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Deployment of 5G Core for 5G Private Networks

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***Abstract*—Private fifth generation (5G) network aims at providing unified connectivity with all its enhanced communication features within a specific area. Despite being a potential catalyst to revolutionize the industries, 5G can also suffice the needs of the ever-increasing number of mobile users and real-time connectivity requirements. To achieve this, there is a demand for use of software and hardware that guarantees scalability, flexibility and be performance-driven those avails all the network functions. This paper provides an in-depth study and setup of 5G Core Network using Open5GS, one of the best open-source platforms for 5G demonstration. With the correct set of network configurations and connection in Linux environment, various sessions and interface are established that would help the users access a wide range of services through network functions, thus setting the base for a 5G private network.**

***Index Terms*—Private 5G, unified connectivity, 5G Core, Open5GS, network configurations and network functions**

I. Introduction

In the world we live today, technology has taken huge strides in all dimensions. The communication and networking domain too has seen unprecedented growth. At the same time, the number of mobile users and demand of network connectivity is on a constant rise. Many aspects of human life have witnessed extraordinary growth and development because of communication technologies and has boosted society, politics, culture and economy. The number of landline telephone users have reduced a lot today. Almost everyone has begun to use mobile phones that keep us connected to the world and keep us entertained seamlessly. The 1980s witnessed the first-generation service in wireless communication and ever since then, the following (next) generations have only brought advancements in technology in terms of network architecture, mobility, coverage, data, privacy and security, spectral efficiencies and many more. The work on 5G technology has been taken up by industrial and academic societies who are constantly trying to incorporate best of the technologies to establish the best network services.[1]

The 5G specification emphasizes on three main use cases- Enhanced Mobile Broadband (eMBB) which implies 5G aims at providing greater data-bandwidth along with improvements in latency on both 5G New Radio (NR) and 4G LTE (Long Term Evolution). This will ultimately benefit emerging Augmented Reality and Virtual Reality applications and OTT streaming services. Ultra-Reliable Low Latency Communication (URLLC) defines the minimum requirement

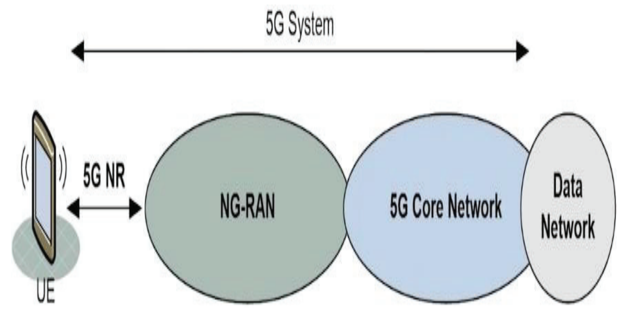

Fig. 1. 5G Networks

for 5G networks to offer communication with high reliability (99.99%) and at the same time extremely low latencies (below 1ms). It also aims at keeping low data rates. This feature makes mission-critical applications and industrial automation easier and feasible. Massive Machine Type Communications (mMTC) through which this use case aims at mass deployment of billions of low-powered and low-cost devices such as in Internet of Things (IoT). These use cases will boost communication resources along with computing and energy resources.

Not only the high demand applications but also features like gearing towards millimeter- wave (mmWave) spectrum, allocation and reallocation of bandwidth using new techniques, the concept of virtualization that would save costs and improvise network standards and the increasing amalgamation of current and previous WiFi and cellular communication protocols and standards to ensure with high levels of low latency.

A. 5G Network and Architecture

To set up any conventional network of any generation, we primarily need to concentrate on three aspects/components- the Core Network, the Access Network and the User Equipment as seen in Fig.1. This paper concentrates exclusively on the Core Network required to set up 5G Private Network. With the correct set of tools and resources as discussed in the upcoming sections, it is feasible to address the requirement of a scalable and reliable setup.

Although 5G has been designed and adopted from basic architectures of previous generation networks, Fig.2 shows the network functions of 5G deployed as service. So, this architecture is also called as Service-based Architecture (SBA). The

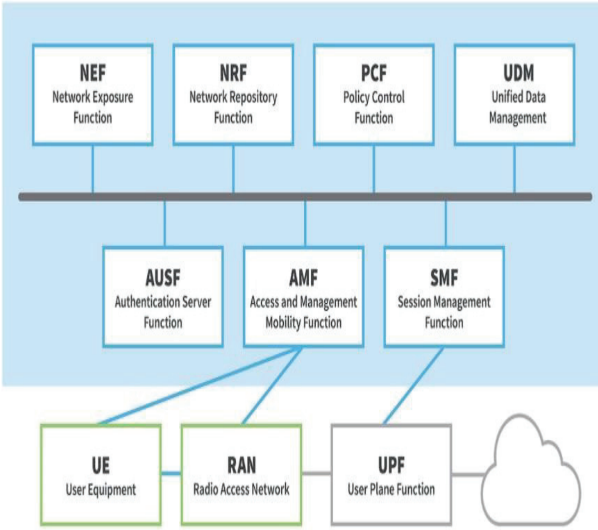

Fig. 2. 5G Architecture

network functions have been divided across two planes-control plane and user plane[5].User Equipment (UE) that includes 5G smartphones or 5G cellular devices connect over the 5G New Radio Access Network to the 5G core and further to Data Networks (DN), like the Internet. The Access and Mobility Management Function (AMF) acts as a single-entry point for the UE connection. Based on the service requested by the UE, the AMF selects the respective Session Management Function (SMF) for managing the user session. The User Plane Function (UPF) transports the IP data traffic (user plane) between the User Equipment (UE) and the external networks. The Authentication Server Function (AUSF) allows the AMF to authenticate the UE and access services of the 5G core. Other functions like the Session Management Function (SMF), the Policy Control Function (PCF), the Application Function (AF) and the Unified Data Management (UDM) function provide the policy control framework, applying policy decisions and accessing subscription information, to govern the network behaviour.

B. 5G Private Networks

A private fifth generation (5G) network is a dedicated 5G network with enhanced communication characteristics, unified connectivity, optimized services, and customized security within a specific area. After having derived from advantages of both public and non-public 5G networks, the potential of private 5G networks have been proven through applications across business, industry, utilities, and the public sector. Also regarded as a promising accelerator for Industry 4.0, industry and academia have developed keen interest in this domain. Private 5G network can also be considered as an alternative to building, buying, and managing a private mobile network. With its prominent feature of reduction of initial costs, it works wonders for industries as the daily management and offloading construction is also less.[1] These networks are non-public mobile networks that can use licensed, unlicensed, or shared spectrum. Private 5G networks have been designed with a vision to explore capabilities of existing networks and work on areas of improvement which most of the other systems would not be able to support and cater to the needs of the users[2].

C. Differences between 4G and 5G Networks

In 4G Network architecture, it can be seen that the LTE RAN and eNodeB are close together running on specialised hardware near the cell tower or base station. Whereas, when it comes to 5G Network architecture, the monolithic EPC was broken and each function was given the provision to run independently which in turn makes the 5G core decentralised and flexible. The communication paths are made shorter and it has increased speed and latency from one end to the other.[3]

Another prominent difference between the architectures of both generations is that 5G networks can be customised by deploying network slicing. Certain slices/chunks of the entire network can thus be allocated to specific functions and applications.[6]

II. Related Work

Miaowen Wen et al. have reviewed the recent research on 5G private networks along with the architectures, deployment methods and scope of research. After having discussed use cases and real demonstrations of 5G Private Networks through key enabling technologies, the focus has been shifted towards identifying research challenges and potential solutions in these setups [1].

Adnan Aijaz has thrown a light on use of private 5G in industrial sector along with conceptual and functional architectures for the same. Further research in this paper provides an overview of spectrum opportunities so as to boost the open innovation ecosystem for private 5G. The licensed and unlicensed spectrums have been discussed along with network slicing which is a crucial design aspect in 5G [2].

J.Prados-Garzon et al. have taken the discussion on 5G private networks by taking into consideration the subscriber configurations, 3GPP standards, privacy and security features. After differentiating between various single-site and multi-site 5G private networks, a few services such as LxVPN have been given importance to accelerate the transformation in vertical industries by tapping into full potential of 5G networks [3].

Edson Amatucci et al. compared three open-source platforms used for 5G Core deployment- Magma, Free5GC and Open5GS on the basis of infrastructure, documentation, community and code maturity, management and other such factors. For the project at hand, the authors selected Magma temporarily while the research is in progress as no specific conclusion has been made on the basis of performances of the three platforms [4].

T.Cogalan et al. evaluated various features of 5G-CLARITY, an integration of LiFi, WiFi and 5GNR, through packet-level simulations and checking the ability of the system to inherit salient features of 5G. Network slicing has been stressed throughout and it came out to be a successful experiment as the needs of 5G Private Networks were satiated in terms of throughput and positioning precision[5].

Mamta Agiwal et al. found a fine balance between 4G and 5G and how the dual connectivity can lead to initial commercialization of 5G keeping the existing LTE system as the base. Benefits of frequency sharing were taken note of followed by an emphasis on Standalone 5G Networks. The research proves to be crucial from the point of view of shifting towards 5G using 4G [6].

Thus, after extensive research on features, advantages, deployment techniques and research challenges on 5G Private Networks, it can be seen that deployment of 5G Core will surely pave the way towards the 5G revolution we wish to see in future. However, the literature review lacks emphasis on difference between various architectures and deployments and fails to give the most appropriate design [1]. There is no special mention about the networking aspects, protocols and specifications that would help to set up the network.[2]. Testing of the entire network remains a dilemma along with certain security aspects.

III. Problem Statement

With an ever-increasing number of mobile users and real-time connectivity requirements, the next generation (5G) would suffice the needs. There is a demand for use of software and hardware that guarantees scalability, flexibility and be performance-driven those avails all the network functions.

IV. Methodology

5G Core network is deployed with Open5GS and gNB/UE simulation with UERANSIM. Open5GS is deployed on one server and UERANSIM deployed on another server. The architecture of the deployment described in Fig.3. Beginning from installation of virtual machines and establishing a Network Address Translation (NAT) connection between them, deployment of 5G Core involves quite a few operations that would lead to further establishment of various sessions and interfaces finally leading to the entire network. Thus, Open5GS serves to be an excellent platform for deploying private 5G Core. The entire setup is done in Linux environment (Ubuntu 20.04 LTS). Throughout the network, it is mandatory to keep a check on all the interfaces and ensure that all of them are established. The gist is to convert the public internet to a private network.

V. Implementation Details

A. Setup of NAT Network

When two virtual machines (VMs) are installed, the initial Network CIDR 10.0.2.0/24 is changed to 192.168.100.0/24. This is done so as to map several private IP addresses into a single public address.IP addresses are allocated and routed using Classless inter-domain routing (CIDR). Unique identifiers are created for individual devices and networks by a collection of IP standards as shown in Fig.4. Unique packets of information are delivered to specific computers via these IP addresses [7].

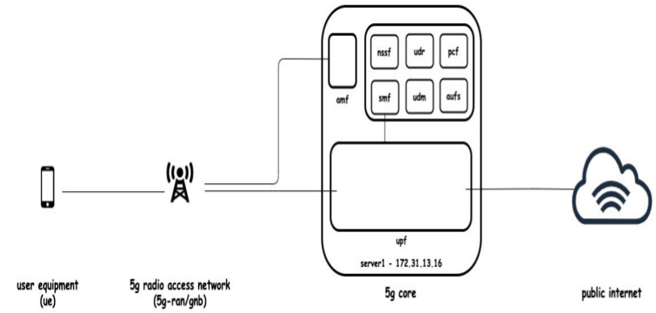

Fig. 3. Methodology for deployment of 5G Core[7]

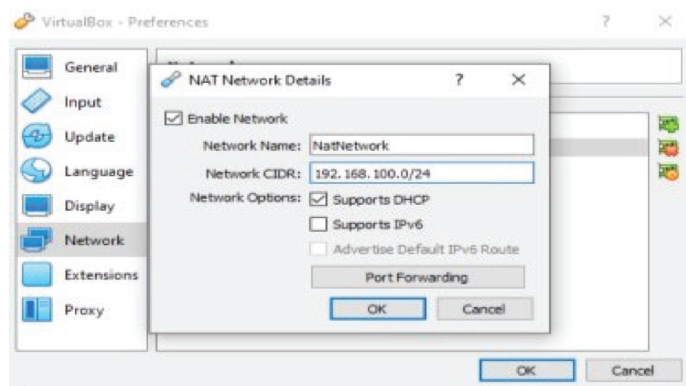

Fig. 4. Network configuration for VMs

Private network gives the leeway of using a private IP address although one public IP address is sufficient for accessing the internet. Network Address Translation (NAT) aims at using a single public address wherein multiple devices get an access to the Internet. Thus, NAT is a favorable setup for the local hosts because of its feature of translation from private to public and vice-versa. NAT translates port numbers of hosts so that routing of packets too occurs systematically(Fig.5.). NAT table maintains the records of IP addresses and port numbers. A firewall or router is generally where the NAT operates.

B. Installation of Open5GS and setting up AMF

After successful installation of Open5GS, it is imperative to start and check the status of the network functions. AMF proves to be the most prominent one. AMF stands for Access and Mobility Management Function. It is a control-plane function in 5G Architecture. The sole aim and reason for addressing this function on priority is its role in establishing the connections and interfaces as stated in methodology earlier. The functions of AMF include Registration Management (to register and de-register a User Equipment in 5G), Connection Management (to establish and release the control plane signaling connections between the UE and AMF across N1 interface), Reachability Management (to ensure that a UE is always reachable), Mobility Management (to maintain knowledge of UE's location within the network). Access and Mobility

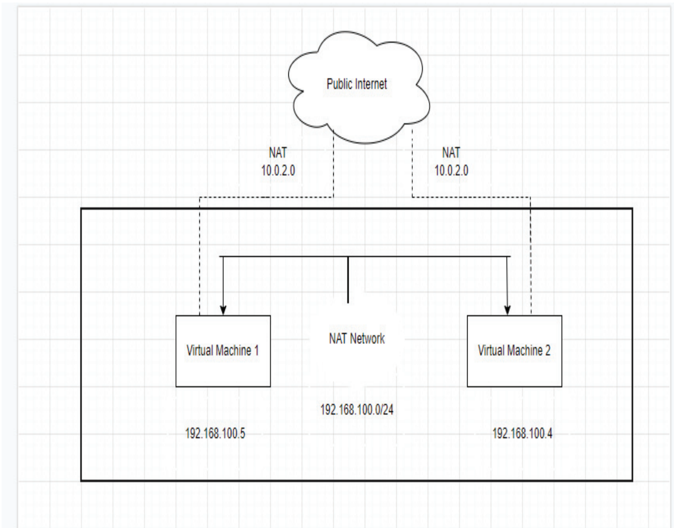

Fig. 5. Setup of NAT Network

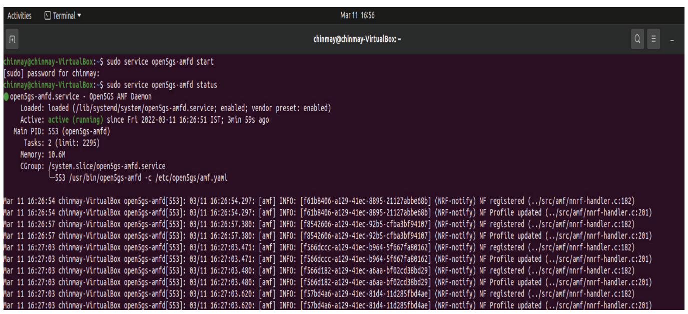

Fig. 6. AMF configuration

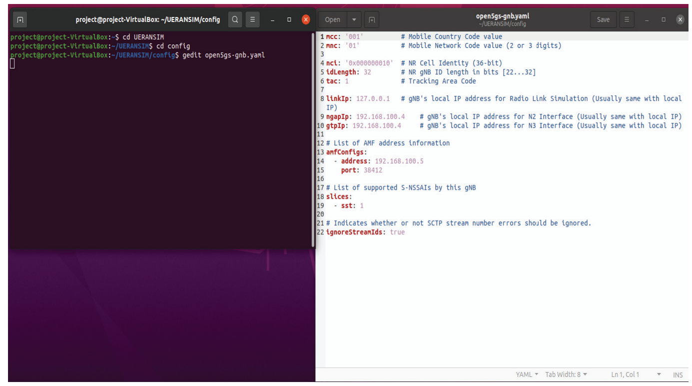

Fig. 7. Setup of gNodeB

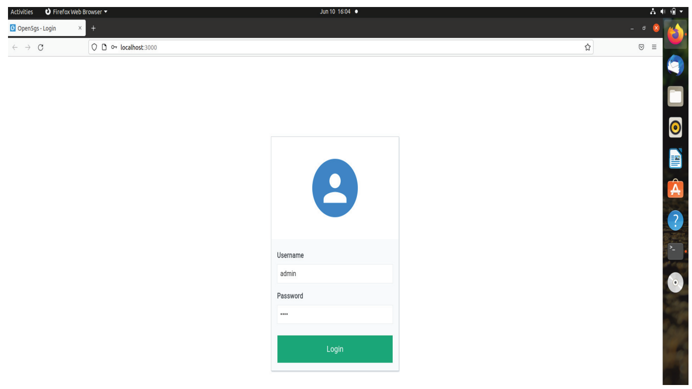

Fig. 8. Setup of Web UI

Management Function is also responsible for handling Next Generation Application Protocol (NGAP). NGAP provides control layer signaling between 5G Radio Access Network and AMF. Any service/network function can be started, ended and restarted in Open5GS using a certain set of commands. The status of the same can be seen as in Fig.6. The actively running AMF indicates that we can proceed further with setting up connections in the network that would ultimately lead to 5G core.

Similarly, other network functions can be verified accordingly with the required set of instructions. It is mandatory for all network functions from both user and control plane as depicted in the architecture to be actively running in upcoming stages of deployment.The three stages-connected, active and idle need to be checked. Provisions of checking the status and restarting the functions as and when required are available in the Open5GS repository.

C. Installation of UERANSIM and setup of gNodeB

As mentioned earlier, gNodeB is one of the parts of UERANSIM. It can be considered as a base station. With the correct set of specification as mentioned in Fig.7, gNodeB can be successfully set up. MNC (Mobile Network Code) and MCC (Mobile Country Code) depend on the country/geographical region and the mobile operator at the same. However, for test networks, we have considered MCC and MNC to be 001 and 01 respectively.[7] Further part of 5G Core Network implementation includes registration of UE so that the network can be tested in real-time environment. The same MCC and MNC need to be used here as well along with certain specifications of the User Equipment.

D. Creating a Web UI for User Equipment Registration

A Web UI has to be created so as to log in and fill in the details of the user equipment and subscriber configuration details. The details include everything from IMSI to the number of network slices. In Open5GS, the profile has been successfully created on http://localhost:3000. Fig.8 and Fig.9 show the successful execution of Web UI and profile creation respectively. The login details are set as: Username- admin and password-1423.

The subscriber configuration includes all the details of the User Equipment staring from IMSI (International Mobile Subscriber Identity) to the number of network slices assigned. Everytime a new user is added, the configurations need to be updated. Note that one AMF can handle only one UE in the entire setup.

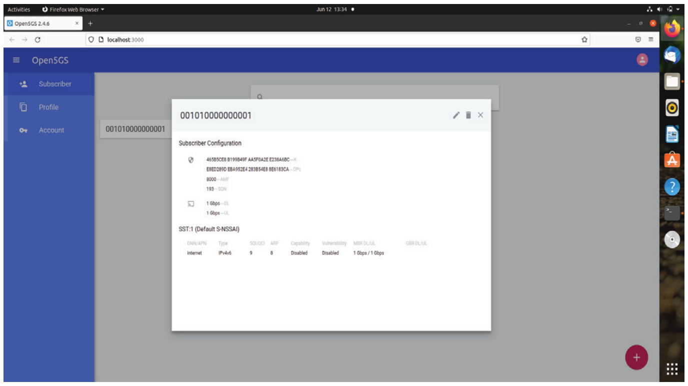

Fig. 9. User Equipment Registration

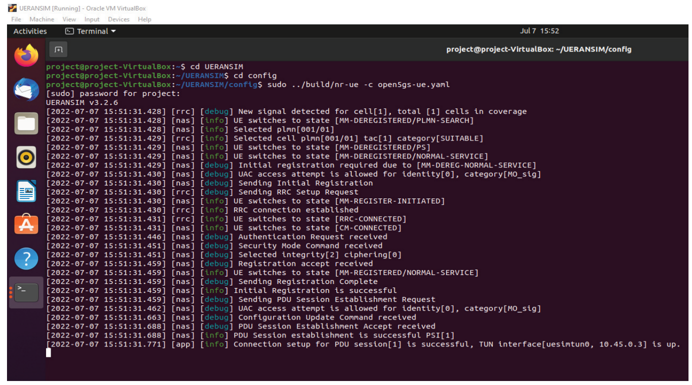

Fig. 10. Establishment of RRC, PDU and TUN sessions

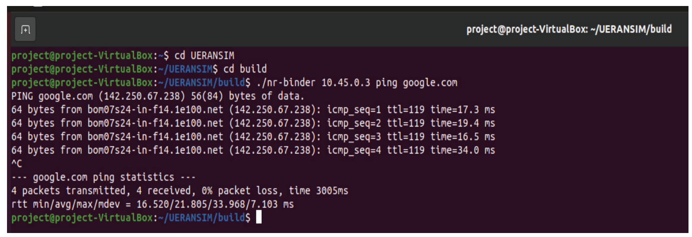

Fig. 11. Accessing external application/website using TUN interface

VI. Results and Analysis

After successful establishment of SCTP connection and setup of NG, it can be seen that a new connection titled 'User Equipment (1)' is detected. The next crucial task is that of RRC setup. The UE establishes an RRC connection with the gNB, which in turn connects to the 5G core network. This is a typical stand-alone deployment scenario. RRC Protocol has a wide range of functions from establishing connection and broadcasting the information received to maintaining mobility procedures and paging notifications. The user and control planes are configured by RRC Protocol depending on the status of network. Strategies for Radio Resource Management are implemented further.(Fig.10)

In 5G System, the networks have to connect User Equipment towards Data Network (DN) known as 5G DNN which is similar to 4G APN. The Data Network (DNN) can be Internet, or an IMS or any other DNN dedicated to an industry.

5G NAS-SM (Session Management) is responsible for setting up and managing the PDU session for user-plane connectivity between UE and Data Networks. The 3GPP specifications kept Session Management design flexible to support diverse 5G use cases that include handling various PDU session protocols, ensure continuity of service and keeping the User Plane Architecture flexible.

TUN devices are replacements for physical networking connections in a virtual manner. These devices are responsible for passing data from one host to another. These are completely virtual interfaces that carry out simulation of physical components within the kernel of the operating system.

Any external application/website can be accessed via TUN which acts as a virtual interface. In the above case, google.com is being accessed by the interface 10.45.0.3. The packet loss here is 0% which implies that the website has been accessed successfully using 5G Core Network (Fig.11). The nr-binder tool available in UERANSIM offers to establish this connection via ping command. Another method of trying this out is using the curl command.

VII. Conclusions

5G Private Networks can prove to be a catalyst in revolutionising the industries globally. A reliable, flexible, scalable and secure network can suffice the ever-increasing demand for network connectivity and also perform efficiently if accurate and sustainable platforms like Open5GS are used for deployment. Open5GS, with all its packages and libraries, helps the user to not only set up an efficient 5G Core network but also ensures smooth functioning of the same with all the sessions and connections established. Various web applications can be accessed using the 5G Core network that has been set up. Many more services including multimedia streaming can be availed using the current setup. Thus, 5G Core Network sets the tone for a 5G Private Network really well. Further scaling up of this setup with various technologies at play can truly unleash the true potential of 5G.

VIII. Future Work

As a part of reliability, the entire setup seems to be well-equipped enough to fit in various test and national networks throughout. It can be seen that basic web applications like Google, Firefox can be easily accessed via the interface. (0% packet loss is a clear indication that web services can be accessed on 5G). Further advancements would include image and multimedia streaming which can be done via setup of other interfaces in the same virtual environment. To test the entire 5G Private Network as a whole, Radio Access Network needs to be set up either in physical or virtual environment. However, to test the 5G Core network as a separate entity, the same installations and setup need to be performed in various virtual machines in a confined space for instance a small lab having PCs, an organisation or even at homes.

Performance testing would further include testing the setup with various subscriber configurations which implies using

SIM cards of various mobile network operators. To test the availability and fault tolerance,two PCs with same Linux environment setups can be connected and see if the data transfer is successful. There are instances wherein either of the interfaces do not get established or take time or require separate execution. In such cases, the time, loss of connectivity, latency and other networking parameters come into picture. In such cases, reboot always works but that cannot be the ultimate solution.Along with changing configurations, it is also imperative to keep track of various sessions and the time required for their establishment. Thus, future work would involve various test cases as mentioned.

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