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Spatial Multiplexing and Hybrid Beamforming Design For 5G Wireless System

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Abstract: The current 5G network needs to achieve a considerably larger link capacity and ultra-low latency to enhance mobile broadband and support emerging mobile applications and massive IoT. Thus, implementing MIMO-OFDM Spatial Multiplexing and Hybrid Beamforming techniques helped increase the information capacity using multiple transmit and receive antennas. At the same time, these can improve the Signal to Noise Ratio (SNR), reducing the interference that leads to lower latency. The whole system comprises four models, namely the antenna array, channel model, spatial multiplexing, and hybrid beamforming. They were designed and simulated using the MATLAB software, and each output produced in the previous model is being utilized in simulating the next one following a parallel design process. An antenna array was first modeled and was used for the subsequent channel model process. The outputs from these two are then used to simulate spatial multiplexing and hybrid beamforming. The results of each model were discussed and analyzed concluding that both transmission techniques are efficient tools for achieving the goals of the emerging 5G mobile technology. It provides a solution to the current difficulties being encountered by the 4G technology.

Keywords: 5G, MIMO, OFDM, Spatial Multiplexing, Hybrid Beamforming

1. Introduction and Overview

Over the years, wireless technologies have rapidly evolved from the second-generation cellular network (2G) to the fourth-generation long-term evolution (LTE) system. The telecommunication providers' deployment of the fifth-generation (5G) networks started in 2018 in response to the increasing consumer demands [1]. Today, it is expected to contribute to the progress of wireless systems by providing benefits such as faster data transmission speed, larger link capacity, ultra-low latency, as well as faster connectivity concerning the Internet of Things (IoT), as well as the machine-to-machine (M2M) applications [2]. Furthermore, the development and deployment of new network technologies are why 5G should coincide with its predecessors. With the increase of wireless mobile devices and services, several issues, such as crowded spectrum and excessive energy consumption, remain unaccommodated even by the current 4G wireless system. A world unbounded from restrictions and impediments of the preceding generations is the primary goal of the fifth generation (5G) which will change the approach to how end-users access their mobile communication devices. Its various advantages include lower energy utilization, compound transmission paths, and lower chances of downtime or interruption. It also provides higher security, a higher spectral efficiency level, and lower traffic costs caused by inexpensive infrastructure deployment [3], [1], [4], [5], [6].

With the rise of new technologies comes the emergence of smart city applications, connected homes, wearable devices with artificial intelligence (AI) capabilities, and sensors generating the internet of things (IoT) environment. These are among the primary services offered and developed for the 21st century. The 5G wireless system is the foundation of IoT application access technology, and it is capable of handling exceptionally high capacity, bandwidth, reliability, and latency. It encompasses a variety of technological breakthroughs that are both innovative and disruptive. Improvements in spectrum efficiency, access scheme evolution, carrier aggregation, and antenna methods are examples of radio and antenna system improvements. Dynamic spectrum sharing and wavelength spectrum in the millimeter and centimeter wave bands will be employed instead of the usual static allocation system. 5G network progression includes streamlined design, flexible duplex method, versatile resource management, small base stations, and coordinated multipoint and heterogeneous connectivity [4].

At present, the 5G network that we have is still under further development and still needs to achieve a considerably large amount of link capacity along with ultra-low latency. These things can be achieved by utilizing the hybrid beamforming and spatial multiplexing techniques. Hybrid beamforming technique usually incurs a cheaper cost but gives results and performance on par with the

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digital beamforming technique [7]. Spatial multiplexing, on the other hand, will provide larger information capacity by utilizing multiple-input multiple-output (MIMO) technology that will allow both transmission and reception of multiple data [8]. Consequently, hybrid beamforming is the preferred approach in assisting spatial multiplexing having considerably few radio frequency (RF) chains as it will incur cheaper cost and increased efficiency. This is due to the reason that hybrid beamforming is able to support multiple data stream transmission which is what spatial multiplexing essentially offers. Aside from being comparably on par with digital beamforming, it also has a much simpler hardware intricacy [9].

Moving forward, the first 5G technology live demonstration in the Philippines, with data speeds of up to 20 gigabit/second, was introduced by Ericsson as they marked their 30th anniversary in the country. This marks and reaffirms the commitment to bringing the newest technological advances to the Philippines and establishing the 5G ecosystem to support a "digital Philippines." Additionally, the country has a promising future as telecommunications providers have an estimated income opportunity of 1.8 billion US dollars in 2026 to address industry digitalization utilizing and maximizing the 5G technology [5].

In line with this, the study focused on designing a 5G wireless system using spatial multiplexing and hybrid beamforming transmission techniques by utilizing the MATLAB® and Simulink® software. It is significant for the development of the emerging 5G wireless technology as it brings a lower cost, an energy-efficient, a high information capacity, and a much lower latency network that will bring satisfaction and convenience to the end users.

2. Literature Review

This section presents some previous articles that discusses the different techniques in 5G in the past years.

A. 5G Mobile Antennas: MIMO Implementation [10]

In the article by Gholb and Idrissi [10] it was stated that phased array technologies and massive MIMO can produce networks with expanded data throughput and immense data integrity through spatial multiplexing, path diversity, and beam steering and beamforming methods. They also discussed some antenna array challenges and solutions for overcoming path loss in mmWave frequencies, as well as how it can improve security by allowing users to direct narrow beams at specific targets. In multiple antenna systems used for diversity and MIMO, good isolation and a low envelope correlation coefficient are critical for achieving good overall performance. Consequently, the aforementioned systems, techniques, and simulation are used in this paper to improve the design of Spatial Multiplexing and Hybrid Beamforming for 5G Wireless System Network.

B. Study of Distributed Phased Array Antenna Array Spacing for 5G User Equipment [11]

The study by Sun *et al.* [11] focuses on designing a distributed phased-array (DPA) which is based on microstrip antennas for the UE. The design of DPA proposes modern design variables such as phased arrays' spacing, mutual coupling, feeding systems' mismatches, and edge diffraction. Moreover, the characteristics of antenna arrays and array spacing (AS) were introduced as relevant model parameters in DPA. Additionally, to examine AS-induced impacts on overall DPA performance as classified by CE, a hybrid far-field radiation model was also established in this research. Throughout the analysis, specific ranges of AS resulted in an improved performance. Consequently, the CE of the 2-layer DPA was considered, and it was found out that about 95 percent or higher CE can be obtained if the least requisite gain is lower than or close to 8 dB. Lastly, in their study, they used Ansys HFSS and MATLAB. The Ansys HFSS software was used for the hybrid model to provide a good approximation for the simulation, excluding the hemisphere under the ground plane. In addition, the hybrid model was developed in MATLAB and simulated a far-field pattern utilizing the evaluated AF and the microstrip antenna element far-field from Ansys HFSS. This study presented design variables for antenna arrays, and the results of this study were obtained using Ansys HFSS and MATLAB software. It's relevant to this study since it provides antenna characteristics and uses MATLAB software to provide more exact antenna array findings.

C. Ray tracing simulations for millimeter wave propagation in 5G wireless communications [12]

The study conducted by Hsiao *et al.* [12] discussed an outdoor ray tracing method which is applied in predicting wave propagations in wireless communications, specifically in the currently emerging 5G wireless technology. However, this method is crucial for computing efficiency since a large number of rays is tracked. The first simulation used 28-GHz and 38-GHz mmWave frequencies and it was utilized in a 200 m street in Taipei City, Taiwan for conducting field measurements and ray tracing simulations. Two isotropic antennas were used and only line of sight (LOS) propagations were considered. Another ray tracing simulation was performed for an urban city with 81 buildings having five transmitting antennas (Tx) and a single receiver antenna (Rx). A digital map was shown and the graphs of its simulation results were also presented. It also explained the comparison of the penetration loss and attenuation caused by brick walls and glasses. The use of a user-centered and cross-linked 5G wireless system was offered in this study as a solution in decreasing the penetration loss. However, more research studies regarding this mentioned solution must be done. This study presented urban environment ray tracing simulations and field measurements using mmWave frequencies in Taiwan. Since the present study will be utilizing the mentioned urban environment ray tracing method, it is beneficial as it can serve as a basis or guide in developing the channel model.

D. Development of spatial channel model and extended spatial channel model for MIMO applications [13]

Another channel model was discussed in the works of Hegde and Geetha [13]. It was explained that the spatial channel model was distinguished in accordance with the three radio propagation environments namely suburban macro environment, urban micro environment, and urban micro environment. In the suburban macro environment, it mainly describes a surrounding environment with residential buildings and structures. It may be rural, having vegetation and hills around the area where macrocells are utilized. On the other hand, urban macro environments use large cells since moderate height urban buildings exist, thus, scatterings may exist. With this, base station antennas are positioned at high elevations. Lastly, the urban micro environment uses small cells having approximately 1km distances. Its base antennas are usually located on rooftops. Since micro cells are implemented, line-of-sight (LOS) components or scenarios may or may not be considered. With this, a ray based approach is implemented for developing the spatial channel model wherein reflections and scatterings are considered in designing it. Furthermore, spatial channel modeling parameters were enumerated and discussed thoroughly. Among the mentioned parameters are angles of arrival and departure, path delay and powers, shadow fading, angle and delay spread, and fast fading coefficients. The authors explained the modeling of these parameters which are used in spatial channel model development. This study discussed radio propagation environments and parameters as well as positioning of base stations and/or antennas. It delivered some relevant information that will be used in the current study for determining the needed parameters of the channel model and specifying locations of base stations and/or antennas.

E. *Performance Analysis of Mutual Information Distribution in a Multiuser Based Environment Using OFDM Spatial Multiplexing [14]*

The study of Ranjani and Bhaskar [14] highlighted the the concepts behind the Orthogonal Frequency Division Multiplexing (OFDM). It was stated that this technique is being used in applications where high data rates are required. Moreover, it was mentioned that OFDM systems are immune to delay spread and frequency-selective fading, and it features high spectral fading and efficiency. MIMO technique was also incorporated in this study wherein it was said that this technique is a great way of enhancing the capacity of wireless networks and systems. This study also presented and discussed the system model with a block diagram of a MIMO-OFDM system using spatial multiplexing which showed the different parameters that need to be defined which play important roles in its process. Subsequently, the expression being used for measuring a system's capacity was also presented which is known as the Shannon's capacity. This study presented the incorporation of OFDM with MIMO technique along with spatial multiplexing. It also introduced the use of Guard Time Insertions to avoid ISI. It is relevant and since the current study will also be employing the same MIMO-OFDM system in the multiplexing process.

F. *Implementation of MIMO-OFDM System for WiMAX [15]*

The study of Gulzar *et al.* [15] discussed the basic principles of OFDM, and here, a diagram of an OFDM system using FFT and IFFT were also presented. This block diagram consists of channel coding/interleaving, QAM modulation, OFDM modulation (IFFT), Guard Interval/Cyclic Prefix windowing (GI/CP), D/A, up conversion, multipath fading channel, down conversion, A/D, Guard Interval/Cyclic, Prefix removal (GI/CP), OFDM modulation (FFT), QAM demodulation, and decoding/deinterleaving. These are the key processes that are involved in both the transmission and reception of data in an OFDM system. In the transmitter side, the input which is a binary data will be transmitted and each parallel branch in the system will do the same. The parallel bit streams will undergo channel coding/interleaving and modulation before the signals are modulated through the IFFT into an OFDM symbol sequence. Then, a GI or CP will be integrated into each OFDM symbol that was created before being converted into RF components through D/A conversion that will be utilized in the transmission. As for the receiver side, the symbols received from the RF component will be first aligned and synchronized using A/D conversion before the added GI/CP are removed. After this, the extracted OFDM symbols will be demodulated through FFT in preparation for decoding/deinterleaving, so that after combining, the original binary data will be recovered. This study tackled the use of IFFT and FFT in an OFDM system to convert signals from time domain to frequency domain and vice versa. It is valuable since the present study will be implementing the same conversion techniques for the transmission and reception process.

G. *Large MIMO systems and Hybrid Beamforming in 5G or Future communication [16]*

The study of Jaoussi and Haddi [16] discussed the process and concept behind the transmission and reception of data in a MIMO-OFDM system. In the study, a scattering-based spatial channel model was used in consideration of various locations for transmission and reception, as well as antenna patterns. Likewise, a channel sounding model was presented which is composed of a preamble, massive MIMO channel, OFDM demodulation, massive MIMO channel estimate and feedback. Full-channel sounding was utilized in the study to identify the channel state information of the transmitter. Moreover, it was said that the precoding could maximize the energy of the signal in the channel when there is an available channel information regarding the transmitter. In the channel sounding process, a reference transmission was utilized to be able to perform channel estimation before calculating the precoding required for the transmission of data. Then, in the process of data transmission, it consists of channel coding, mapping, OFDM modulation, and precoding. Each data stream is mapped from individual users going to an individual RF chain. Next is the signal propagation wherein interference, losses, and noise are added to the system. The signal will then be received and amplified before being recovered. Lastly, in the process of signal reception at the receiver, it consists of OFDM demodulation, massive MIMO equalization, de-mapping and channel decoding.

In addition, it also discussed hybrid beamforming as a relevant solution for massive MIMO that utilized high data rates as a requirement of the 5G wireless communication. The study focused on the improvement techniques of the 5G communication, large MIMO, and beamforming. Consequently, as 5G offers high data rates

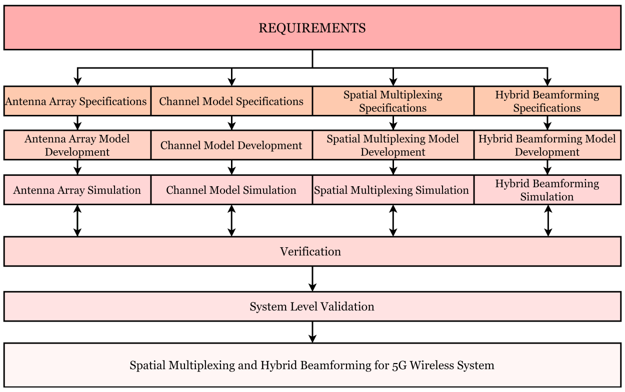

Figure 1. Parallel Design Process

and large bandwidth it still has its own drawbacks that suffer from short wavelength or shorter range. That is the reason why large MIMO systems are considered to perform beamforming. As a result, the ability of large MIMO channel technology demonstrates that adding the amount of antennas for transmitting and receiving enhances the capacity of wireless communication link. Furthermore, the large antenna array performs beamforming in order to obtain large antenna gains, which helps to reduce interference and increase link capacity.

H. Hybrid Precoding Design in Millimeter Wave MIMO Systems: An Alternating Minimization Approach [17]

The study conducted by Yu *et al.* [17] showed a method to improve mmWave MIMO systems' hybrid precoding design by applying a fully connected with higher efficiency for spectral. This strategy turns out to be used in one of the techniques that will improve the 5G wireless network, which is the hybrid beamforming method included in the Capstone Project. Similarly, fully connected structures seek to improve spectral efficiency in order to avoid poor system performance. Simultaneously, the growth in spectral efficiency will aid in the development of energy efficiency. Resulting to a higher achievable spectral efficiency and the better system's performance.

3. Design Process

The specific method and process utilized in the study is the parallel design process shown in Fig. 1 which depicts a parallel flow of process. This denotes that sub-processes may occur simultaneously when they are in parallel in the process of producing the output. The study has four important models to form the proposed design namely the Antenna Array, Channel Model, Spatial Multiplexing and Hybrid Beamforming. As can be seen in figure, they occur in parallel, and eventually, the outputs were collaboratively used to achieve the desired result. Fig. 1 shows the step-by-step process that the proponents utilized to obtain the specific objectives of the study. It comprises six stages: requirements, specifications, development, simulation, verification, and system level validation.

A. Design Requirements

The primary software for designing and simulating the 5G wireless system using spatial multiplexing and hybrid beamforming is the MathWorks MATLAB and Simulink.

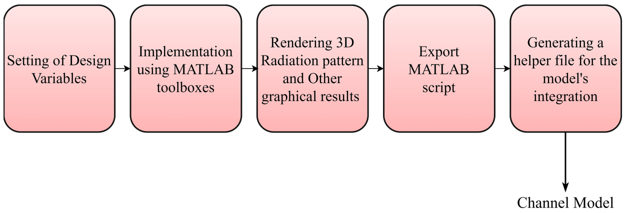

Figure 2. Antenna Array Modeling Process

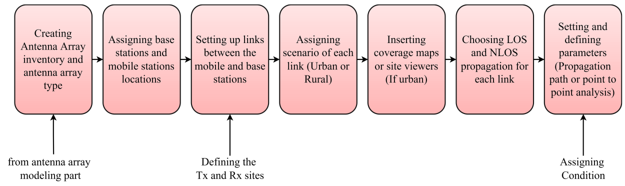

Figure 3. Channel Modeling Process

Moreover, the most critical and significant requirements needed for the design is the frequency to be used, the location of the transmitter and receiver sites, and the base station and its network coverage to be utilized in the design.

B. Antenna Array Model

The purpose of the antenna array in the system is to provide visualization of the antenna in the chosen location of transmitter sites. Referring to Fig. 2, the design of an antenna array begins with identifying the parameters to be used and setting them in the sensor array analyzer application. In the application, array geometry, grid formation, and element type are utilized to process the different representations to analyze the properties of the antenna array. The azimuth cut, elevation cut, and 3D radiation pattern are the following derived from the values collected. After plots are interpreted and confirmed using the antenna array characteristics from the MATLAB simulation, the data is ready to be exported into a script file. All the information obtained was used as data to create a helper file required for the Channel model simulation.

C. Channel Model

Channel models are representations that show the propagation effects of the signals across the medium or the communication channel as well as its system performance. The channel model design, shown in Fig. 3 started with the created antenna array design from the previous model. It is followed by defining the location of the transmitter and receiver sites by its longitudes and latitudes. Then, assign a scenario, which is an urban environment. Coverage maps were included, and both line-of-sight (LOS) and non-line-of-sight (NLOS) links were considered. Lastly, setting and defining other parameters, such as assigning different types of conditions, took place.

D. Spatial Multiplexing

As per the spatial multiplexing process, shown in Fig. 4, the data bits were encoded and mapped before they underwent precoding involving channel sounding. In channel sounding, the preamble signal was sent to the MIMO channel before it was refined at the receiver, and OFDM demodulation and channel estimation took

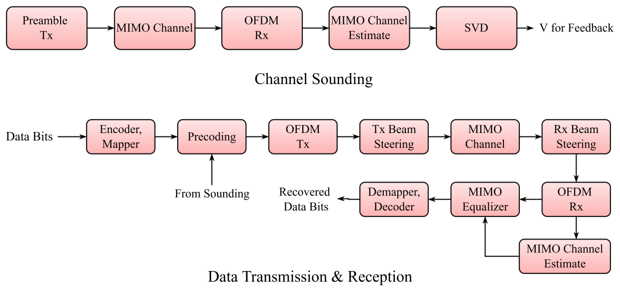

Figure 4. Spatial Multiplexing Process

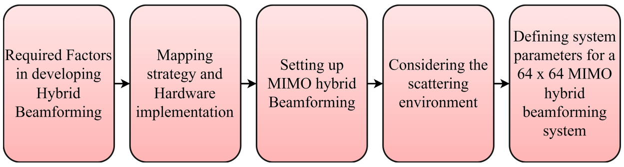

Figure 5. Hybrid Beamforming Process

place along with feedback calculation depending on the diagonalization of the channel through singular value decomposition (SVD). After this, the signal went through OFDM modulation, where the Inverse Fast Fourier Transform (IFFT) technique was used to convert the signal in the frequency domain to the time domain before being subjected to transmit beam steering, where the propagated signal was steered towards the direction of the receiver. Moving forward, propagation of the signal occurred through the MIMO channel before the signal underwent receive beam steering, where the incident signal was directed towards the transmitter. Moreover, the final part is signal recovery, where the received signal containing the symbols and bits was decoded to verify the success of the whole transmission and reception process. The Fast Fourier Transform (FFT) technique was also utilized to convert the signal in the time domain back to its corresponding frequency domain.

E. Hybrid Beamforming

To design a hybrid beamforming transmission technique, which is shown in Fig. 5, the necessary factors must first be considered, which are balancing cost and performance. It became the basis for selecting a mapping strategy and implementing the hardware. This design used a double phase shifter fully connected method to meet system performance while guaranteeing the cost of the hardware components. After conceptualizing the factors and implementation, the next stage was to set up MIMO hybrid beamforming according to the mapping strategy and hardware implementation employed. Furthermore, the scattering environment must be identified in order to compute the path gain for each scatterer, as this may interfere with the system process. Then after that, the system parameters will be analyzed and assessed to develop a 64×64 MIMO hybrid beamforming system.

4. Results and Verification

A. Design Requirements

This section presents the significant requirements needed in designing the 5G wireless system.

1) Frequency

The frequency range was based on Smart Communication Incorporation's 5G trial frequency range which is 3.4 GHz to 3.6 GHz. Hence, the frequency used in the design is 3.6 GHz since it is the highest frequency range available in the country.

2) Location of Transmitter and Receiver Sites

This project was made to design a fifth-generation (5G) wireless communication system that aims to increase users' capacity to experience fewer problems in the network traffic. Hence, the design was implemented in an urban area to be able to have a trial in a high population density location. Makati City, located at the center of the National Capital Region (NCR), was the chosen location as it has a total population of 629, 616 residents as of May 2020 [18]. It is also considered as a smart city as the installation of signal boosters, and their Makatizen Card was a technological development as it was used for online payments, e-currency, and access to the services of the government. Smart Communications' first 5G "standalone" network was launched in the said city.

3) Base Station and Network Coverage

As this project's scope is to be implemented in an urban area to test the goal of having an increased network capacity, it can be implemented by using smaller cell sizes. However, these cell sizes are not recommended to be used in urban and outdoor environments.

According to [13], a channel model can be distinguished between three radio propagation environments, suburban macro-environment, urban macro environment, and urban microenvironment. Among these three, the urban macro-environment used large cell sizes in urban environments having moderate heights. Thus, the project utilized the use of a macrocell base station for the 5G wireless system.

A macro cell base station, according to the ITU-R Recommendation M.1305 [19], has a large cell radius or network coverage of less than or equal to 35 kilometers. It is usually installed or placed at high elevations, usually on top of buildings or towers so that there will only be moderate building blockage. Moreover, aside from having a low to medium traffic density, it also supports narrowband services and moderate mobile station speeds.

B. Antenna Array Model

Elements with 1/2 lambda spacing and a Chebyshev tapering method with 30-dB sidelobe attenuation is used in subarray geometry (Fig. 6). For the grid information, it was set as a rectangular ULA with 1 by 8 elements and 1/2 lambda spacing. The element selection is set into an isotropic antenna with a propagation speed of 3×10^8 m/s and a signal frequency of 3.6 GHz.

Fig. 7, depicts the outcome of a 3D radiation pattern that demonstrates how the antenna distributes its energy in space that was based on the parameters set. The array characteristics are shown in Table I, and the design achieved the proposed directivity values of 15-20 dBi. The antenna array model has a directivity of 18.46 dBi, which is good considering the design uses the 3.6 GHz frequency spectrum for 5G systems.

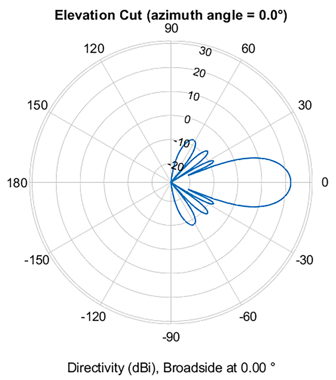

Figure 6. Elevation Cut

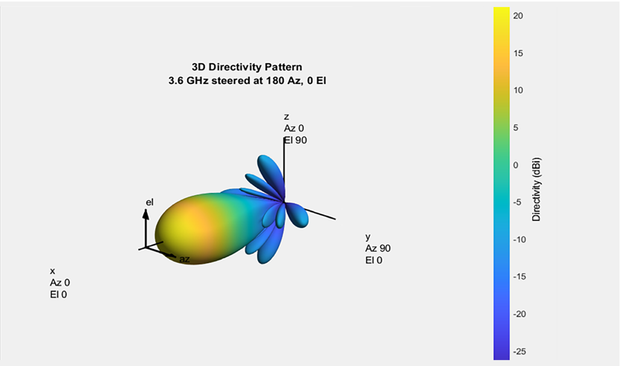

Figure 7. 3D Directivity Pattern

C. Channel Model

This design utilized two channel models, the ray tracing channel model, and the spatial channel model. Ray tracing channel model is used for the visualization of the outdoor and urban propagation of the signals as it specifies the exact location of the transmitter and receiver sites. On the other hand, the spatial channel model was used for the simulation of the spatial multiplexing transmission technique.

1) Ray Tracing Channel Model

Simulation of the channel model resulted in different signal strengths as five conditions were done: single reflection, perfect reflection, the effect of material, which is concrete, weather loss, and beam steering. As shown in the table, each condition affects the signal, indicating that it can strengthen or weaken its power.

It can be seen from the results in Table II that the lowest received power came from the simulation with a single reflection. Since they also tried simulating the propagation paths of the signals with perfect reflection, as shown above, that the signal strength became stronger.

TABLE I. Array Characteristics

Array Directivity	18.46 dBi at 180 Az; 0 El
Array Span	x=0m ; y=291.67mm; z=291.67
Number of Elements	64
HPBW	16.42° Az/ 18.00 ° El
FNBW	44.87° Az/ 44..00 ° El
SLL	30.00 dB Az/ 30.01 dB El

TABLE II. List of the simulated signal strengths (dBm)

Transmitter 1			
Receiver	**1**	**2**	**3**
Single Reflection	-59.1	-56.4	-63.4
Perfect Reflection	-53.0782	-53.3847	-60.3444
Effect of Material (Concrete)	-55.0340	-54.9059	-61.2726
Weather Loss	-55.0506	-54.9186	-61.2962
Beam Steering	-36.0072	-45.5247	-71.7359
Transmitter 2			
Receiver	**4**	**5**	**6**
Single Reflection	-	-69	-70.7
Perfect Reflection	-64.7106	-64.1984	-67.7106
Effect of Material (Concrete)	-64.7106	-64.9167	-68.1151
Weather Loss	-64.7370	-64.9555	-68.1610
Beam Steering	-44.2998	-48.1554	-55.6366

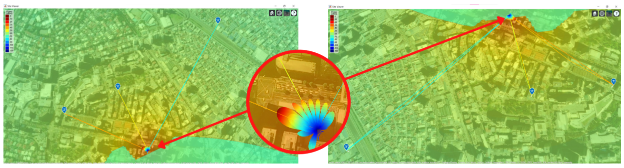

Figure 8. Beamsteering in Transmitter 1

However, it can be seen in the simulation of the use of realistic material, which is concrete. The results showed an approximately 1 dB of power loss compared to the previous simulation. Moreover, they also included simulation with weather conditions to show the effect of rain and gas to the signals, and it showed another loss in the signal strength.

Lastly, when beam steering was applied, as shown in Fig. 8 and Fig. 9, the signal strengths increased since the antenna's beam is now directly pointing to its respective antennas. It results in beam steering being an essential factor in the simulation since it positively affects the signal strength. The closer the number to 0, the better the signal is, thus, better data transmission.

2) Spatial Channel Model

The spatial channel model was designed to be used in the propagation subprocess of spatial multiplexing. Its important parameter is the scatterers, as it may affect or disrupt the propagation of the signals from the transmitter to its receiver. These scatterers reflect the transmitted signals to the receivers, thus, may cause signal interruption such as attenuation. The number of scatterers was simulated from the number of single-reflected propagation paths from the ray tracing channel model.

Fig. 10 exhibits the simulated scatterers from the simulated reflection paths from Transmitter 1 to its respective receivers. One scatterer was allotted for a single reflection

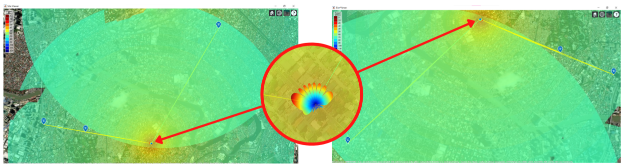

Figure 9. Beamsteering in Transmitter 2

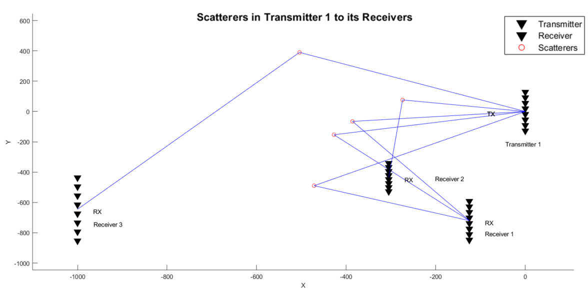

Figure 10. Scatterers in Transmitter 1

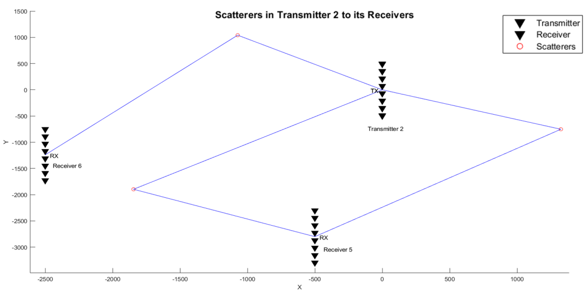

Figure 11. Scatterers in Transmitter 2

path resulting in the said figure. Three single reflection paths were simulated from Transmitter 1 to Receiver 1, thus, resulting in three scatterers. On the other hand, both Transmitter 1 to Receivers 2 and 3 resulted in a single reflection path each. Hence, a single scatterer each was shown.

On the other hand, Fig. 11 shows the simulated scatterers from the Transmitter 2 to Receivers 4, 5, and 6. A single scatterer is present in a single reflection path. There is no reflection path in the transmission from Transmitter 2 to Receiver 4; hence, there is no path with a scatterer shown in the mentioned figure. The transmission from Transmitter 2 to Receiver 5, on the other hand, had gained two single reflection paths exhibiting two scatterers each path. Lastly, one scatterer exists on the transmission path from Transmitter 2 to Receiver 6 since a single reflection path occurred.

D. Spatial Multiplexing

Spatial multiplexing provided multiple independent data streams between the transmitter and the receiver antennas, which created multiple subchannels in a scatterer-rich environment that allowed independent transmission and reception of multiple data streams. The figures shown are the results obtained from the simulation conducted using MATLAB. The signal above Fig. 12 is the modulated signal at the transmitter, and below is its corresponding steered signal. As can be noticed, the signal became more closely packed after being steered, which suggests that there was an improvement in the transmission.

Additionally, the division between the two (2) signals became more evident. This slightly noticeable division signifies and implies that the two signals are traveling simultaneously and independently along its respective

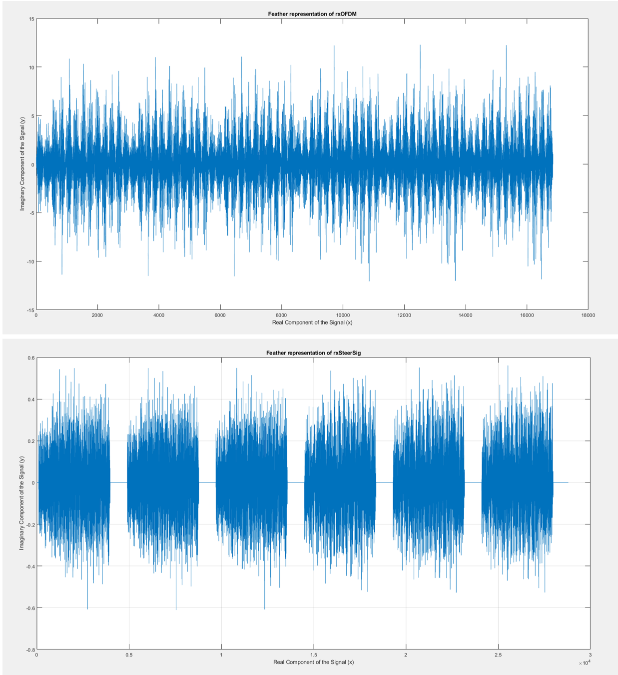

Figure 12. 2D representation of txOFDM and txSteerSig

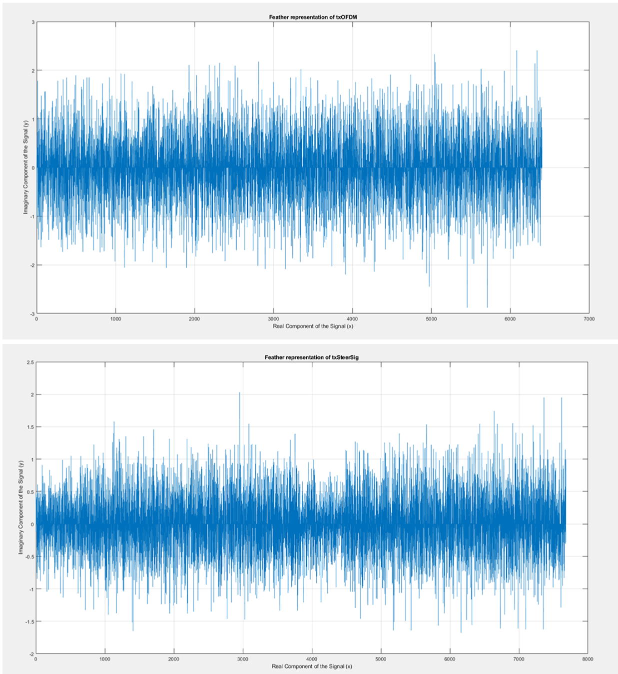

Figure 13. 2D representation of rxOFDM and rxSteerSig

data streams. Likewise, the same thing can be observed in Fig. 13, the demodulated signal at the receiver; however, this time, there are six signals that were simultaneously and independently received at the receiver. Hence, the concept and purpose of spatial multiplexing were clearly shown and demonstrated.

Furthermore, Fig. 14 is the Channel State Information (CSI) visual representation. Here, two channels can be observed that represent each transmitter. Based on the plot, it can be said that the signal in transmitter 1 has

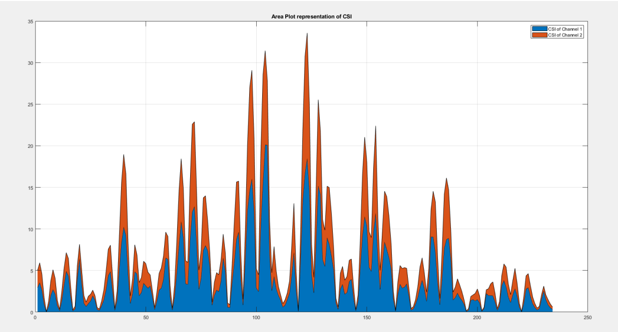

Figure 14. Channel State Information (CSI)

```
>> MIMOOFDMSpatialMultiplexing
BER = 0.00000; No. of Bits = 6234; No. of errors = 0
```

Figure 15. BER Result

higher signal characteristics compared to the other one. With the application of CSI prior to decoding, the system was able to have an increased capacity which is implied through the BER result shown in Fig. 15. This is since CSI helps increase the capacity of a system by improving the system's performance in terms of BER, and since the BER obtained was very low, equal to zero, it is a clear indication that the system has an excellent performance, implying an increased capacity. Moving forward, the next two figures shown in Fig. 16 are the mapped and received symbols. It is very evident that these two are identical, thereby signifying a successful transmission and reception of signals.

Finally, Fig. 17 is the constellation diagram plot of the received equalized symbols embedded within the signal, which is followed by the BER result that is very low, equal to zero (0), suggesting an excellent and ideal Spatial Multiplexing data transmission and reception, and thereby, implying an increased system capacity.

E. Hybrid Beamforming

1) Hybrid Weights Comparison

The beam patterns and spectral efficiency comparison were the results of the MATLAB code simulation for hybrid beamforming. The results for the first simulation were shown, which are the beam patterns generated from the hybrid weight calculation. The first figure, Fig. 18, represents the optimal weights obtained by diagonalizing the channel matrix and extracting the initial number of transmitting dominant antenna modes. The response pattern here demonstrates only a few dominant directions, even in a multipath environment. While Fig. 19 shows the beam pattern of the hybrid weights, which is closely similar to the beam pattern obtained using the optimal weights, especially for dominant beams. This means that by utilizing hybrid weights, data streams can be successfully transferred through those beams.

2) Spectral Efficiency

Fig. 20 compares the spectral efficiency obtained with optimal and hybrid weights. The simulation contains two data streams, and the signal can stream in from any direction. For each SNR, 50 Monte-Carlo trials are used

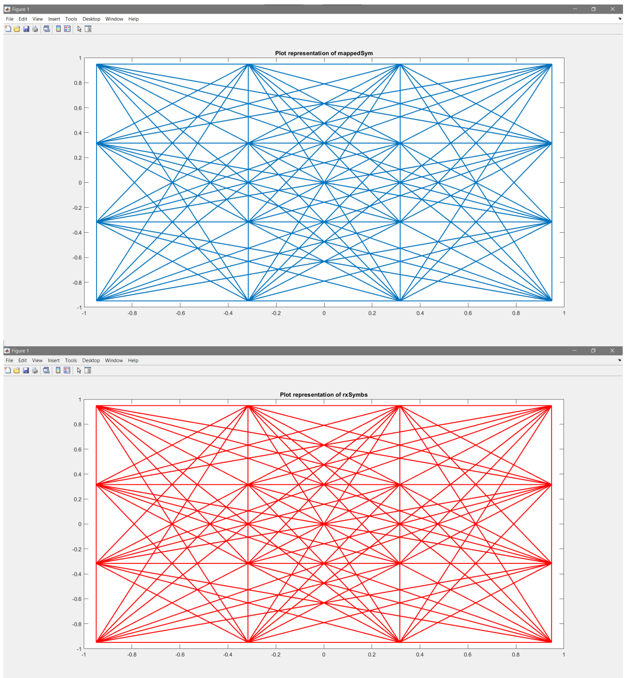

Figure 16. Mapped Symbols (mappedSym) and Received Symbols(rxSymbs)

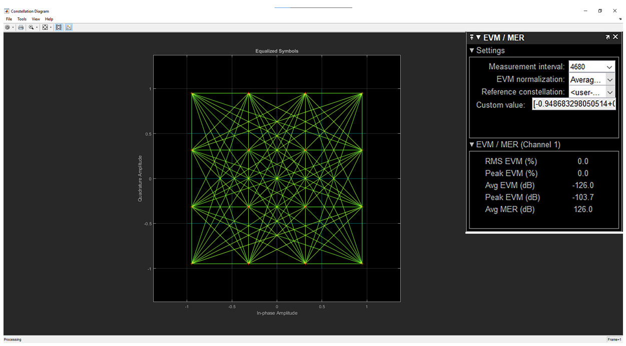

Figure 17. Received Symbols Constellation Diagram

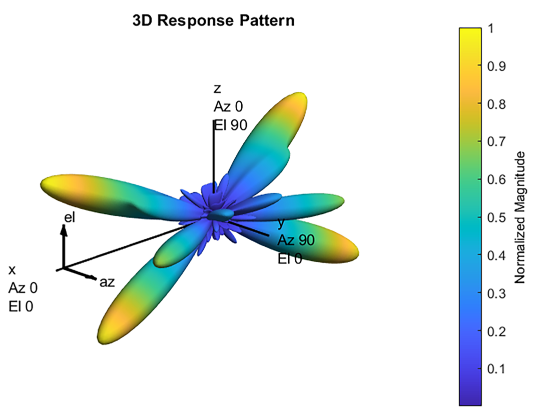

Figure 18. Beam Pattern using Antenna Optimal Weights (Full Digital)

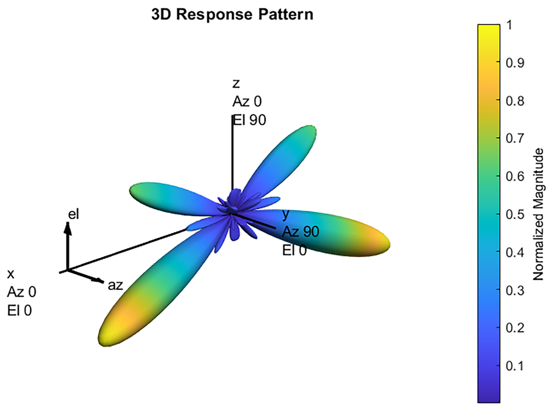

Figure 19. Beam Pattern using Antenna Hybrid Weights

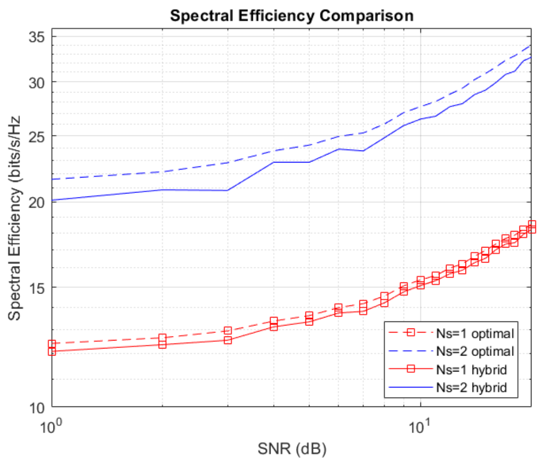

Figure 20. Spectral Efficiency Comparison

to generate the resulting spectral efficiency curve. This graph indicates that when the SNR decreases, the spectral efficiency increases, achieving the goal of utilizing hybrid beamforming. Additionally, hybrid beamforming can achieve optimal weight performance using fewer hardware components.

3) Simulink Model

Fig. 21 shows the Simulink model of the study. The MIMO transmitter generated the signal streams, which were then precoded, partly in baseband and partly in the RF band. The modulated signal was then transmitted via a scattering channel configured in the MIMO channel,

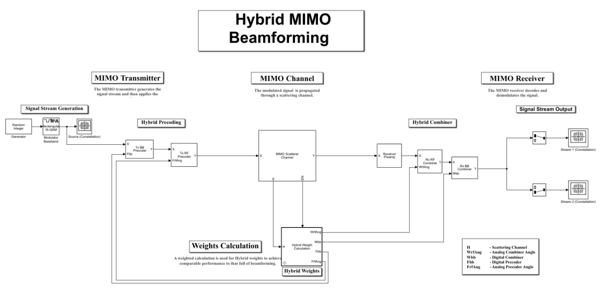

Figure 21. Simulink Model of Hybrid MIMO Beamforming Model with QSHB and HBSP Algorithms

and the signals were decoded and demodulated at the receiving end. However, because it employs an enabled subsystem to update the matrix constantly, the channel matrix represents the MIMO scattering channel, which may vary over time. Aside from that, one of the most important components in these was the weight calculation, which employed the channel matrix to compute the precoding and combining weights, F_{BB} and FrfAng, as well as the combining weights, W_{BB} and WrfAng. Furthermore, the QSHB and HBPS algorithms were found to be similar, which led to the use of HBPS rather than QSHB because HBPS is significantly simpler than QSHB.

5. Conclusion

The 5G wireless transmission design requirements were determined at the end of careful simulation and evaluation. The location of both the transmitter and receiver sites were defined to be situated in an urban environment, Makati City, along with the type of base station and network coverage based on the recommendations of ITU-R 1035. Moreover, the various blocks involved in the system were designed and simulated successfully using MATLAB R2021a, which comprises the antenna array, channel model, spatial multiplexing, and hybrid beamforming. The antenna array model results represented the antenna in 2D elevation, azimuth cut, and 3D radiation pattern that shows the signal's power and capacity based on its directivity pattern and frequency. Then, the channel model showed the different conditions that may affect the received power of the signal and the reflection paths that appeared during the propagation that resulted in scatterers. Consequently, spatial multiplexing created multiple independent data streams between the transmitter and receiver and created multiple subchannels in a scatterer-rich environment that allowed independent transmission and reception. The system was able to have an improved capacity as the BER obtained is very low, indicating that the system has an excellent performance, thereby implying an increased system capacity. Finally, by utilizing fewer RF chains, using hybrid weights as an alternative to digital weights, and increasing spectral efficiency through improving the SNR, hybrid beamforming was able to improve the signal-to-noise ratio (SNR) and lower the latency, and incur cheaper implementation costs. In conclusion, the research created a system with the two transmission techniques that shows an excellent performance. With a obtained BER, an improved capacity was achieved. On the other hand, hybrid weights were used to improve signal-to-noise ratio, thus resulting in lower latency and implementation costs. With the results obtained, it is recommended to use the millimeter-wave (mmWave) frequency band as it provides the anticipated and expected outcome of 5G. Moreover, including more transmitter and receiver sites were suggested to ensure that the whole area is able to connect and experience the said technology. Also, the creation of the Simulink model of the whole system is encouraged to be made as it visualizes and represents the system clearly. Lastly, calculations of the system capacity is recommended to get the actual value and have a clearer visualization that there is an increase in the system's capacity.

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