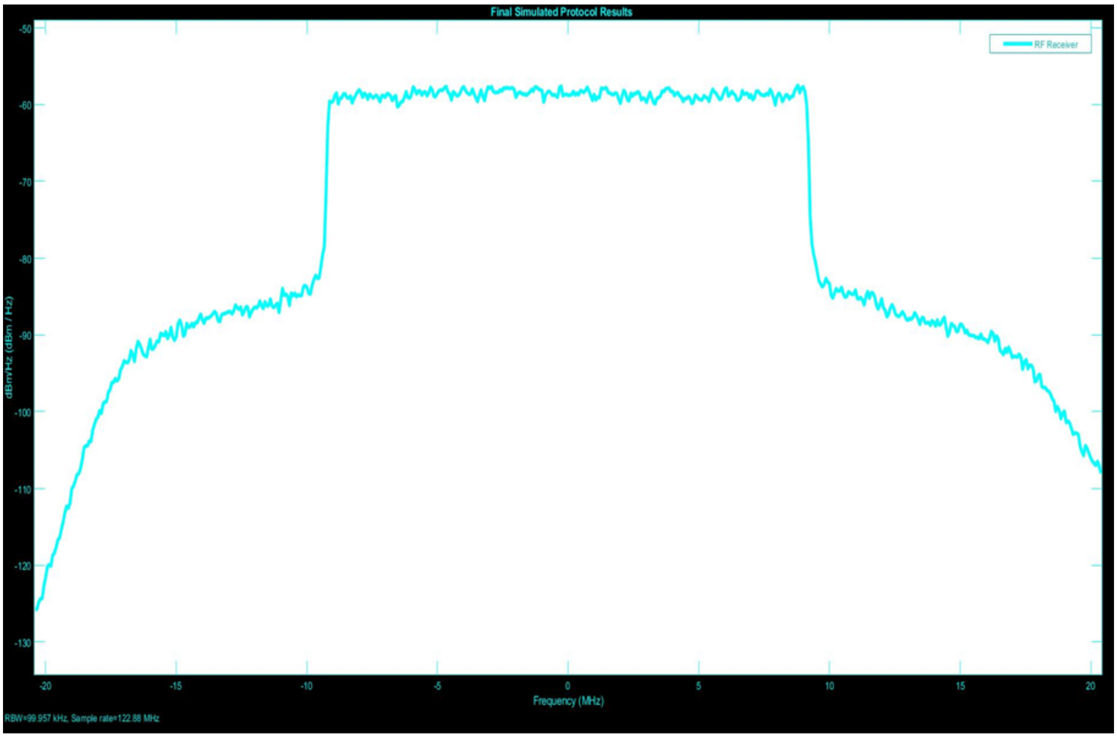

Figure 34: Coexistence of 5GNR and NB-IoT with mitigated Interference

On Figure 34 it is observed that the interference was mitigated because there are no spikes other than the amplitude of the signal occurring once or more and the SINR shows the magnitude of mitigated interference as per the below calculation:

From equation (10) The S/N before optimisation was 2H/h = 2(-72.833dBm/Hz)/-1200dBmdBm/Hz = 1,214

The S/N after optimisation = 2H/h = 2(-80dBm)/-70dBm) = 2,286

4.4 CONCLUSION

The right modulation scheme for this study was identified to be the 256QAM, the correct frequency which is the FR1 in the set of frequencies lower than 6GHz was identified to give correct output.

As an example: It was denoted that when one technology is occupying the whole spectrum band it allows for maximum bandwidth possible as in the below simulated NB-IoT not coexisting and 5GNR not coexisting.

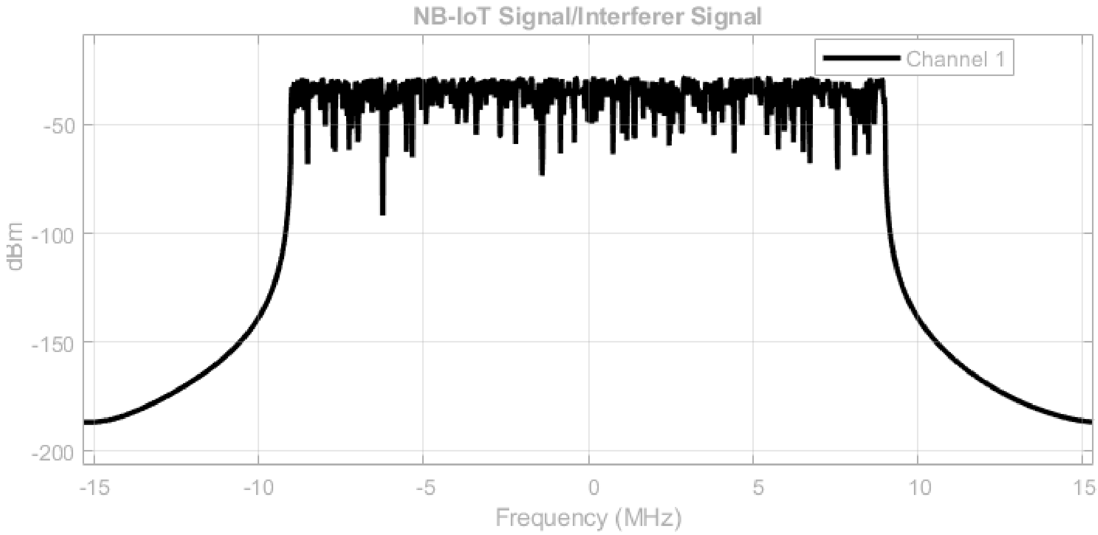

Figure 35: NB-IoT Signal without coexistence on spectrum analyser

In Figure 35 NB-IoT was simulated without the coexistence of the 5GNR to show the bandwidth it occupies without 5GNR coexistence on the spectrum.

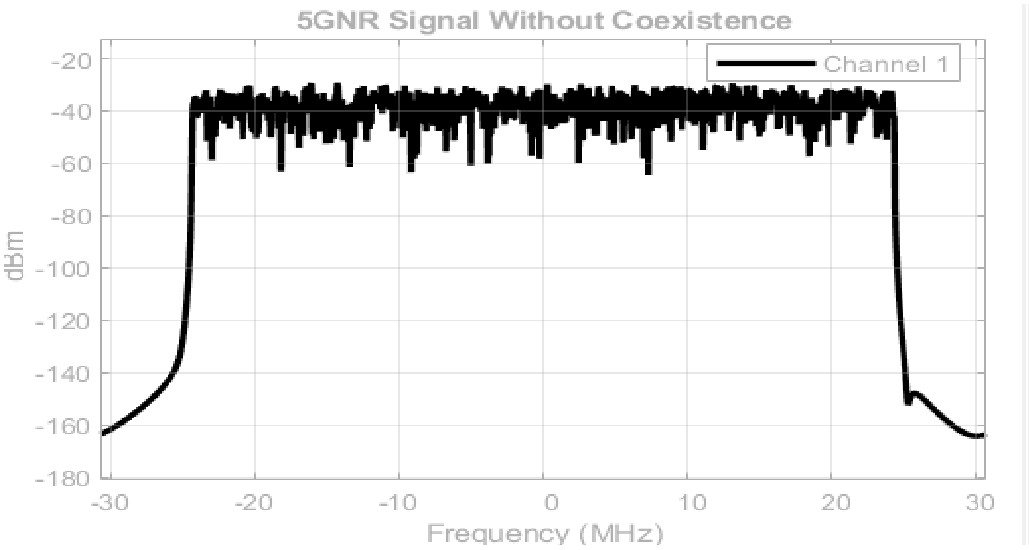

Figure 36: 5GNR without coexistence on spectrum analyser

Figure 36 shows a 5GNR without coexistence on spectrum analyser. This is because there is no interference and any frequency range in the spectrum can be selected but when other technology is introduced in the same spectrum band i.e., coexistence of 5NR and NB-IoT there was interference which was mitigated in this study.

CHAPTER 5
CONCLUSION AND FUTURE WORK

5.1 APPLICATION

Due to the scarcity of the spectrum, a lot of technologies or emerging network generations are forced to co-exist or undergo spectrum sharing. There is an increasing demand for access to many segments of the spectrum. Variety of new applications are allowed by new technologies to make use of a range of frequency bands. For example, the International Mobile Telecommunications (IMT) applications that use 5G competes with prudent services in mid-, low-, and high-band spectrum whereas the most common frequency bands for mobile networks to current date have been only focused on mid- and low- band spectrum. The increase in demand makes efficiency in spectrum use more important. Additionally, applications such as the High-Altitude Platform Systems (HAPS) and Non-Geostationary Orbit (NGSO) satellites have increased the pressure to access different bands of the spectrum while the interconnected devices operating through applications such as Wi-Fi and Bluetooth have further increased competition for valuable and finite spectrum. An example is a 2nd Generation (2G) wireless network sharing the Band with LTE Network. Another example is in this study whereby a 5GNR is co-existing with NB-IoT and as result there is interference. The result of this study enhances mitigation of the interference challenges by showing the result of an improved SINR on integrated NB-IoT into 5GNR as we are now more focused on 5GNR networks because of the advantages it offers over other wireless networks.

5GNR has a lot of advantages in the world that we live in, as technology evolves, and we have M2M communication and self-driving cars. With Interference, 5GNR will not meet its goal. An example is self-driving cars accidents due to interference that leads to poor quality of service. This study contributes towards the goal of avoiding such cases.

5.2 CONCLUSION

The key result for this study is the SINR improvement as a measure of mitigated interference which is enhanced by the choice of the filter used and the modulation scheme of choice. To mitigate interference in coexistence system of signals in the same spectrum, they must be transmitted in different frequencies or channels. This study concluded that when coexisting signals are transmitted in higher frequencies, they are likely to interfere than in lower frequencies. In telecommunication networks, lower frequencies are good for penetration than higher frequencies which is good for the latest technologies such as 5GNR, LTE, NB-IoT etc. when they are used in lower frequency (Spectrum reuse).

5.3 SUGGESTION FOR FURTHER STUDIES

Improvement of the signal quality was also one of the challenges in this study and the below were denoted. More power was not a solution because the goal was to get energy efficient communications. To achieve that, power had to be used more efficiently, gain of the secondary RF signal (NB-IoT) had to be kept low One of the key implementations in telecommunications transmission is to transmit in one direction for better signal strength and improved SINR.

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APPENDIX A: EDITING CERTIFICATE

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26/10/2023

LEBOHANG CASWEL TLAKE

Central University of Technology

RE: EDITING CERTIFICATE

FOCUS AREA: MITIGATING INTERFERENCE CHALLENGES IN INTEGRATED 5G NEW RADIO AND NARROWBAND INTERNET OF THINGS

A thesis submitted in fulfilment of the requirements for the **Degree Master of Engineering: Electrical Engineering** in the **Faculty of Engineering, Built Environment and Information Technology**: **Department of Electrical, Electronic and Computer Engineering** at the **Central University of Technology, Free State**

This serves to confirm that this research has been edited for clarity, language and layout.

Kind regards,

Nereshnee Govender (PhD)