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5G Campus Network : First Measurement Study

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Abstract: *5G campus networks (private networks dedicated to specific organisations)are envisioned to enable industry 4.0 use cases, such as cyclic delay-sensitive robot control .However ,prior testing has focused primarily on physical layer characteristics or public networks, leaving a knowledge gap regarding the actual packet-level performance(latency and loss)of private 5G standalone (SA) and Non-standalone (NSA) networks.*

Keywords: 5G Non-Standalone, packet loss,5G Standalone (SA),latency, one-way delay, Quality of service (QoS), Industrial internet of Things, Industry 4.0,Time-sensitive Networking, packet core, Radio Access Network

I. INTRODUCTION

5G Campus Network

A network dedicated to a specific organization covering a prescribed geographical area.

Modes of Operation:

Non-Standalone (NSA): Uses 4G LTE for control plane/spectrum anchor, 5G NR for data plane. Standalone (SA): Operates exclusively on 5G NR and 5G Core (5GC); no LTE required.

The Motivation Gap:

Prior studies focused on physical layer (EMF exposure, coverage) or used public networks (RTT/Ping only).

The Problem: Packet-level performance (One-Way Delay, Core Processing Delay) for private campus networks was largely unknown.

The Goal: Design a rigorous testbed to measure delay components with sub-microsecond precision

II. METHODOLOGY

1. Testbed Architecture and Setup

The testbed was constructed using real 5G SA and 5G NSA hardware to ensure realistic measurements.

Network Components :

- Packet Cores: The setup used Open5GS (Version 2.2.1) open-source core for SA measurements, and a proprietary Nokia packet core for NSA measurements.
- Radio Access Network (RAN): Consisted of Nokia Baseband Units (BBUs) and antennas for both the 4G (LTE) and 5G (NR) parts.
- End Devices: A WNC SKM-5xE Router was used for SA, and a Nokia FastMile 5G Gateway for NSA.
- Connectivity: The SA and NSA cores and RAN were connected via an ICX 7850 switch by Ruckus.
- Traffic Directions: Measurements were conducted separately for two directions:
- Download (Downstream): From the core to the end device.
- Upload (Upstream): From the end device to the core.
- Duration: Each single measurement scenario was run for 1000 seconds to ensure stable results, in contrast to earlier studies that used smaller packet sets.

2. Data Traffic Generation and Measurement

A dedicated traffic generation and capture system was used to ensure high measurement precision.

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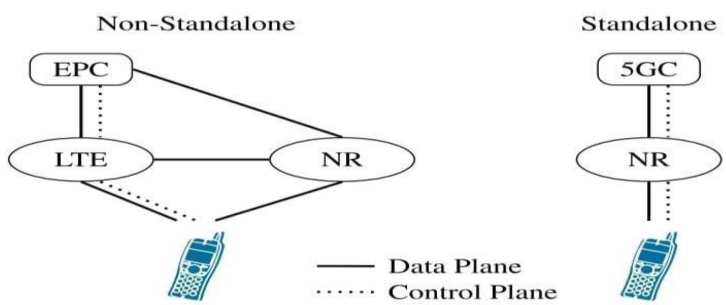
- Traffic Tool: The MoonGen software was selected for traffic generation and capture, running on a commodity PC with Intel x550 Network Interface Cards (NICs).
- Traffic Type: Constant Bit Rate (CBR) traffic was generated, which is typical for automation use cases.
- Precision: The NICs are capable of generating and capturing timestamps for every incoming packet with nanosecond precision for core delay measurements, and sub-microsecond precision was achieved for the one-way delay measurements.
- One-Way Delay (OWD) Measurement: The OWD (ΔT_{OWD}) was measured as the difference between the receive timestamp (T_{RX}) and the transmit timestamp (T_{TX}). Crucially, both timestamps were captured on the same machine clock to eliminate the need for complex machine synchronization.
- Core Delay Measurement: To measure the processing delay caused by the SA and NSA packet cores in isolation, the mirror function of the switch was utilized. This allowed a copy of the packet before and after core processing to be captured on the same NIC port, allowing the time difference (core processing delay) to be measured with nanosecond precision.

3. Performance Metrics

The study focused on two key packet-level performance characteristics:

- One-Way Delay (OWD): Measured to allow for a detailed investigation of the individual download and upload delay components, which is a benefit over traditional Round-Trip Time (RTT) measurements.
- Packet Loss: The study aimed to evaluate the overall end-to-end (ϵ_{E2E}) packet loss probability. The RAN packet loss probability (ϵ_{RAN}) was calculated indirectly by subtracting the measured core packet loss probability (ϵ_{Core}) from the overall E2E loss.

DIAGRAM



Non-Standalone (NSA)

This mode is on the left side of the diagram.

- Core Network: It utilizes the existing Evolved Packet Core (EPC) from the 4G LTE network.
- Control Plane (Dotted Lines): The LTE eNodeB is responsible for the control plane signaling (like connection setup, mobility management) between the user equipment (mobile device) and the EPC.
- Data Plane (Solid Lines): Data traffic can be carried over both the LTE access network and the new 5G NR access network, often simultaneously, offering higher data rates by aggregating the two.
- Key Feature: NSA provides a faster way to deploy 5G services by leveraging the existing 4G core and infrastructure, using 5G NR primarily for faster data speeds. It relies on the 4G network as an anchor.

Standalone (SA)

This mode is on the right side of the diagram.

- Core Network: It utilizes the new, cloud-native 5G Core (5GC).

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- Control Plane & Data Plane (Dotted and Solid Lines): The 5G NR gNB handles both the control plane and data plane connections between the user equipment and the 5GC independently of 4G.
- Key Feature: SA is the true 5G architecture, enabling all advanced 5G capabilities, such as ultra- low latency, massive device connectivity, and Network Slicing. It does not rely on the 4G network for its co

III. CONCLUSION

The study developed a high-precision measurement testbed to rigorously evaluate the one-way end-to-end download and upload packet delays and losses in private 5G Standalone (SA) and 5G Non-Standalone (NSA) campus networks. The setup allowed for isolating the delays in the Radio Access Network (RAN) and the packet core.

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