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A hybrid beamforming Massive MIMO system for 5G: Performance assessment study

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***Abstract*—Recently, massive MIMO (multiple-input multiple-output) technology has been employed to improve the coverage and capacity of 5G cellular networks. This paper investigates the impact of different factors on the performance of a hybrid MIMO system for 5G. This study is essential to find a suitable configuration when designing a hybrid MIMO system for 5G. Specifically, we investigate the effect of changing several variables, including the number of users, the number of transmitters, receiver antennas, the type of used modulation, and noisy data on the performance of a hybrid MIMO system for 5G. Furthermore, the Bit Error Rate (BER) is computed under different considered scenarios and used as an indicator of the effectiveness. Finally, simulations are conducted to accomplish this study. This assessment provides relevant information about the performance of a hybrid MIMO system for 5G under different circumstances.**

I. INTRODUCTION

Technological advances in mobile networks are continuously upgraded with broadband, improved capacity, reduced latency, and quality of service. Technological advances in mobile networks are continuously upgraded with broadband, improved capacity, reduced latency, and quality of service. On the other hand, 4G networks have faced many challenges, including supporting the increased number of users and ensuring higher performance. To alleviate these limitations, the new generation of 5G mobile networks has been developed [1], [2]. Notably, 5G comes up with great architecture flexibility, which can support the increased number of devices, the higher spectrum to support high speeds of Gbps, and very dense networks [3], [4], [5].

Recently, the requirements in terms of the number of devices raised in the network and of capacity pushed the researchers to be interested in the band 30 to 300 GHz called millimeter-wave band (millimeter waves). The frequencies of the unlicensed band available in the mm band suitably meet the requirements of 5G in terms of capacity, but the challenge now is that the channel properties in such bands considerably alter from channels for lower frequencies. The high demand for speed and reliability of communications within mobile networks has been significantly increased. Thus, massive MIMO systems are employed to remedy these limitations. Essentially, MIMO systems use several antennas at the emission and the reception by exploiting the spatial dimension [6]. These antennas combine the preferred signal antenna to rejecting the interfering signals, optimizing data speed, and improving capacity [7]. The Massive MIMO Network is based on the condition of orthogonality. Thanks to this feature, which enables eliminating the effects of fading. It should be highlighted that the implementation of m-MIMO results in high interference caused by the large number of antennas installed on a small-sized array. Crucially, beamforming is introduced to mitigate this problem [8], [9], [10].

Over the last decade, hybrid beamforming techniques in 5G have gained significant attention from the research community and practitioners [11], [12]. Much work has been done in the literature to design efficient and robust MIMO systems. For instance, in [13], a study on beamforming is conducted under different challenges, such as inter-user interference and thermal noise arise when many antennas at the same base station are used. It has been shown that these problems can be overpassed by adopting hybrid beamforming at the base station. Here, modulation type (16-QAM) using 10 OFDM symbols has been employed. In [7], it has been shown that increasing the number of transmitter and receiver antennas leads to increased SE, especially for users who use more data streams. Moreover, this study concluded that the SE levels become closer to those obtained using the optimal scheme by employing hybrid beams.

This paper aims to investigate the impact of various parameters on designing a Massive Mimo hybrid beamforming system. Importantly, we assess the performance of the Massive Mimo hybrid beamforming system under different scenarios, including the increase of the number of antennas, the number of users, and the type of modulation. In addition, we examined the robustness of this system under different SNR levels. The remaining of this article is organized as follows. Section 2 provides a brief presentation about hybrid beamforming in 5G communication systems. In Section 3, hybrid beamforming implementation is briefly described. The results and discussions were given in section 4. The conclusions were drawn in section 5.

II. HYBRID BEAMFORMING IN 5G COMMUNICATION SYSTEM

In short, the term beamforming relates to the capability of the antenna array to focus energy along a specific direction in space. Thus, in multiple access communications, the desired user must be serviced in "clutter" conditions. In this case, "clutter" means the presence of other users located in the area of service. Essentially, beamforming enables the antenna to focus energy to reach a solicited user and nulls in the undesired directions [14]. Beamforming can also be defined as a signal processing technique used mainly to transmit and reception directional signals [15]. It is achieved by using the RF elements in an antenna array such that signals at particular angles interfere constructively while other signals experience destructive interference [15]. The beamforming can be realized from M identical antenna elements with 120° half-power beamwidth (HPBW). Of course, beamforming ensures the transmission of signals with high power directed precisely to the desired station and minimizes the transmission power to other stations (Figure 1).

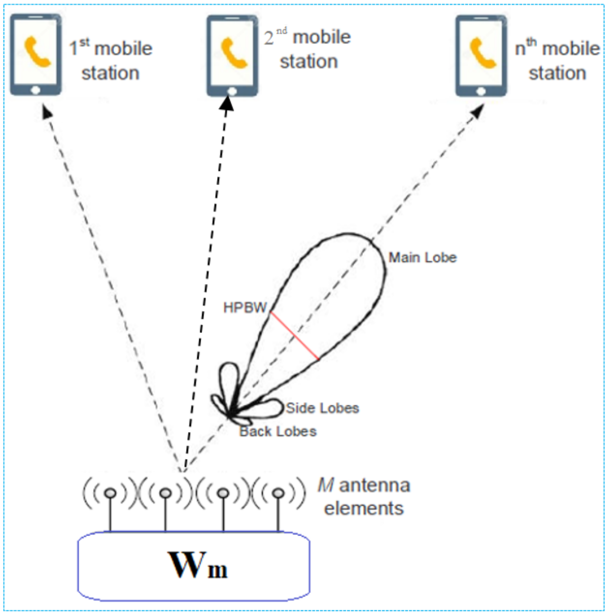

Fig. 1. Beamforming transmitter for an M antennas elements.

The output of the beamforming system can be expressed as a weighted basis [13]:

$$y(t,\alpha) = \sum_{m=1}^{M} W_m\, x[t-(m-1)\tfrac{a}{d}\sin\alpha] \quad (1)$$

where $y(t,\alpha)$ denotes the output signal, w_m refers to the complex weight, $x(t)$ represents the signal sent by the first antenna element, d is the separation distance between the multiple elements, c denotes the speed of the wave and a refers to the direction of departure (or arrival).

The output signal in Equation (1) can also be written in the frequency domain as:

$$y(f,a) = \sum_{m=1}^{M} W_m\, X(f) e^{-j2\pi f(m-1)\frac{d}{c} sin\alpha} \quad (2)$$

For the beam that we want to transmit towards the direction α_1, and for the case of $d = \frac{\lambda}{2}$, we have [8]:

$$W_m = e^{j\pi f(m-1)\sin\alpha_1} \quad (3)$$

For $\alpha = \alpha_1$, Equation (2) will be expressed as [13]:

$$Y(f,a) = MX(f) \quad (4)$$

or equivalently

$$\frac{Y(f,a)}{X(f)} = M \quad (5)$$

This represents the maximum amplitude that can be obtained by beamforming. In [4], a study was carried out on the digital beamforming technique (DBF). In this case, a set of pre-coding and the combined weights are obtained from the channel matrix. The weights are composed of magnitude and phase terms and are usually employed in the digital domain. Among the desirable characteristics of DBF are the beams, super-resolution, and pattern of correction array elements. In the presence of n antenna elements, the DBF procedure passes every of the n signals throughout an analog-to-digital converter and an amplifier power supply to generate n digital data streams. These data streams are digitally summed with proper scale factors or phase shifts to obtain the composite signals. This is the major drawback of this method since this operation has a high cost of implementation, particularly in the MUm-MIMO systems that require the installation of independent RF chains and necessitate large energy consumption. Unlike DBF, analog the beamforming approach (ABF) recommends taking the analog n signals, phase shifts those using analog techniques, and combining them, leading to a single output which is then digitized. Figure 2 displays the main structural difference separating DBF and ABF systems.

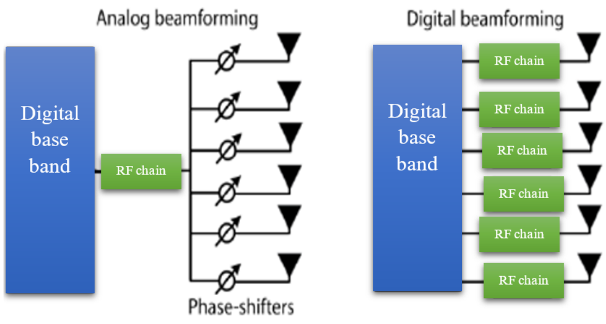

Fig. 2. ABF and DBF architectures.

III. HYBRID BEAMFORMING IMPLEMENTATION

For this implementation, we relied on a Mathworks documentation test system that was implemented using Phased Array System Toolbox in Matlab as well as hybrid beamforming at the sending end of a large multi-user OFDM MIMO system. For simulation of real conditions, configurable amplitude thermal noise is added.

This example illustrates hybrid beamforming and its use at the end of a Massive Mimo communication system; this applies to multi-user and single-user systems. To this end, a full channel poll is performed to receive information related to the state of the channel at the transmitter level. The required precoding is divided into baseband digital and Analog RF components for multi-user and single-user cases.

The multiple transmitted data streams are retrieved by digital receivers to highlight the common values of merit for a communication system, namely EVM and BER. In this example, a broadcast-based spatial channel model is used, which takes into consideration spatial transmit/receive locations and antenna patterns. For link validations, a simpler static-flat MiMo channel is also offered [16]. Precoding relies on transmitter channel information for spatial multiplexing systems to maximize the signal energy in the channel and direction of interest. in the first step, a reference transmission is made for the transmission of the channel for an estimation of the information. Then it is used to calculate the precoding required for the next data transmission. Figure 3 shows a diagram for the sounding channel model.

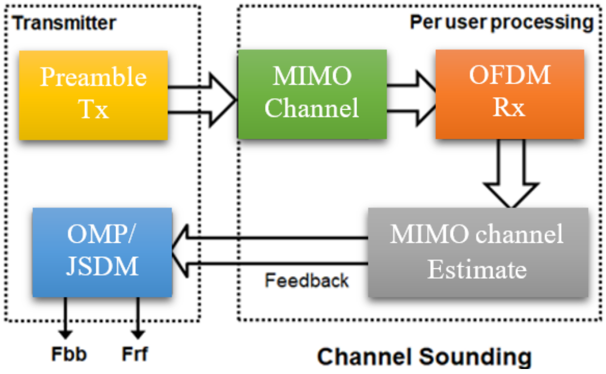

Fig. 3. Block diagram of the channel sounding model.

The next step is to form hybrid beams. For this, the JSDM (Joint Spatial Division Multiplexing) method is used to calculate the analog and baseband RF precoding weights. After calculating the weights, users who have similar transmission channel covariances are grouped, and the analog precoder removes intergroup interference. Then comes the stage of data transmission. This system starts by associating each data flow of each user with an individual RF chain. Subsequently, antennas are connected to each RF chain. Figure 4 illustrates data transmission. After the data transmission, the signal propagation is simulated using the helper Apply MUChannel function. The use of this function is to add various losses, interference, and noise to the system. After propagation, the signal is received, amplified, and recovered. The receiver compensates for the path loss through the amplification of each user.

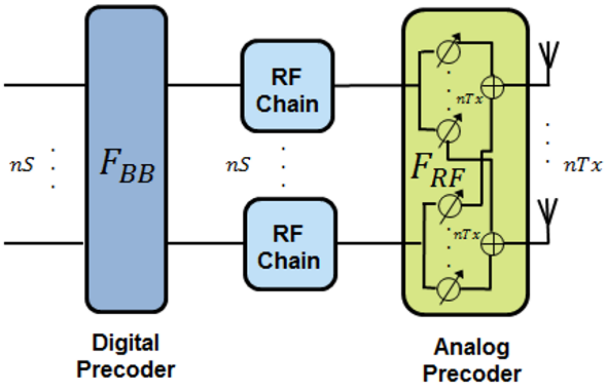

Fig. 4. Data transmission architecture.

The receiver also adds thermal noise to better simulate real-world conditions. Similar to the transmitter, the receiver of this large MIMO system consists of many steps such as OFDM demodulation, large MIMO equalization, quadrature amplitude modulation (QAM) de-mapping, and channel decoding [16]. The overall data transmission and reception architecture are shown in Figure 5.

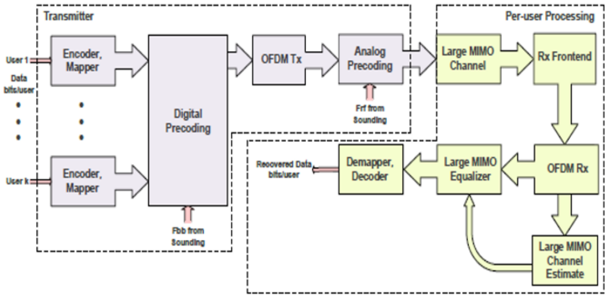

Fig. 5. Data transmission and reception architecture.

IV. SIMULATIONS AND RESULTS

Beamforming in a massive MIMO system is defined by the controlled interference of multiple waves, which increases the signal strength in the target direction. In Figure 6, the 3D response pattern of the system is plotted. It summarizes the radiation patterns in QPSK modulation for different numbers of users ranging from 4 to 32. we can see that the radiation patterns have more lobes as the number of users increases and are much more directive.

In Figure 7, we variate the number of users from 4 to 32 for different types of modulations QPSK, 256 QAM, 16 QAM, and 64 QAM. We take the Error Vector Magnitude (EVM) values in dB for each case. According to the EVM values taken, we see that the 256 QAM modulation presents

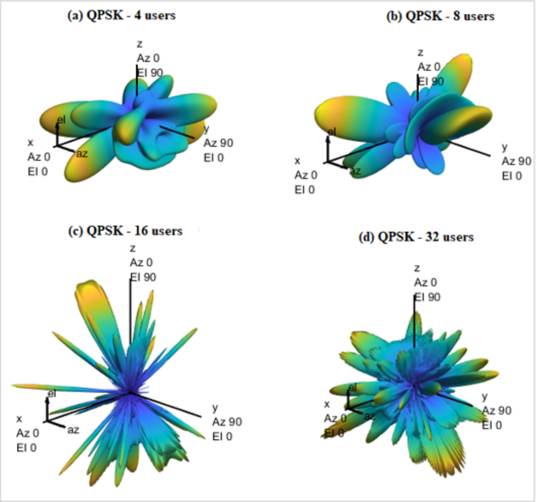

Fig. 6. 3D response pattern.

the best performance thanks to its EVM value equal to -0.39 for 32 users. We can confirm that this modulation type presents the best performance in the mmWave by highlighting the constellation of modulation.

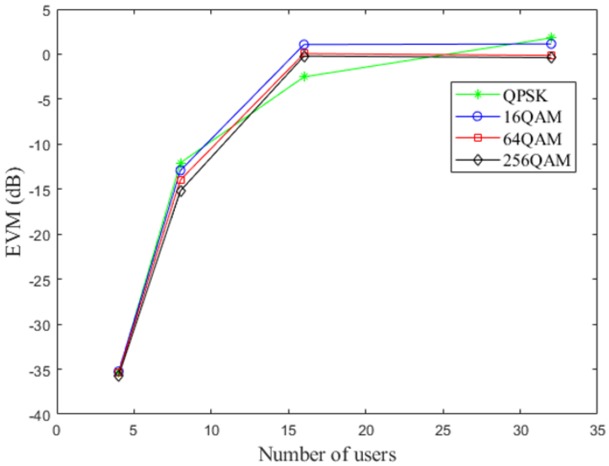

Fig. 7. Relationship between number of users and EVM for different modulation (users=32).

In Figures 8 and 9, we demonstrate the impact of the number of antennas on the system's performance, namely that a large number of antennas on transmission increases the EVM, which is evident since the interference between stations is increased. The low value of EVM is -25.85 dB, corresponding to 16 antennas at transmission.

In the case of reception, the EVM is optimal for a large number of antennas because of the ability to detect all signals with o low Errors. In figure 9, we have the value of EVM equal to -40.2021 dB for 16 antennas at reception.

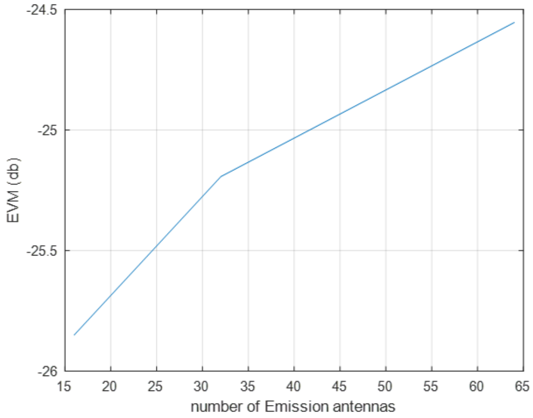

Fig. 8. Number of Emission Antennas vs. EVM.

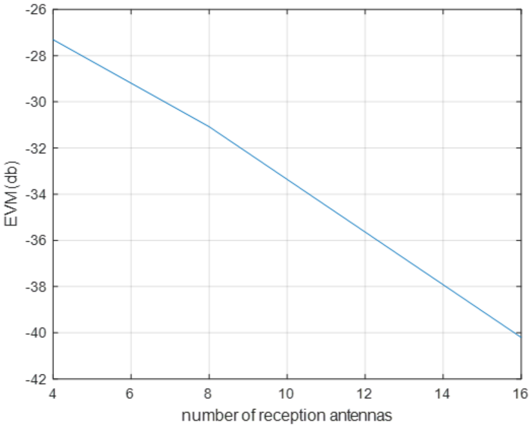

Fig. 9. Number of reception Antennas vs. EVM.

In Table 1, we investigate the impact of different values of SNR on EVM with different modulations. The negative value in dB is good for communication quality. The first observation is that QAM modulation is more robust than QPSK to noise measurement. The second observation is that 256 QAM is providing the best performance even under noisy conditions (i.e., higher SNR).

TABLE I
EVM VALUES FOR DIFFERENT MODULATION WITH DIFFERENT VALUES OF SNR.

SNR	**EVM (dB) QPSK**	**EVM (dB) 16QAM**	**EVM (dB) 64QAM**	**EVM (dB) 256QAM**
2	0.55	-0.54	-0.99	-1.13
4	0.67	-0.27	-0.68	-0.76
6	0.87	-0.58	-0.52	-0.716
8	1.42	0.69	0.06	-0.218
10	1.1	1.1	0.44	0.098

V. CONCLUSION

This study investigated the impact of the various factors on the performance of a Hybrid Beamforming Massive Mimo system. Specifically, results showed that the use of 256 QAM modulation results in suitable performance as even under a large number of users, a small value of the EVM of -0.39db has been reached. It provided better results compared to the used QPSK, 16 QAM, and 64 QAM. This investigation highlights that the greater the number at transmission is, the greater the EVM is obtained. Furthermore, this is mainly due to interference between devices, then a reduced number of the EVM value for a large number of antennas at reception. Finally, it has been shown that the use of the 256 QAM modulation provides more robustness to noise compared to the other modulation types. In future work, we plan to investigate the impact of faulty antennas on the Massive Mimo system's performance. Also, we are interested in developing deep learning-driven detectors to automatically recognize the type of modulation that corresponds to a particular desired situation.

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