Measurement of Communication Performance Between 5G Devices in a 5G SA Network

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Abstract. *This work presents an end-to-end performance analysis of 5G devices connected to a private 5G Standalone (SA) network complied with Rel 15. The experiment was carry out in an indoor environment with two typical setups, using direct connection to the network core and wireless connection through 5G UEs. The metrics evaluated were: jitter, latency, throughput and the coverage parameters (SINR, RSRP and RSRQ). The results presented converged to a better performance in the setup with the server connected directly to the network core. In addition, the datasets containing the values of the collected parameters are made available for possible studies and reproduction of the results obtained.*

1. Introduction

Since their launch, 5G networks have become fundamental to industry and everyday life, enabling new applications with multi-Gbps data rates and high reliability [TM 2019]. In this context, private networks stand out even more, which focus on restricted use by companies or government agencies, providing improvements about reliability, latency and data transmission rate [Wen et al. 2021]. With the global adoption of 5G Standalone (SA) networks, the promise of ultra-fast and highly reliable connectivity is getting closer to reality [Wijethilaka and M. 2021]. Therefore, measuring and analyzing the performance of mobile networks is essential to ensure that service parameters not only meet theoretical expectations, but also the users practical demands and applications [Zhang 2019].

This study aims to analyze the 5G SA network performance in an indoor environment (enterprise plant). We will discuss the results obtained from two automated measurement setups and examine how the evaluated parameters may vary according to the configuration of each setup, providing material for possible future studies involving 5G SA networks. Moreover, we have released our datasets (5G-GitFrontIo) for facilitating future research.

The remainder of this paper is organized as follows: Section II describes 5G SA Network, Section III provides an overview of related works that measure 5G network performance, Section IV presents the methodology employed, Section V presents our Testbed experiments and results; and, finally, Section VI presents conclusions.

2. 5G Standalone (SA) Network

The 5G Standalone (SA) architecture was primarily introduced in the 3GPP Release 15 [TM 2019]. This release laid the foundation framework for 5G networks, including the specifications for 5G New Radio (NR) and the 5G Core Network (5GC), which are essential components of the 5G SA architecture. The 5GC handles control plane signaling, while the 5G RAN and its NR interface (cell base stations) operates independently, managing the user plane for data transfer. This setup eliminates reliance on the 4G LTE core and radio network. The 5G packet core architecture incorporates advanced features like network slicing and multi-Gbps support, maximizing the capacity and reduced latency offered by 5G NR technology [Ullah et al. 2023].

The implementation of these private networks can be done through different deployment models, which vary according to spectrum ownership and management, Quality of Service (QoS) requirements, and the company's specific characteristics [TM 2019]. This type of network is already being used in various environments, such as airports and university campus, surpassing the private LTE networks [Mallikarjun et al. 2022].

3. Related Works

In recent years, many papers have evaluated and analyzed 5G network performance. In [Mallikarjun et al. 2022] the performance evaluation of a private 5G SA network on a university campus is addressed, where the focus was on testing and measuring different network parameters, such as download and upload throughput, latency, jitter, and signal intensity in indoor and outdoor environments. In [Gabilondo et al. 2021] the interoperability of 5G SA networks with multiple suppliers is explored through the study of connectivity, interoperability and performance of varied modems in a multi-vendor network environment, comparing the performance of these different modems in terms of bandwidth and latency. The other works mentioned focus on applications involving performance measurement in drones that communicate with a 5G Non-Standalone (NSA) network [Festag et al. 2021], analysis of coverage, energy consumption [Xu et al. 2020], and evaluation of network slicing performance for aerial vehicle communications [Garcia et al. 2019].

Table 1 presents a comparative summary of the papers selected to support this work. An initial observation reveals the diversity of test configurations found in the selected papers. Some papers explores 5G NSA networks while others focus on private 5G networks (SA). Both indoor and outdoor environments were exploited and the end devices used vary, including smart phones, drones, SoC (System on a Chip), laptops and desktop PCs. Their organization of experimental scenarios follows a linear complexity progression, starting with a limited number of devices and progressively increasing network traffic in subsequent scenarios [Djuitcheu et al. 2023; Mallikarjun et al. 2022; Festag et al. 2021; Gabilondo et al. 2021; Xu et al. 2020; Garcia et al. 2019].

The metrics commonly used to evaluate the performance of 5G networks converge to Jitter, RTT Latency (Round-Trip Time), Bandwidth and Throughput. Additionally, radio parameters such as RSRP (Received Signal Reference Power), RSRQ (Reference Signal Received Quality) and SINR (Signal-to-Interference-plus-Noise Ratio) are often extracted to evaluate the network quality. As for network performance metrics generation tools, the reviewed works converge on three main open source tools: *iPerf3*, used to generate traffic between devices and extract metrics such as Throughput, Bandwidth, Jitter and Packet Loss [Djuitcheu et al. 2023; Festag et al. 2021; Xu et al. 2020; Garcia et al. 2019]; *Ping*, responsible for measuring RTT Latency [Djuitcheu et al. 2023; Gabilondo et al. 2021; Garcia et al. 2019]; and *Proprietary modem software* like specific software provided by modem manufacturers [Djuitcheu et al. 2023; Mallikarjun et al. 2022].

Table 1. Comparative summary between related works.

Article	Environment	5G Network	Hardware	Metrics	Auxiliary Tools
Djuitcheu et al. 2023	Indoor	SA	Intel NUC i5, Galaxy S22+, Quectel RM500Q-GL, Telit FN980m, Amarisoft callbox Ultimate, Raspberry Pi 3, VERT2450 Antenna and SIM card	Latency, RTT, Bandwidth, Bitrate, Jitter, Packet Loss	Ping, iPerf3, hping3, LOIC
Mallikarjun et al. [2022]	Indoor Outdoor	SA	Quectel RM500Q-GL, Telit FN980 and Huawei P40 Pro	Throughput (DL/UL), Latency, Jitter, RSRP, SINR and RSS	LibreSpeed, Romes, TSME6, TSMA6
Gabilondo et al. [2021]	Indoor	SA	Telit FN980, Sierra Wireless EM9191, Quectel RG500Q-EA and OAI	Latency, Packet Loss and Bandwidth (DL/UL)	Ping
Festag et al. [2021]	Outdoor	NSA	UAV Trinity F90+ by Quantum, Raspberry Pi 4, Telit LM940A11	Throughput, RSRP and Latency RTT	ICPM echo, iPerf3, tcpdump
Xu et al. [2020]	Indoor Outdoor	NSA	ZTE Axon10 Pro, Huawei Mate20 and Huawei Mate30 Pro	RSRP, RSRQ, SINR, CQI, MCS, PRB, UDP and TCP Throughput, Packet Loss and Latency RTT	XCAL-Mobile, iPerf3, Wireshark, traceroute, pwrStrip
Garcia et al. [2019]	Outdoor	NSA	UAV DJI S1000+ Octocopter, Intel NUC computer and Telit LM940	Throughput (DL/UL) and Latency	iPerf3, Ping
This paper	**Indoor**	**SA**	**Telit FN980m, Lenovo Legion 5E, Nokia SIM card**	**RSRP, RSRQ, SINR, UL and DL Throughput, Jitter and Latency RTT**	**iPerf3, Ping**

In this context, this work complements existing literature and lays groundwork for future research on 5G network performance analysis. In addition, the data collected is available in the repository **5G-GitFrontIo**, offering a 5G SA network dataset for researchers lacking a 5G SA test network or requiring comparison in indoor environments.

4. Methodology

To investigate the effectiveness and coverage of the private 5G SA network in an enterprise (INDT building), the following methodology was adopted: first, a Testbed scenario was defined, which consists of defining its duration, which and how many UEs will be used and where they will be positioned and connected - directly to the network Core or to the 5G RAN and NR antennas infrastructure. Next, once the Testbed scenario has been defined, the devices begin to exchange messages through the network, characterizing the Testbed execution stage. At this stage, the logs with the metrics will be saved in $.csv$ files. Finally, the Testbed's execution is completed once the predetermined time limit is reached.

The metrics used to evaluate the network performance through the devices connected to it were: Jitter, Throughput, Latency, RSRP, RSRQ, and SINR. Throughput and jitter analyzes highlight data transmission performance and stability, which are key for understanding network capacity and user experience in time-sensitive applications [Wijethilaka and M. 2021]. The combined coverage metrics offer a comprehensive view of signal quality, crucial for a reliable communication link, by assessing the efficiency of signal reception and the impact of interference and noise. Latency evaluation emphasizes the network's response times, and packet loss rates serve as indicators of data transmission reliability, with high rates pointing to potential network quality issues [Xu et al. 2020].

The hardware used to capture data from the 5G network included the Telit FN980m module, which is an advanced device specifically designed for 5G applications. This device enabled the extraction of RSRP, RSRQ, and SINR data from the network.

5. Experiments and Results

The experiments were conducted in the INDT project laboratory, where the entire 5G network infrastructure is installed. In total, the network has 3 antennas spread across the company's plant, with antenna 1 positioned in the laboratory environment, antenna 2 positioned in the entrance hall and antenna 3 positioned in the office environment. Figure 1 illustrates the place where the antennas are installed.

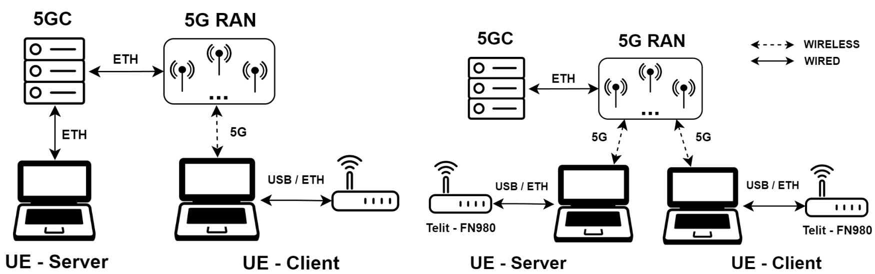
(a) INDT Lab. (b) INDT Hall. (c) INDT Offices.

Figure 1. Antenna position.

5.1. Testbed scenarios

In this research, two testbed scenarios were defined to evaluate 5G SA network performance, Figure 2 presents both scenarios. In the first one (Figure 2(a)), two UEs were chosen. One of them, called UE Server, is connected directly to 5GC because we want to reach the maximum performance of the 5G SA network, eliminating the connection picocels component (5G RAN and 5G NR infrastructure). The Server sends and receives messages to/from the UE Client through UDP and TCP protocols. The UE - Client is connected to a 5G module, that enables 5G wireless communication. The UE Client uses 5G RAN and NR infrastructure.

In the second scenario (Figure 2(b)), both UE client and server are connected to a 5G module, that enables 5G wireless communication. This scenario aims to perform and evaluated a typical UE disposition and use in a 5G SA network. And as well as the previous scenario.

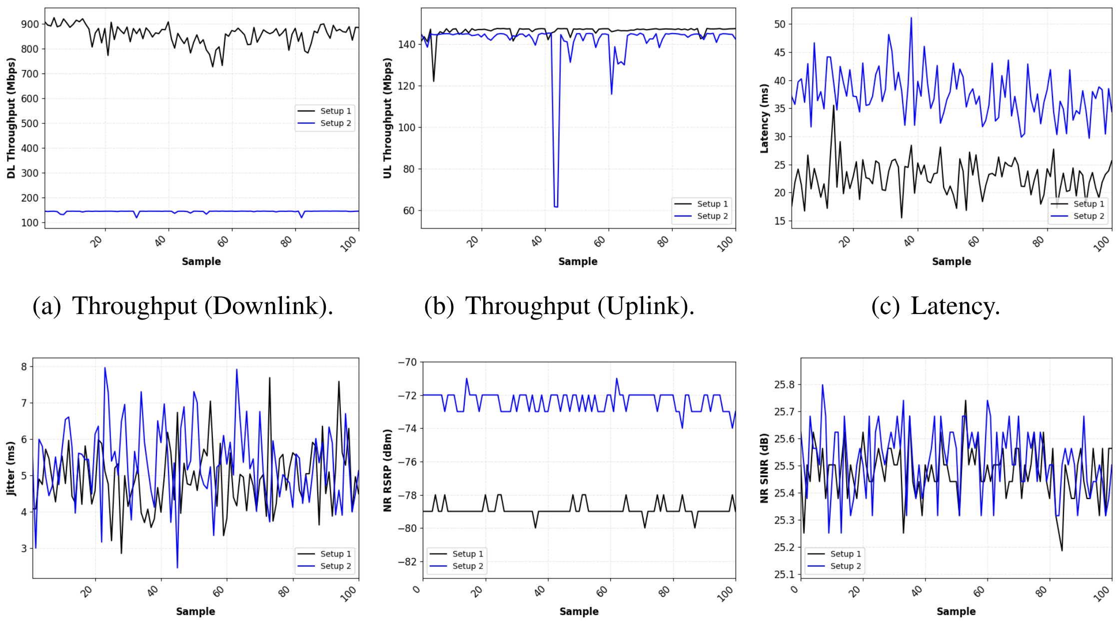


(a) Setup 1. (b) Setup 2.

Figure 2. Testbed Setups.

5.2. Data acquisition and Results Comparison

The experiments were conducted over a period of 1 day. Data acquisition was performed autonomously using scripts developed in Python, generating a dataset with all the parameters obtained. The scripts were responsible for configuring iPerf3, enabling TCP (Throughput and Latency acquisition) and UDP (Jitter acquisition) clients, and also responsible for acquiring the coverage parameters (RSRP, SINR and RSRQ) from the FN980m module control. Figure 3 presents all the metrics obtained during the experiments. Table 2 presents a summary of the main results.



(a) Throughput (Downlink). (b) Throughput (Uplink). (c) Latency.

(d) Jitter. (e) RSRP. (f) SINR.

Figure 3. Collected results.

Table 2. Summary of Results

Metric	Setup	Best Value	Worst value
DL Throughput (Mbps)	1	925.71	727.57
	2	146.12	118.76
UL Throughput (Mbps)	1	147.33	121.94
	2	145.11	61.56
Jitter (ms)	1	2.86	7.69
	2	2.46	7.96
Latency (ms)	1	15.46	35.54
	2	29.64	37.58
RSRP (dBm)	1	-78.00	-80.00
	2	-71.00	-74.00
SINR (dB)	1	25.74	25.19
	2	25.80	25.25
RSRQ (dB)	Both	10	

Regarding the results, it is possible to state that: Latency and jitter exhibited variability across both setups, with Setup 2 experiencing higher and more erratic values, suggesting potential communication interference caused by wireless connection. The SINR, RSRP and RSRQ were measured and compared for both setups. The results obtained did not show relevant differences, as in both setups the client was positioned in the same place. The DL Throughput of Setup 1 significantly surpassed Setup 2, which is justified by the fact that the Setup 1 connection is wired, and does not require certain 5G RAN components (Picocels). The UL Throughput was similar between the configurations because of the 5GC configuration itself, which limits the UL to 15% of the total Throughput value. Investigations into the throughput limitations imposed by the Telit FN980m (Hardware used in Setup 2) are pending, and future studies may provide further insights. In summary, setup 1 presented better performance, with lower and more stable latency and jitter, and higher throughput (UL and DL). This advantage can be explained by the device's wired connection directly to the 5GC, enabling more direct access to the 5G network.

6. Conclusions

In this work, a performance analysis was performed between 5G devices in a private 5G SA network. In this way, parameters such as Jitter, Throughput, Latency, RSRP, RSRQ and SINR were observed. The chosen methodology was successfully implemented, validating the objectives proposed in this work, contributing to the enrichment of the literature on the topic. The results obtained showed differences between the setups used, serving as a reference for future studies of connectivity between 5G devices. Finally, we have publicly released our datasets to facilitate 5G exploration in future studies.

In future work, the concepts of this work will be applied in configurations involving autonomous robots, optimizing the collection process from automated drive-tests, and facilitating the process of measuring and analyzing the parameters of a 5G network.

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