Improvement in the Quality of Services in Sub-6 GHz/mm Wave Using Equalizers and Decoupling of UL and DL with Machine Learning Approach

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***Abstract*—Massive Multiple-Input Multiple-Output (MIMO) is a wireless access technology used to enable 5G and next-generation mobile communications. This 5G network operates in a Frequency Range1(FR1) band, which includes sub-6GHz bands, and a Frequency Range2(FR2) band, which determines bands in the mm-wave range. The sub-6GHz/mm-wave 5G networks encounter a range of difficulties in terms of adaptability, latency, throughput, and improved signal to noise ratio (SNR), where it is desirable for the User Equipment (UE) to limit the transmit power and efficiently manage radio resources to improve battery life. Fading, Bit Error Rate (BER) and noise are significant features in wireless technologies that have an impact on the quality of data and signals, such effects can be efficiently suppressed by Sub-Optimal MIMO detection/equalizer algorithms. The performance of BER Versus SNR is interpreted between Zero Forcing (ZF), ZF-Successive Interference Cancellation (SIC), Minimum Mean Square Error (MMSE), and MMSE-SIC equalizers through different modulation schemes and observed that MMSE-SIC performs best coping with low BER compared to other algorithms, and with its low BER and interference followed by admiring SNR is strongly advised at Uplink (UL)/Downlink(DL) regions. A semi-blind UL/DL decoupling algorithm is also proposed in this context, where the processing unit collects measurements of the Rician K-factor reflecting the line of sight (LOS) condition of the UE and DL reference signal receive power (RSRP) for both 2.6 GHz and 28 GHz frequency bands, followed by the training of a machine learning algorithms. For these frequency bands, the trained algorithm is utilized to make blind predictions about the target frequencies and access points that may be used separately for the UL and DL. Hence, decoupling of UL and DL has been assessed by adapting MMSE-SIC equalizer and various Machine learning and Deep learning algorithms, it is found that Convolutional neural network (CNN) achieves the highest decoupling success rate, with an average accuracy of 98.93% but a maximum accuracy of 99.83% for a small number of training samples.**

***Keywords*—massive MIMO, decoupling, sub-optimum MIMO equalizers, uplink, downlink, rician K-factor, reference signal receive power, fading, BER**

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I. Introduction

A base station (also known as an eNB) is a transceiver used in the telecommunication sector to enable wireless transmission between user equipment (UE) and a network. Mobile phones and laptops with wireless Internet access are examples of UE. Any wireless transmission technology, including GSM, CDMA, Wi-Fi, WiMAX, and wide area network (WAN) technology, may be used for the network. A mobile network comprises of many sorts of cells depending on the range, they include macro cells, microcells, Pico cells and femtocells, in these cells the base station is positioned either at the center of each cell or on the corner of a group of cells.

Massive MIMO, a newly developed wireless access method utilized in 5G communications, offers good service in situations with high levels of mobility. The key idea is to outfit base stations with arrays of numerous antennas that can serve multiple users at once. It is difficult for the receiver side to identify the MIMO signal since the base station has more antennas than it needs. Therefore, a detection algorithm with low computational complexity is needed to achieve optimal performance; many established detection algorithms, also referred to as equalizers, such as Minimum Mean Square Error (MMSE), Successive Interference Cancellation (SIC), and Zero-forcing (ZF), are used to deal with Massive MIMO detection.

Uplink (UL) and downlink (DL) are the transmission paths used in cellular networks to transmit data from a mobile station (a cell phone) to a base station (a cell site), respectively. The downlink and uplink of cellular networks have been associated [1] since the invention of cellular telephony, meaning that mobile devices or user equipment are connected to the same base station in both the downlink and the uplink. This coupling lowers the quality of services, which may be enhanced by interconnecting two distinct UL and DL base stations—a process known as decoupling.

The Sub-6GHz or FR1 band, which has a frequency range of 1GHz to 6GHz, is referred to as mid-band spectrum and is thought to be perfect for 5G since it can transmit a lot of data over long distances. The FR2 band, often known as high band spectrum, has a frequency range of 24 GHz to 40 GHz and offers ultrafast speed across short distances.

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In order to identify MIMO signals with a better Signal to Noise ratio and a lower bit error rate at the base station, this article analyzes different sub-optimal Massive MIMO detection techniques. It discusses the idea of decoupling in addition to the adaptation of an efficient MIMO detection algorithm, i.e., an equalizer at the base station, in order to improve the quality of services such as low latency, to reduce base station load, to limit transmit power, and to achieve high signal to noise ratio, etc.

II. Literature Review

As technology advances daily, new algorithms are being presented, which improves the channel's performance. Massive MIMO is a wireless technique used in 5G that increases spectral efficiency by employing many antennas, leading to an expansion of the coverage area, capacity, and throughput.

Waliullah *et al.* [2], the performance of Bit Error Rate (BER) is compared between Zero-Forcing (ZF) equalizer receiver and Minimum Mean Square Error (MMSE) equalizer receiver for both 2x2 and 4x4 Multiple-Input Multiple-Output (MIMO) systems using Binary Phase Shift Keying (BPSK) modulation, considering Signal-to-Noise Ratio (SNR). It is concluded that MMSE is a better performer than ZF receiver as it cannot detect signals due to its limitations: ZF is primarily thought of as a good receiver only under noise-free conditions. Second, the channel's frequency response may be zero, but that cannot be reversed. Moreover, the channel's impulse response has a limited length, but because of that length, it does not completely satisfy the criteria.

Liu *et al.* [3] Decoupling involves a bidirectional communication concept where either the uplink (UL) or downlink (DL) utilizes a direct link connecting the User Equipment (UE) and the Base Station (BS), whereas the opposite direction's signal is relayed through an intermediary relay station.. They introduced the orthogonal decoupled UL/DL buffer-aided (ODBA) and non-orthogonal decoupled UL/DL buffer-aided (NODBA) relaying protocols, both of which employ decoupled transmission. For UL and DL transmission, mutual independent choices are made in ODBA, but in NODBA, UL and DL are active at the same time and the receiver employs successive interference cancellation (SIC). Based on instantaneous CSI and average channel gain, they came up with the best criteria.

Smiljkovikj *et al.* [4] used a straight forward UL power adaption to examine the performance of a two-tier heterogeneous cellular network with decoupled DL/UL access. The major findings clearly demonstrate that a straightforward, two-level power adaptation may increase the system's spectral and energy efficiency. In addition, the association and power adaptation offer some degree of fairness among the devices in order to raise the system's average performance.

Elshaer *et al*. [5] decoupled of UL and DL architecture for 5G networks is defined.

Padmasree *et al.* [6] discussed the effectiveness of the Minimum mean square error-successive interference cancellation detection method, which is superior to the Zero forcing, Minimum mean square error, and zero forcing-Successive interference cancellation detectors. The algorithm also performs better with relatively small SER when compared to other strategies, regardless of the modulation scheme and the number of transmitters and receivers used.

Chergui *et al.* [7] In order to facilitate rapid and partial independent separation of uplink (UL) and downlink (DL) communications within hybrid sub-6GHz/mmWave cell-free 5G networks, a machine learning technique was introduced. This approach was evaluated against a benchmark threshold approximating blind handovers in 4G networks. Remarkably, by employing the support vector machine (SVM) machine learning method for the separation process, they achieved an impressive accuracy rate of 95%. This noteworthy outcome was attained even with a limited number of training samples, highlighting the efficacy of the SVM technique in enabling efficient UL and DL decoupling.

III. System Model

Aiming to be quicker than the present 4G networks and to provide better data rates, less latency, and improved reliability, the 5G mobile networks are already commencing to be deployed. In order to address the difficulties that 5G mobile networks experience, it employs Massive MIMO technology, which is to be detected at the receiver with less complexity by adopting an efficient equalizer with the approach of decoupling.

A. Massive MIMO

Massive MIMO, an expansion of MIMO technology, is used by 5G mobile networks to address issues brought on by data traffic and users. This technology connects several antennas at the base station and provides simultaneous service to more users. Massive MIMO employs more antennas to help concentrate energy into a more condensed area of space for increased throughput and spectral efficiency.

1) Massive MIMO uplink transmission

As indicated in Fig. 1, the uplink channel is utilized to transport data from the user terminal to the base station.

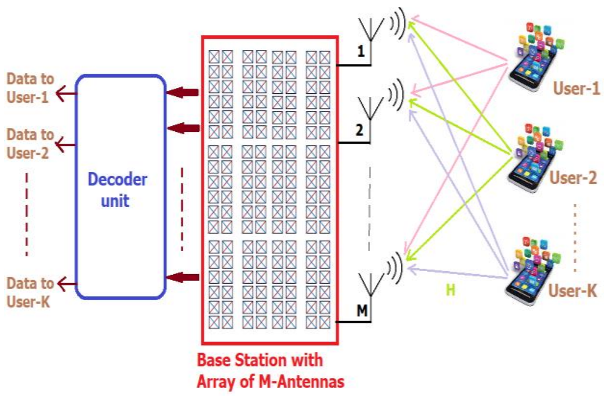

Figure 1. Massive MIMO uplink transmission.

Let's assume a huge MIMO uplink system that can communicate with K single-antenna consumers while having M (M>>K) antennas at the base station. During up-linking, the base station's signal is shown as:

$$Y = HX + n_{uplink} \quad (1)$$

where, H is the channel vector between the user terminal and the base station,

Y is the signal received at the base station,

X is the signal provided by the user, and

The components of H have a unit variance, zero mean, and independent, identical distributions. The additional interference from multiple transmissions and the receiver noise are referred to as n_{uplink}. The extra interference might rely on the channel vector H but is independent of the user signal x.

$$n_{uplink} = n_{uplink-interference} + n_{noise} \quad (2)$$

2) *Massive MIMO downlink transmission*

As indicated in Fig. 2, the downlink channel is utilized to transfer data or estimate channel (detection of sent MIMO signal) from base station to user.

Consider a downlink massive MIMO system where the base station has M antenna and is simultaneously servicing N users, each of which has a single antenna. Many users receive independent information from the base station at once. When the Nth user receives the signal, it is Y_N.

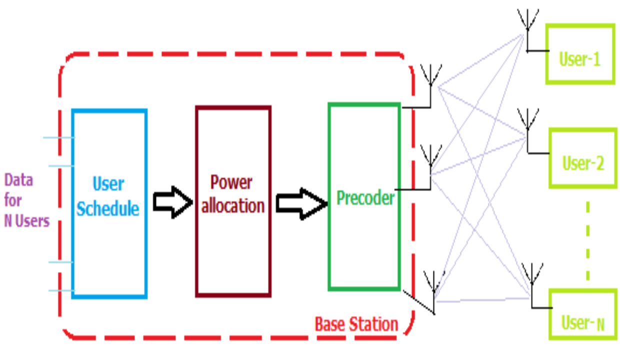

Figure 2. Massive MIMO downlink transmission

$$Y_N = H_N X_N + n_{downlink} \quad (3)$$

where X_N denotes the signal that the base station is sending to user N.

H_N is a channel vector with independent, identically distributed elements, zero mean, and unit variance between the *Nth* user and the base station.

$n_{downlink}$ is the extra noise that is made up of receiver noise and interference during downlink and is given as:

$$n_{downlink} = n_{downlink-interference} + n_{noise} \quad (4)$$

B. *Massive MIMO Detection Algorithms*

Massive MIMO is a new area of study in which it is difficult to detect the signal at the receiver side due to the complexity of the signal detection caused by competing sub-streams. Finding the most likely sent symbols using the perfect channel state information (CSI) at the receiver and the received signal is known as the "signal detection issue." Fig. 3 illustrates the various Massive MIMO detectors [8] that are utilized for signal detection

While near-optimal performance is needed since optimum detectors are thought to be impractical due to computing cost, numerous current sub-optimum detection techniques, such as Zero forcing (ZF) and Minimal mean-square error, are available (MMSE). Massive MIMO detection is addressed using successive interference cancellation (SIC), which are also employed.

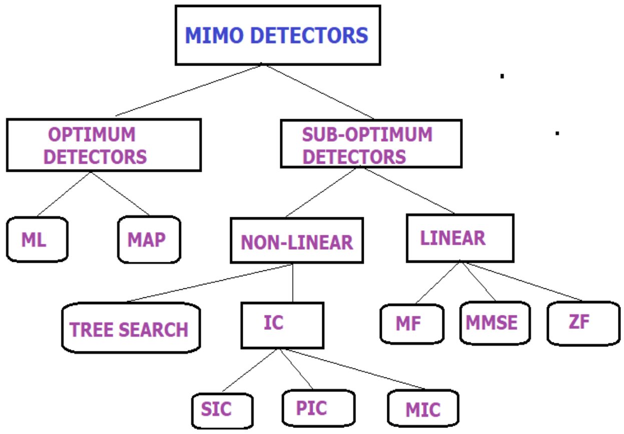

Figure 3. Massive MIMO detection algorithms.

1) *Zero forcing detector*

The commonly used Zero Forcing detection technique applies in the opposite direction to the received signal in order to recover the signal. It is feasible to set the value of Inter Symbol Interference (ISI) for a noise-free channel to zero by using the ZF detection approach. When ISI is significant in comparison to noise, this will be helpful. The Zero Forcing detection of signal $C(f)$ is represented by $C(f) = 1/F(f)$ where $F(f)$ is the channel frequency response, $F(f)C(f) = 1$ is displayed by the channel and ZF detection of the signal, which together produce a flat frequency response. For fulfilling this requirement, the Zero Forcing (ZF) detector is provided by

$$W = (H^H H)^{-1} H^H \quad (5)$$

where W is the equalization matrix,

H is the channel matrix, and

H^H is the channel matrix conjugate

The Zero forcing detection method makes an effort to eliminate the interference terms during the detection process. The input signal is multiplied by its reciprocal if the channel response (or channel transfer function) for a certain channel is $H(s)$. This aims to eliminate the inter-symbol interference (ISI) caused by channel from the received signal.

The zero-forcing detector, which eliminates all ISI when the channel is noiseless, is the best option. The zero-forcing detector will, however, greatly enhance the noise on a noisy channel. ZF detector is therefore not a suitable detector for signal detection, but it is straight forward and simple to use.

The following equation may be used to get the bit error rate.

$$P_b = \frac{1}{2}\left(1 - \sqrt{\frac{\frac{E_b}{N_o}}{1+\frac{E_b}{N_o}}}\right) \tag{6}$$

where,

P_b is bit error rate,

$\frac{E_b}{N_o}$ is signal to noise ratio

The following is the flow chart for Zero force detection in Fig. 4:

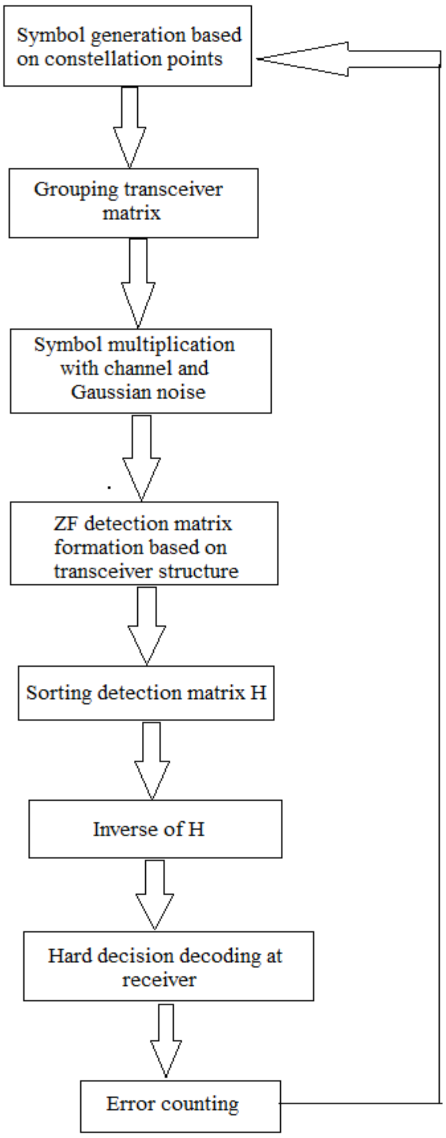

Figure 4. Flowchart for ZF Equalizer [9].

2) Minimum mean square error detector

The minimal mean-square error detector, which computes the mean square error (MSE) and attempts to minimize the error, is a more balanced linear detector in this scenario. The key characteristic of MMSE is that it often reduces the overall power of the noise and ISI components in the output rather than totally eliminating ISI. Let x be a random variable that is unknown, and let y be a random variable that is known. An estimator x^(y) is any function of the measurement y, and its mean square error is given by

$$\text{MSE} = E[(X - \hat{x}(y))^{\,2}]] \tag{7}$$

Both x and y are given the expectation.

Since it is a linear estimator, by using the phrase AY + b, where measurement Y is a random vector, A is a matrix, and b is a vector, can obtain a minimal MSE.

In order to minimize the criteria, the Minimum Mean Square Error (MMSE) technique looks for a coefficient W.

$$E[(W_{y-x})(W_{y-x})H] \tag{8}$$

where

y is the received signal,

x is the broadcast signal,

and W is the equalization matrix.

There must locate a matrix W that satisfies WH = I in order to solve for the sent signal. For satisfying this requirement, the Minimum Mean Square Error (MMSE) detector is provided by

$$W = [H^H H + N_0 I]^{-1} H^H \tag{9}$$

It can observe that both equations, given in Eq. (9) and Eq. (5), are equivalent in the Zero Forcing detector with the exception of $N_0 I$. In fact, the MMSE detector minimizes to the Zero Forcing detector when the noise term's value is zero, Fig. 5 depicts the flow chart for MMSE detection as shown below:

3) Successive interference cancellation detectors

SIC detectors perform more effectively than ZF and MMSE detectors. The SIC detectors choose a two-step iterative process: first, a determination is made on the initial position X1, and then, assuming that the determination was accurate, the detector corrects Y by reducing the interference that would have been produced by X1.

Then, until the entire vector is obtained, SIC detectors continue this procedure on the next entry of X. Fig. 6 depicts the SIC detection flow chart.

ZF-SIC and MMSE-SIC [10] are two distinct SIC detectors utilized for Massive MIMO detection.

ZF-SIC

The following are the steps of SIC Algorithm Zero Forcing

Step 1: *Ordering*

The transmitted stream with the lowest error variance should be found.

Step 2: *Nullifying interference*

Measurement of the strongest transmitted signal after nulling out all other weaker signals.
Step 3: *Cancelling interference*
Demodulate the data bits, take their contribution out of the signal vector that was received, and then go back to the ordering step.
MMSE-SIC
The following are the MMSE with SIC algorithm steps.
Step 1: Finding MMSE
Step 2: Input vector information based on the signal obtained for each dimension
Step 3: Sorting the group vector from the input vector
Step 4: Based on the group vector in order, remove noise and the ISI effect.
Step 5: SNR-based selection of the best group vectors
Step 6: At the receiver, hard decision decoding.
Step 7: Counting errors

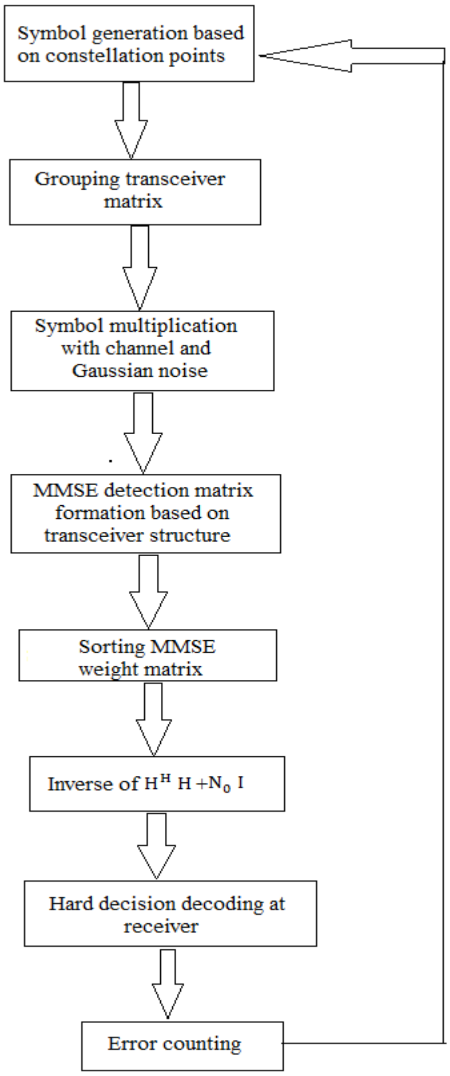

Figure 5. Flowchart for MMSE equalizer [9].

C. Decoupling of UL and DL

In order to improve the quality of services in 5G mobile networks, the downlink and uplink of 5G cellular networks [11] must be separated, i.e., UE must be connected to two different base stations in the UL and DL, i.e., UE is connected to a small cell in the UL region and to a macro cell in the DL region. The decoupling of UL and DL is seen here in Fig. 7.

The parameters that can be enhanced by UL and DL decoupling are as follows:

D. Decreased Transmit Power

The transmit powers of the UL and DL region are significantly influenced by the coverage area, base station heights, and aerial gains. A connection to a nearby base station offers a greater Signal to noise ratio in this typical Decoupling scenario because the uplink coverage area of a small cell is substantially less than the downlink coverage area of a macro cell (SNR). Moreover, the decreased route loss in the UL area enables optionally transmit power reduction in the UL via power management with a set target SNR.

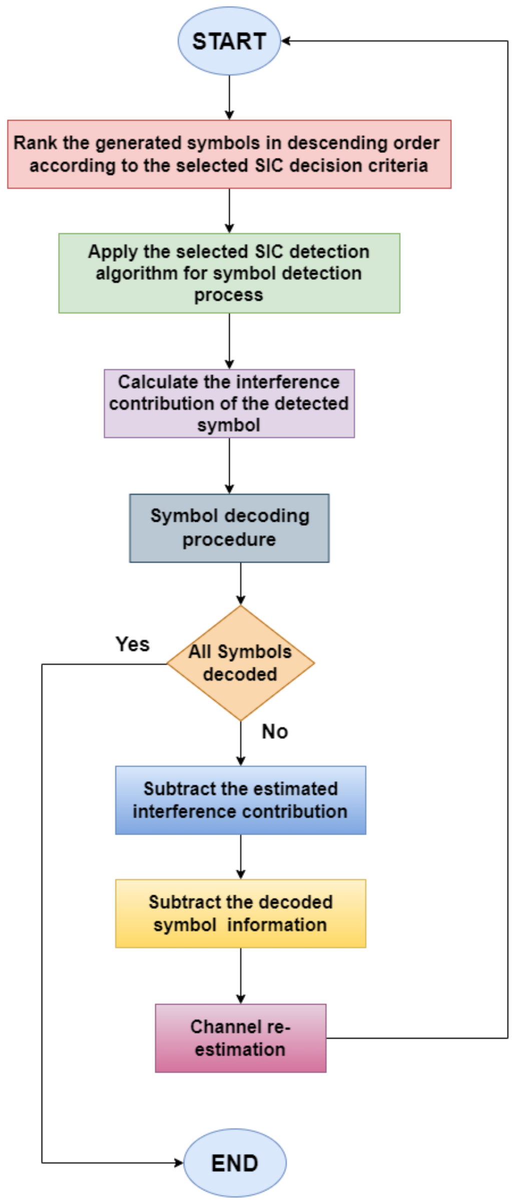

Figure 6. Flowchart for SIC equalizer.

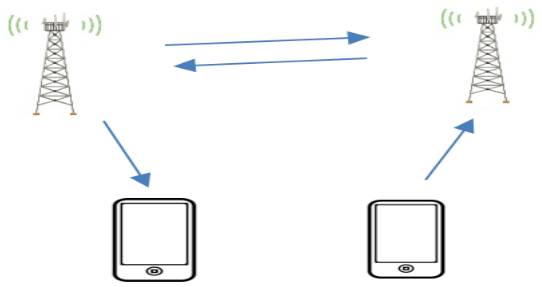

Figure 7. Decoupling of UL and DL.

E. Minimizing of Interference

The decoupled association enables the flexibility to separately pick the association that minimizes interference at both the UE and the BS.

F. Increasing Throughput

As the UL region is connected with small cells i.e. path between UE and BS is smaller this results in lower path loss, high SNR and minimizing the interference leads to better SINR, and thus a greater spectral efficiency and enhanced data rate in UL region.

G. Minimal Latency

The main requirement of a decoupled association is a low latency connection between the downlink and the uplink base stations, which results in a quick exchange of control messages. Implementing a decoupled cell association in a real network requires excellent connectivity and cooperation between different base stations.

H. Base Station Load Balancing

It is possible for a given BS to have a different load in the UL than in the DL. This suggests that it is preferable for at least part of the UEs to employ decoupled access and that it is not ideal to have the same set of UEs linked to the same BS in both the uplink and the downlink. Moreover, since decoupled association is not constrained by interference as it is in the DL, it enables pushing additional UEs to under-utilized small cells in the UL solely. This improves the allocation of UEs between macro and small cells, allowing for improved resource usage and higher UL rates.

I. Data Set Collection

The data set produced by the QuaDRiGa simulator to a mixed sub-6GHz/mm wave is gathered, where it is assumed that five access points (AP) are outfitted with eight and sixty-four antenna arrays that operate at 2.6 GHz and 28GHz, respectively. The CPU gathers measurement reports at 2.6GHz and 28GHz that include the RSRP and K-factors with regard to five APs during its first activation. This measurement data is then labelled and designated as four classes as shown below.

- Class-1: DL and UL at 2.6GHz.
- Class-2: UL at 28 GHz with a best providing AP and DL at 2.6 GHz.
- Class-3: UL at 28 GHz with a best serving AP and DL at 28 GHz.
- Class-4: UL at 2.6 GHz and DL at 28 GHz.

The CPU then decisively stops measuring the mm wave bands and makes semi-blind decoupling choices, using the relevant K-factors and RSRPs as features to aid various machine learning algorithms in predicting the success rate of the decoupling process. As shown in Table I below, the sample data set, which consists of K-factors and RSRP for various cell areas, is divided into four groups.

TABLE I. DATA SET WITH K-RICIAN FACTORS AND RSRP VALUES FOR DIFFERENT CELL REGIONS

K1	K2	K3	K4	K5	P1	P2	P3	P4	P5	Class
28.3	21.42	45.2	7.6	11.77	−86.02	−108.73	−83.43	−112.55	−94.2	3
−93.2	−78.76	−89.51	−74.32	−89.50	−99.9	−146.72	−112.7	−148.93	−137.5	4
12.83	8.418	20.33	14.32	3.66	−106.85	−120.19	−97.73	−125.4	−115.82	2
−70.98	−101.78	−78.16	−95.61	−83.06	−125.75	−110.15	−98.3	−121.05	−115.61	1

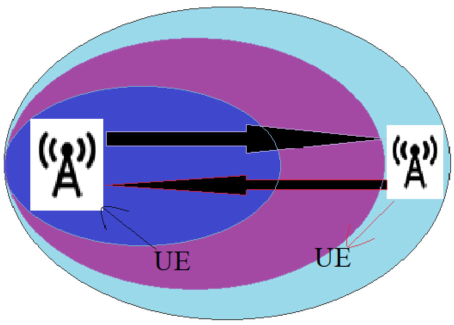

Figure 8. Proposed structure of decoupling of UL and DL with Massive MIMO base station.

J. Proposed Structure

The suggested topology is as followed in Fig. 8, and the base station for Massive MIMO is outfitted with an improved equalizer/detector [12] for detecting Massive MIMO signal.

In order to decouple UL and DL, two distinct Massive MIMO base stations will be needed for the proposed structure, as indicated in the suggested structure Fig. 9, and will each have a greater number of antennas that are responsible for interacting with K numbers of users to improve throughput and other services.

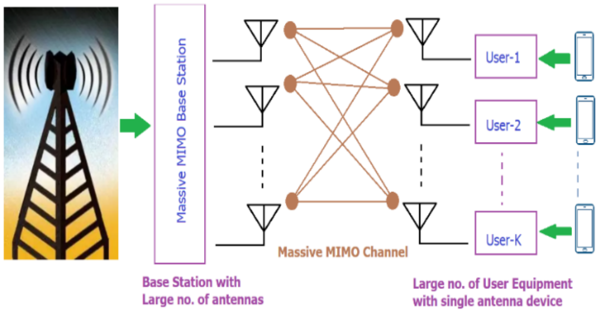

Figure 9. Massive MIMO base station.

IV. Result and Discussion

The Massive MIMO signal has to be identified at the receiver side with reduced computational complexity and interference, this may be done using Equalizers whose performance is measured in terms of bit-error rate and signal to noise ratio.

Here Considering Massive MIMO system with configuration of 2 antennas at base station and 2 antennas at user side and 4 antennas at base station and 4 antennas at user side utilizing available modulation methods that is BPSK and PAM for 1000 iterations. The same is performance assessments are represented by the Figs. 10-13.

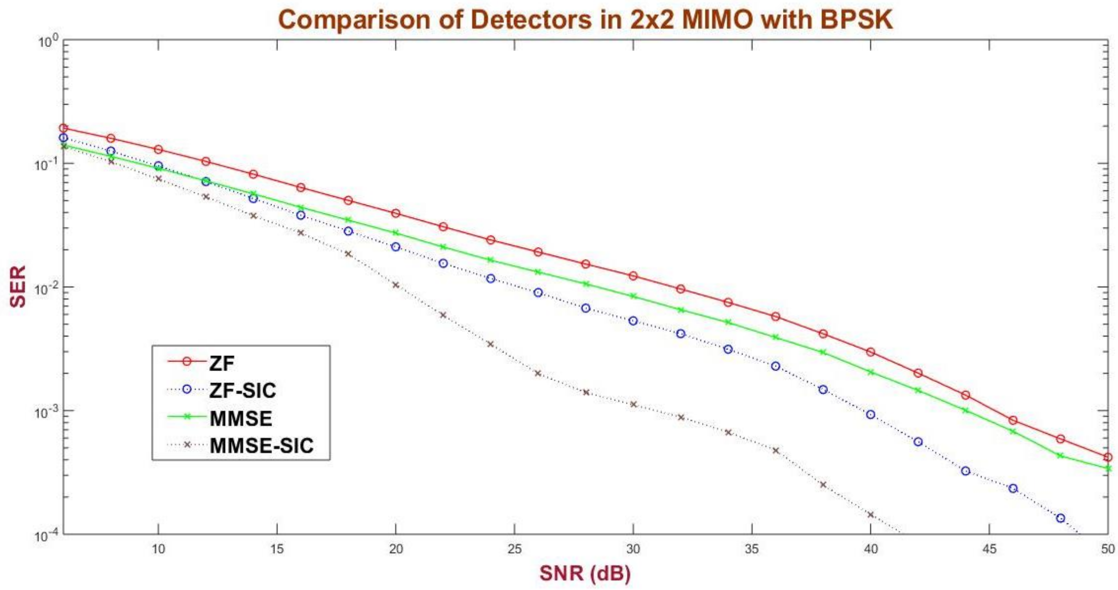

Figure 10. Comparison of various detectors with BPSK modulation of 2×2 MIMO system [6].

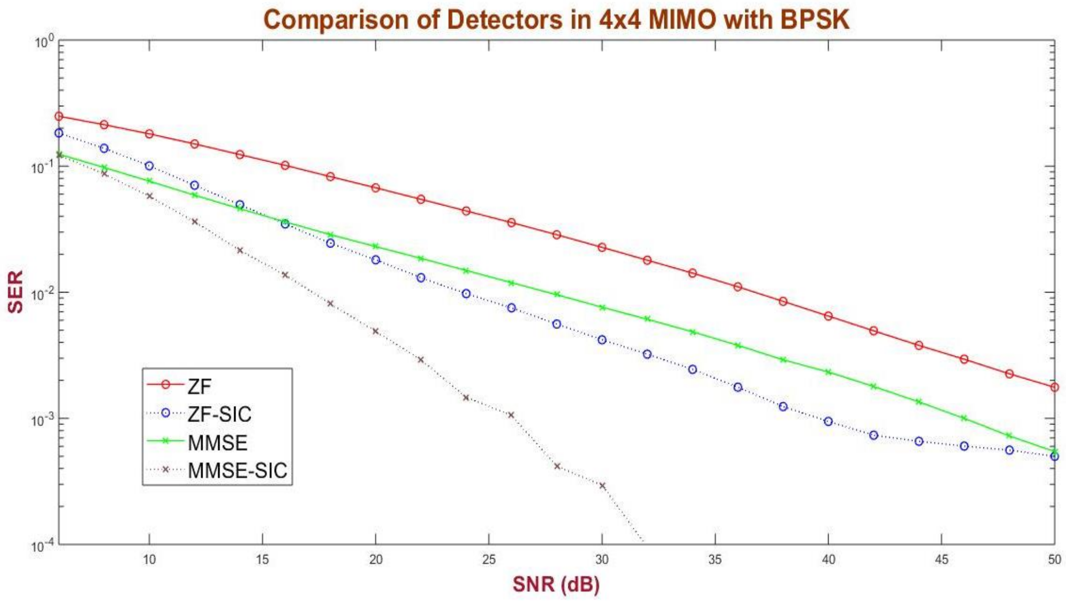

Figure 11. Comparison of various detectors with BPSK modulation of 4×4 MIMO system [6].

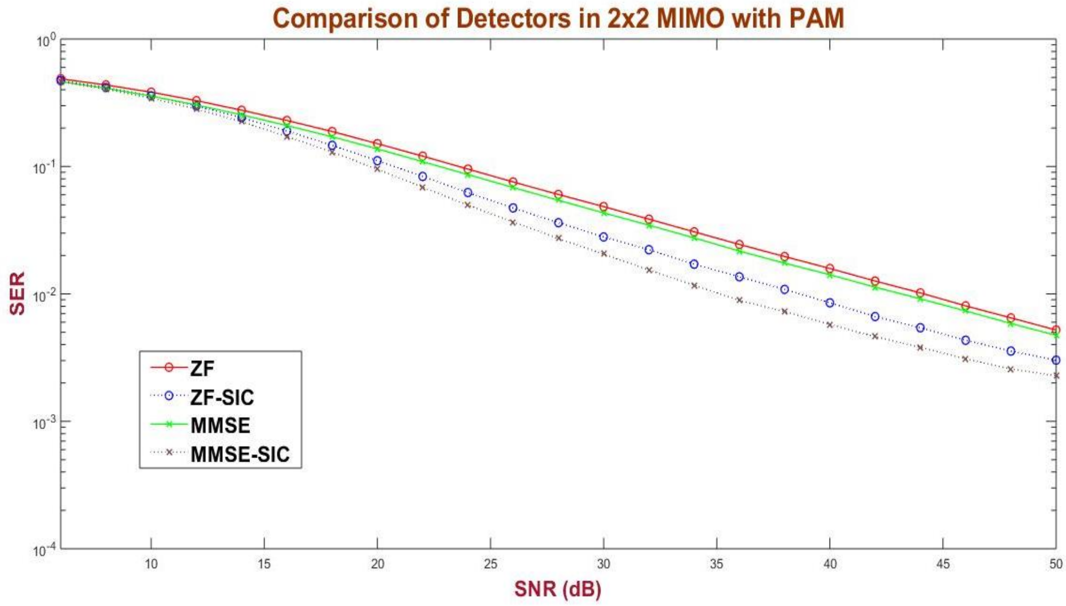

Figure 12. Comparison of various detectors with PAM modulation of 2×2 MIMO system [6].

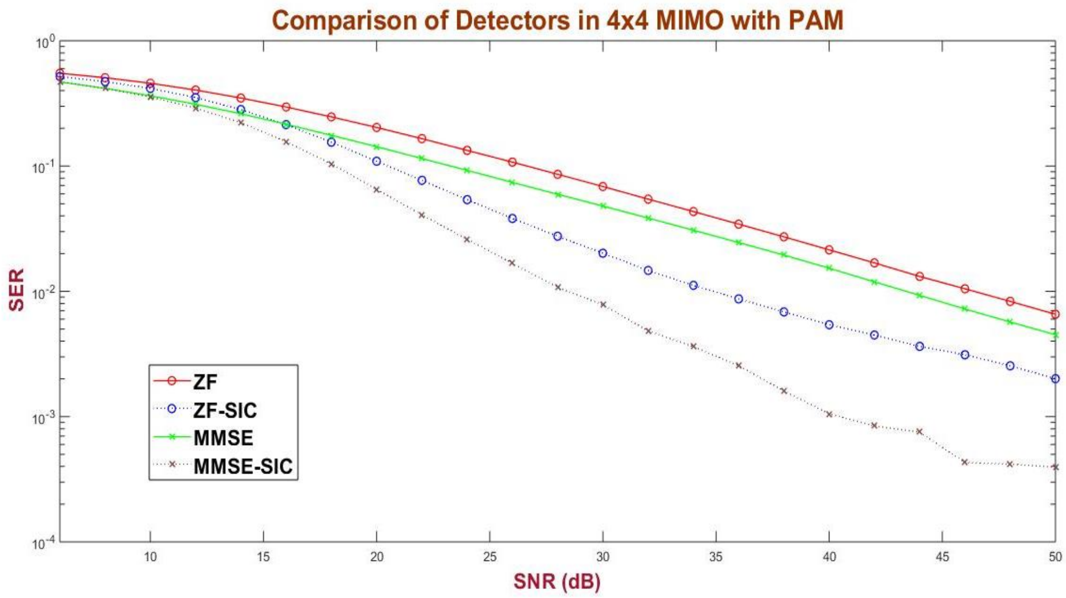

Figure 13. Comparison of various detectors with PAM modulation of 4×4 MIMO system [6].

The results of the simulation above demonstrate that the MMSE-SIC equalizer, which is used to detect signals, performs better with a lower bit error rate and a higher signal to noise ratio: as a result, this detector is used at the receiver side to detect signals with less complexity and interference.

To enhance the quality of services in 5G and future generations, the UL and DL have been dissociated using an adaptation of the MMSE-SIC equalizer. The dataset is gathered from the QuaDRiGa simulator and consists of measurements made using K-Rician and RSRP in two different frequency bands. For these measurements, a semi-blind decoupling algorithm is implemented in Python using a variety of machine learning (ML) and deep learning (DL) algorithms, and the accuracy scores of these algorithms are listed below.

TABLE II: PERFORMANCE ANALYSIS

Algorithm	Percentage of Accuracy
Naïve Bayes	69.57
Random forest	81.79
Decision tree	82.4
KNN	83.22
SVM	96.6
CNN	98.93(Avg.)

In Table II, it can be seen that the effectiveness of decoupling UL and DL by modifying the MMSE-SIC equalizer has been assessed by various ML and DL algorithms. It is found that Convolutional neural networks (CNN) achieve the highest decoupling success rate, with an average accuracy of 98.93% but a maximum accuracy of 99.83% for a small number of training samples.

V. Conclusion

In this study, the effectiveness of different Massive MIMO detectors is assessed with various modulation schemes, and it is found that MMSE-SIC is a better Massive MIMO detector with lower BER, so it is used at the receiver side in the decoupling of UL and DL. Additionally, different Machine Learning and Deep learning algorithms, such as Naïve Bayes classifier, Random Forest, K-nearest neighbors, Decision tree, Support vector machine, and Convolutional neural networks, are used to enable semi-blind decoupling. The proposed scheme achieves 98.93% accuracy on average for the CNN algorithm, which is highest among all algorithms, but for a small number of training samples, the accuracy achieved by CNN is 99.83%. Therefore, through CNN, fast and reliable decoupling of UL and DL is achieved in 5G networks and beyond.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

R. Padmasree developed the idea on design and development of decoupling of 5g by adapting equalizers. Rajendra Naik mentored in design and simulation of the proposed technique. Further, the authors discussed in detail simulation, comparative analysis and results contributing towards this final manuscript; all authors had approved the final version.

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