Performance Evaluation and Comparison between SA and NSA 5G Networks in Indoor Environment

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***Abstract*—Providing omnipresent 5G cellular connectivity is very appealing to advance a wide range of use cases and industry verticals. However, it is expected that the commercial rollout of 5G networks will be progressive starting from 5G radio access network (RAN) integrated with existing 4G networks, i.e., non-standalone (NSA), to full 5G architecture with both 5G RAN and 5G core, i.e standalone (SA). Hence, it is of utmost importance to evaluate and compare the performance of these SA and NSA networks so as to examine if the requirements of 5G-reliant use cases can be met. In this regard, this paper conducts preliminary field trials for SA and NSA 5G networks based on a self-contained 5G base station. The performance of both networks is compared under different system setups, and key performance indicators (KPIs) such as data rate and latency are measured. Preliminary results reveal that the achievable uplink rate from SA 5G networks slightly outperforms that of the NSA counterpart under the same 5G RAN setup. Moreover, the network latency of SA and NSA networks are shown to be comparable.**

***Index Terms*—5G core (5GC), new radio (NR), standalone 5G, non-standalone 5G.**

I. INTRODUCTION

A. Background

With the emergence of new use cases and applications in the telco mobile space, the fourth-generation (4G) mobile communication limitations have become a bottleneck standing in the way of mobile networks adoption in a number of strategic industry verticals with specific and stringent requirements. These verticals include, but not limited to, virtual reality (VR), factories of the future (FoF), smart transportation, smart cities and buildings, and smart ports. The fifth-generation (5G) mobile communication is introduced to enable mobile and ubiquitous communications for such industry verticals as it designed with key pillars, particularly, *programmability, openness, resource sharing, and edgification* [1]. This includes improvements in both the core and radio access network (RAN), which warrants high multi-gigabit speeds, ultra-high reliability, low-latency, and high connection density. This paved the road for the introduction of three service classes referred to as slices, namely, enhanced mobile broadband (eMBB), massive machine-type communication (mMTC) and ultra-reliable low-latency communications (URLLC).

To allow for a swift transition from 4G to 5G networks, non-standalone (NSA) 5G architecture is introduced, whereby the 5G RAN is integrated with the current 4G systems [2]. This is considered the first phase of the 5G rollout. The rollout second phase will then allow unleashing the full potential of 5G by integrating 5G RAN to the 5G core (5GC) forming the standalone (SA) 5G networks [3]. In this paper, we focus mainly on highlighting the key technical differences between the two 5G architectures and conducting preliminary field trials based on a 5G testbed. Next, we review some of the works relevant to performance evaluation and field trials of 5G networks.

B. State-of-the-Art and our Contributions

Recently, there has been significant research related to the 5G performance evaluation and field trials driven by the increasing pace of rollout of this foreseen technology. For example, the authors in [4] conducted real measurements on an NSA 5G architecture. They showed that if the traffic preferences are well-configured, latency and jitter are not significantly impacted by the load of the cell or the core network (CN). In addition, based on simulations in [5], the authors compared the performance of SA and NSA 5G new radio (NR) deployments in terms of coverage, network capability, and cost of deployment. Moreover, the authors in [6] conducted performance analysis of the NSA 5G architecture by means of simulations and alluded to the dual-connectivity options in 5G. However, while the works in [4]–[6] explored the performance of SA and NSA 5G networks, they did not conduct field trials to compare their performance under different environmental setups.

The performance of NSA 5G networks was also evaluated in the recent works, see, e.g., [7] and [8]. The authors in [7] addressed the shortcomings of NSA operation by means of quality-of-service (QoS) configurations. Moreover, in [8], the authors reviewed the beam management procedures included in the 3GPP NR specifications and proposed possible enhancements to improve the network control operations. While interesting, none of these prior works compared the SA and NSA 5G networks based on real field trials. To the best of our knowledge, the performance evaluation and comparison between 5G SA and NSA networks based on a real 5G deployment has not been yet carried out in the literature.

The main contributions of this work are as follows:

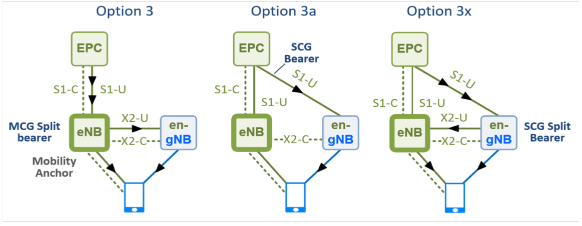

Fig. 1: NSA 5G Option 3 variants (source 3GPP TR 38.801).

- We provide a comprehensive technical comparison between SA and NSA 5G networks and highlight the key advantages of leveraging 5GC in SA 5G networks.
- We describe the key configuration setup of SA and NSA 5G technologies based on a self-contained 5G base station deployed in our testbed. We then leverage this base station to evaluate the performance of these 5G networks.
- Under different network setups, we measure multiple key performance indicators (KPIs) such as downlink (DL) and uplink (UL) data rates and latency for both SA and NSA 5G networks. Overall, preliminary results show that the UL data rate is slightly higher for SA 5G network, while the NSA 5G network achieves a higher DL data rate.

The rest of this paper is organized as follows. Section II and Section III present, respectively, the NSA and SA 5G networks. Section IV studies the performance of the two network models under different environmental setups where our numerical results are presented. Section VI concludes the paper and presents future work.

II. 5G NON-STANDALONE NETWORKS

In this section, we focus on the 5G NSA architecture with a detailed description of its components, network functions and interfaces, as well as its operation mode. We also describe our NSA 5G testbed with regards to the reference architecture.

A. *Background*

5G NSA architecture is proposed by the 3rd generation partnership project (3GPP) as part of Release 15 in order to help mobile network vendors and operators in their transition from 4G to 5G [9]. This release defined a number of optional architectures for NSA 5G networks. However, among many candidates, one architecture stood out as the typical approach supported by mobile networks, whereby 4G core, i.e., evolved packet core (EPC), is interfaced with the next-generation node B (gNB) to enable 5G NR functionalities. This architecture is referred to as Option 3 in 3GPP (see Fig. 1) [10]. In this configuration, two cells are used: an evolved node B (eNB) and a gNB. The dual cells configuration enables the dual connectivity (DC) feature which is carried over to 5G from 4G. This feature allows a user equipment (UE) to connect to two cells simultaneously which help improve the throughput and mobility support. DC defines a master cell group (MCG) as the eNB and a secondary cell group (SCG) as the gNB. The connection between the two cell groups is then ensured via the X2 reference interface.

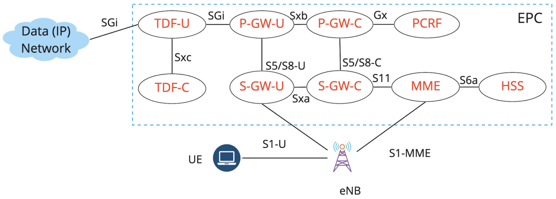

Fig. 2: Architecture of the EPC with CUPS adopted.

Option 3 is categorized into three variants or with subtle differences. The key differences are in selecting the bearer for the user plane (UP), which are the tunnels that connect the UE to a packet data network (PDN) such as the Internet. These configurations are illustrated in Fig. 1, which can be understood as follows: (i) Option 3 uses the eNB as a MCG split bearer. This means that UP data is routed using the S1-U interface through the eNB to both the gNB (using X2-U interface) and directly to the UE; (ii) Option 3a uses a SCG bearer which means the UP data for 5G NR UEs is only routed through the gNB (using S1-U interface); (iii) Option 3x uses a SCG split bearer which means the UP data is routed through the gNB (using S1-U interface) to both the eNB (using X2-U interface) and directly to the UE. As stated earlier, the connection between the NSA 5G core and the RAN is ensured through the S1 reference interface. This interface is defined in Fig. 1 as S1-C for the control plane (CP) and S1-U for the UP. This separation is introduced in 3GPP Release 14 and defined an updated EPC architecture with the control/user plane separation (CUPS) [2].

The NSA 5G core functions are explained the sequel. The NSA 5G core is composed of the following functions (see Fig. 2) [10]. The mobility management entity (MME) controls the high-level operation of the UE such as storing the UE's idle state context, temporary identities, authorisation as well as authentication. It is connected to the eNB through the S1-MME interface. The home subscriber server (HSS) interfaces with the MME via S6a interface and represents a database containing information about the subscribers' profiles. It also performs user authentication and provides information about the user's IP and location. The serving gateway (S-GW) represents a gateway as it forwards the incoming data from the PDN such as the Internet towards the eNB via S1-U interface. It is also connected to the MME through the S11 interface. The S-GW is split into S-GW-user (S-GW-U) and S-GW-control (S-GW-C) for the UP and CP, respectively. A new interface called Sxa is defined to ensure communication between the two newly-split functions. The packet data network gateway (P-GW) provides functionality for interfacing with external IP networks such as the Internet. It is connected to the S-GW through the S5/S8 interface. The P-GW is also split into P-GW-user (P-GW-U) and P-GW-control (P-GW-C) with Sxb being the linking interface. The policy control and charging rules function (PCRF) is responsible for policy enforcement, service flow detection, as well as controlling the flow-based charging functionalities. It uses the Gx interface to connect to the P-GW.

Moreover, it uses the Rx interface to connect to external application functions (AFs) such as an IP multimedia subsystem (IMS). Finally, the traffic detection function (TDF) provides functionality for managing data services by enabling traffic optimisation as well as charging and content manipulation. The TDF enforces static or dynamic policies on real-time traffic flows. It uses the SGi interface and sits between the PDN and the P-GW. The main communication protocol within the NSA 5G core is GPRS tunneling protocol (GTP) [11]. It provides tunnels between the gNB and both the S-GW and the MME, as well as between the S-GW and the P-GW. The GTP protocol is also divided into GTP-control (GTP-C) and GTP-user (GTP-U) following the move to CUPS. However, GTP is replaced by packet forwarding control protocol (PFCP) for the new interfaces Sxa and Sxb [12].

B. Testbed for NSA 5G networks

In our testbed, we use Amarisoft Callbox Classic, which is a self-contained 5G base station deployed in an indoor environment. The base station accommodates the functionalities of 5GC and 5G RAN and supports SA and NSA modes of operation [13]. It contains two pre-deployed network slices, namely, eMBB and mMTC. The NSA 5G setup consists of two cells, namely, eNB and gNB, and SCG configuration, where the gNB acts the bearer for UP traffic. This configuration setup is motivated by our intention to present a fair and accurate comparison between SA and NSA 5G performances where in both cases, only 5G NR is used for the UP data with the same radio parameters (bandwidth, duplex mode, etc.). The full list of parameters used in our study is presented in Section IV.

C. 5G Radio Access Network

Having described the NSA 5G CN, for completeness, we next highlight the key enhancements adopted in 5G RAN as opposed to the 4G counterpart. Noticeably, the 5G RAN architecture is the same for both SA and NSA 5G networks. The CP of 5G RAN incorporates the radio resource control (RRC) and non-access stratum (NAS) as sub-layers of its Layer 3. For Layer 2, the service data adaptation protocol (SDAP) is introduced in the UP of 5G RAN to be responsible for mapping between QoS flow and data radio bearer (DRB). Some new features are also added to the packet data convergence protocol (PDCP) regarding reordering and duplicate detection and duplication of the PDCP protocol data units (PDUs). Moreover, concatenation and reordering are not provided in the radio link control (RLC) so as to meet extreme latency demands in 5G. Finally, logical channel prioritization is supported in the medium access control (MAC) [14].

III. 5G STANDALONE NETWORKS

We next turn our attention to the description of SA 5G CN. In principle, 5GC is at the heart of the 5G specification to meet the stringent service requirements in future wireless networks. It utilizes cloud-aligned service based architecture (SBA) that spans across all 5G functions and interactions including, authentication, security, session management and aggregation of traffic from end devices [15]. 5GC further emphasizes network function virtualizatio (NFV) as an integral design concept with virtualized software functions [16].

A. Background

Let us first explain how session requests are handled within the 5GC [17]. UEs as well as the gNB use next generation application protocol (NGAP) to carry NAS messages across the N1 and N2 reference interfaces, respectively (see Fig. 3). Within the 5GC, the access and mobility management function (AMF) receives these requests and handles anything to do with connection or mobility management while forwarding session management requirements over the N11 interface to the session management function (SMF). The N11 interface, which is assigned by the NF repository function (NRF), uses the service based interface (SBI) message bus to which all service-based application elements are connected. In addition to the AMF, the SMF is another key element for the 5G SBA as it is responsible for interacting with the decoupled UP to create, update, and remove PDUs sessions and manage session context with the user plane function (UPF).

The AMF is connected to unified data management (UDM), authentication server function (AUSF), and policy and charging function (PCF) through the interfaces N8, N12, and N15, respectively [18]. Besides, the SMF is connected to the PCF and UDM through the interfaces N7 and N10, respectively [17]. The AUSF is part of the 3GPP 5G architecture to facilitate the 5G security processes. The PCF is also part of the 3GPP 5G architecture used to provide policy rules to CP functions, including network slicing, roaming, and mobility management, charging and enforcing subscriber policies. To do so, the subscription information is gathered from the UDM. The UDM is basically a centralized way to control network user data either statefully, i.e., from data stores local to where the UDM is running, or statelessly, i.e., from data stores in the unified data repository (UDR). The UDR is a converged repository used by other network functionns (NFs) to store data. As per the 3GPP, the UDR supports the functionality of storage and retrieval of subscription data by the UDM [18]. The AMF is also linked to the network slicing selection function (NSSF) through the N22 interface and to another AMF through the N14 interface (for configuration transfer and handover management) [18]. The NSSF system is a 5G solution that is leveraged to select the optimal network slice available for the requested services.

To enable SBA within 5GC, CP functions are configured to register with the NRF, which, in turn, helps them discover the other core NFs. In other words, SBA employs a centralized discovery framework that leverages NRF to maintain a record of available NF instances and their supported services so as to allow the other NF instances to subscribe and be notified of registrations from NF instances of a given type [3]. In this regard, NRF is considered as the internal broker for internal NFs while network exposure function (NEF) is the external

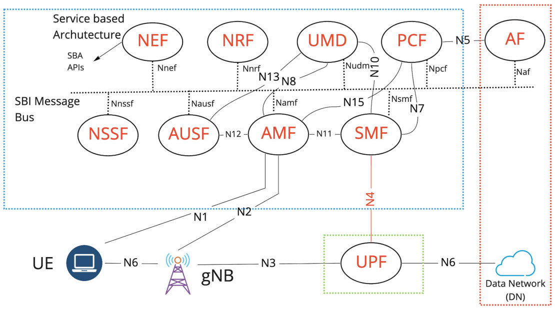

Fig. 3: Standalone 5GC architecture.

TABLE I: NSA 5G core versus 5GC

Item	NSA 5G Core	5GC
RAN-to-CP interface (protocol)	S1-MME to MME (S1AP)	N2 to AMF (NGAP)
RAN-to-UP interface (protocol)	S1-U to S-GW-U (GTP-U)	N3 to UPF (GTP-U)
Intra-UP interface (protocol)	S5/S8-C and S5/S8-U from S-GW-U to P-GW-U (GTP-C and GTP-U)	Not available
CP-to-UP interface (protocol)	S11 and Gx from MME and PCRF to S-GW-U and P-GW-U (GTP-C)	N4 from SMF to UPF (PFCP)
Policy control function	PCRF	PCF
Session management functions	MME/S-GW-C/P-GW-C	SMF
User database	HSS	UDM/AUSF/UDR
Data network	PDN	DN
Interface to external AF	Rx/Cx from PCRF	N5 from PCF
Interface to external data network	SGi to PDN	N6 to DN

broker for external NFs. For example, AFs are the external NFs that perform operations like accessing NEF for retrieving resources, interaction with PCF for policy control, applications traffic routing, exposing services to end-users, etc. N5 reference point is the link between the PCF and an AF.

Unlike 5G NSA, 5GC has a single UP NF, namely, UPF for transport of data between the gNB (via N3 interface) and the core as well as external WAN (via N6 interface to data network (DN) such as operator services, Internet access or 3rd party services). That said, the UPF also connects back to the SMF via the N4 interface. The PFCP is used on the N4 interface between the CP and the UP (specified in 3GPP TS 29.244). It is one of the main protocols introduced in the 5GC. For the reader's convenience, we summarize the key differences between the SA and NSA 5G architectures in Table II.

Having explained the key components of 5GC and compared it to that of the NSA 5G network, we next pinpoint the key advantages of adopting 5GC: The 5GC undergoes SBA, whereby the CP functionality and common data repositories of a 5G network are delivered by a set of interconnected NFs [15]. These NFs are self-contained, independent and reusable with authorization to access each other's services. Each NF service exposes its functionality through a SBI, which employs a well-defined REST interface (see Fig. 3). In addition, the UP of 5GC is much simpler than that of NSA 5G core as it contains a single NF only, namely, UPF. This enables CUPS where all UP functionalities are handled by the UPF, and the remainder of 5GC is dedicated for the CP-related functions. Finally, 5G enforces QoS at the flow level, where each flow is identified by a QoS flow identifier (QFI) [19]. Each QoS flow on N3 is mapped to a single GTP-U tunnel. The gNB may then map individual QoS flows to one or more DRBs. Therefore, a PDU session may contain multiple QoS flows and several DRBs but only a single N3 GTP-U tunnel. This 5G QoS framework is more granular compared to 4G, where QoS is enforced at the evolved packet system (EPS) bearer level (i.e., from the UE to the P-GW-U).

TABLE II: Environmental Parameter Setup

Variable	Value
NR bandwidth, band	50 MHz, n78
4G bandwidth, band	10 MHz, B3
DL and UL modulation	QAM 256 and QAM 64
4G and 5G frequency mode	TDD
Distance to UE	100 cm
Number of slots (DL test)	DL slots=7 and UL slots=2
Number of slots (UL test)	DL slots=6 and UL slots=3
Number of antennas	2×2
Base station height	150 cm
TX gain, RX gain	90.0 dB, 60.0 dB
Maximum power by UE	10.0 dBm
5G UE	Huawei CPE H122-370

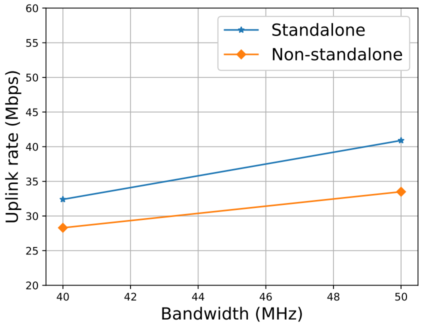

Fig. 4: Uplink data rate versus 5G NR bandwidth.

B. Testbed for SA 5G Networks

We use the same Amarisoft self-contained 5G base station to test the performance of an SA 5G network in an indoor environment. For this, eMBB network slice is deployed. The 5G RAN is connected to the 5GC, where the NGAP connection over N2 interface is established between the gNB and the AMF. The rest of the test parameters are provided in the sequel.

IV. PERFORMANCE EVALUATIONS AND RESULTS

The main configuration parameters adopted in our trials are presented in Table II. We use Iperf software to measure the KPIs by transmitting user datagram protocol (UDP) packets between the base station and the UE.[1]

Next, we compare the performance of SA and NSA 5G networks under the same 5G RAN setup. As an example, in Fig .4, we plot the UL data rate versus the NR cell bandwidth

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[1] Noticeably, the achievable performance from the base station relies on multiple factors, e.g., allocated bandwidth, distance to the base station, transmit ed power, etc. Since we deploy a small base station for testing and comparison purposes, the achievable KPIs do not necessarily represent the ultimate performance of 5G networks. However, they represent preliminary results to help understand the 5G system behaviour and obtain useful insights and design guidelines for SA and NSA 5G networks.

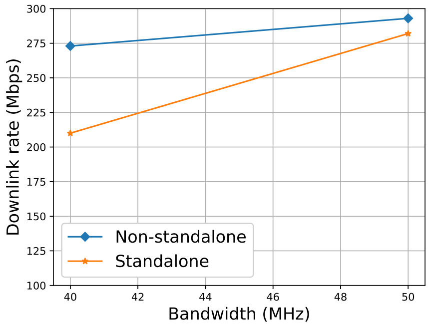

Fig. 5: Downlink data rate versus 5G NR bandwidth.

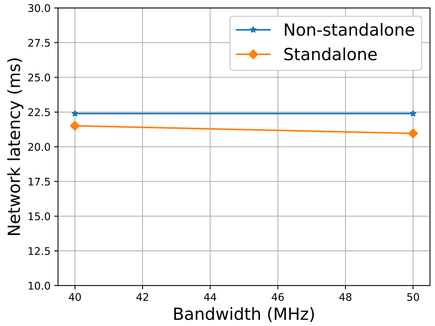

Fig. 6: Network latency versus 5G NR bandwidth.

for both network architectures. Preliminary results in Fig .4 first show that the achievable UL rate increases monotonically with the NR bandwidth. This is intuitive because more bandwidth corresponds to a higher maximum rate of data transfer. Results in Fig .4 also shows that the UL data rate of the 5G SA network slightly outperforms that of the NSA 5G network. It is worth recalling that for the SA network, we use 5GC connected to the 5G RAN, while the 4G CN is used for the NSA 5G network.

In Fig .5, we plot the DL data rate versus the NR cell bandwidth for SA and NSA 5G networks. Similar to Fig .4, the achievable DL rate is shown to increase with the NR bandwidth for both SA and NSA 5G networks. Moreover, the impact of using a 4G core in a self-contained node is not prominent as the downlink rate of NSA 5G could outperform that of the SA 5G network. It is worth recalling that, for fairness, Option 3a is adopted in the NSA mode where the UP data is carried only over the gNB.

Finally, we plot the network latency from the UE to the 5G CN versus the NR cell bandwidth in Fig .6. Results in Fig .6 first shows that the network latency slightly decreases with the increase of the NR bandwidth, e.g., when the NR bandwidth is increased from 40 MHz to 50 MHz. However, this decrease is less tangible for the NSA 5G network. Moreover, the perceived network latency for both SA and NSA 5G networks is shown to be relatively close.

V. Conclusions and Future Work

In this paper, we have provided a comprehensive technical comparison between 5G NSA and SA networks. We have also evaluated the performance of these two networks and presented preliminary results based on a real 5G testbed. For both networks, multiple KPIs such as DL/UL data rate and network latency are obtained and compared. Our future will focus on how map the 5G network KPIs to application KPIs for a use case of smart building and smart campus. Other future work will also cover slicing, orchestration, and QoS in 5G networks. For this, we explore the use of self-contained base station as well as a base station whose RAN and core components are separated.

Acknowledgements

The research leading to this work has been performed as part of the H2020 5G-PPP project 5G-SOLUTIONS. This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 856691.

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