An Empirical Analysis of 5G-NR MIMO Schemes under 3GPP Standards

Mohd Adnan, Chaitali J. Pawase, Sara Sualiheen, and KyungHi Chang*
Dept. of Electronics Engineering, Inha University, Incheon, Republic of Korea.
m.adnan1821@gmail.com, chaitalipawase17@gmail.com, sarasualiheen@gmail.com, khchang@inha.ac.kr*

***Abstract*—In the fifth-generation new radio (5G-NR) network, multiple input multiple output (MIMO) is revolutionizing wireless communications by significantly enhancing data throughput and signal quality through its advanced multiple antenna configurations. In the rapidly evolving field of wireless communications, this paper analyzes the 5G-NR MIMO scheme performance under 3GPP standards. The analysis evaluates the impact of various quadrature amplitude modulation (QAM) schemes on the bit error rate (BER) and throughput of the signals offering critical insights into enhancing 5G network capabilities.**

Keywords—5G-NR, MIMO, BER, Throughput, Link Level Simulation.

I. Introduction

In the rapidly evolving domain of wireless communications, 5G technology stands as a pivotal development, leading to a new era of enhanced connectivity. The New Radio (NR) Multiple Input Multiple Output (MIMO) system is central to this technological revolution. 5G-NR MIMO technology represents a significant advancement over previous generations, offering substantial improvements in speed, capacity, and efficiency of data transmission during communication.

Characterized by deploying multiple antennas at both the transmitter and receiver ends, MIMO technology in 5G-NR optimizes communication performance, crucially augmenting data throughput and signal quality. This enhancement is particularly vital in addressing the surging data traffic and accommodating the increasing demand for connected devices in 5G networks [1]. The implementation and effectiveness of 5G-NR MIMO systems are intricately defined within the framework of 3GPP standards, which provide a comprehensive global structure for mobile telecommunications [2]. These standards are instrumental in assuring interoperability, reliability, and security across diverse network operators.

This paper presents an empirical analysis of the 5G-NR MIMO system performance under the 3GPP standards, focusing on different Quadrature Amplitude Modulation (QAM) schemes such as 16-QAM, 64-QAM, and 256-QAM various antenna scenarios. The study aims to evaluate the performance implications of these modulation techniques, which are integral to enhancing spectral efficiency and overall network capacity in 5G systems.

The rest of the paper is as follows. Section II presents a brief overview of 3GPP standards for 5G-NR. Section III overviews the 5G-NR MIMO configurations. Section IV presents the link-level performance analysis of 5G-NR. Finally, section V presents the conclusions and the Future Work.

II. OVERVIEW OF 5G-NR 3GPP STANDARDS

5G-NR is the global standard for next-generation cellular communication which addresses the high demand for mobile broadband. The 3GPP interface for NR is a crucial element in 5G technology. 3GPP 5G-NR standards offer a comprehensive set of guidelines for the development of mobile networks. These standards include protocols for assessing MIMO system performance under various channel conditions, such as clustered delay line (CDL) and tapped delay line (TDL), ensuring consistent and reliable performance. The Clustered Delay Line (CDL) channel model is utilized in scenarios where the incoming signal is composed of multiple, distinctively delayed signal clusters. This model extends the tapped delay line (TDL) profiles to accommodate 3D channel environments, offering five unique CDL profiles. For Non-Line-of-Sight (NLOS) conditions, CDL-A, CDL-B, and CDL-C are the applicable models. In contrast, CDL-D and CDL-E are designed for Line-of-Sight (LOS) settings. The TDL channel model, on the other hand, provides five distinct profiles depending on various environmental conditions. Specifically, TDL-A, TDL-B, and TDL-C are designated for NLOS situations, while TDL-D and TDL-E are intended for LOS scenarios [3][4].

III. 5G-NR MIMO Configurations

The 5G-NR standard developed by 3GPP utilized advanced MIMO transmission techniques. These techniques are essential for delivering the high data speeds, reduced transmission delays, and greater network capacity that 5G networks aim to provide. The table 1 discusses the MIMO transmission schemes in 5G-NR system.

Table 1. MIMO Schemes in 5G-NR System.

Transmission Schemes	Descriptions
SU-MIMO (closed-loop spatial multiplexing)	• Advanced code book and non-codebook-based precoding • Multiple data streams to single users • Supports up to 8 Layers
SU-MIMO (open loop spatial multiplexing	• Cyclic delay diversity • No feedback for precoder selection
MU-MIMO	• Multiple users served simultaneously • Advanced beamforming for user separation • Liner precoding techniques
Massive MIMO	• Large number of Antennas at base stations • Enhance beamforming and spatial multiplexing capabilities
Transmit/Receive Diversity	• Space-frequency block coding • Improves signal reliability and reduces fading effects
Beamforming	• Essential in mm-Wave frequencies • Adaptive beam steering and shaping

In 5G-NR, instead of having multiple transmission modes like LTE systems, there is just one unified mode. This single mode is designed to make the whole system simpler and more flexible.

This makes things easier for devices and improves performance, the challenge is to ensure this one mode can handle all the different ways of sending data that were used in LTE systems. The goal is to make the single

* Address Correspondence to Prof. KyungHi Chang

transmission mode efficient, adaptable, and not too complicated to use. Fully dynamic switching within all MIMO transmission schemes may provide scheduling flexibility at the base station (BS) scheduler, it may increase blind decoding complexity or control signaling overhead. Therefore, to enable fast transmission scheme switching, it is necessary to specify one mode integrating multiple transmission schemes, to balance between the scheduling flexibility and receiver complexity [5]. The channel bandwidth of frequency range (FR)1-sub-6GHz to 100MHz, FR2- mm-wave up to 400 MHz, and carrier frequency FR1- 410 MHz to 7.125 GHz FR2- 24.25 GHz to 52.6 GHz are available to be utilize for 5G-NR system.

IV. Link-Level Analysis of 5G-NR MIMO

This section observes the effect of different numerologies on 5G-NR MIMO in terms of BER and throughput. The simulation parameters for performance observation are shown in Table 2.

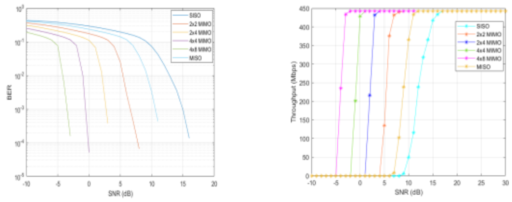
Table 2. 5G-NR Link-level Simulation Parameters.

Parameters	Values
Carrier Frequency	6 GHz
Bandwidth	200 MHz
Sub-carrier spacing	120 KHz
Cyclic Prefix	Normal
Propagation Channel Model	TDL-D
UE Mobility	500 km/h
Channel Estimation	Perfect
Modulation Scheme	QAM (16, 64, 256)
Number of TX Antennas	2, 4
Number of Rx Antennas	2, 4, 8
Beamforming Technique	Precoding
Number of Transmission Layer	1

Figure 1 shows the BER and throughput performance of 5G-NR MIMO schemes under a physical downlink shared channel and TDL channel model at different signal-to-noise ratio (SNR) and modulation schemes. We simulated SISO and various MIMO (2x2, 2x4, 4x4, and 4x8) cases for 16QAM and 240KHz sub-carrier spacing at 500km/h under the TDL-D channel model and perfect channel estimation. In this figure, with the increasing SNR, BER decreases for all MIMO configurations, which is consistent with the expected behavior that a stronger signal relative to noise leads to fewer errors in bit transmission.

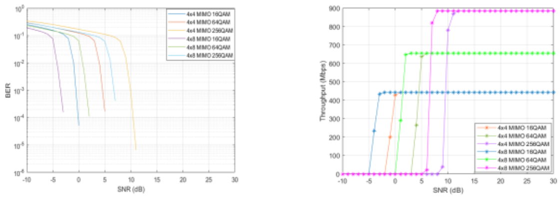
Figure 2 shows the BER and throughput performance of 4x8 and 4x4 MIMO with 16-QAM, 64-QAM, and 256-QAM modulation schemes. The result of Figure 2(a) indicates that as SNR increases, the BER decreases for all configurations. The 4x4 MIMO with 256-QAM shows the highest BER at lower SNRs, indicating that higher-order modulations are more susceptible to noise but can achieve lower BER at high SNR levels. In contrast, the 4x8 MIMO with 16-QAM maintains a lower BER across the SNR range, suggesting that increasing the number of antennas can improve reliability. Figure 2(b) shows the throughput in Mbps, which is the rate of successful data transmission over a communication channel.

The 4x8 MIMO with 256-QAM achieves the highest throughput, suggesting that higher-order modulations can transmit more data at once, given a sufficiently high SNR.



(a) (b)

Fig. 1. Performance of 5G-NR MIMO schemes at various configurations: (a) BER, (b) Throughput.



(a) (b)

Fig.2. Impact of modulation schemes on various 5G-NR MIMO configurations: (a) BER, (b) Throughput.

V. Conclusions

The 5G-NR 3GPP standards are evolving significantly to boost wireless system performance, targeting higher data rates, improved energy efficiency, and enhanced reliability for 6G technology. This paper presents an empirical analysis of 5G-NR MIMO scheme performance under 3GPP standards. The simulation results analyze the effect of various MIMO configurations on the BER and throughput with various modulation schemes. The analysis also shows the effect of different QAM schemes on the MIMO configurations. In our future work, we aim to analyze the 6G non-terrestrial network's system-level performance in managing and mitigating interference.

ACKNOWLEDGMENT

This work was supported by Institute of Information & communications Technology Planning & Evaluation (IITP) grant funded by the Korea government (MSIT) (No. 2021-0-00794, Development of 3D Spatial Mobile Communication Technology)

References

[1] M. Z. Chowdhury, M. Shahjalal, S. Ahmed and Y. M. Jang, "6G wireless communication systems: Applications, requirements, technologies, challenges, and research directions," *IEEE Open J. Commun. Soc.*, vol. 1, pp. 957-975, 2020.

[2] H. Jin, K. Liu, M. Zhang, L. Zhang, G. Lee, E.Farag, D. Zhu, E. Onggosanusi, M. Shafi, H. Tataria, "Massive MIMO Evolution Toward 3GPP Release 18," *IEEE Journal on Selected Areas in Communications*, vol. 41, no. 6, pp. 1635-1654, 2023.

[3] 3GPP TR 38.901 V16.1.0. Study on channel model for frequencies from 0.5 to 100 GHz. Tech. Spec. Group Radio Access Network, Release 16. Dec 2019.

[4] 3GPP TR 38.821 V16.0.0. Solutions for NR to support non-terrestrial networks (NTN). Tech. Spec. Group Radio Access Network, Release 16. Dec 2019.

[5] C. C. Tsai, T. Y. Yeh, W. H. Chou, W. C. Pao and J. Y. Pan, "A low complexity PMI selection scheme for 3GPP 5G-NR FDD systems," *in Proc. IEEE* 13th *Asia-Pacific Signal and Information Processing Association Annual Summit and Conference (APSIPA ASC)*, Dec. 2021, pp. 1917-1922.

* Address Correspondence to Prof. KyungHi Chang