Performance Analysis of Various 5G Mobile Architectures

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Abstract—The field of Telecommunication has progressed and emerged to be a successful field of technology. From communicating via pigeons and cannonballs to video conferencing for a meeting, the communication has improved surpassing every user's expectation. With the introduction of wireless communication, the field of communication took a different turn. Just when we thought we reached the zenith of wireless communication, an esoteric concept of Standalone (S.A.) and Non-Standalone (N.S.A.) opened the gates to more efficient communication, expanding the horizons of technology. The 5G network has started developing over some regions in the world but the real question remains; which is, whether an efficient communication is worth the economy spent on developing it or certain advantages of this networks should be given up to protect the country's economy. 3rd Generation Partnership Project (3GPP) introduces mainly two network architectures for the deployment of 5G cellular systems over existing LTE networks: Non-Standalone (NSA) and Standalone (SA). NSA permits a quick 5G advantage course of action with the least speculation by leveraging the LTE frameworks which has already been established by cellular Radio Access Technology (RAT), i.e. it follows full 5G protocols and works within the 5G New Radio (NR). This analytical paper elaborates on the performance of these two architectures for the implementation of 5G cellular technology, where the first one would be a high technology-centric approach with less cost efficiency and the other one would be the economy savvy aspect with a little bit of negotiation with technology upgrades.

Keywords—5G communication, mm-Wave, Beamforming, Standalone & Non-Standalone

1 Overview of 5G

Rapid changes in Technology Development around the World provide high demands in Telecommunication Systems. Modern lifestyle increases the number of consumers to access information frequently at any place and any time with a higher speed rate. The powerful and fast connection was once an imagination that has turned into a necessity in the current world. There is no possible limit to developing a faster communication technology than already exists. A newly researched communication technology hardly runs for a decade where another modified and more powerful communication technology overtakes the existing one. When 4G was first introduced in 2009, it was only made available to Stockholm (Sweden) and Oslo (Norway)[3]. But soon, it started capturing the communication market worldwide. 4G outgrew 3G and other generations of wireless communication due to its high throughput and decreased latency. Just when the world thought communication technology couldn't get better, a new network technology with even higher throughput, lesser delay, capability for plenty of attached end users, lower inter-channel disturbance, improved performance, and great bandwidth, widely known as the 5G communication, is now almost ready to take over the worldwide networking system[1]. Starting with Chicago and Minneapolis in late 2009, this South Korean-developed technology by Qualcomm has proven to be a significant improvement in the world of telecommunications and is expected to realize full economic effect across the globe by 2035.

The following section of the paper describes the basic physical layer architecture of the upcoming 5G system.

2 Physical layer architecture of 5G telecommunication system

Figure 1 illustrates the physical layer layout of 5G wireless communications which comprises various units of coder and decoder units, modulator and demodulator blocks, OFDM, and respective demultiplexer units along with an advanced antenna diversity mechanism. 5G was developed based on various techniques listed as

(i) Advance OFDM technique, i.e. f-OFDM
(ii) Massive MIMO
(iii) Beamforming

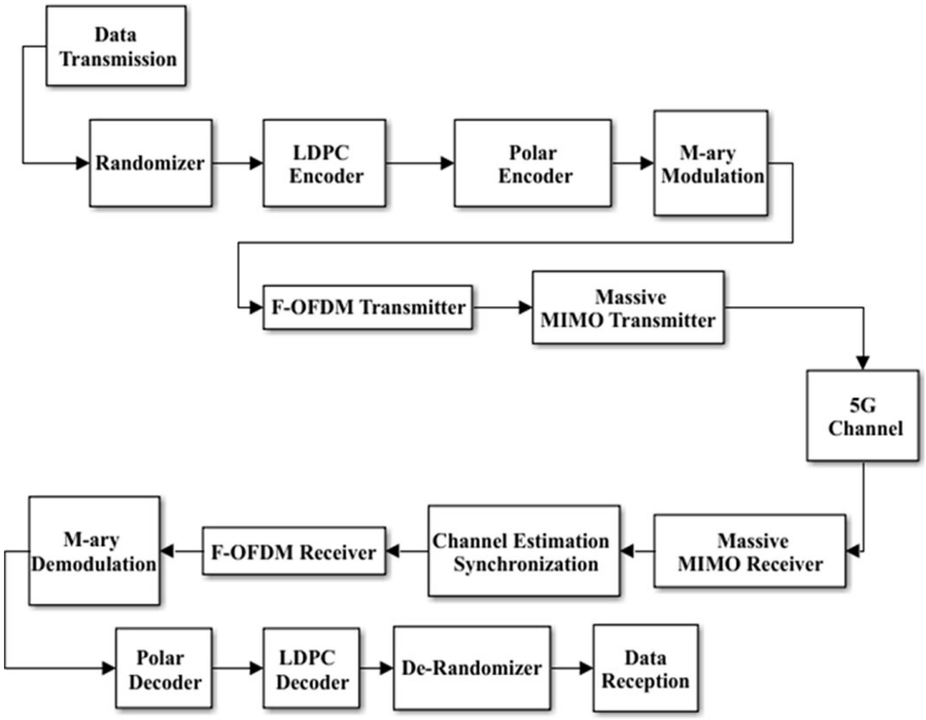

Fig. 1. Basic physical layer architecture of 5G system

The above prototype is initiated by randomizer block which generates a random stream of bits that is to be further coded in two steps of inner and outer coding employing polar coder and LDPC coder. On the receiver side, practically proper data or signal is not going to be received because of the existing noise of the communication channels. So to obtain a correct or proper signal on the receiver side, channel coding is utilized on both the transmitter and receiver side that is based on a group of algorithmic iterations. These encoded signals are further modulated through any kind of M-ary modulation technique according to the requirement of data rate. Generally, for the 5G communication system, higher modulation order is chosen such as the 256-are QAM method.

Further, these modulated data streams will be fed to multiplexer arrangement from where the 5G technology is getting differed drastically from the 4G standards. Here the advanced OFDM techniques are to be used such as f-OFDM which is elaborated in the following section.

Orthogonal Frequency Division Multiplexing (OFDM) is used to increase efficiency in current wireless communication technologies i.e. 4G and 5G. It anticipates the advantages of both Frequency Division Multiplexing (FDM) and Quadrature Amplitude Multiplexing (QAM) which results in a higher data transmission rate[11]. With OFDM, the multiple frequency bands are rather allowed to overlap in the frequency domain in such a way that each subcarrier frequencies are perpendicular to each other and frequency separation among them is developed with the use of fast Fourier transform (FFT). In f-OFDM, a band can be divided into multiple sub-bands.

Each of the bands can have variations in the range of frequencies. Every sub-band comprises multiple subcarriers and the separation in frequency among the subcarriers can change with each sub-band. Combining this sub-band flexibility and subcarrier flexibility, we can create a very changeable structure of sub-frame that can carry the different types of service data within the same sub-frame.

The multiplexed data stream would be further processed in the space domain to achieve diversity and thereby gain high spectral efficiency. To achieve the highest spectral efficiency, an advanced MIMO technique is utilized in 5G. This advanced MIMO technique is Massive MIMO which comprises multiple numbers of antennas on a base station that are greater in number concerning some devices[4]. More antennas at the base station for end devices turn out huge gains in spectral efficiency[5]. To get the benefit of this huge architecture, all the antenna elements of the array must obey the principle of beam-forming. Here, a very directional pencil-type radiation beam from the transmitting antenna is generated to communicate with the receiver device. The advantage of this kind of directional beam is to reduce interference from adjacent & co-channel signals and we can use maximum bandwidth of channel because signal bandwidth is very narrow here[10]. We can connect so many devices at a time with the help of this technique. As we increase the radiating antennas at the base station, we will get a sharper and more directional beam with very minor side lobes[9]. So, we can see the direct relation between Massive MIMO and Beamforming from this point or we can use both the words Massive MIMO and Beamforming interchangeably. The types of Beamforming include Analog Beamforming, Digital Beamforming & Hybrid Beamforming.

Finally, the 5G compatible signal would be radiated into the air with the specific spectrum that anticipates its distinguished advantages of it. The band allocated for 5G applications is the millimeter-wave band.One of the key features of 5G which sets it apart from the previous wireless communication technologies is the increase in an accessible frequency range. It not only covers the bands of 4G LTE but also extends towards the range of 24 GHz–100 GHz. Since this network also operates on high frequency, it is frequently referred to as mm-Wave (microwave) due to its short wavelength that can be considered in millimeters[6]. This massive increase in the range will thus result in an increase in the access of the number of users and hence, greater connectivity[7]. The concern with not using mm-Wave in the previous technologies was due to the vulnerabilities against gases, humidity absorption, and rain and hence long propagations were not possible. Moreover, only a few electronic components could receive mm Waves. This challenge was eventually overcome by constructing smaller antennas that accumulate signals into greatly pinpointed beams along with appropriate gain[8].

According to the design layout of the 5G structure, research is going on for the implementation of the same. To date, the studies and experiments are going with two approaches i.e. Standalone approach and Non-Stand alone aspect which are discussed in the following sections. In general, cellular service providers carefully decide which 5G architecture selection suits their new network deployment by analyzing several parameters. For outline, a speedy 5G architecture establishment concerning cost point of view, NSA may be the sensible selection since it leverages birthright LTE frameworks[13]. Be that as it may, the main limitation is NSA architecture can't completely satisfy all 5G protocols and back all the 5G services, such as Ultra-Reliable Low-Latency Communication (URLLC)[22] and network slicing.

3 Standalone (SA) and non-standalone (NSA) architecture in 5G

3.1 Standalone (SA) architecture

As compared to normal voice or broadband LTE 4G network, SA 5G can empower much higher data rates, lower latency and also allows un-used commercial opportunities. As the term suggests, SA network functions independently from EPC (Evolved Packet Core). The previous legacies of communication used to travel through the same channel inducing slower throughput speed and an increase in latency than expected theoretically. Thus, an independent channel provides the network with faster communication. Owing to a separate channel, this system hence results in being more vulnerable to cyber-attacks. Yet, the advantage of an individual transmission channel is of greater worth. As promised by 5G, the latency is expected to be reduced from 200 ms (millisecond) in 4G to 1ms (millisecond) in 5G and the standalone system plays a significant role in this massive reduction rate. The SA Architecture used in the 5G network is completely new architecture from the current architecture, which will provide the 'Real 5G' experience to mobile data subscribers. Here, the Mobile Network Operators (MNOs) will establish a whole new structure to serve the new transmission and receiver network with reduced antenna size, a small coverage area compared to earlier networks, and highly increased channel bandwidth. The increased channel bandwidth will give a new insight to the subscriber in terms of internet data speed. 5G Standalone is a completely virtualized and cloud-native network (CNA) network that is utilized to expand and direct applications. It also supports advanced network-slicing functions. The 3300–3800 MHz frequency band is used for pure 5G SA Communication. Figure 2 gives the basic idea about the technology used in 5G SA architecture. In 4G Communication, our handset is using the Long-Term Evolution (LTE) technique to establish a connection with EPC. Similarly, in the 5G SA architecture, our handset will communicate directly to the 5G Mast, and using the New Radio (NR) concept, it will connect to 5G core channels. This SA architecture in 5G is completely new and separate architecture from existing architecture in terms of establishment and that is the reason behind the "Real 5G" which we will experience in near time.

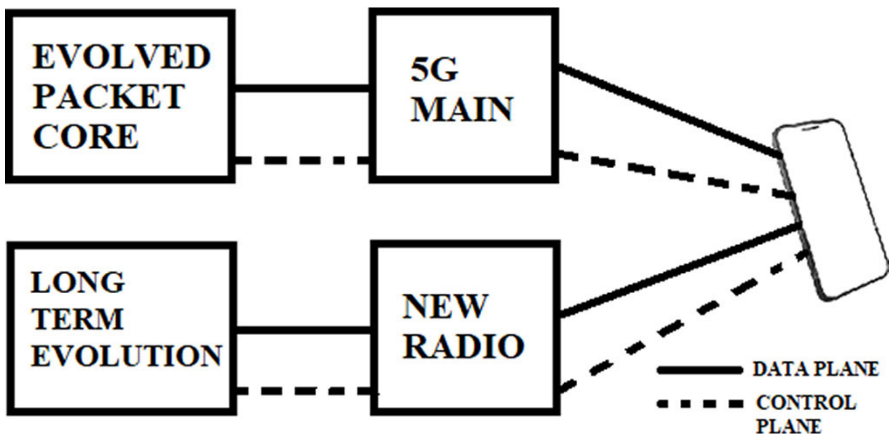

Fig. 2. Standalone architecture of 5G communication

3.2 Non-standalone architecture

If the wireless service is provided without an end-to-end network, and so the signal travels through the same channel as the previous network system, it is known as Non-Standalone (NSA) network. The 5G network can use the NSA system by relying on 4G LTE infrastructure instead of Standalone architecture. However, this condition has its own merits as well as demerits. Using the NSA model, telecom service providers can give 5G a quick start as it will not require a massive and expensive infrastructure to be developed. This will imply faster outreach by 5G. But faster growth will be at the cost of its efficiency. Using the previous infrastructure, the latency will be reduced to 4G with a major increase in throughput but not up to the level 5G has promised to be. Hence, the NSA model is a good option for initial stage growth but it is not preferred when it comes to an increased number of nodes to be connected on the same network with minimum latency. In the NSA architecture of 5G, the MNOs will slightly increase the bandwidth of the current 4G LTE network instead of giving real 5G channel bands. So, this will start the 5G at an early stage but it cannot give us a "Real 5G" experience as SA architecture is giving us. It can be seen from Figure 3 that 4G will establish its connection to EPC using LTE and in the same way, 5G is establishing its connection to the same EPC via NR concept. So, the EPC and channel both are the same for 4G and 5G here but the technology which they are using to connect with the EPC is different and this is the reason for getting a high speed of 5G compared to 4G in the same channel.

NSA 5G New Radio will supply improved data rate and bandwidth with anticipation of the two New Radiofrequency ranges:

- First Range of Frequency (450 Mhz to 6000 Mhz)—extended with 4G LTE frequencies and is specified as sub-6 GHz. The numbering given to bands is from 1 to 255.
- Second Range of Frequency (24 GHz to 52 GHz)—is the major mm-Wave band of frequency. These are given numbers from 257 to 511.

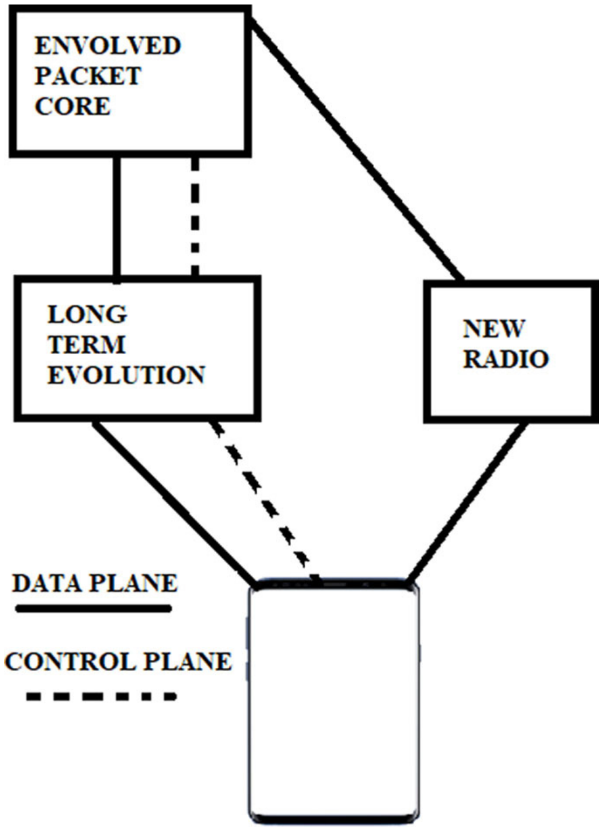

Fig. 3. Non-Standalone architecture of 5G communication

So, this NSA architecture is beneficial for MNOs because they don't have to establish the whole new infrastructure for 5G and the subscribers will get the slightly higher speed of the Internet because of the increased channel bandwidth. Also, we can say that the MNOs are maximizing the efficiency of existing 4G networks by giving us 5G experiences from them. Although the speed of 5G in NSA is slow compared to SA, still we run our AR/VR devices, can do live video streaming, and can run our gadgets without any lag[14,16,17].

4 Comparative analysis between standalone (SA) & non-standalone (NSA)

The concept of the difference between the architecture of SA & NSA architecture in 5G can be explained by using the analogy of a sidecar shown in Figure 4. Consider New Radio (NR) interface & Radio access technology as the motorcycle/carrier for 5G network. As NR is the only driving channel, only the 5G network bandwidth will be travelling through the carrier, thus forming a "Standalone" model. But if this network is travelling through the infrastructure carrying previous bandwidth range and legacies like 4G, this legacy will act like a sidecar to the system and this model will thus be a "non-standalone" model. Here the sidecar is not an obstruction to the motorcycle but it will slow the vehicle down due to the extra weight clung on. Similarly, when the 5G network adopts the non-standalone architecture, it will serve the purpose of connection as well as speed but it won't be up to its efficiency. To sum it all, the 5G speed that we receive via NSA architecture is 4G boosted a bit due to the additional 5G spectrum.

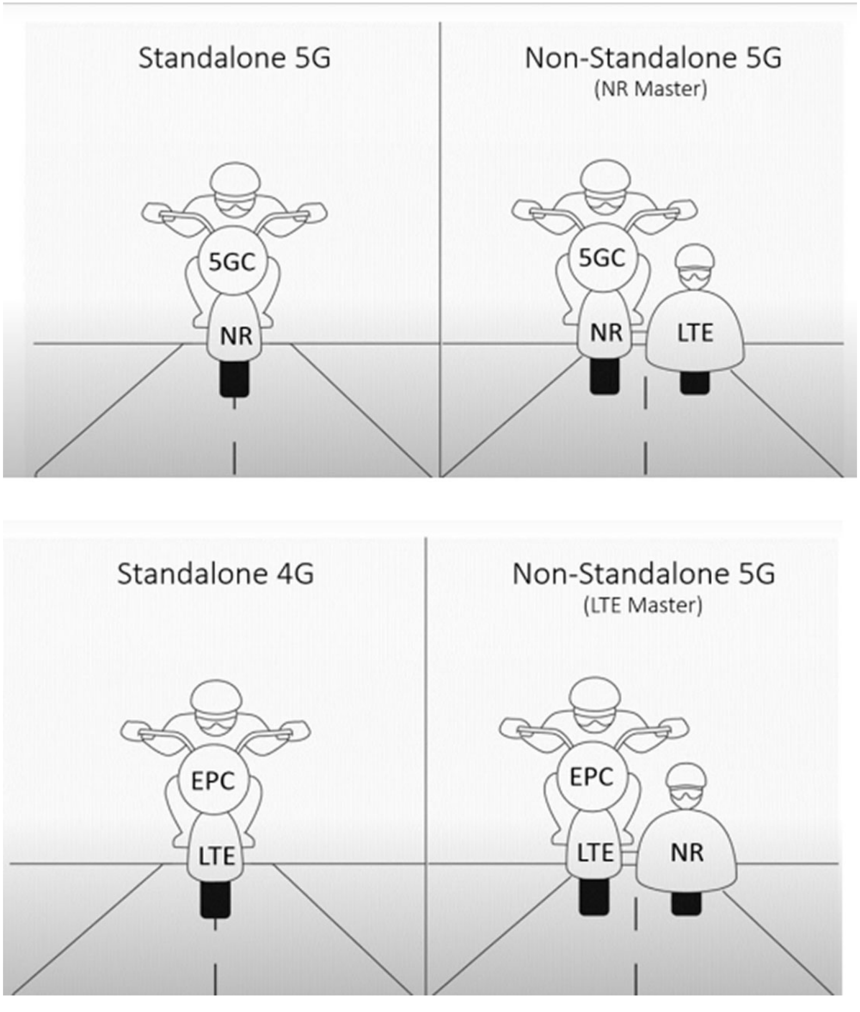

Fig. 4. Comparison of SA & NSA

One of the vital differences between SA & NSA architecture is that in NSA architecture, in case of poor signal, the mobile network can switch to 4G and thus provide its service. Whereas in SA, if the signal bandwidth is lost, the entire connection is terminated due to the absence of another bandwidth channel.

Also, from a coverage point of view, both these architectures show different execution. Coverage which is measured by maximum passable loss is the geographic distance or range in which cellular communication between a base transceiver and the user is possible and basic coverage is governed by various distinctive factors like the power of the transmitter, antenna picks up, the value of frequency band, system characteristics, and recipient execution. Among these, frequency groups can cause a major influence on coverage. For outline, the higher carrier frequency gets to be, the smaller the coverage zone gets to be due to the higher radio signal attenuation. In this way, concerning coverage constrain, SA frameworks offer smaller coverage because of utilizing mid-frequency or high-frequency bands, and at the same time, NSA LTE frameworks offer more coverage by utilizing low or mid-frequency bands.

Hence, SA frameworks using mid-frequency band or high-frequency band offer a smaller coverage than that specified by the NSA LTE framework collectively utilizing low or mid-band frequency group.

Moreover, from the economic point of view, NSA will be more pocket-friendly for the service providers as there is no need to build an entire infrastructure. It also gives a boost to the deployment of the 5G network due to faster implementation. On the other hand, SA requires it to function with a space-based architecture (SBA) to meet the expectations of a superfast network and ultra-low latency. In NSA, the latency of the idle-to-active process is larger than in SA. Because of the signalling dissimilarities in both the networks, the difference in latencies is turned up. In NSA, to switch over from idle to the active state, the user mobile equipment first performs an idle-to-active modus operandi in LTE, which serves as the master node. After this, the user equipment connects to the NR through the secondary node addition procedure. However, in SA, user equipment connects to NR without additional signalling procedures during the idle-to-active procedure. The latency can also be calculated regarding handover interruption time. NSA requires both LTE handover and NR cell handover, while SA needs NR cell change only. Therefore NSA handover interruption time approximately twice concerning SA.In this way, low latency is one of the major advantages of the 5G SA network. While the NSA 5G also provides a lower latency compared to 4G LTE, it, however, fails to exceed the capacity of SA architecture.

About mobility, SA architecture is less complicated compared to NSA. This is because user types of equipment can handle LTE and NR connection independently, as it can connect with either of any one network at any given time so users can experience dedicated 5G protocols when equipment connects to 5G network, dedicated 5G protocols, till it remains within the coverage of NR. If two frequencies exist in the 5G network, the user mobile equipment can aggregate user traffic in both paths by using NR direct coupling. While in NSA, NR will generally use mid or high-band frequencies due to low-band is mainly engaged by LTE. Now Mid-band has a larger propagation loss compared to the low-frequency band, so this physical condition confines mid-band's NR coverage in NSA architecture and creates a much more complicated network. However, this coverage issue can be compensated by implementing Massive MIMO and Beamforming techniques.

Voice transmission is still a crucial part of cellular mobile communication networks though the request for data services is the dominant driver behind the evolution of the 5G network as the primary goal of mobile communication was to provide good quality voice service. Similar to VoLTE in 4G, VoNRi.e Voice over New Radio feature is provided in 5G. In the early stage of 5G, it may happen that the network may not boost the VoNR feature on SA architecture. In NSA, voice service is characterized by utilizing LTE, and data service is characterized by NR. In SA architecture, VoLTE isn't supported. Now in that case, for a persistent voice service when a VoLTE call moves to a 5G SA network, the 3GPP has presented voice fallback features. A client can move back to the 5G network after the voice session is ended. In general, SA architecture is dominating more in urban areas due to core 5G infrastructure. The spread of SL implementation is comparatively lesser in rural areas due to the limitation of core 5G infrastructure. When the user is accessing the cellular services in the urban area, the user can enjoy all the benefits of SA implementation and after reaching towards high wave and rural areas, conversion of SL to NSL takes place. All the cellular service providers are trying to implement SL communication throughout the area.

The graphs represented in Figure 5 are pellucid enough to state that the type of architecture matters for the efficient use of the network in urban areas and rural areas. Owing to this, the type of architecture holds an impact on the performance of the network.

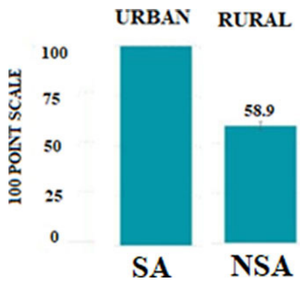

Fig. 5. Improvement of SA vs. NSA on a relative scale where the slowest latency is 100-point

5 Conclusion

Standalone architecture proves to be efficient in the performance of data speed but not so efficient in terms of cost and budget for MNOs. Non-standalone, on the other hand, tick marks the cost efficiency criteria but cannot meet the "Real 5G" expectations. It all narrows down to prioritizing the affordability factor for creating a whole new infrastructure. It should also be noted that in urban areas, due to multi-storied buildings, a high number of vehicles, and dense population the signal speed is affected compared to the plains in villages and rural areas where the signal can flow easily with less interference. In such a case, even the network with NSA architecture can provide enough speed to carry out efficient communication in rural areas as compared to SA architecture in urban areas. The conclusion drawn from the above situation can be that urban areas should be prioritized for the deployment of 5G SA due to the various obstructions faced by the city residents.

The 5G network has immense potential to conquer the limits that the world of telecommunication didn't even know it could achieve. But the pros of 5G SA come with its cons. This dilemma can be solved only by prioritizing rather than generalizing as there are various countries where faster and more efficient communication is not a priority. They have their citizens' basic needs to be fulfilled first. In such developing countries, building a whole new infrastructure for better communication is baseless. Hence, 5G SA is recommendable for the areas where the service providers can afford such a heavy dent in the economy; else, 5G NSA proves to be a better alternative.

When the signal strength is poor in SA architecture, we will lose our signal and Internet data whereas in NSA, when signal strength is poor, the MSC will change our Internet generation from 5G NR to 4G LTE to 3G H+ and so on and try to keep the handset connected with the MSC. This is one of the major advantages of 5G NSA architecture.

The 5th Generation of the Internet in Telecommunications will open the new doors to the Internet of Things (IoT), Industrial Internet of Things (IIoT), Artificial Intelligence (AI), Machine Learning (ML), Neural Networks, etc. As the 5th Generation is burgeoning, the M2M connections and the IoT will represent an industry worth $66 Billion by 2026, according to ABI Research. The Electric Vehicle Industry is also increasing rapidly just because of the High Data Speed of 5G Internet.

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