Comparison of 5G Networks Non-Standalone Architecture (NSA) and Standalone Architecture (SA)

M. Alnaas[1], O. Alhodairy[2]

[1]Department of Computer Science, Libyan Academy for Postgraduate Studies, Tripoli, Libya
info.cs@academy.edu.ly
[2]National School of Electronics and Telecommunications of Sfax ENETCOM, Sfax, Tunisia
osamaalhodairy@gmail.com

Abstract

The non-standalone architecture (NSA) of 5G networks builds upon existing 4G long-term evolution (LTE) infrastructure, integrating 5G new radio (NR) technology while still relying on the 4G core network. In contrast the standalone architecture (SA) of 5G networks is designed as a fully independent system, with its own 5G core network. It does not rely on the existing 4G LTE infrastructure. The NSA integrates 5G NR technology into existing 4G LTE networks, utilizing the 4G core network for control and signaling. On the other hand, the SA establishes a fully independent 5G network with its own core components, providing more advanced features and greater autonomy. The transition from NSA to SA architecture is expected as network operators deploy more comprehensive 5G networks. This paper investigated in details the major different between both architectures NSA and SA of 5G networks.

***Keywords*—**5G, RAN, NR, 5GC, mMTC, Latency, Massive IoT.

I. INTRODUCTION

The 5G network architecture is a framework that defines the arrangement and interconnection of various components and entities involved in delivering 5G services. It comprises multiple layers, each with specific functions to enable efficient and reliable communication. It is designed to provide significant improvements over previous generations of mobile networks, such as 4G LTE [1].

The 5G network architecture is designed to provide enhanced data rates, ultra-low latency, massive connectivity, and support for emerging applications like internet of things (IoT) and mission-critical services. It enables the efficient and scalable delivery of 5G services to meet the evolving demands of users and industries [2].

The 5G network architecture can be categorized into two main types NSA and SA. The NSA architecture is an initial deployment option for 5G networks that leverages the existing 4G LTE infrastructure. In NSA, the 5G NR is deployed alongside the existing LTE infrastructure, utilizing LTE as the anchor for control signaling. The 5G NR is responsible for providing enhanced data rates, increased capacity, and improved performance compared to LTE [3].

The core network in the NSA architecture is primarily based on the existing LTE evolved packet core (EPC). It handles control plane functions, such as mobility management and session management, for both LTE and 5G NR connections. The existing LTE EPC components, such as the mobility management entity (MME) and serving gateway (S-GW) are utilized for control plane functions.

The SA architecture is a fully independent 5G network deployment that does not rely on existing LTE infrastructure. The 5G NR is the primary air interface in the SA architecture, providing advanced features and capabilities designed specifically for 5G communication. The SA architecture enables higher data rates, ultra-low latency, and advanced functionalities like network slicing, massive machine-type communication (mMTC), and ultra-reliable low-latency communication (URLLC) [4].

In SA, the 5G core (5GC) is deployed, replacing the LTE EPC used in NSA. The 5GC consists of several key components, including the access and mobility management function (AMF), session management function (SMF), user plane function (UPF) and network slice selection function (NSSF). The 5GC enables more flexible network management, control, and service delivery compared to the LTE EPC.

While NSA allows for a faster initial deployment of 5G by leveraging the existing LTE infrastructure, SA is considered the long-term vision for 5G networks, providing increased performance and enabling advanced features and services. Network operators are expected to transition from NSA to SA as they expand and mature their 5G networks [5].

This paper will explore the performance capabilities for both architectures NSA and SA of 5G networks to define the different between them.

II. 5G STANDALONE ARCHITECTURE (SA)

5G is a completely new mobile network architecture, which enables all of the capabilities of 5G, given that it is not dependent on any existing 4G LTE infrastructure. 5G SA involves a new 5G packet core architecture, which means that 5G services can be deployed without pre-existing 4G LTE equipment in the network [6].

As illustrated in Fig 1 in 5G SA architecture, the 5G RAN and its New Radio (NR) interface, consisting of gNodeB (gNB) macro cell base stations (BS) is connected to the 5G packet core network and operates as a standalone entity.

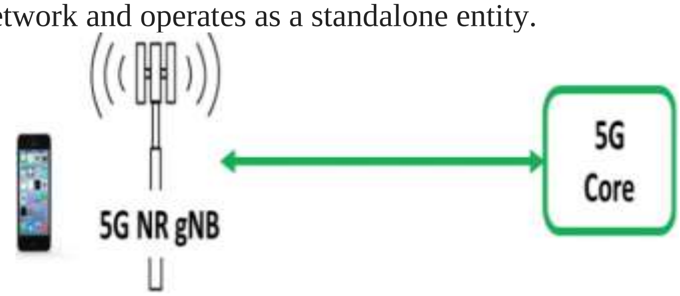

Fig 2. Standalone Architecture (SA) 5G

In 5G SA, the 5G core network provides the control plane signaling, while the 5G radio access network (RAN) provides the user (or data) plane, meaning the transfer of data traffic between a user's device and the network. Therefore, this architecture removes any dependency on the 4G LTE core and radio network [7].

Additionally, the 5G packet core architecture offers many new, natively built-in network functions and capabilities within those functions. For example, these new capabilities include: network slicing, control and user plane separation (CUPS), virtualization, automation, multi-gigabit per second (Gbps) support, and URLLC [8, 9].

As a result, the 5G core network is designed to make full use of the added capacity (throughput) and reduced latency that the new 5G radio (NR) can provide.

Benefits

1. Power consumption is lesser than NSA 5G.

2. Offers multiple 5G use cases.
3. Lowers latency.
4. Increases bandwidth caps
5. Gives powerful, fast, and scalable networks

Drawbacks

1. Costly to implement at all stages.
2. Time-consuming for experts to learn the new core infrastructure.
3. Difficult to roll out 5G in every corner of the region due to limited SA infrastructure and devices which support the SA technology.

III. 5G NON-STANDALONE ARCHITECTURE (NSA)

5G NSA is the first version of 5G network architecture, considered to be a steppingstone to the true 5G network that is 5G SA. As the name suggests, 5G NSA is not standalone, meaning it is designed to be deployed on top of existing 4G LTE network infrastructure [9, 10].

5G NSA enables the 5G RAN and its NR interface to be deployed and to connect to a 4G LTE network, meaning 4G radio access for control plane signaling and an EPC network. As illustrated in Fig 2, in this architecture, the 5G radio (NR) cannot connect to the 4G LTE control plane core network on its own. Instead, the 5G radio depends on the 4G LTE eNodeB (eNB) macro cell BS for all control plane signaling, while the 5G radio (NR) is utilized for the user (or data) plane.

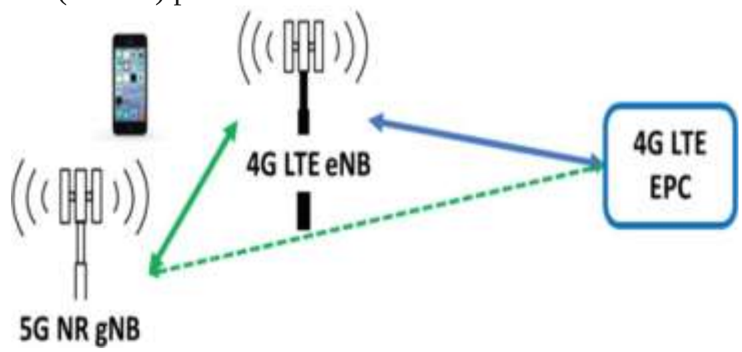

Fig 2. Non-Standalone Architecture (NSA) 5G

Globally, 5G NSA has been primarily used by wireless carriers to quickly and easily deliver 5G services to end users. With 5G NSA, wireless carriers have been able to offer introductory 5G services to their customers, while using this transitionary time to resolve any issues in the 5G RAN and in parallel, maintain the stability of the rest of their 4G LTE network [11, 12].

For end users, the initial benefits of using 5G NSA have been better coverage and enhanced throughput over 4G LTE services.

Benefits

1. It is cost-effective, since the 5G network is anchored on the existing 4G network, there is no need to invest in the expensive 5G core.
2. It is quite easy to deploy a 5G NSA network, because the telecoms are familiar with the infrastructure and its configuration process.
3. Thanks to existing 4G infrastructure and the familiarization with the same, the process of rolling out the 5G network is extremely fast.

Drawbacks

1. NSA can't deliver low latency, one of the biggest attractions for a 5G network.
2. More power consumption due to the usage of two forms of the cellular network.
3. NSA 5G can't deliver the pure and best form of 5G in the initial stage.

Even with its drawbacks, NSA mode 5G is perfect for the initial rollout of 5G services in any region.

IV. WHY 5G REQUIRES BOTH SA AND NSA DEPLOYMENT

While there is considerable discussion about the pros and cons of the two different 5G architectures, it doesn't come down to one or the other. Successful 5G deployment requires both SA and NSA. While 5G SA and the network performance it offers is the ultimate goal, it is currently limited to a small number of territories. However, NSA is offering improved network performance to many users right now.
Many mobile networks operator (MNOs) see the advantage of investing in 5G NSA and migrating its functionality to the 5G core as it becomes more prevalent [11, 13]

V. NEW RADIO (NR) ARCHITECTURE

The 3rd generation partnership project (3GPP) introduces six architecture options for NR deployment as shown in Fig 3. The SA provides NR service by using a single RAT, whereas the NSA enables NR deployment by utilizing the existing LTE systems.
Options 1, 2 and 5 belong to the SA category, while options 3, 4 and 7 belong to the NSA category [9].
However, since option 1 is a legacy LTE system, in which an evolved universal terrestrial radio access network (E-UTRAN) NodeB (eNB) is connected to an EPC, also referred to as 4G core network (CN), it is not considered when dealing with NR deployment scenarios.

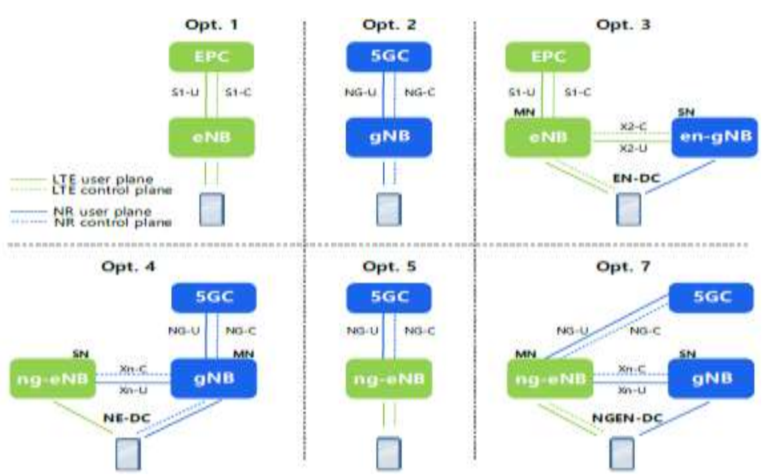

Fig 3. NR Deployment Architecture Options

In a NSA deployment, multi-radio dual connectivity (MR-DC) provides a user equipment (UE) with simultaneous connectivity to two different generation RAN nodes (i.e., next generation NodeB (gNB) and eNB). Of the two nodes, one acts as a master node (MN) and the other as a secondary node (SN). The MN is connected with the SN and 4G/5G CN, the SN can be connected with the core depending on options [11, 14].

Generally, MR-DC is categorized as shown in Table 1. In MR-DC, a UE connects with the MN/CN and can communicate with SN via MN for control plane. For user plane, a UE can connect with either MN/SN directly or SN via MN.

Table 1. MR-DC Lists

Lists	Associated CN	Associated Option	Note
E-UTRA-NR Dual Connectivity (EN-DC)	EPC	Option 3	eNB acts as an MN and en-gNB acts as a SN.
NR-E-UTRA Dual Connectivity (NE-DC)	5GC	Option 4	gNB acts as an MN and ng-eNB acts as a SN
NG-RAN E-UTRA-NR Dual Connectivity (NGEN-DC)	5GC	Option 7	ng-eNB acts as an MN and gNB acts as a SN
NR-NR Dual Connectivity (NR-DC)	5GC	Option 2	One gNB acts as an MN and another gNB acts as a SN

The en-gNB represents a gNB that can connect with EPC and eNB. An ng-eNB stands for enhanced LTE (eLTE) eNB which can communicate with 5G Core (5GC) and gNB. The en-gNB provides NR control/user plane protocol terminations towards the UE, while ng-eNB provides LTE control/user plane protocol terminations towards the UE.

VI. 5G NR SPECIFICATIONS IN NSA AND SA

Ultimately, the biggest difference between NSA and SA is how each mode provides 5G. NSA uses a 5G RAN, as well as a 4G LTE core, while SA is an end-to-end 5G network with both a 5G RAN and NR core [8, 9]. Their methods of deployment determine how each mode supports the 3rd generation partnership project (3GPP) defined NR specifications. As illustrated in Fig 4 5G NR specifications include the following:

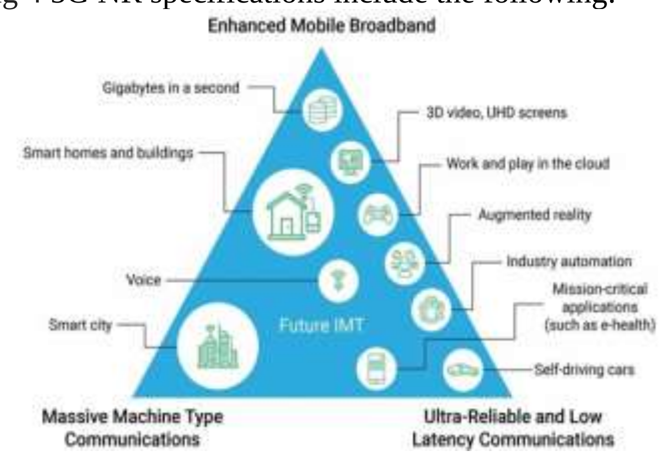

Fig 4. Major 5G Usage Scenarios

1. Enhanced mobile broadband (eMBB) functions as an extension of 4G that increases data rates to improve network speeds.

2. mMTC connects up to 1 million devices and facilitates quick, seamless communication between them.
3. URLLC ensures network reliability by reducing latency to below 5 milliseconds.

All three features support an array of industries and services, including emerging sectors, like IoT, satellite communications and more [14]. However, 5G SA is the only deployment mode that supports all three specifications. 5G NSA can only enable eMBB, because it has a 4G core that can extend to support the specification. SA can enable all three features, because it has a more powerful and more flexible 5G core.

Even though 5G SA is an improvement over 5G NSA, few operators have deployed the latest technology. In September 2023, counterpoint research reported that only 47 MNOs worldwide have released commercial 5G SA deployments.

Many MNOs previously said they were eager to develop SA 5G, but installments are behind. The global economy is in a downturn, and MNOs also find it difficult to earn return on investment (ROI) on 5G. Because carriers have yet to find many lucrative or killer applications that justify the transition to 5G SA, NSA currently reigns supreme [1, 7].

However, research showed the advanced capabilities 5G SA offers, such as enhanced mobile broadband, fixed wireless access, network slicing and more, show revenue potential.

SA 5G itself could be the killer use case that increases 5G's ROI and provides reason to support the transition to 5G SA. Despite the simplicity and inexpensive costs of deploying NSA, carriers should make the move to 5G SA to reap the most beneficial and anticipated capabilities of the technology.

VII. 5G CORE NETWORK (5GC)

5GC holds a key role in realizing the full potential of 5G, which is responsible for a variety of functions within the cellular network that makes communication possible, it also referred to as the core, is a key component of 5G networks.

It provides the underlying infrastructure and functionalities necessary to support the advanced features and capabilities of 5G technology. The 5GC is designed to be flexible, scalable, and capable of handling the diverse requirements of various 5G use cases.

The 5GC follows a service-based architecture, where network functions are decoupled and deployed as modular services. This allows for flexibility, scalability, and efficient resource utilization. It comprises several network functions, each responsible for specific aspects of the core network's operation [15].

The 5GC is a crucial component of 5G infrastructure, enabling the deployment of advanced services, massive IoT connectivity, ultra-reliable communication, and low-latency applications. It forms the backbone of the 5G network, supporting the seamless and efficient delivery of data and services to end-users. The 5GC consists of various network functions, including:

1. AMF: The AMF handles the mobility management and control plane functions for the UE, including registration, session management, and authentication.
2. Session management function (SMF): The SMF is responsible for managing the data plane of user sessions, including routing, policy enforcement, and quality of services (QoS) management.
3. User plane function (UPF): The UPF handles the user data plane, including packet routing, forwarding, and traffic management.

4. Policy control function (PCF): The PCF is responsible for policy and QoS control, enforcing service-specific policies and managing the QoS parameters for different services.
5. Authentication server function (AUSF): The AUSF provides authentication and security functions, including user authentication and key management.
6. Unified data management (UDM): The UDM manages user-related data, including subscriber profiles, authentication credentials, and subscription information.
7. Network exposure function (NEF): The NEF enables external applications and services to securely access and interact with the 5GC's services and capabilities.

There are other several network functions that handle specific aspects such as policy enforcement, charging, network slicing, etc.

In NSA, the 5GC is primarily responsible for offloading data traffic from the LTE network, providing higher data rates and increased capacity. The UPF in the 5GC handles the data plane for 5G devices.

For the 5GC in SA, the AMF handles control plane functions, while the SMF and UPF handle data plane functions, providing efficient and optimized data transmission for 5G devices [16].

Overall, the 5GC in NSA works in conjunction with the LTE infrastructure, while the 5GC in SA provides a native and standalone 5G core network. The SA offers the full potential of 5G with advanced features and capabilities, while the NSA facilitates a faster rollout by leveraging existing LTE infrastructure.

VIII. NETWORK CAPACITY

In 5G networks, the network capacity refers to the ability of the network to handle a high volume of data traffic, support a large number of connected devices, and deliver consistent performance.

While NSA provides certain 5G features, it still relies on the underlying 4G network for control signaling and certain functionalities. Here's how network capacity is affected in NSA:

NSA allows for the aggregation of 4G LTE and 5G resources. This means that the overall network capacity is a combination of the capacity provided by both 4G LTE and 5G technologies. The 4G LTE network acts as the anchor, while 5G provides additional capacity.

While NSA can offer increased data rates and improved capacity compared to 4G LTE, the full capacity potential of standalone 5G is not realized. NSA architecture cannot fully leverage the advanced capabilities and optimizations specific to 5G network components.

The network capacity in NSA can vary based on factors such as the spectrum bands used, the implementation of carrier aggregation, and the availability of 5G resources in a given area. The capacity benefits may be more pronounced in cases where higher-frequency bands, like millimeter-wave (mmWave) are used.

SA architecture represents a fully independent deployment of 5G networks without relying on 4G LTE infrastructure. SA offers the complete set of 5G capabilities and optimizations, resulting in improved network capacity.

SA architecture unlocks the full capacity potential of 5G. It leverages advanced 5G NR technology, including wider frequency bands, advanced modulation schemes, and improved multiple-input multiple-output (MIMO) configurations. This enables higher data rates and increased network capacity compared to NSA [17].

SA architecture benefits from improved spectral efficiency due to the use of NR waveforms, advanced coding techniques, and beamforming technologies. These advancements allow for the transmission of more data within the available frequency resources, resulting in increased network capacity.
SA architecture is designed to efficiently handle mMTC and the deployment of a vast number of IoT devices. It provides the necessary capacity and support for IoT use cases, enabling a scalable IoT ecosystem [18].
5G SA architecture offers higher network capacity compared to 5G NSA architecture, as it fully utilizes the advanced capabilities and optimizations of standalone 5G. SA leverages improved spectral efficiency, advanced NR technologies and network slicing to deliver increased data rates, support more connected devices and cater to diverse use cases.

IX. LATENCY

Latency refers to the time delay between the transmission of data from a source to its reception at a destination. In the context of 5G networks, both NSA and SA architectures aim to reduce latency compared to previous generations of networks. However, there are differences in the latency performance between the two architectures.
NSA can provide latency improvements compared to 4G LTE due to enhancements in the radio interface and network optimizations. It can offer lower latency for data transmission, signaling, and control procedures [1, 3].
However, NSA architecture may not achieve the ultra-low latency capabilities of standalone 5G. The reliance on 4G LTE infrastructure and protocols can introduce additional latency compared to SA, as some signaling and control processes need to traverse both 4G and 5G networks.
The latency performance in NSA can vary based on factors such as network configuration, deployment scenario, and the specific 5G features utilized. The use of higher-frequency bands, like mmWave, can introduce shorter-range communications, but may also require closer proximity to BSs, potentially impacting latency.
SA aims to deliver ultra-low latency and improved responsiveness for various applications.
SA architecture is designed to achieve ultra-low latency, which is a key feature of 5G. It significantly reduces the time delay between data transmission and reception, enabling near-real-time communication for applications that require immediate responsiveness.
SA optimizes the network design by eliminating the reliance on legacy 4G LTE components and protocols. This streamlines the data flow, reduces complexity and minimizes latency introduced by interworking between different generations of networks.
SA architecture facilitates the integration of edge computing capabilities, where computing resources are placed closer to the network edge. This reduces the round-trip time for data processing, enabling faster response times and lower latency for edge-enabled applications [6].
SA supports time-sensitive networking (TSN) protocols, which prioritize critical traffic and ensure timely delivery of data for applications with stringent latency requirements, such as industrial automation and autonomous vehicles [8].
While both 5G NSA and SA architectures aim to reduce latency compared to previous generations, SA architecture offers the potential for lower latency due to its independence from 4G LTE infrastructure and its focus on ultra-low latency capabilities. SA leverages optimized network design, edge computing, and time-sensitive networking to achieve improved latency performance for a wide range of applications.

X. MASSIVE IOT

Massive IoT refers to the deployment of a large number of interconnected devices that require low-power, low-cost and scalable connectivity solutions. Both 5G NSA and SA architectures are designed to support Massive IoT deployments, but there are differences in how they address the requirements of IoT devices.

NSA allows for the use of low-power, wide-area (LPWA) technologies such as Narrowband IoT (NB-IoT) and LTE-M (LTE-MTC or LTE Cat-M1). These technologies provide extended coverage, allowing IoT devices to connect over long distances and penetrate deep into buildings [1, 4].

NSA architecture ensures backward compatibility with existing 4G LTE networks, enabling a smooth transition for IoT deployments that are already utilizing LTE-based connectivity solutions. This compatibility allows for the continued use of existing IoT devices and infrastructure.

SA architecture offers dedicated support for low-power connectivity technologies like NB-IoT and LTE-M. These technologies are designed specifically for IoT devices that require long battery life, low data rates, and cost-efficient connectivity.

SA architecture enables enhanced scalability and density for IoT deployments. It supports a significantly larger number of simultaneous connections per unit area compared to NSA, making it suitable for scenarios with a massive number of IoT devices in close proximity [10].

SA architecture simplifies the network design by eliminating the need for interworking with legacy 4G LTE components. This reduces complexity and overhead, making it more efficient and cost-effective to support a large number of IoT devices.

SA supports network slicing, allowing the creation of dedicated virtual networks optimized for IoT use cases. Each network slice can be tailored to meet specific requirements such as low latency, high reliability, and efficient resource utilization, ensuring the scalability and customization needed for Massive IoT [5, 7].

Both 5G NSA and SA architectures provide support for Massive IoT deployments. However, SA architecture offers advantages in terms of low-power connectivity, scalability, reduced complexity and the ability to create dedicated network slices optimized for IoT use cases. SA's independent deployment approach and focus on 5G-specific optimizations make it well-suited for addressing the requirements of Massive IoT applications.

XI. LIMITATIONS OF NSA COMPARED TO SA

NSA does have some limitations compared to SA, which relies solely on the 5G core network. For instance, NSA may not deliver the same level of low latency and high reliability as SA since it still relies on the 4G network for certain functions.

Additionally, NSA may not provide the same level of flexibility and scalability as SA since it is not designed to be a fully independent 5G network.

Despite these limitations, NSA serves as an intermediate step toward full 5G deployment, allowing operators to maximize their existing infrastructure investments while gradually transitioning to a more robust 5G network. By adopting NSA, operators can kick start the delivery of enhanced connectivity, improved data speeds, and advanced 5G services to their customers in a timely and cost-efficient manner [9].

The deployment of 5G SA networks is currently in its early stages, and it is expected to be rolled out gradually in the coming years. As it expands, 5G SA will play a pivotal role in driving innovation and powering emerging technologies.
For instance, autonomous vehicles, virtual reality experiences and the IoT are anticipated to benefit greatly from the capabilities of 5G SA networks.
By optimizing their networks for 5G SA, service providers can offer enhanced connectivity, enabling faster data transfer and improved user experiences. This, in turn, opens up new opportunities for businesses and individuals alike, fostering a more connected and technologically advanced society [10, 14].
Embracing the potential of 5G SA, industries can unlock unprecedented possibilities, from enabling real-time remote operations and seamless automation to revolutionizing healthcare and enabling smart cities. The widespread adoption of 5G SA will drive digital transformation, fuel innovation, and reshape the way we live, work, and connect with the world.

XII. FEATURES AND CAPABILITIES OF 5G INCLUDES NSA AND SA

NSA provides enhanced data rates, increased capacity, and improved performance compared to LTE. However, it does not offer the full range of advanced features and capabilities of native 5G. 5G NSA provides higher data rates compared to 4G LTE, allowing for faster download and upload speeds. This enables enhanced user experiences for applications such as video streaming, gaming, and large file transfers.
NSA allows for the aggregation of 4G and 5G resources, increasing the overall network capacity. This helps accommodate more connected devices and support higher data demand [1].
NSA architecture focuses primarily on delivering high-speed mobile broadband services. It offers significantly faster data rates and improved network efficiency, enabling seamless multimedia experiences and bandwidth-intensive applications.
As NSA relies on existing 4G infrastructure, it does not fully utilize the advanced capabilities of 5G. It may not achieve the URLLC and mMTC capabilities of standalone 5G.
SA architecture unlocks the full potential of 5G, providing higher data rates, ultra-low latency, network slicing, mMTC and URLLC. It enables the realization of advanced use cases and services that require native 5G capabilities.
SA architecture enables network slicing, which allows the creation of multiple virtual networks with different characteristics tailored to specific use cases. This enables efficient resource allocation, improved security and customized services for different industries and applications [3].
SA architecture significantly reduces latency, enabling near-real-time communication. This is crucial for applications like autonomous vehicles, remote surgery and industrial automation that require instantaneous response times.
SA architecture supports a massive number of connected devices, allowing for scalable deployments of IoT devices. This facilitates smart city applications, smart homes and industrial IoT use cases [4].
SA architecture provides enhanced reliability and resilience, ensuring mission-critical applications have robust connectivity and uninterrupted service. It includes features like improved network slicing, redundancy and high availability.

The deployment strategy (NSA or SA) may vary based on the specific requirements and priorities of network operators and the stage of 5G deployment in different regions.

XIII. CONCLUSION

The network architecture and deployment models used by SA and NSA 5G differ significantly. While NSA 5G is a deployment strategy that incorporates 5G technology with current 4G LTE infrastructure, SA 5G is a standalone design that makes use of an entirely new network infrastructure.

NSA architecture allows for a faster rollout of 5G by leveraging existing LTE infrastructure. It provides a smooth transition to 5G while maximizing investment in LTE.

SA architecture represents the ultimate vision of a fully independent 5G network. It requires the deployment of a complete 5G core network and provides the full potential of 5G capabilities.

SA 5G needs considerable investment in new infrastructure, but delivers faster bandwidth, lower latency and the capacity to handle more connected devices. However, it might not be able to handle all of the advanced capabilities of 5G and might not be as scalable as SA 5G. On the other hand, NSA 5G offers a quicker and more affordable approach to establishing 5G networks.

The decision between SA and NSA 5G will ultimately be based on several variables, including the availability of infrastructure, the desired degree of network performance and the amount of investment that the network operator is willing to undertake.

Both SA and NSA 5G have their benefits and drawbacks, the network operator must decide which architecture best meets their requirements.

NSA allows for quicker 5G deployment, while SA provides the full suite of 5G capabilities. As 5G networks continue to evolve, SA architecture is expected to become more prevalent, enabling the realization of advanced use cases and unlocking the full potential of 5G technology. The transition from NSA to SA architecture is expected as network operators deploy more comprehensive 5G networks.

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