Interference Detection Algorithms and Mitigation Techniques for 5G Waveforms

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I. Abstract

The advent of Fifth Generation (5G) cellular networks has revolutionized wireless communication, providing significant improvements compared to previous technologies by integrating a diverse range of devices and machines. The simultaneous operation of many small cells in a multi-tier 5G cellular network is hampered by different types of interference that severely limit the user's quality of experience and fall short of current 5G expectations. The objective of this research is to study the existing techniques for detecting and mitigating interference in the 5G New Radio (NR) framework, utilizing MATLAB's 5G toolbox to implement techniques such as interference nulling, alignment, and cancellation in the 5G NR framework. The research goal is unique in that it aims to address the interference challenges that arise in the next-generation cellular network. The simulations that have been undertaken aim to mitigate interference for UEs with less receiver diversity or increase the total throughput of a system beyond traditional MIMO limitation of number of antennas. We have been successful in performing all the three cases within 5dB on average of the no interference case. The implementation of effective interference detection and mitigation techniques will improve the reliability and efficiency of 5G NR systems, contributing to the development of new interference management techniques that can be used in the design and implementation of future wireless communication systems.

II. Introduction

Wireless communication has undergone a paradigm shift from the conventional communication system to a new radio communication network in the modern technological world. The advent of Fifth Generation (5G) cellular networks has revolutionized wireless communication by integrating a diverse range of devices and machines, resulting in significant improvements compared to previous technologies. The primary objective of 5G technology is to enhance the user experience and meet their potential necessities for efficient communication. 5G technology incorporates various schemes, such as HetNet, D2D communication, IoT, RN, Beamforming, MMIMO, mm-wave, etc.

However, the introduction of new radio requires the enhancement of predecessor's techniques to ensure compatibility with traditional networks. Despite these efforts, the design and concurrent use of disparate technological models have led to unacceptable interference in each other's signals, significantly deteriorating overall network performance.

In cellular communication, interference is the undesired addition of a signal that obstructs the transmission of the actual signal. It varies from noise, which can be any commotion that interferes with the important signal, such temperature or contaminants. On the other hand, interference severely reduces network performance and user experience. The system is vulnerable to serious interference problems in the next-generation cellular network, which includes numerous low power nodes, random deployment, and frequency re-use scenarios.

These vulnerable interferences are a significant concern in 5G and beyond networks, as they negatively impact network performance, reliability, and efficiency. The interference management techniques are, therefore, crucial to mitigate these interferences and enhance network performance. In summary, while 5G technology has brought about significant improvements in wireless communication, in order to create a new and practical spectrum for the present 5G cellular systems, interference management is a crucial task.

The simultaneous operation of many small cells in a multi-tier 5G cellular network is hampered by different types of interferences that severely limit the user's quality of experience and fall short of current 5G expectations. The novel architecture of 5G, the broadcast nature of the wireless medium, and the complex coordination of low-power small cells contribute to heavy interference issues. Moreover, the heterogeneity structure and newer modulation and multiple access techniques also introduce unique types of interference.

Interference mitigation is a crucial aspect of 5G wireless networks, as it plays a key role in improving the quality of service for users. Therefore, effective management, mitigation, and cancellation of interferences play a critical part in the current 5G mobile communication ecosystem. Inadequate interference management can lead to degraded network performance, reduced network capacity, and user dissatisfaction, ultimately impacting the growth and profitability of service providers.

Our objective is to study the existing techniques for detecting and mitigating interference in the 5G New Radio (NR) framework. The central research goal is to utilize MATLAB's 5G toolbox to implement techniques such as interference nulling, alignment, and cancellation in the 5G NR framework. The successful implementation of these techniques will allow base stations (gNodeBs) to communicate effectively with user equipment (UE) even in the presence of interference. This will be beneficial in improving the overall performance and quality of 5G NR networks by reducing the impact of interference on network efficiency and user experience.

The research goal is unique in that it aims to address the interference challenges that arise in the next-generation cellular network. It offers a comprehensive approach to understanding and solving the interference challenges. MATLAB's 5G toolbox provides a powerful simulation environment for developing and testing interference detection and mitigation algorithms. The gNodeB and user equipment (UE) communication scenarios that are implemented in the MATLAB environment can help researchers evaluate the effectiveness of different interference detection and mitigation techniques in a controlled setting.

This is essential for advancing the field of 5G NR and addressing the critical challenge of interference. The implementation of effective interference detection and mitigation techniques will improve the reliability and efficiency of 5G NR systems. It can also help in developing new interference management techniques that can be used in the design and implementation of future wireless communication systems.

The simulations that have been undertaken aim to mitigate interference for UEs with less receiver diversity or increase the total throughput of a system beyond traditional MIMO limitation of number of antennas. Adapted precoding and equalization algorithms have been used to achieve interference nulling, alignment, and cancellation within the 5G framework. Most importantly, The 5G NR PDSCH has been utilized to communicate data from a gNodeB to UE, implementing demodulation reference signals (DMRS) and hybrid automatic repeat request (HARQ) FEC. Three interference mitigation cases were modeled in this 5G framework, which are as follows: Scenario 1- Interference Nulling, Scenario 2 - Interference Alignment and Cancellation, Scenario 3 - Interference Nulling and Alignment.

We have been successful in performing all the three cases within 5dB on an average of the no interference case. The large gap is due to the fact that LMMSE Equalization is used for non-interference cases, whereas a Pseudo Inverse is employed for IAC Case. Currently, nothing has been done to minimise the error, but this is in the works for the future.

III. Background and Related Work

A. Interference Detection and Mitigation

In recent years, various interference detection and mitigation techniques have been proposed to improve the performance of 5G networks. This related works section provides an overview of some of the recent research papers on interference detection and mitigation techniques for 5G wireless networks.

Interference mitigation is a critical challenge in 5G wireless networks. In recent years, several techniques have been proposed to address this issue. Lee et al. [4] demonstrated the effectiveness of their approach in reducing interference in a 5G wireless network. Their work highlights the importance of interference cancellation as a key component of interference mitigation in 5G wireless networks.

The paper by Hattab et al. [5] on "Interference Mitigation via Beam Range Biasing for 5G mmWave Coexistence with Incumbents" proposes a technique for mitigating interference in 5G mmWave networks that coexist with incumbent systems. The authors use beam range biasing to improve the coexistence between 5G and incumbent systems. This work is related to other studies that aim to mitigate interference in 5G networks, such as "Interference Coordination for 5G Cellular Networks" by Jiang et al. [6] and "Interference Mitigation in Millimeter Wave Cellular Networks: Challenges and Opportunities" by Alkhateeb et al [7]. Both of these studies propose interference mitigation techniques for 5G networks, but they address different aspects of interference and use different techniques to mitigate it. The work by Hattab et al. specifically addresses the challenge of coexistence with incumbent systems, which is not addressed in the other studies.

Some studies [10] have proposed the use of beamforming techniques to reduce interference between D2D devices and improve discovery performance. Other approaches include the use of frequency hopping and power control techniques to mitigate interference.

B. Interference Nulling

Huang et al. [3] proposed a method of interference nulling for offloaded heterogeneous users in such networks. Their method uses a macro generalized inverse precoder to mitigate interference and improve system performance. They showed that their approach outperformed conventional methods in terms of system throughput and user fairness. The work by Huang et al. highlights the importance of advanced interference management techniques for improving the performance of heterogeneous wireless networks.

Li et al. [2] proposed a user-centric interference nulling method for downlink small cell networks. Their approach focuses on minimizing the intercell interference experienced by each user, rather than the network as a whole.

The key difference between the two approaches is that Li et al.'s approach is more targeted towards improving the overall performance of the small cell network, whereas Huang et al.'s approach is more targeted towards improving the SINR of specific offloaded users with the help of a macro base station.

C. Interference Alignment and Cancellation

Gollakota [9] has proposed a technique called interference alignment (IA) that can align the interfering signals in wireless communication networks. IA can enable the receiver to cancel out the interference, thereby achieving the optimal capacity of wireless networks. The paper presents a theoretical analysis of IA and shows that it can achieve the optimal capacity for certain network topologies. The paper concludes that IA is a promising technique that can complement the existing techniques, such as MIMO and OFDM, to enhance the performance of wireless communication systems. Interference Alignment and Cancellation (IAC) is implemented in WiFi Framework in the paper, using that as a reference, we have tried to achieve the effectiveness of the mitigation techniques in a 5G PDSCH Framework.

The paper by Li et al. [4] on ”Inter-Relay Interference Cancellation Using MIMO Detection” proposes a technique to mitigate inter-relay interference in wireless communication networks. The authors use multiple-input multiple-output (MIMO) detection to cancel the interference caused by the relays. This work is related to the paper by Gollakota et al. on ”Interference Alignment and Cancellation,” as both propose techniques to mitigate interference in wireless communication networks. However, Lee et al. focus on inter-relay interference, while Gollakota et al. propose a more general technique for aligning and canceling interference in wireless networks.

In summary, a variety of interference detection and mitigation techniques have been proposed for 5G wireless networks. These techniques utilize different approaches, such as exploiting CSI, using beamforming techniques, joint interference detection and channel estimation, interference detection and nulling, and iterative interference cancellation, to mitigate interference and improve the quality of service in 5G wireless networks. These approaches have the potential to address the interference challenges faced by 5G wireless networks and improve their performance. However, there is still room for improvement, and future research should focus on developing more efficient and effective interference mitigation techniques.

IV. Design

Our project aims to achieve interference mitigation techniques in a 5G framework utilizing MATLABs 5G toolboxes to transmit downlink shared channel (DL-SCH) information over the Physical Downlink Shared Channel (PDSCH). In this project we investigated three different scenarios in an effort to mitigate interference for UEs (User Equipment) with less receiver diversity or increase the total throughput of a system beyond traditional MIMO limitations imposed by the of number of antennas at the UE.

- Scenario 1 - Interference Nulling
- Scenario 2 - Interference Alignment and Cancellation
- Scenario 3 - Interference Nulling and Alignment

Scenario 1 - Interference Nulling

In scenario 1 which is shown in figure 1 there are two gNBs transmitting DL-SCH information at the same time to two separate UEs. Since these gNBs are transmitting in the same time and frequency allocation they will cause undesirable interference to the adjacent UE. To mitigate this effect gNB2 applies a precoding on its data to achieve a beam null at UE1.

Scenario 2 - Interference Alignment and Cancellation

In scenario 2 which is shown in figure 2 there are two gNBs transmitting DL-SCH information at the same time to two separate UEs. In this case however both gNBs and both UEs

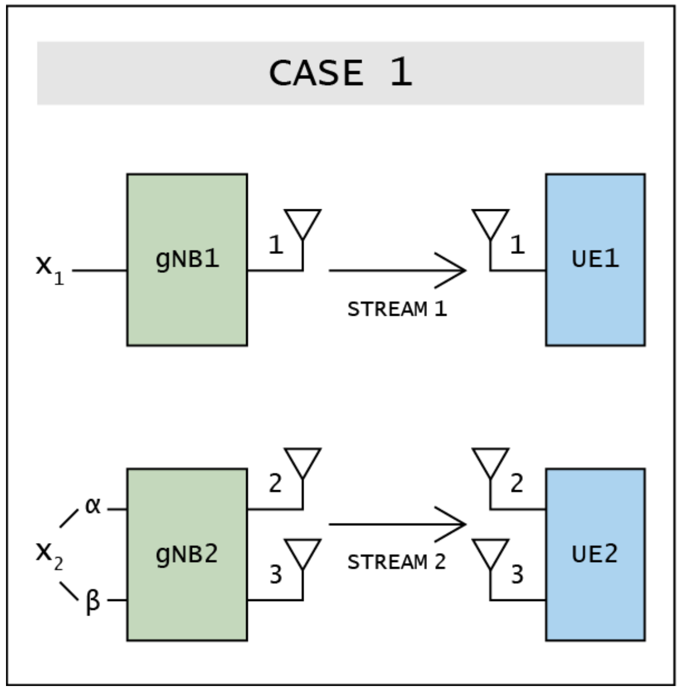

Fig. 1. Case 1 - Interference Nulling from gNB2 to UE1

have two antennas meaning that they could in fact employ traditional MIMO techniques and achieve communication without significant degradation due to interference. However, in this scenario our objective is to actually increase the overall throughput of our system, increasing the systems overall throughput from two data streams or layers to three layers. This can be achieved by utilizing interference alignment and cancellation (IAC) at the UEs. In this scenario we are making an unrealistic assumption that we have a wired link between the two UEs which is required for IAC to communicate the decoded data that was not interfered allowing the second UE to cancel that inference and recover the remaining data communicated. In this scenario it would be a much more realistic assumption to make that the gNBs are connected over the core network and they instead could achieve this interference nulling through that connection. We attempted to achieve this in a 5G framework with the uplink shared channel (UL-SCH) communicating data over the physical uplink shared channel (PUSCH), however due to time limitations we were unable to get this simulation working.

Scenario 3 - Interference Nulling and Alignment

In scenario 3 which is shown in figure 3 aims to achieve both interference nulling at gNB2 similar to scenario 1, however it also employs interference nulling and alignment at gNB3 to achieve an interference null at UE1 and align with gNB1 interference at UE2. In this case gNB 1/2 and UE 1/2 operate the same as in scenario 1 since gNB3 nulls to UE1 and aligns with gNB1 interference to UE2. The additional antennas at gNB3 and UE3 give this link the additional degrees of freedom needed to implement both interference nulling and interference

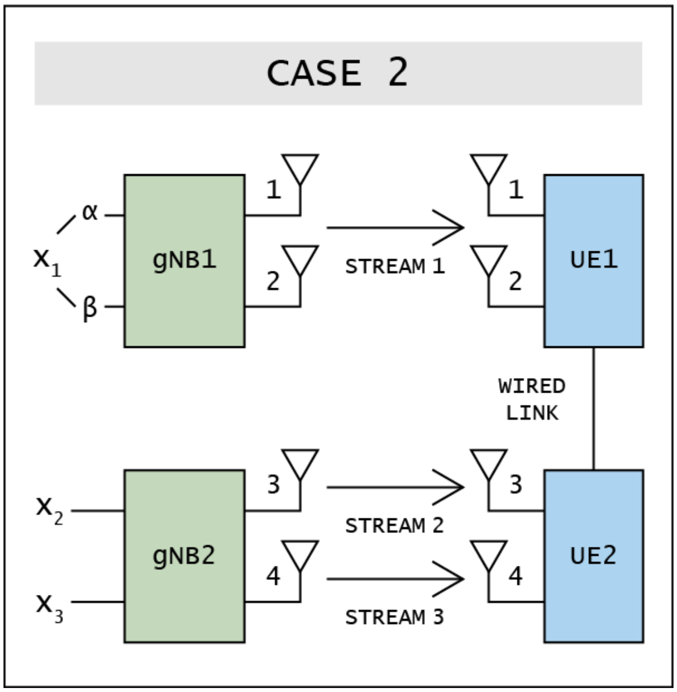

Fig. 2. Case 2 - Interference Alignment and Cancellation

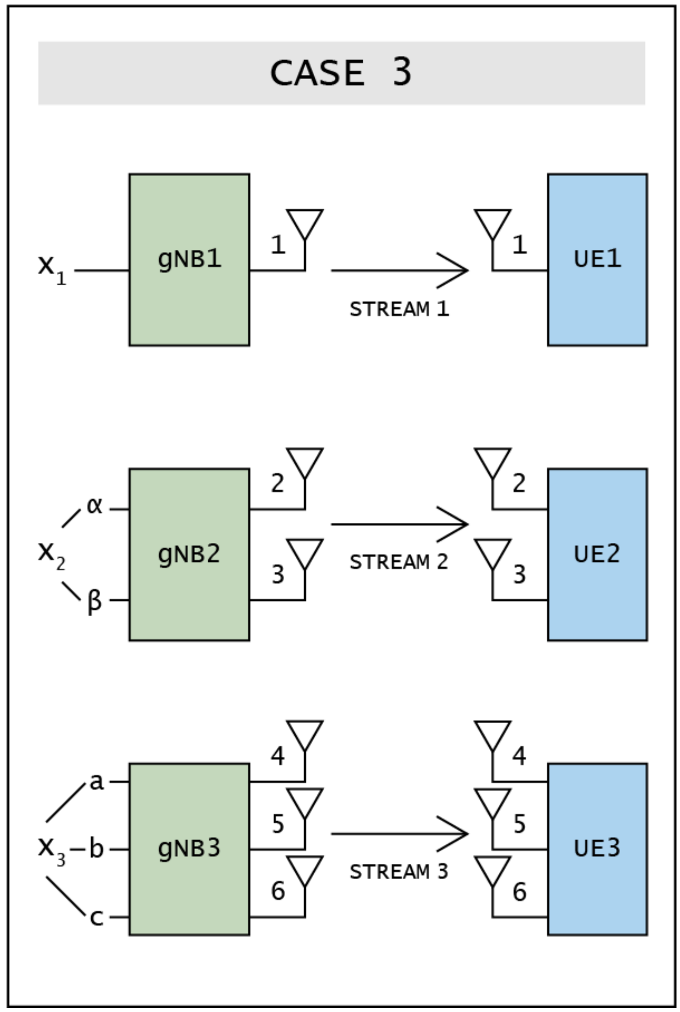

Fig. 3. Case 2 - Interference Nulling and Alignment

alignment and still be able to recover its data at UE3.

5G PDSCH Processing with Interference Mitigation

Our simulations for these three scenarios generally aimed to adapt the precoding applied at the gNBs and and modify the equalization techniques applied at the UEs to achieve interference nulling, alignment, and or cancellation within this 5G framework. Each scenario requires a variation in precoding and equalization to achieve this interference mitigation since the UEs have different number of antennas allowing for varying degrees of freedom.

The overall PDSCH processing for each of the scenarios follows the same steps to generate PDSCH data, precode the PDSCH data as well as the DMRS symbols accordingly for interference nulling, interference alignment, or interference alignment and cancellation, passed through a channel and then recovered at the UE. The detailed steps are as follows.

PDSCH and DM-RS (Demodulation Reference Signal) configuration

In this step we configure the PDSCH channel of the 5G grid to use QPSK modulation, 1 layer (one data stream), the physical resource block set (utilizing the whole grid size in this example) and the DMRS configuration type and length (number of symbols that the DMRS are populated for). In scenario 2 gNB2 utilizes a second layer to achieve the three data streams with IAC, however all other gNBs simply use one layer. Our simulations only were measured using a QPSK modulation for all links, however as mentioned in [**?**] IAC works with various modulations and FEC codes since IAC subtracts interference before passing a signal to the rest of the demodulation processing. Therefore, this applies regardless of the modulation and FEC used at the gNBs. Some simulations were run with one gNB transmitting QPSK and another transmitting 16QAM, and in this case these interference mitigation techniques were still successful at decoding.

DL-SCH Configuration / HARQ

In this step we configure the downlink shared channel for the hybrid automatic repeat request (HARQ) configuration as well as the coding rate and iteration count for the low density parity check (LDPC) decoder with the nrDLSCHDecoder object from the 5G toolbox. This configuration was adopted from examples with the 5G toolbox.

Channel Configuration

This portion of the simulation configures the channel that the PDSCH and DMRS symbols will be passed through. This includes specifying parameters such as the number of transmit and receive antennas, the path delay times and average gains, as well as a delay profile if selecting from default tap delay line (TDL) channels provided by the toolbox. In our experiments the channel used for all simulations and users was a statistical Rayleigh fading tap delay line channel (TDL-A from the NR standard) with unique seeds for each channel. This unique seed was required to ensure that the channels between devices were not correlated such that our interference mitigation techniques applied would still allow for successful communication and not create a null at both UEs.

Channel Estimation

In our simulations we assumed an ideal channel estimation based on the channel configuration in the previous step. This channel estimation will be used by the gNBs to implement the appropriate precoding to achieve either interference nulling or alignment for the desired UE. Then this channel estimation is also used at the UEs for equalization to recover the transmitted signal.

Precoding Matrix Generation

In this step each of the scenarios require a unique precoding technique to achieve the desired interference mitigation throughout the system. The traditional precoding used for the PDSCH averaged the channel estimate grid across time and frequency (over the 624 subcarriers, for the 52 PRBs in use, and 28 OFDM symbols), it would then result in a matrix of size $N_{TX} \times N_{RX}$ and compute a unitary matrix with singular value decomposition (SVD) to obtain a new precoding matrix of size $N_{TX} \times N_{TX}$ to be used for precoding. For interference nulling or alignment we require a modified precoding technique to either null the interference at a desired antenna or align the interference from another transmitter. Each case utilizes a slightly modified precoding however in all cases we implement a precoding on a per-subcarrier basis. This is to combat the issue observed in our midterm report where the TDL-A channel used is not a flat fading channel across the entire band.

- Scenario 1

For scenario one gNB2 implements precoding such that its interference is nulled at UE1 allowing UE1 to decode x_1 with minimal interference due to this null. Then UE2 is able to decode an estimate of x_1 and x_2 and successfully recover x_2 at is receiver due to the added antennas of UE2. The precoding then applied at gNB2 for α and β are as follows (where h_{ij} represents the channel from the j^{th} transmit antenna to the i^{th} receive antenna).

$$\alpha = -h_{13}$$

$$\beta = h_{12}$$

- Scenario 2

For scenario two gNB1 implements precoding to achieve interference alignment with x_2 allowing UE2 to successfully decode x_3 and then provide that information to UE1 allowing UE1 to then successfully decode both x_1 and x_2 by cancelling the interference of x_3. The precoding then applied at gNB1 for α and β are as follows.

$$\begin{bmatrix} \alpha \\ \beta \end{bmatrix} = \begin{bmatrix} h_{31} & h_{32} \\ h_{41} & h_{42} \end{bmatrix}^{-1} \begin{bmatrix} h_{33} \\ h_{43} \end{bmatrix}$$

- Scenario 3

For scenario three gNB1 and gNB2 operate the same as in scenario 1 since they do not need to achieve any interference mitigation for UE3. Now as for gNB3, a interference null needs to be achieved at UE1 since it only has one antenna and at UE2 we need to align with the interference coming from gNB1. The precoding applied at gNB3 to achieve these two results at UE1 and UE2 is as follows.

$$\begin{bmatrix} a \\ b \\ c \end{bmatrix} = \begin{bmatrix} h_{14} & h_{15} & h_{16} \\ h_{24} & h_{25} & h_{26} \\ h_{34} & h_{35} & h_{36} \end{bmatrix}^{-1} \begin{bmatrix} 0 \\ h_{21} \\ h_{31} \end{bmatrix}$$

As can be seen above, what we're achieving with this precoding is a null at receive antenna 1 (for UE1) and then an alignment of interference with transmit antenna 1 (gNB1) at receive antennas 2 and 3 (UE2).

Transmission and Reception

In this step we precode the generated PDSCH and DRMS symbols with the generated precoding matrices discussed in the previous section, populate the resource grid, OFDM modulate the resource grid to obtain a TX waveform, pass the TX waveform through the configured channel, add noise, do timing and channel estimation and finally demodulate, extract resources from the grid, equalize and decode.

Since these cases are all implementing slightly different techniques the equalization used in each case differs slightly.

- Scenario 1

For scenario one at UE2 the equalization used is as follows.

$$\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} h_{21} & \alpha h_{22} + \beta h_{23} \\ h_{31} & \alpha h_{32} + \beta h_{33} \end{bmatrix}^{-1} \begin{bmatrix} y_2 \\ y_3 \end{bmatrix}$$

- Scenario 2

Scenario two requires a bit more care since we're implementing IAC in this case. In this case we first equalize and decode x_3 at UE2 since the interference from x_1 is aligned with x_2 at UE2.

$$\begin{bmatrix} ax_1 + x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} h_{33} & h_{34} \\ h_{43} & h_{44} \end{bmatrix}^{-1} \begin{bmatrix} y_3 \\ y_4 \end{bmatrix}$$

So once x_3 is determined from above then x_1 and x_2 can be determined at UE1 by canceling this interference from x_3 at receive antennas 1 and 2.

$$\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} \alpha h_{11} + \beta h_{12} & h_{13} \\ \alpha h_{21} + \beta h_{22} & h_{23} \end{bmatrix}^{-1} \left(\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} - \begin{bmatrix} h_{14} \\ h_{24} \end{bmatrix} x_3 \right)$$

- Scenario 3

Scenario three is very similar to scenario one with just the added data stream from gNB3. Since gNB3 implements interference nulling and alignment, UE1 and UE2 can operate the same as in scenario one, and only UE3 needs to take into consideration the interference from gNB1 and gNB2. In this case UE3 will equalize it's received signals as follows.

$$\begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} = \begin{bmatrix} H_1 & H_2 & H_3 \end{bmatrix}^{-1} \begin{bmatrix} y_4 \\ y_5 \\ y_6 \end{bmatrix}$$

Where H_1, H_2, and H_3 are defined as

$$H_1 = \begin{bmatrix} h_{41} \\ h_{51} \\ h_{61} \end{bmatrix}$$

$$H_2 = \begin{bmatrix} \alpha h_{42} + \beta h_{43} \\ \alpha h_{52} + \beta h_{53} \\ \alpha h_{62} + \beta h_{63} \end{bmatrix}$$

$$H_3 = \begin{bmatrix} ah_{44} + bh_{45} + ch_{46} \\ ah_{54} + bh_{55} + ch_{56} \\ ah_{64} + bh_{65} + ch_{66} \end{bmatrix}$$

V. Implementation

In our simulations we evaluated our interference mitigation techniques using the BER of each UE within the system and evaluated against two baselines, interference and no interference. In our simulations the no interference baseline is defined as transmitting the same number of layers over the same channel with no precoding used, transmitting directly to the desired UE with no interference added from the other transmitting gNBs. In this no interference baseline is the performance of each link within the scenario if each link was transmitting independently and having no interference introduced from adjacent gNBs. The interference baseline is the same as the no interference case where no precoding is applied however the interference from adjacent gNBs were introduced to the received signals.

The way that BER was calculated in this single slot case was that the transmitted bit were compared against the received bits to determine the number of bit errors in each transmission for the two baseline cases and then interference mitigation case. This was then performed for multiple iterations over a range of SNRs to compare performance of each link as SNR varies.

It came to our attention that this BER calculation may not be the most accurate representation of the error rate of our system since a HARQ process was implemented in our simulation and therefore in the event of a transport block decoding error the transport block would be dropped and re-transmitted. Therefore, the most appropriate way to determine this BER would be to run this simulation over a large number of slots / transport blocks and treat each failing transport block decoding as N bit errors where N represents the size of the transport block. Then over many slots this would converge to the true BER rate. Due to high simulation times and time limitations this update was not made for our evaluations, however this would be a good future work area.

VI. Evaluation

For our evaluation of our performance for each scenario we looked at the BER of each UE in the system against the two baselines, no interference, and interference.

- Scenario 1
In scenario 1 our objective is to be able to effectively decode x_1, and x_2 in the presence of interference where with traditional MIMO techniques we would not be able to achieve this successful decoding. As observed in figures 4 and 5 it's observed that as we very SNR we are able to achieve near ideal decoding at UE1 and a slight degradation to performance at UE2. This degradation at UE2 is still outperforming the interference case and nulls the interference at UE1 which enables this decoding even with only one antenna.

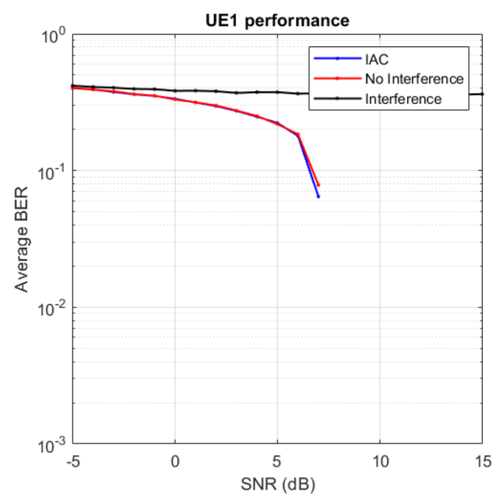

Fig. 4. Scenario 1 - UE 1 Performance

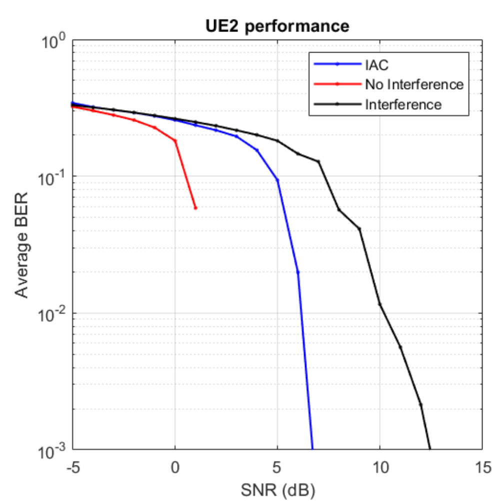

Fig. 5. Scenario 1 - UE 2 Performance

- Scenario 2

In scenario 2 the objective is to increase the overall throughput of our system by transmitting three layers of information as opposed to the two layers that with transitional MIMO techniques would be able to be decoded in this MIMO configuration. Leveraging the techniques of IAC in this 5G framework it was observed that we are now able to successfully decode these three layers of PDSCH data at UEs 1 and 2 with this collaboration effort where without IAC we would not be able to achieve this level of communication.

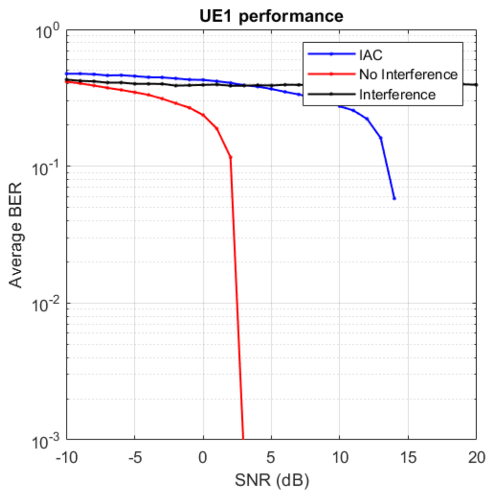

Fig. 6. Scenario 2 - UE 1 Performance

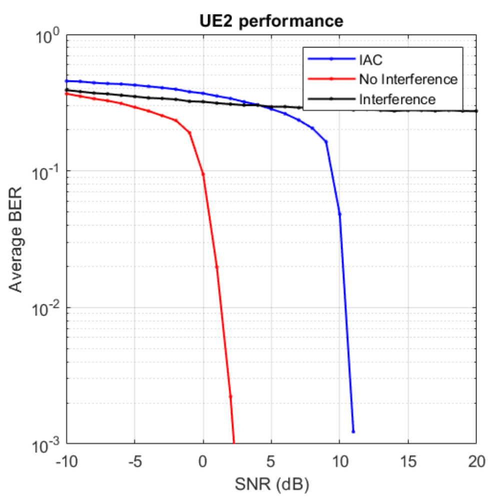

Fig. 7. Scenario 2 - UE 2 Performance

- Scenario 3

In scenario 3 we are able to see that with the interference nulling applied by gNB2 and gNB3 to UE1, UE1 is able to successfully decode data with little to no degradation in performance. And then UE2 is applying the same equalization as scenario 1 where we're able to decode in the presence of interference from gNB1 and gNB3 aligning. And UE3 is able to decode its packet for x_3 since it has three available antennas to determine an estimate for x_1, x_2, and x_3 and then successfully decode the desired x_3.

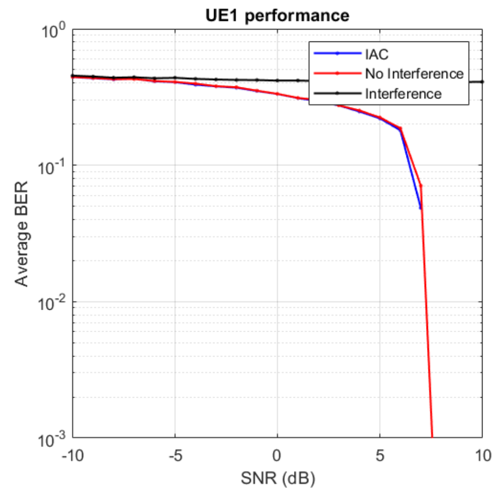

Fig. 8. Scenario 3 - UE 1 Performance

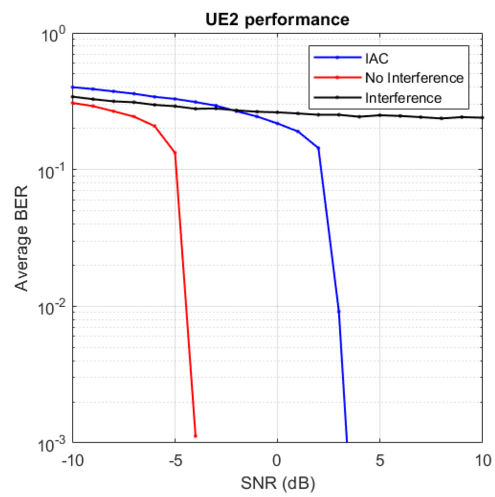

Fig. 9. Scenario 3 - UE 2 Performance

VII. Conclusion

In conclusion, the simulations show that interference mitigation strategies can greatly increase a 5G NR system's total throughput. By using correlation, matched filtering, and PSD analysis, interference detection accuracy can be improved. Additionally, interference nulling, alignment, and cancellation have been made possible with the use of modified precoding and equalization algorithms. It is important to note that IAC can successfully demodulate regardless of the modulation utilized at the TX. But further effort is needed to reduce the inaccuracy, particularly when a pseudo inverse is applied to IAC situations.

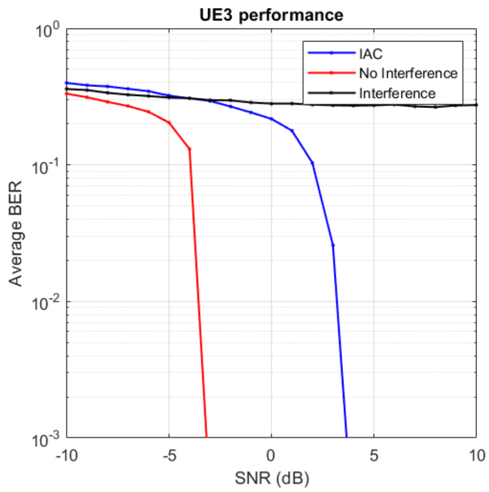

Fig. 10. Scenario 3 - UE 3 Performance

The immediate next steps that would be taken is to primarily implement all these simulations for Physical Uplink Shared Channel (PUSCH). We would also work on optimizing the existing code, and try to perform simulations for many more slots. Another aspect that we would consider is to evaluate the overall throughput of each system/scenario for the varying SNR levels.

The best learning experience from this work is the importance of adapting and optimizing the system to the specific characteristics of the channel and the interference environment. The development of advanced algorithms for interference detection and mitigation is crucial to achieving high-performance communication systems. As future work, focus would be developing new techniques to improve the accuracy of interference detection and the robustness of interference mitigation algorithms. Additionally, the investigation of the trade-off between complexity and performance is necessary to make these techniques feasible for practical implementations.

VIII. Acknowledgement

We would like to express our gratitude to our professor, Dr. Dinesh Bharadia for giving us the opportunity to embark on this project. We thank him for his help in guiding us to choose a project topic to begin with, and for indirectly helping us for the project team. We also want to thank our TAs for the course, Ish Jain and Aditya Arun for their support and encouragement throughout the project. Our sincere thanks go to Ish for always helping us out with technical difficulties, and helpful suggestions and nudges. Finally, we acknowledge the contributions of our fellow classmates who generously gave their time to listen to our presentation and cheered us on.

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