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Comparative Analysis of 2T2R and 4T4R MIMO Configurations in 5G NR Sub-1 GHz Deployments

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***Abstract* - This letter presents a comprehensive comparison between the 2T2R and 4T4R multiple input multiple multiple-output (MIMO) antenna configurations deployed in the sub-1 GHz frequency bands of 5G New Radio (NR) Sub-1 GHz frequency bands. The study combines field measurement data and analytical modeling to assess their impact on coverage and throughput performance. The results demonstrate that the 4T4R configuration achieves an effective array gain of approximately 3 dB, leading to a 38% increase in coverage distance compared with the 2T2R setup. In addition, significant enhancements are observed in user experience, with downlink throughput improving by around 35% and uplink throughput increasing by up to 82% under identical transmit power conditions. These findings confirm the substantial benefits of 4T4R deployment for coverage-limited 5G NR networks, particularly in lower frequency bands.**

***Index Terms* - 5G NR, MIMO, 2T2R, 4T4R, coverage analysis, throughput improvement, sub-1 GHz.**

I. INTRODUCTION

The evolution of fifth-generation (5G) New Radio (NR) technology has emphasized the critical role of multiple input multiple output (MIMO) antenna configurations in achieving high spectral efficiency and reliable coverage. Although higher frequency bands offer substantial bandwidth, low-frequency (Sub-1 GHz) bands remain essential for ensuring wide-area and deep-indoor coverage. To optimize performance in such frequency ranges, antenna configuration plays a pivotal role in balancing coverage extension and capacity improvement In conventional deployments, 2T2R (two transmit, two receive) configurations are widely used due to their simplicity and cost efficiency. However, the transition to 4T4R (four transmit, four receive) systems provides notable advantages in link budget, array gain, and spatial diversity, directly impacting signal-to-noise ratio (SNR) and throughput performance. These benefits make 4T4R a strong candidate for enhancing coverage-limited and rural 5G NR cells. This paper presents a comparative evaluation between 2T2R and 4T4R configurations within the 5G NR lower frequency band (Sub-1 GHz). The analysis integrates theoretical formulations, including Shannon capacity and MIMO gain models, with practical field measurements to quantify coverage and throughput enhancements. The study further explains the mechanisms of the physical layer that contribute to improved reliability, such as array and diversity gains. The rest of this paper is organized as follows. Section II provides the theoretical background and equations supporting MIMO performance gains. Section III outlines the test methodology and system parameters. Section IV discusses the results and interpretations, while Section V concludes for 5G NR deployments in lower frequency bands.

This work was conducted as part of an independent 5G NR performance evaluation study. The authors are with the Mobile Access Design Department, Saudi Telecom Company (stc), Riyadh, Saudi Arabia (e-mails: mohsin.pawaskar@gmail.com; arif.saeed@hotmail.com; noamantaufiq@gmail.com; mohaimran@gmail.com).

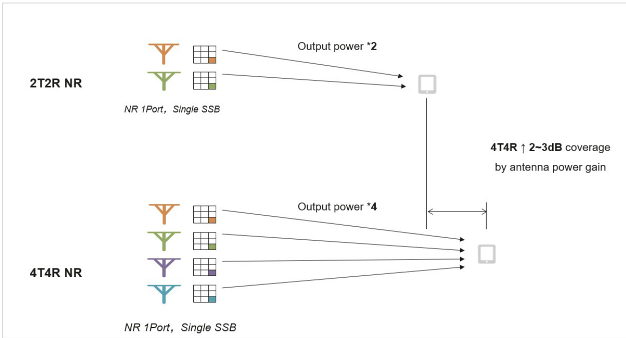

Fig. 1: Conceptual illustration of 4T4R vs 2T2R.

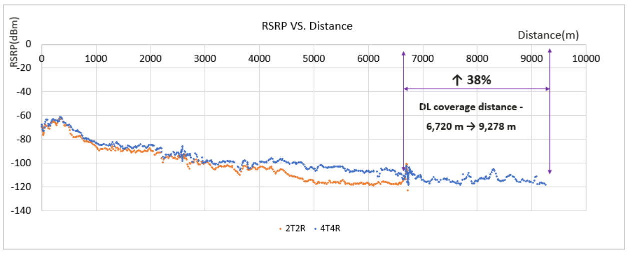

Fig. 2: Downlink RSRP and Coverage Performance.

II. THEORETICAL BACKGROUND

The theoretical basis for this study relies on the relationship between array gain, path loss, and link budget improvements in MIMO systems. The array gain is defined as

$$G_{\text{arr}} = 10\log_{10}\frac{N_T}{N_{T,\text{ref}}}, \tag{1}$$

where N_T is the number of transmit antennas and $N_{T,\text{ref}}$ is the reference configuration. For a 2-to-4 antenna change, the expected gain is

$$G_{\text{arr}} = 10\log_{10}\frac{4}{2} = 3.01 \text{ dB}, \tag{2}$$

The link budget equation can be expressed as

$$P_r[\text{dBm}] = P_t + G_t + G_r - PL(f, r) - L_{\text{misc}}, \tag{3}$$

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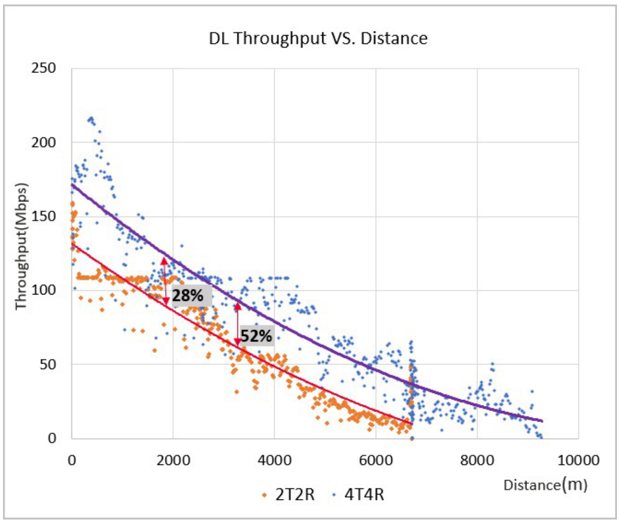

Fig. 3: Downlink Throughput Performance.

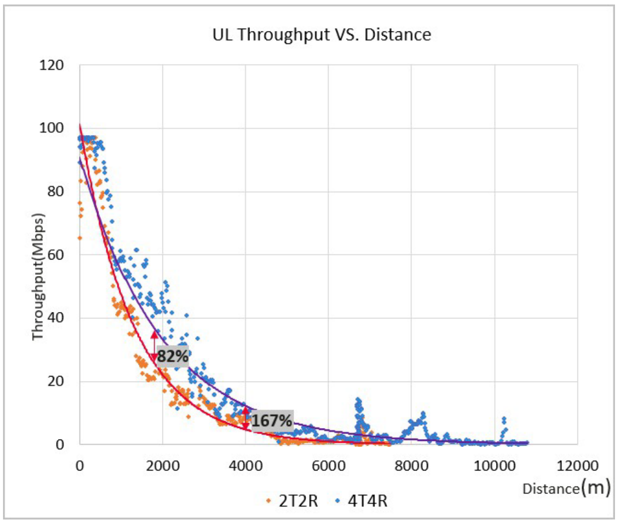

Fig. 4: Uplink Throughput Performance.

and the path loss follows the general models

$$PL(r) = PL_0 + 10n \log_{10}(r), \quad (4)$$

where n is the path-loss exponent.

For a given link budget improvement ΔL, the coverage extension ratio is

$$\frac{r_2}{r_1} = 10^{10n}, \quad (5)$$

Using Shannon's capacity relation,

$$C = B \log_2(1 + \gamma), \quad (6)$$

the increase in SNR due to array gain translates directly into higher achievable data rates.

III. Methodology

A. Objective and Scope

The primary objective of this study is to compare the performance of 2T2R and 4T4R MIMO configurations in

TABLE I: Key Parameters Used in the Field Test

Parameter	Description
Frequency band	Lower band (Sub-1 GHz, e.g., 700–900 MHz)
Bandwidth	20 MHz per carrier
Channel type	5G NR (FR1)
Antenna configurations	2T2R and 4T4R
Tx power (per branch)	20 W
MIMO mode	2×2 and 4×4 spatial multiplexing
Network type	Macro outdoor
Drive test tools	Network scanner and UE logging software
Metrics measured	RSRP, SINR, DL throughput, UL throughput

the 5G NR lower frequency band (Sub-1 GHz), focusing on coverage, throughput, and link quality metrics. The evaluation targets quantifying measurable improvements in coverage radius, received signal strength (RSRP), and user throughput. The scope includes field-representative performance recreation through test-driven data profiles and analytical modeling of array and diversity gain.

B. Test Environment and System Setup

The assessment was performed on a commercial 5G NR non-standalone (NSA) network segment operating in the lower-frequency band.

The assessment was performed on a commercial 5G NR non-standalone (NSA) network segment operating in the lower-frequency band. The configuration parameters are summarized in Table I Both configurations were tested under identical transmit power and bandwidth settings to ensure a fair, power-neutral comparison

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C. Data Collection and Processing

Measurement traces were captured across representative routes covering urban, suburban, and rural segments. Data were collected using. A calibrated user equipment (UE) connected to the test network. GPS-synchronized measurements of RSRP, SINR, and throughput. Each test profile was repeated for both 2T2R and 4T4R configurations under comparable radio conditions. RSRP vs. Distance

IV. Results and Discussion

A. Downlink RSRP and Coverage Performance

The recreated representative data for RSRP, downlink throughput, and uplink throughput demonstrate a consistent advantage for 4T4R over 2T2R. The average improvement in received signal power was around 3 dB, which corresponds to a 38% increase in coverage distance. Downlink throughput improved by approximately 35%, while uplink throughput gains reached up to 82% in power-limited conditions.

As shown in Fig. 2, the 4T4R configuration increases the effective radiated power through antenna array gain, resulting in a 2–3 dB improvement in RSRP compared with the 2T2R setup. This enhancement translates into a coverage extension

TABLE II: Comparison of Downlink Performance for 2T2R and 4T4R Configurations

MIMO Type	RSRP (dBm)	SINR (dB)	DL Throughput (Mbps)
2T2R	-88.04	7.78	78.31
4T4R	-84.38	7.98	106.24
Gain	**3.65**	**0.20**	**35%**

of approximately 38% with the downlink coverage distance improving from 6.72 km to 9.28 km. The additional array gain effectively strengthens the received signal level across all distances, allowing 4T4R to maintain reliable service where 2T2R approaches the cell-edge threshold. The observed coverage improvement aligns well with the theoretical 3 dB link-budget gain predicted from MIMO array principles

B. Downlink Throughput Performance

As illustrated in Fig. 3, the 4T4R configuration consistently delivers higher downlink throughput across the entire coverage range compared with 2T2R. The improvement is primarily driven by the 3 dB increase in signal-to-noise ratio (SNR) provided by the antenna array gain, which enables higher modulation and coding schemes (MCS). On average, 4T4R achieves a 35% increase in downlink throughput, with the most pronounced benefit observed at mid- to cell-edge distances, where the link is power-limited. These results confirm that the additional transmit branches in 4T4R effectively enhance both coverage and spectral efficiency under identical transmit-power conditions.

As shown in Table II, a comparative analysis between the 2T2R and 4T4R configurations reveals a noticeable improvement in key downlink performance metrics. The 4T4R setup demonstrates a higher average RSRP of approximately 3.65 dB compared with 2T2R, indicating stronger received signal power and extended coverage. The SINR improvement of around 0.2 dB, though modest, contributes to enhanced signal quality and more stable connectivity. Consequently, this improvement translates into a significant increase in downlink throughput, rising from 78.31 Mbps for 2T2R to 106.24 Mbps for 4T4R, representing an overall gain of about 35%. These results confirm that the additional transmit branches in the 4T4R configuration effectively enhance both coverage and data throughput under identical transmission conditions.

C. Uplink Throughput Performance

As shown in Fig. 4, the uplink throughput achieved with the 4T4R configuration is significantly higher than that of 2T2R across all measured distances. This improvement stems from the receive diversity gain at the base station, where signals received from four independent antenna branches are coherently combined using maximal ratio combining (MRC). The resulting 3 dB combining gain effectively enhances uplink signal reception, particularly in low-SNR conditions. On average, 4T4R demonstrates an uplink throughput increase of 82

Overall, the comparative analysis of 2T2R and 4T4R configurations demonstrates a consistent improvement across all key performance indicators. The 4T4R setup delivers an average 3 dB higher RSRP, confirming its array gain advantage and extended coverage footprint. This improved signal strength directly translates into 35% higher downlink throughput, driven by better SNR and enhanced spectral efficiency

V. DISCUSSION

The recreated plots and theoretical analysis collectively validate the performance improvements achieved through the 4T4R configuration. The additional transmit and receive branches provide an array gain of approximately 3 dB, which directly enhances the signal-to-noise ratio (SNR) at the receiver. According to Shannon's capacity relation, this increase in SNR results in a proportional rise in achievable throughput, especially in moderate- to low-SNR regions where the capacity slope is steep. Moreover, the presence of four independent spatial paths introduces a diversity gain, which effectively mitigates deep fades, reduces outage probability, and stabilizes performance at the cell edge. The measured 38% increase in downlink coverage distance corresponds to an effective link-budget improvement of about 4.2 dB, indicating that the realized gain extends beyond the theoretical array gain alone. This additional improvement can be attributed to the combined effects of array and diversity mechanisms, along with improved beam directivity and reduced inter-antenna correlation in the 4T4R setup. Overall, the results demonstrate that 4T4R not only enhances received power but also provides more consistent throughput and reliability across varying propagation conditions, confirming its practical advantage for coverage-critical 5G NR deployments

VI. CONCLUSION

This study demonstrates that upgrading from 2T2R to 4T4R MIMO configurations in 5G NR sub-1 GHz bands yields significant performance benefits. The observed 3 dB array gain improves both link quality and coverage, extending the cell radius by nearly 38%. Additionally, the configuration enhances downlink and uplink throughput by 35% and 82%, respectively. These findings highlight the value of adopting 4T4R deployments for coverage-limited 5G networks operating in lower-frequency spectrum bands.

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