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Implementation of 5G Standalone Private Network for UHD Video Streaming

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Abstract – *The limited 5G access in Palembang, with the public provider primarily using a Non-Standalone (NSA) architecture across only nine locations, presents a significant challenge for applications requiring high-performance connectivity, such as Ultra High Definition (UHD) video streaming. This study demonstrates the development and implementation of an affordable private 5G Standalone (SA) network as a viable, high-performance alternative. A private 5G SA network was constructed using open-source Open5GS software and a Universal Software Radio Peripheral (USRP) B210. Its performance was evaluated through speed tests and traffic analysis during 4K and 8K video streaming and then compared against the public 5G NSA network in Palembang. The results showed that the private SA network delivered a significantly faster upload speed of 179.91 Mbps, outperforming the public NSA network's maximum of 103.75 Mbps. The private network also maintained a more consistent low latency of 40.00 ms, whereas the public network's performance was inconsistent, with latency varying up to 144.00 ms. Although some public NSA locations provided higher download speeds, both network configurations achieved flawless data transmission with zero packet loss during UHD streaming. This research further confirms that the private SA network not only meets but exceeds the essential Quality of Service (QoS) thresholds for UHD streaming, demonstrating superior performance in jitter and delay parameters. The experimental setup also provides a concrete reference for practical implementation using accessible tools and components, filling the gap between simulated environments and real-world low-cost deployments. The novelty of this study lies in its end-to-end deployment using a SISO architecture and unlicensed spectrum, a configuration rarely explored in comparable studies. It establishes a baseline performance benchmark that can be scaled for future enhancements, such as multi-user support or MIMO-based expansion. This study provides a practical contribution by demonstrating a cost-effective, real-world deployment that bridges the gap between theoretical simulations and expensive private network deployments, proving that a private SA network can outperform existing public infrastructure in key metrics.*

Keywords – *5G Standalone; Private Network; Software-Defined Radio; UHD Video Streaming; Quality of Service.*

I. INTRODUCTION

THE digital revolution has become a catalyst for innovation within society. One of its primary forms is creative content in visual formats, such as images and videos. As a result, a wide variety of creative content is now widely found on various Over-the-Top (OTT) platforms, like YouTube, Instagram, and TikTok. According to surveys, users on OTT platforms tend to prefer Ultra High Definition (UHD) video content over High Definition (HD) [1]. This preference could be a key driver for the shift towards next-generation mobile networks.

Today, 5G networks are designed for many usage scenarios, including flawless UHD video streaming [2]. However, the reality in Indonesia presents significant challenges. As of April 2025, 5G network coverage had only reached 4.44% of the total national area [3]. Moreover, the 5G network in several regions is predominantly based on the Non-Standalone (NSA) architecture [4, 5]. These issues might make it difficult to satisfy the demand from Indonesian OTT users for a higher-quality streaming experience.

As an alternative mitigation strategy, 5G networks can be built independently by leveraging open-source technology and Software-Defined Radio (SDR) [6]. One SDR platform that can be used to build a 5G network is the Universal Software Radio Peripheral (USRP). There are many types of USRPs, namely the B, E, N, and X series [7]. In this setup, the USRP will act as the Base Transceiver Station (BTS) for the 5G network.

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To build an independent 5G network, it's essential to understand the different 5G architectures. There are two primary architectures for deploying a 5G network. Standalone (SA) and Non-Standalone (NSA) are the global architecture options to build 5G network [8].

The Core Network (CN) of a Standalone architecture differs from Non-Standalone. Unlike NSA, which relies on the existing 4G Evolved Packet Core (EPC), the SA architecture uses a new, cloud-native 5G Core (5GC) [8]. 5G Standalone exclusively uses Next Generation NodeB (gNB) base stations that connect directly to the 5GC. In contrast, Non-Standalone uses "dual connectivity," which combines both 4G's eNB and 5G's gNB base stations [9].

In a Standalone setup, control is handled end-to-end within the 5G ecosystem [10]. In a Non-Standalone setup, however, all signalling control still depends on the 4G core [11]. Additionally, the Standalone architecture is more flexible because a new 5G Core can be deployed privately [12].

This study demonstrates the development of a private 5G Standalone (SA) network using a USRP B210 and Open5GS, offering a fully functional and affordable solution. Unlike previous research, which was often limited to simulations [13–18], relied on more expensive hardware [19, 20], or used different 3GPP-compliant 5G core networks [21–23], the network's performance was evaluated through speed tests and traffic sniffing analysis during UHD video streaming to validate its potential as an alternative for 5G network deployment.

II. RESEARCH METHODS

This study uses a comparative experimental approach, which involves designing and testing a private 5G Standalone (SA) network and then comparing its performance with a public 5G Non-Standalone (NSA) network.

i. Private 5G SA Testbed

As illustrated in Figure 1, the private 5G Standalone (SA) network architecture is built using the srsRAN stack. The stack runs on a gaming laptop with an x86-64 architecture and the Linux operating system. This laptop serves as the Baseband Unit (BBU), responsible for all data processing. Meanwhile, radio signal transmission and reception are handled by a USRP B210 from Ettus Research.

USRP device acts as the Remote Radio Unit (RRU), responsible for receiving, transmitting, filtering, and amplifying radio frequency signals. Due to its flexibility and reprogrammability, the USRP is ideal for this project. It allows for the dynamic configuration of key parameters (e.g., radio protocol, frequency, modulation, gain), ensuring adaptability to diverse conditions such as interference, noise, or high data traffic. To achieve a moderate level of throughput, the USRP is configured to operate in SISO (Single-Input Single-Output) mode, which uses a single transmit and a single receive antenna, without beamforming technology.

The BBU and RRU (fronthaul) are bridged using a USB 3.0 Type B cable to ensure high-speed data transfer. Meanwhile, the Core Network is implemented with Open5GS. The backhaul connection between the BBU and the Core Network is established using a 1 Gbps switch and LAN cable. A Samsung A56 handset is used as the User Equipment (UE) to test the network's functionality.

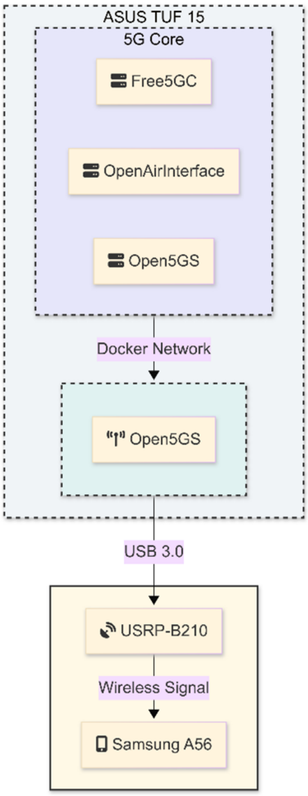


Figure 1: Testbed for Private 5G Standalone

As depicted in Figure 2, the workflow for building a private 5G SA network on unlicensed bands begins with configuring the 5G Core Network (CN) on Ubuntu by setting up Open5GS and its primary functions (AMF, SMF, UPF, and UDM). Once the Core Network is operational, the administrator provisions subscriber data, such as IMSI and authentication keys, into the Open5GS database. Subsequently, the gNB (next-generation NodeB) is configured using srsRAN, which manages communication between the radio unit and the Core Network. After completing the gNB configuration, prepare the User Equipment (UE) by setting the Access Point Name (APN) and inserting the registered SIM card. Lastly, verify system connectivity by checking if the UE can access the internet via the 5G SA network. The entire process is considered successful if a stable and accessible internet connection is established.

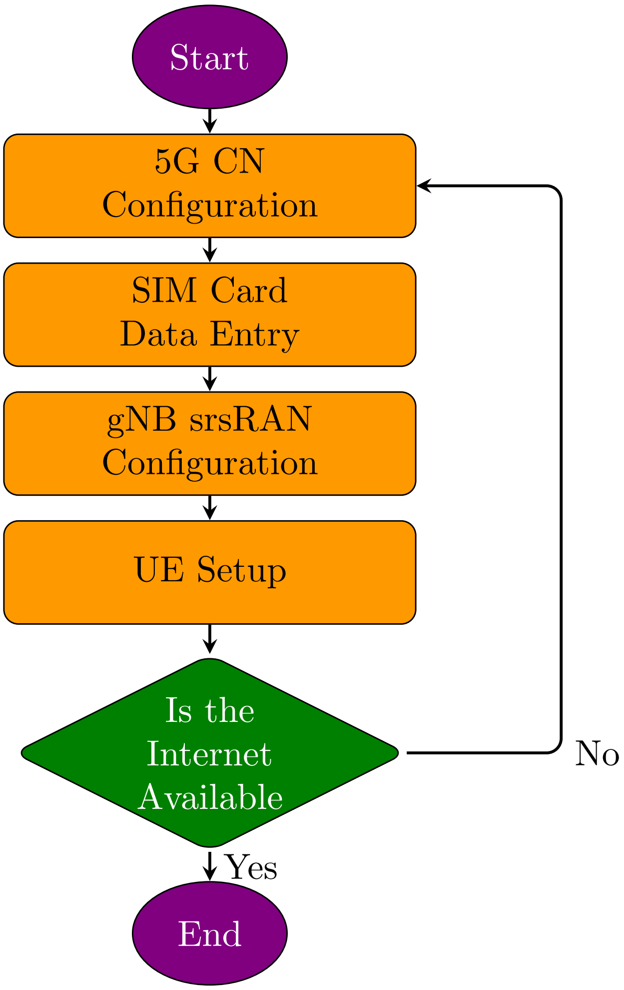


Figure 2: Flowchart of Private 5G SA Deployment

ii. 5G CN Configuration

The 5G Core Network (CN) configuration process is relatively straightforward and does not require significant changes from the default parameters. The main adjustments are focused on `gnb.conf` and `rr.conf`. Within `gnb.conf`, the Access and Mobility Management Function (AMF) and User Plane Function (UPF) IP address, Mobile Country Code (MCC), and Mobile Network Code (MNC) are adjusted. Meanwhile, in `rr.conf`, the operating frequency band is configured as needed. For example, to operate on band n3, the band parameter is set to 3. Upon completing the AMF and UPF configuration, the service is restarted, and its log is monitored in a separate window for verification.

iii. 5G NSA Location Identification

To provide a comparative result for the private network, a commercial 5G Non-Standalone (NSA) network in Palembang was also tested. The testing locations were selected based on the officially published 5G coverage points provided by the internet service provider (ISP), Telkomsel [24].

iv. Performance Evaluation

The performance evaluation methodology involved two primary activities: speed testing and traffic sniffing. Tests were conducted to validate whether network performance met the recommended thresholds of 50 Mbps for 4K video and 300 Mbps for 8K video [25]. The procedure was carried out as follows.

The test preparation phase involves installing nPerf and Wireshark, and selecting a YouTube video with specific technical specifications for data traffic analysis. The selected video (ID: `t51rXwQk1zw`) has 4K and 8K resolutions at 60 fps, using the VP9 video codec and the Opus audio codec. It includes BT.709 color space, DRC (0.7 dB) audio normalization, and a test viewport of 720×405 pixels (1.35 scale).

The throughput is measured by calculating the total amount of data transmitted over the entire duration of the video. Two metrics are collected: the total number of bytes transferred and the total duration of the transfer. The throughput is then computed using Equation (1):

$$\text{Throughput} = \frac{\text{Total Bytes}}{\text{Time Span}} \tag{1}$$

Packet loss is calculated by comparing the number of packets sent to the number of packets successfully received. The percentage of packet loss is determined using Equation (2):

$$\text{Packet Loss (\%)} = \frac{\text{Packet Sent} - \text{Packet Received}}{\text{Packet Sent}} \times 100 \tag{2}$$

Delay is measured by calculating the time difference between the transmission and reception of packets. The average delay is computed using Equation (3):

$$\text{Average Delay} = \frac{\text{Total Delay}}{\text{Total Packets}} \tag{3}$$

Jitter, defined as the variation in delay between successive packets, is calculated using Equation (4):

$$\text{Average Jitter} = \frac{\text{Total Jitter}}{\text{Total Packets}} \tag{4}$$

v. Quality Classification (ITU-T G.1010)

Measurement results are categorized based on ITU-T G.1010 standards [25], as shown below.

Table 1: Jitter Classification

Degradation Category	Peak Jitter
Excellent	0 ms
Good	0–75 ms
Poor	76–125 ms
Unacceptable	> 125 ms

Table 2: Packet Loss Classification

Degradation Category	Packet Loss
Excellent	0%
Good	1–3%
Poor	4–15%
Unacceptable	> 16%

Table 3: Delay Classification

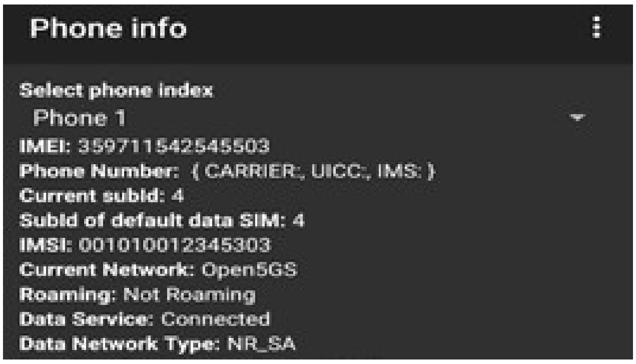
Delay Category	**Delay**
Excellent	< 150 ms
Good	150–300 ms
Poor	300–450 ms
Unacceptable	> 450 ms

III. RESULTS AND DISCUSSION

In this study, we derived the results from conducting and interpreting trials.

i. Private 5G SA Initial Testing

After the gNB is configured and the APN is set on the UE, phone information is checked by dialing `*#*#4636#*#*` as shown in Figure 3, to ensure connectivity to the 5G SA network and verify active data communication.



Phone info

Select phone index
Phone 1
IMEI: 359711542545503
Phone Number: { CARRIER:, UICC:, IMS: }
Current subId: 4
SubId of default data SIM: 4
IMSI: 001010012345303
Current Network: Open5GS
Roaming: Not Roaming
Data Service: Connected
Data Network Type: NR_SA

Figure 3: Phone Information Display

Following UE's connection to the NR_SA network, real-time automated statistics are monitored using the Text User Interface (TUI) of the srsRAN gNB, shown in Figure 4. The following observations are made:

1. The Physical Cell ID (PCI) remains consistently at 4601, confirming data from a single BTS.
2. Channel Quality Indicator (CQI) is 15, indicating excellent SINR.
3. Modulation and Coding Scheme (MCS) ranges from 23–27, corresponding to 256-QAM modulation (3GPP TS 38.214).
4. Despite single spatial layer use (Rank Indicator = 1), the HARQ is flawless, and BLER is nearly zero.
5. Buffer Status Reports (BSR) and Power Headroom Reports (PHR) confirm active transmission and ample power margin.

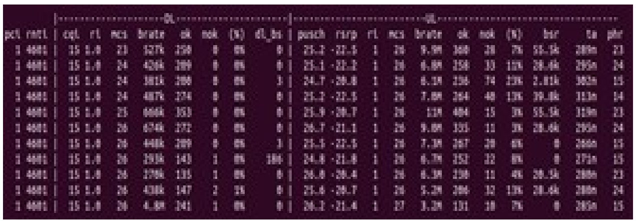


Figure 4: srsRAN gNB Trace

ii. 5G NSA Location

Once 5G SA connectivity is verified, the next step is identifying Telkomsel's 5G NSA locations in Palembang, as seen in Figure 5. Nine active locations are summarized in Table 4.

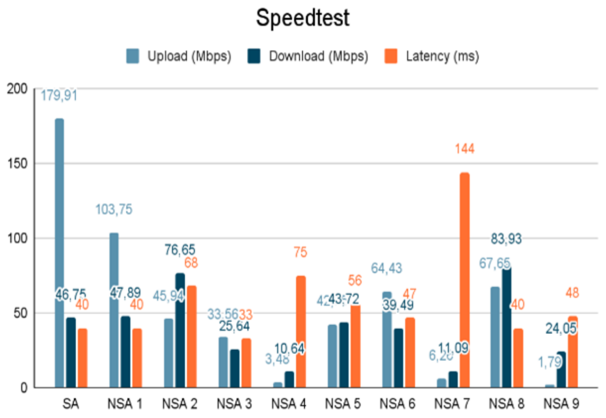


Figure 5: 5G NSA Coverage Map in Palembang

iii. Speed Test

This test aims to measure availability and latency performance of SA/NSA networks using the nPerf app. Results are shown in Table 5.

The data reveals that SA networks show superior upload performance (179.91 Mbps) compared to NSA.

Table 4: 5G NSA Locations in Palembang

Name	**Location**
NSA 1	Benteng Kuto Besak
NSA 2	Telkomsel Smart Office
NSA 3	Telkom Akses Sumsel
NSA 4	Palembang Square Mall
NSA 5	The Arista Hotel
NSA 6	Jalan Papera
NSA 7	RSUP Dr. Moh Hoesin
NSA 8	PT Telkom Indonesia
NSA 9	PTC Mall

Table 5: Speed Test Result on 5G SA and NSA

Name	Upload (Mbps)	Download (Mbps)	Latency (ms)
SA	179.91	46.75	40.00
NSA 1	103.75	47.89	40.00
NSA 2	45.94	76.65	68.00
NSA 3	33.56	25.64	33.00
NSA 4	3.48	10.64	75.00
NSA 5	42.35	43.72	56.00
NSA 6	64.43	39.49	47.00
NSA 7	6.26	11.09	144.00
NSA 8	67.65	83.93	40.00
NSA 9	1.79	24.05	48.00

However, NSA 2 and NSA 8 outperform SA in download speed. Latency on SA is consistent (40 ms) and matches the best NSA cases, but NSA networks show wide variation (40–144 ms). The performance levels support both 4K and 8K video streaming.

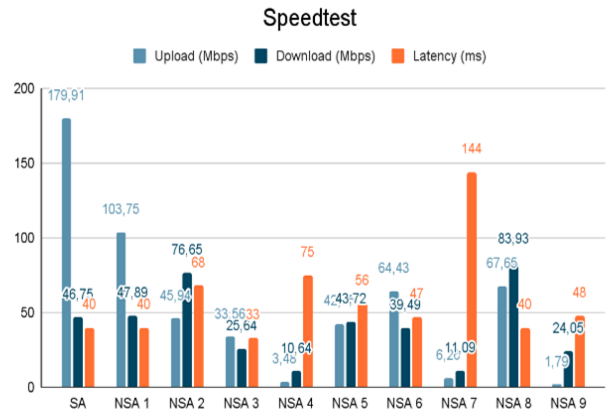


Figure 6: Speed Test Results Comparison

iv. *Traffic Sniffing*

Data on throughput, packet loss, delay, and jitter were collected by sniffing 4K and 8K video stream traffic. This traffic sniffing was performed on the 5G SA network and NSA 1 network.

v. *Throughput*

Table 6 shows that for 4K video streaming, the 5G SA network achieved a throughput of 1821 kbps, while the 5G NSA network reached 1363 kbps. This performance increased substantially for 8K video, with throughput values of 460,339 kbps (SA) and 443,622 kbps (NSA). Overall, both network configurations delivered very high throughput, with the SA network offering slightly better performance.

Table 6: Throughput Result

Network	4K Throughput (kbps)	8K Throughput (kbps)
5G SA	1821	460339
5G NSA	1363	443622

vi. *Packet Loss*

The test results for the Packet Loss parameter indicated optimal performance across both network architectures. A Packet Loss value of 0% was recorded in all streaming test sessions on both the 5G SA and 5G NSA networks. This indicates a 100% packet delivery rate and highly reliable data transmission.

vii. *Delay*

The average delay values for both 5G networks demonstrate their capability to minimize travel time to under 10 ms. As shown in Figure 6, the SA network maintained slightly better performance compared to NSA. This capability is important for real-time applications and UHD streaming.

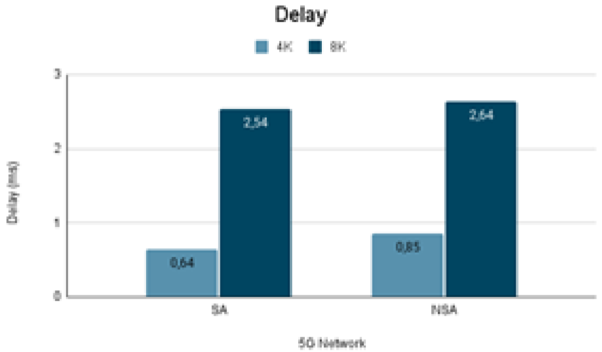


Figure 7: Graph Delay 5G SA and NSA

viii. *Jitter*

Jitter analysis in Figure 7 reveals that while the NSA network showed the lowest jitter overall (0.00002 ms), the SA network proved to be more stable during 8K video streaming, recording lower jitter (0.00003 ms) than NSA in that scenario. According to international standards, jitter performance for both networks is classified as excellent.

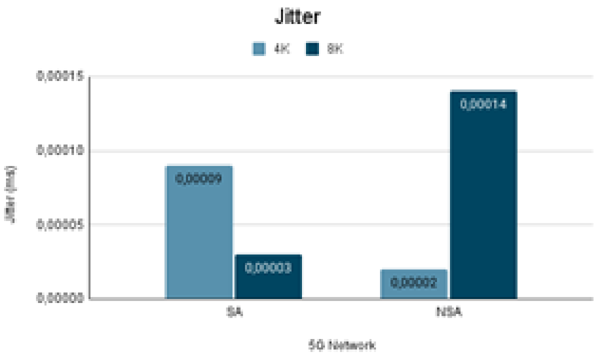


Figure 8: Graph Jitter 5G SA and NSA

IV. CONCLUSION

This study successfully demonstrated that a private 5G Standalone (SA) network, built with affordable open-source Open5GS software and a USRP B210, is a highly effective and flexible alternative to public 5G Non-Standalone (NSA) networks. The results showed that while some public NSA locations offered higher download speeds, the private SA network delivered a significantly faster upload speed of 179.91 Mbps compared to the public network's maximum of 103.75 Mbps.

The private network also maintained a consistent low latency of 40.00 ms, in contrast to the public NSA network's variable performance, which ranged up to 144.00 ms. Both configurations achieved flawless data transmission with zero packet loss during UHD streaming, confirming their reliability for 5G usage scenarios.

The primary contribution of this research is the practical validation of this low-cost architecture, providing a replicable model for deploying localized 5G services. Although this evaluation was limited to a single-user, single-antenna (SISO) setup, it confirms the architecture's potential. Future work should therefore focus on scalability testing with multiple users and the implementation of more advanced 5G features.

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