Impact of Symbol and Slot Configurations on 5G Downlink Throughput Performance in TDD Band

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Abstract— **The widespread adoption of 5G-capable smartphones has made high-speed connectivity accessible to most users, with Enhanced Mobile Broadband (eMBB) technology playing a pivotal role in delivering faster download and upload rates. The diverse range of services enabled by 5G networks demands innovative solutions for optimizing resource allocation and enhancing overall network performance. To address these challenges, 5G New Radio (NR) introduces several critical features, including flexible Time Division Duplexing (TDD), which dynamically allocates time slots based on traffic demand to maximize spectral efficiency and adaptability under varying network conditions. This paper investigates the impact of different TDD band configurations on throughput performance, specifically focusing on downlink traffic in 5G networks.**

Keywords— **5GNR, SA, TDD, Slots, Symbols, Performance.**

I. Introduction

The fifth-generation (5G) wireless technology is built upon three foundational pillars: Enhanced Mobile Broadband (eMBB), Ultra Reliable Low Latency Communication (URLLC), and Massive Machine Type Communication (mMTC). As compared to its predecessor, 5G is anticipated to offer significantly enhanced download and upload data rates, increased adaptability for diverse communication scenarios, and reduced latency between the end-user and the network. Therefore, 5G Stand-Alone (SA) as the new mobile telecommunication generation requires new transmission equipment that supports New Radio (NR) technology to deliver superior performance to that offered by fourth-generation (4G) network generation [1] [2].

One of the key innovations inherited from 4G and that underpinning 5G is the flexible Time Division Duplexing (TDD) technique. This approach enables network systems to dynamically adjust the allocation of Uplink (UL) and Downlink (DL) time slots in response to real-time traffic conditions and service demands. TDD is particularly beneficial for applications exhibiting asymmetric traffic patterns, where data transfer rates are not symmetric between DL and UL directions. By allocating time slots according to traffic needs, this technology optimizes spectrum usage, ultimately leading to improved network performance in terms of throughput, latency, and energy efficiency for the end-user [3]

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Given its importance, the flexible TDD for throughput scenario has been investigated as feature to improve network performance. In [4], Penda et al. demonstrated through simulation results that dynamic TDD significantly improves energy and spectral allocation efficiency in Device-to-Device (D2D) communications compared to traditional cellular communication. Chowdhury and Murthy [5] analysed the spectral efficiency of flexible TDD in massive Multiple-Input Multiple Output (MIMO) systems. Finally, Lai et al. [6] studied the impact of different flexible TDD configuration on UL and DL data rate under different traffic patterns using a 5G-SA open source software, while Adamuz-Hinojosa et al. [7] conducted empirical measurements to investigate the impact of different TDD configuration in packet transmission delay in industrial environments.

This study aims to investigate how varying symbol and slot configurations impact DL throughput performance in 5G TDD networks. By adjusting these parameters in laboratory experiments with a emulated real network, the research manipulates network balance to evaluate changes in throughput values, focusing on understanding their effects on data rate performance.

II. Key Concept

A. Time Division Duplexing (TDD)

The introduction of TDD techniques was driven by the need to load balance a diverse numerous data that can be transmitted in a telecommunication channel. This technique provides flexibility, in some cases reduces latency, and optimizes radio resource management to meet to the requirements of different services. TDD enables asymmetric radio resource allocation between DL and UL transmissions, allowing for dynamic adaptation to traffic demands within the same frequency band. Specifically, it involves alternating transmission directions at different time intervals, allocating resources based on needs of the communication [6] [3].

In TDD, the DL and UL slots of information are configurable based on diverse traffic patterns. The configuration involves assigning specific time slots for DL (D) and UL (U) transmission, as well as a Special slot (S). The S slot contains both DL and UL symbols, separated by silent guard symbols to ensure seamless switching between the two directions of the transmission. Each 10 slots in a sub-frame typically repeats at a periodicity of 5ms, resulting in a duration of approximately 0.5ms per slot. However, this periodicity can be adapted to specific communication requirements, such as dividing it into 3ms + 2ms. The flexibility of TDD allows for customized configurations to meet the unique demands of various services and applications Figure 1 illustrates how the DL/UL time slots can be configured in a 5G TDD connection according to different traffic patterns [6] [8].

DL/UL Periodicity	Pattern									
Slot	0	1	2	3	4	5	6	7	8	9
DL/UL Allocation	D	D	D	D	D	D	D	S	U	U
DL/UL Allocation	D	D	D	S	U	U	D	D	D	D
DL/UL Allocation	D	S	U	U	U	U	D	S	U	U

Fig. 1: TDD time slot configurations for different DL/UL traffic patterns.

III. METHODOLOGY

The scenario used in this work was generated using a 5G NR simulator box Anritsu MT8000A. The Test Equipment (TE) was controlled by the software Smart Studio New Radio (SSNR), which provides the visual interface for the tester to control the parameters of the 5G NR Cell. A Control PC was used to run the software, connected with the mentioned TE. Finally, four RF cables were linked to 4 RF antennas with support for sub-6 gigahertz frequencies. In addition, all equipment were handled inside a RF shield room to ensure the stability channel connection and avoid all external and internal interfering signals. This configuration irradiated 5G SA Cell over the air to a high-end 5G SA Capable Device Under Test (DUT). In the Figure 2 it is possible to see the configuration of the test environment used in this work.

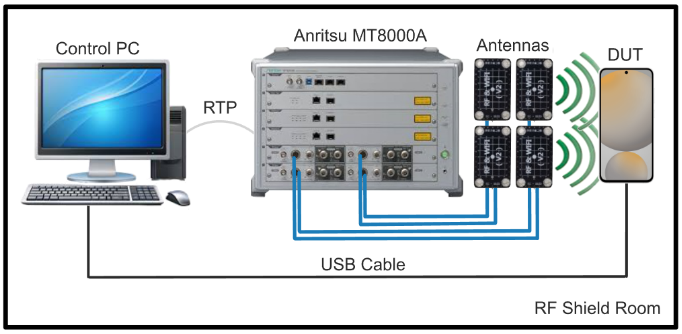

Fig. 2: Simulation design for the high-level test environment.

The 5G cell was configured using NR N78 Band at 3.5GHz.,more specifically with the frequency channel of the NR Absolute Radio-Frequency Channel Number (NRARFCN) 636666. To run tests in full channel capacity, the entirety of its 100 MHz of bandwidth was used. Also, DL modulation order and Modulation Code Scheme (MCS) were set at maximum level supported by the test scenario: respectively 256 QAM and 27 MCS. The number of DL antennas was changed between SISO, MIMO 2x2, and MIMO 4x4, within an arrangement of 7 different Allocation Patterns. Table I compiles the parameters used in simulations scenario.

TABLE I: Simulation settings used for measuring downlink rates.

Parameter	Value
NR Band	N78 (3.5GHz)
Bandwidth	100 MHz
NRARFCN	636666
MCS	27
Modulation	256 QAM
Number of antennas	SISO, MIMO 2x2, MIMO 4x4

Also, as mentioned before, we used a high-end DUT with a configuration of 5000 mAh of battery, Snapdragon Elite, modem-RF Snapdragon X75 5G, using One UI 7.1 Android 15 as operating system and supporting the latest mobile network technologies for TDD connection to ensure the best performance. The DUT configuration described is showed in the Table II.

TABLE II: DUT Hardware specifications

Components	Hardware Specifications
Battery	5000 mAh
Chipset	Snapdragon Elite
Modem-RF	Snapdragon™ X75 5G
Operating System	One UI 7.1, based on Android 15

Once the simulation was started, we disabled airplane mode in DUT so that it could register to 5G SA N78 Band configured with the desired Allocation Pattern and establish the data connection. In order to obtain DL throughput measurements, we used iperf software, which can be the traffic generator (client) or traffic receiver (server) when is configured with a command-line option of -c or -s, respectively. In addition, iperf supports both TCP and UDP traffics.

In this experiment, the TCP protocol was preferred over UDP because it ensures data delivery without failures, and also re-transmits any lost packets. In addition, only downlink traffic

TABLE III: Throughput values for each antenna configuration.

Allocation ID	Pattern										Throughput DL (Mbps)		
Slot	0	1	2	3	4	5	6	7	8	9	SISO	MIMO 2X2	MIMO 4X4
1	D	S	U	U	U	U	D	S	U	U	130.94	291.49	523.74
2	D	D	S	U	U	U	D	S	U	U	175.78	386.11	702.90
3	D	D	D	S	U	U	D	S	U	U	229.51	504.24	901.35
4	D	D	D	S	U	D	D	D	S	U	366.45	804.82	1456.32
5	D	D	D	D	D	D	D	S	U	U	367.20	820.51	1505.63
6	D	D	D	S	U	U	D	D	D	D	376.23	821.93	1505.37
7	D	D	D	D	D	D	D	D	U	U	405.26	885.60	1618.70

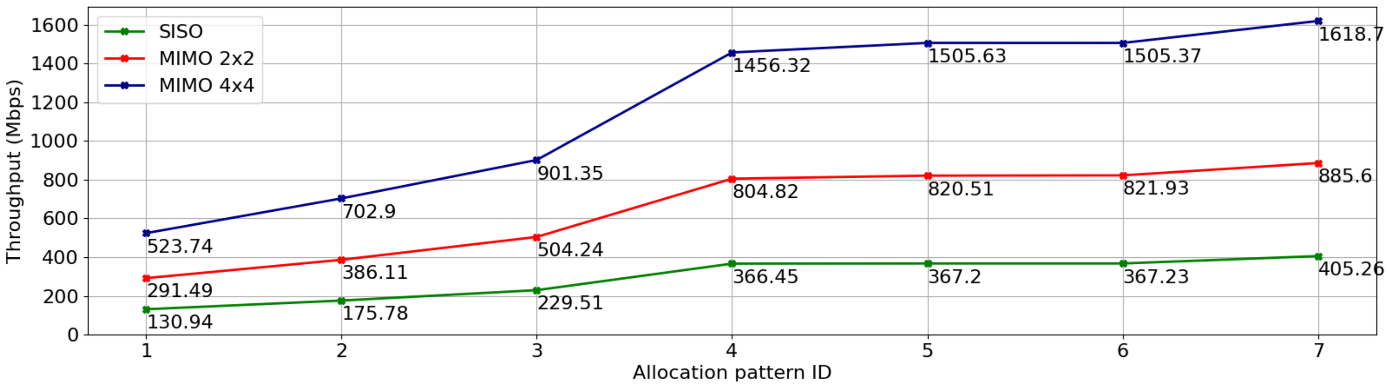

Fig. 3: Throughput values for each antenna configuration.

was considered. We conducted throughput measurements by sending TCP packets to the DUT. To perform this DL TCP communication, we used the Hurricane Electric Network Tools application, which provides a graphical interface. Using this interface, we inserted the command-line argument -s to configure the DUT as a receiving data server. Subsequently, we set the 5G network side as the iperf client. Traffic was generated at a fixed rate, with TCP packets sent every 1 second during each test. The data transfer interval was set to 60 seconds, and we concluded each measurement when the DUT maintained a stable connection for at least 30 seconds. Throughput results were obtained by analyzing the real time throughput curves plotted by SmartStudio. After completing each measurement, we enabled airplane mode to disconnect the device. The entire experiment was performed in a isolated RF shield room to avoid any external interference. This process was repeated for each Allocation Pattern tested.

IV. Results

A thorough analysis of the measurement data reveals a clear trend, where the increased throughput values are directly correlated with more D slots in the Allocation Patterns as expected. Specifically, comparing IDs 5 and 6 demonstrates that similar DL rate values can be achieved with the same numbers of D Slots. Although SISO measurements exhibit some variance, the differences remain minimal (less than 3%). As expected, MIMO 4x4 outperforms both SISO and MIMO 2x2 in terms of DL data rates. Furthermore, results from IDs 1, 2, and 3 indicate that groups with more U slots tend to exhibit lower DL throughput. However, this configuration can offering improved performance for UL data shared services. This is consistent with the expectation that increased U slot allocations can lead to better support for applications requiring high performance for UL based services. A summary of the lab test results for SISO, MIMO 2x2, and MIMO 4x4 configurations across each allocation pattern is presented in Table III. In addition, the Figure 3 illustrating these measurements, arranged from the lowest to highest throughput, for easy comparison. Each allocation pattern is assigned with a unique ID (e.g., IDs 1-7) for convenient reference.

V. Conclusions

The objective of this paper was to investigate the influence of different 5G TDD allocation patterns on DL throughput. The results revealed that allocation pattern IDs 4 to 7, which have more slots allocated for DL traffic, had the most impact on throughput performance. As predicted, configurations with more D slots offered higher throughput. Furthermore, it was observed that allocation patterns with a comparable quantity of D slots showed a small difference in throughput measurement, less than 3%, indicating that the allocation pattern with the same quantitative slot of DL does not directly influence the throughput service offered. For future work, we intend to extend this TDD allocation patterns analysis for different DL/UL traffic conditions focusing on asymmetric traffic to analyze the benefits of flexible dynamic TDD slot allocation. We also intend to evaluate other network performance parameters, such as latency, energy consumption, and the impact of different channel conditions.

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