4G Radio Access Network Simulator for Lab as a Service: Operation, Administration and Maintenance Scenarios in Indonesia

1st Sinta Novanana
Broadband Multimedia, Electrical Engineering Department
State Polytechnic Jakarta
Jakarta, Indonesia
n.sinta@gmail,com , sinta.novanana@elektro-pnj.ac.id

2nd Alfin Hikmaturokhman
Telecommunication Engineering, Engineering Department
Institut Teknologi Telkom Purwokerto
Purwokerto, Indonesia
alfin@iitelkom-pwt.ac.id

*Corresponding author: alfin@ittelkom-pwt.ac.id
Received: December 16, 2022; **Accepted:** May 29, 2023

***Abstract*—The 4th Generation of Mobile Cellular Communication is known for its connectivity the all-IP based network infrastructures. The infrastructure of 4G consists of radio access network, core network and transport network. 4G (Long Term Evolution – LTE) is the foundation of the 5th Generation where the infrastructure would be based on Software defined. The software defined technology is the key to this generation as the virtualization, modularity and abstraction become more popular in the implementation and that the cloud computing is nowadays becoming the trend of technology. To catch up with the latest technology in the higher education environment there's a need to have Lab as a Service in education to simulate the real network experience. In this paper, there will be scenarios explained using the Open5GS opensource program to have the lab simulation implemented.**

Keywords—Cellular, 4G Network, Radio Access Network, LaaS, LTE.

I. INTRODUCTION

The 4th generation is the all-IP based network that proves supporting the increased of internet demand and connectivity. The usage of internet in Indonesia based on Survey done by *Asosiasi Penyelenggara Jasa Internet Indonesia (APJII)* [1] is around 77% or 78.19% in 2023 or reaching out to 215.626.156 people out of 276.400.000 Indonesian people. Figure 1. Shows the fact that from the total of 276.4 million population, the cellular mobile connection reaching out to 353.8 million. It certainly means that every people in Indonesia might have more than one mobile connection and possibly more than one operator for the subscription.

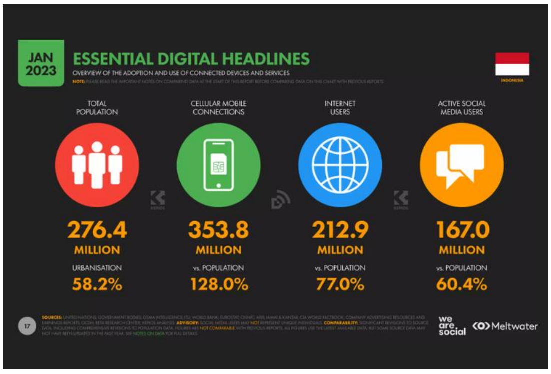


Figure 1. Essential Digital Headlines (source: Meltwater)

The importance of internet usage especially increasing on the demand during COVID-19 breakout, it becomes government attention to increase the connectivity throughout Indonesia. The Solutions for this matter mostly to speed up the digital transformation. The human capitals development, the process and infrastructure readiness mainly in this case should focus on the installation of 4G infrastructures all over Indonesia especially in the *3T* area. The *3T* areas are *Terdepan, Terpencil dan Tertinggal* (At the front, far away from the city and less developed area). The objective of this scenarios solutions is to prepare the Lab as a service [8] in the need of developing the capacity building of the human capital in Indonesia in affordable and achievable way.

I. METHODS

A. *Selecting the Software and Infrastructures*

The Lab as a Service needs to be designed to be easily accessible, secure [6] and capable of handling hundreds of users as the objective of this LaaS is to support the capacity building of 4G infrastructure readiness in Indonesia. Open5gs software is used in this paper to be able to accommodate these requirements [2]. Open5GS [20] consist of two core architecture segments – Open5GS 4G/5G NSA Core and Open5GS 5G SA Core. Open5GS 4G/5G NSA contains the components: Mobility Management Entity – MME; Home Subscriber Server – HSS; Policy and Charging Rules Function - PCRF; Serving Gateway Control Plane – SGWC; Serving Gateway User Plane – SGWU; Gateway Control Plane – PGWC; and Gateway User Plane – PGWU. In this architecture, the core is physically divided into two main levels – the control level and the user level. All eNodeBs of the mobile network – 4G base stations – are connected to the MME. The MME is the main component of the control plane axis in the core. Table I shows the installation of Open5GS could be done using Docker or Container [19].

TABLE 2. ELEMENTS NECESSARY TO DEPLOY [2]

Software		
Magma	***Open5GS***	***Free5GC***
Docker/ Container +Bare Metal	Docker/ Container	Virtual Machine

B. Simulation and the Scenarios

The method used in this paper is simulation. The scenarios are created based on competency that are listed down in the *Standard Kompetensi Kerja Nasional Indonesia* (SKKNI) number 633 year 2016 in relation with occupation map of Telecommunications, the Radio Access Network Operation, Administration and Maintenance Engineer [3]. The Scenarios explained in this paper are Common monitoring eNodeB, Managing eNodeB files (logfile), eNodeB Configuration, eNodeB Backup, eNodeB Troubleshooting and Corrective action.

II. OPERATION, ADMINISTRATION AND MAINTENANCE SCENARIOS

As mentioned previously, the scenarios prepared for the simulations are all Software based so no physical hardware on the eNodeB side as well as the Core Network side. The server used for the solution created could be placed locally or cloud based depends on the readiness of the equipment.

To access the Lab, there is an application that can be used. The name of the application is MobaXterm [4].

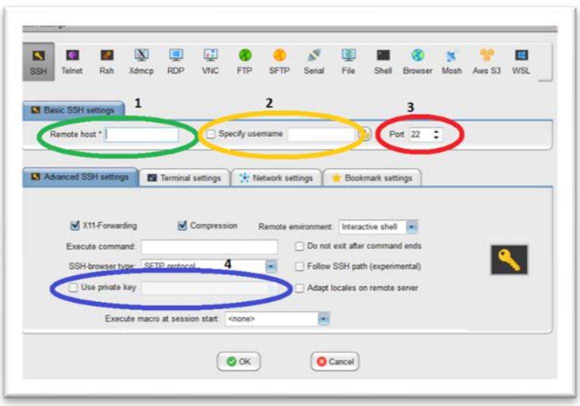


Figure 2. MobaXterm software to access the Lab remotely

Steps to access the system:

1. Enter the IP address of the system
2. Enter the username, e.g.: ubuntu
3. Make sure that port 22 is used
4. Click Advanced Setting and choose Private Key if it is used (optional)
5. Click the OK button.

The system configuration of the Lab is shown in the Figure 3

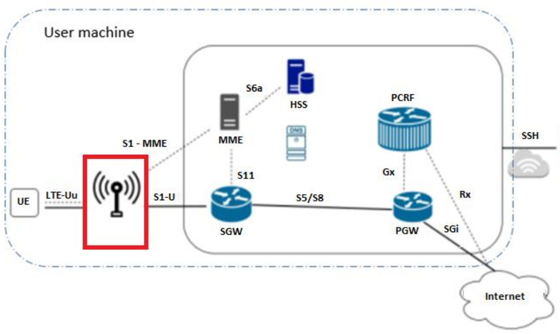


Figure 3. The Lab Configuration for RAN OAM

A. Common Monitoring eNodeB

The Common Monitoring eNodeB is the part where the system monitoring is taken place. The importance parameters need to be monitored are such as: system machine type, system OS, system clock, system CPU resource, disk usages, and system memory. The commands enter to monitor the system can be seen in Table 2.

TABLE 2. Common Monitoring eNodeB – the commands

No	Monitoring List	Command
1	System machine type	$ uname - - machine
2	System OS	$ lsb_release - - all
3	System clock	date
4	System CPU resource	mpstat
5	Disk usage	df - - human-readable
6	System Memory	free - human

To monitor visually the ELK could be configured and used. Figure 4. shows The ELK stands for Elasticsearch, Logstash and Kibana.

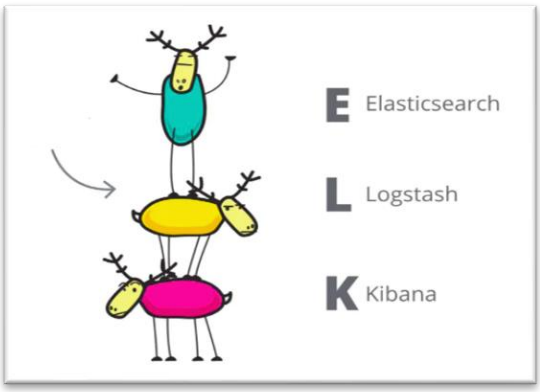


Figure 4. Elasticsearch, Logstash and Kibana.

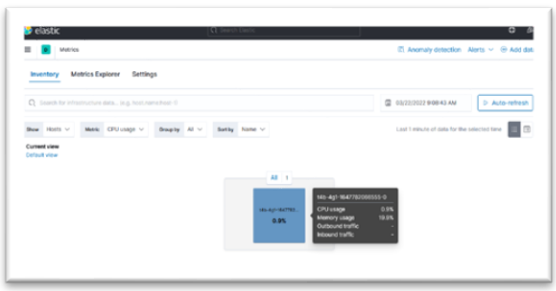


Figure 5. Metricbeat in diagram or chart

Figure 5 and 6 show the possibilities to access and monitoring the system using Graphical User Interface.

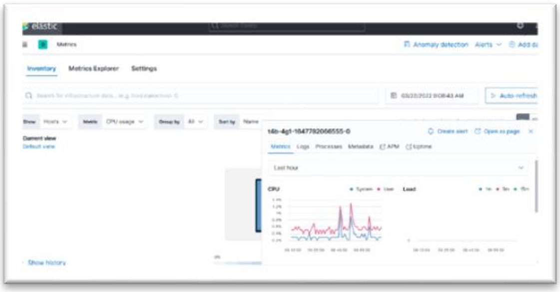


Figure 6. Metricbeat in diagram or chart

Metricbeat GUI based could be seen in Figure 6. Metricbeat is used to monitor the System, users and CPU load.

B. Managing eNodeB files (logfile)

In order to continue having the eNodeB services in good quality and reliability, The logfile(s) are important parts of the whole eNodeB system. Normally the logfile(s) created if there's something wrong with the system and then this logfile(s) could help to identify the problem and followed by the solutions.

C. eNodeB Configuration

The eNodeB Configuration can be checked, it consists of the following parameters: enb_id, mcc, mme_addr, gtp_bind_addr, gtp_advertise_addr, s1c_bind_addr, n_prb, Tm, and nof_ports. The explanation of each parameter is listed in table 3.

TABLE 3. eNodeB Configuration

enb_id	20-bit eNodeB identifier
mcc	Mobile Country Code
mnc	Mobile Network Code
mme_addr	IP address of MME for S1 Connection
gtp_bind_addr	Local IP address to bind for GTP connection
gtp_aderstise_addr	IP address of eNodeB to advertise for DL GTP-U traffic
s1c_bind_addr	Local IP address to bind for S1AP connection
n_prb	Number of Physical Resource Blocks (6,15, 25, 50, 75, 100)
Tm	Transmission mode 1-4 (TM1 default)
nof_ports	Number of TX ports (1 port default, set to 2 for TM2/3/4)

The command to check the eNodeB configuration is in figure 7.

Besides the eNodeB Configuration, there are other configurations in the system. The eNodeB, RF and RR configurations. The eNodeB configuration is shown in figure 8, the RF configuration in figure 9 and the RR configuration in figure 10.

```
$ cat /home/ubuntu/.config/srsran/enb.conf
```

Figure 7. Command to get the eNodeB Configuration

```
#########################################################################
enb]
nb_id = 0x19B

cc = 901

nc = 70

me_addr = 10.0.0.3

tp_bind_addr = 127.0.1.1

1c_bind_addr = 127.0.1.1

_prb = 50
tm = 4
nof_ports = 2

.........................................................................
```

Figure 8. eNodeB Configuration content

```
#####################################################################
# RF configuration
#
# dl_earfcn: EARFCN code for DL (only valid if a single cell is configured in rr
.conf)
# tx_gain: Transmit gain (dB).
# rx_gain: Optional receive gain (dB). If disabled, AGC if enabled
#
# Optional parameters:
# dl_freq:            Override DL frequency corresponding to dl_earfcn
# ul_freq:            Override UL frequency corresponding to dl_earfcn (must be
set if dl_freq is set)
# device_name:        Device driver family.
#                     Supported options: "auto" (uses first found), "UHD", "blad
eRF", "soapy" or "zmq".
# device_args:        Arguments for the device driver. Options are "auto" or any
 string.
#                     Default for UHD: "recv_frame_size=9232,send_frame_size=923
2"
#                     Default for bladeRF: ""
# time_adv_nsamples:  Transmission time advance (in number of samples) to compen
sate for RF delay
#                     from antenna to timestamp insertion.
#                     Default "auto". B210 USRP: 100 samples, bladeRF: 27.
#####################################################################
```

Figure 9. RF Configuration content

```
ubuntu@t4b-4g1-1648545842201-0:~$ more /home/ubuntu/.config/srsran/rr.conf
mac_cnfg =
{
  phr_cnfg =
  {
    dl_pathloss_change = "dB3"; // Valid: 1, 3, 6 or INFINITY
    periodic_phr_timer = 50;
    prohibit_phr_timer = 0;
  };
  ulsch_cnfg =
  {
    max_harq_tx = 4;
    periodic_bsr_timer = 20; // in ms
    retx_bsr_timer = 320;   // in ms
  };

  time_alignment_timer = -1; // -1 is infinity
};

phy_cnfg =
{
  phich_cnfg =
  {
    duration  = "Normal";
    resources = "1/6";
  };
--More--(18%)
```

```
{
  // rf_port = 0;
  cell_id = 0x01;
  tac = 0x0007;
  pci = 1;
  // root_seq_idx = 204;
  dl_earfcn =2850
  //ul_earfcn = 21400;
  ho_active = false;
  //meas_gap_period = 0; // 0 (inactive), 40 or 80
  // target_pusch_sinr = -1;
  // target_pucch_sinr = -1;
  // allowed_meas_bw = 6;

  // CA cells
  scell_list = (
    // {cell_id = 0x02; cross_carrier_scheduling = false; scheduling_cell_id = 0x02; ul_allowed = true}
  )

  // Cells available for handover
  meas_cell_list =
  (
    {
      eci = 0x19C02;
      dl_earfcn =2850
      pci = 2;
      //direct_forward_path_available = false;
      //allowed_meas_bw = 6;
    }
  );

  // ReportCfg (only A3 supported)
  meas_report_desc = {
    a3_report_type = "RSRP";
    a3_offset = 6;
    a3_hysteresis = 0;
    a3_time_to_trigger = 480;
    rsrq_config = 4;
  };
```

Figure 10. RR Configuration Conent

D. eNodeB Backup

Backup of a system [14] is important to prevent the lost of important data and configuration. Backup is an Equipment Basic Configuration Operation and Maintenance activity. Because if there is a failure or damage to the system it will be a disaster for operators that's why routine backup activity becomes very important. Normally backup is taken place every two weeks or every month depends on the operator.

Step-by-step of Backup:

- Create a directory for backup
- Change the access for user for SFTP
- Upload the file for backup
- Check if the backup is upload (successfully created)

Figure 11 is the command for creating a directory for backup, figure 12 is the command for uploading the file as backup file and figure 13 is the command for checking that the upload of the backup file has successfully created.

```
$ mkdir configBackups
ubuntu@t4b-4g1-1647782066555-0:~$ mkdir configBackups
ubuntu@t4b-4g1-1647782066555-0:~$ ls
configBackups   handover_broker.grc   open5gs
```

Figure 11. mkdir command to create a directory for backup

```
$ sftp {user}@{host} <<< $'put {local_file_path} {remote_file_path}'
```

Figure 12. Command to upload the file as backup

```
$ cd configBackups
$ ls
```

Figure 13. Command to check the backup file has successfully created

```
ubuntu@t4b-4g1-1647782066555-0:~/configBackups$ ls -l
total 100
-rw-r--r-- 1 sftpuser sftpuser   968 Mar 22 09:11 drb.conf
-rw-r--r-- 1 sftpuser sftpuser 12771 Mar 22 09:11 enb.conf
-rwxr-xr-x 1 sftpuser sftpuser   359 Mar 22 09:11 enb1.sh
-rw-r--r-- 1 sftpuser sftpuser 12772 Mar 22 09:11 enb2.conf
-rwxr-xr-x 1 sftpuser sftpuser   437 Mar 22 09:11 enb2.sh
-rw-r--r-- 1 sftpuser sftpuser  3545 Mar 22 09:11 epc.conf
-rw-r--r-- 1 sftpuser sftpuser  1688 Mar 22 09:11 mbms.conf
-rw-r--r-- 1 sftpuser sftpuser  2204 Mar 22 09:11 rr.conf
-rw-r--r-- 1 sftpuser sftpuser  2054 Mar 22 09:11 rr1.conf
-rw-r--r-- 1 sftpuser sftpuser  2053 Mar 22 09:11 rr2.conf
-rw-r--r-- 1 sftpuser sftpuser  4887 Mar 22 09:11 sib.conf
-rw-r--r-- 1 sftpuser sftpuser 16806 Mar 22 09:11 ue.conf
-rw-r--r-- 1 sftpuser sftpuser   510 Mar 22 09:11 ue.sh
-rw-r--r-- 1 sftpuser sftpuser  1275 Mar 22 09:11 user_db.csv
```

Figure 14. The files in the directory configBackups

In Figure 14, the files are created as the backup of the system. The OAM engineer could check the backup files. There's also the need to do the cross check and consistency of the database, and that's why there's an activity called comparison of the Backup files and those could be done in the following steps and command as shown in figure 15.

```
$ diff file1 file2

$ diff /home/ubuntu/.config/srsran/enb.conf  /home/ubuntu/.config/srsran/enb2.conf
```

Figure 15. Command to compare file 1 and file 2

The comparison is needed to check the inconsistency of the file (backup and existing or actual file) according to the configuration.

This comparison should be done routinely as the database of backup is expected to be always consistent and up to date.

E. eNodeB Troubleshooting

In case there's a problem in the system, troubleshooting becomes one of the most important and very crucial in the term of Service Level Agreement, the Key Performance Indicator and Quality of the operator especially the customer experience. Engineer should be able to analyze and understand the problem and how to perform troubleshooting to the system.

Step-by-step of Troubleshooting

- Check the alarm (severity, type, etc)
- Classify the problem (Hardware, Software, Database, Connections, etc)
- Create a report regarding the problem

Figure 17 shows the command to check the alarms, figure 18 shows the example of possible problem classifications and figure 19 explains the example of problem and the troubleshooting. And Figure 15 below is the example of a case where the subscriber or UE could not attach to the network.

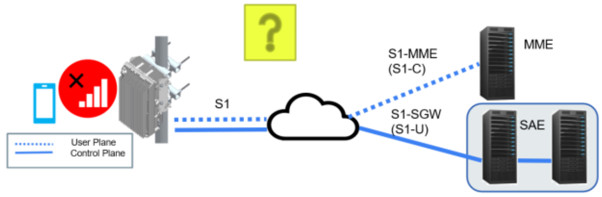


Figure 15. The Subscriber could not attach to the network

```
$ show-alarms

ubuntu@t4b-4g1-1648545842201-0:~$ show-alarms
ID    NAME       DESCRIPTION
----------------------------
1     MME-ENB    LTE Core is Down(S1 connection Cant be established)
ubuntu@t4b-4g1-1648545842201-0:~$
```

Figure 17. show-alarms command

From the Alarm information, there's a problem in S1 connection mentioning that the LTE core is in down status. Checking should be done also through the Hardware alarms as well.

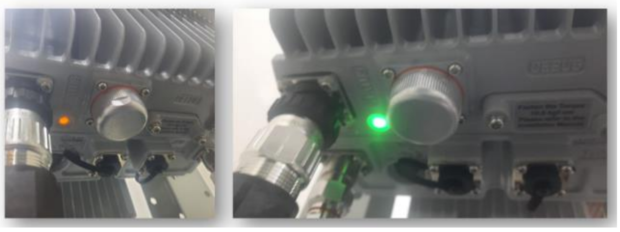


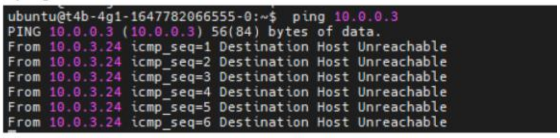
Figure 18. Hardware problem could be checked from the alarms status, check as well the transmission alarm (source: parallel wireless)

If there's a problem always several possible causes could be considered such as hardware failure, connection problem, transmission problem or database problem.

Perform Hardware check (power on/off), Check light on Hardware (Red or yellow or green), Check if the UE has access to the Network legally (SIM Card, Quota, no restrictions, others), Check the Interface towards the Core Network, especially MME (especially for attaching to a failed network).

If there is no Hardware problem, and that the UE has already created and managed well in the core network part (HSS database, charging related things is confirmed not to be a problem) then suspect the transmission problem. Use the PING command to check whether or not it is successful. MME IP address is 10.0.0.3 according to the eNodeB Configuration database.

$ ping 10.0.0.3



```
ubuntu@t4b-4g1-1647782066555-0:~$  ping 10.0.0.3
PING 10.0.0.3 (10.0.0.3) 56(84) bytes of data.
From 10.0.3.24 icmp_seq=1 Destination Host Unreachable
From 10.0.3.24 icmp_seq=2 Destination Host Unreachable
From 10.0.3.24 icmp_seq=3 Destination Host Unreachable
From 10.0.3.24 icmp_seq=4 Destination Host Unreachable
From 10.0.3.24 icmp_seq=5 Destination Host Unreachable
From 10.0.3.24 icmp_seq=6 Destination Host Unreachable
```

Figure 19. Ping 10.0.0.3 is not successful

$ cat /home/ubuntu/.config/srsran/enb.conf

```
# eNB configuration
#
# enb_id:             20-bit eNB identifier.
# mcc:                Mobile Country Code
# mnc:                Mobile Network Code
# mme_addr:           IP address of MME for S1 connnection
# gtp_bind_addr:      Local IP address to bind for GTP connection
# gtp_advertise_addr: IP address of eNB to advertise for DL GTP-U Traffic
# s1c_bind_addr:      Local IP address to bind for S1AP connection
# n_prb:              Number of Physical Resource Blocks (6,15,25,50,75,100)
# tm:                 Transmission mode 1-4 (TM1 default)
# nof_ports:          Number of Tx ports (1 port default, set to 2 for TM2/3/4)
```

Figure 20. Crosscheck whether or not the IP address is the problem.

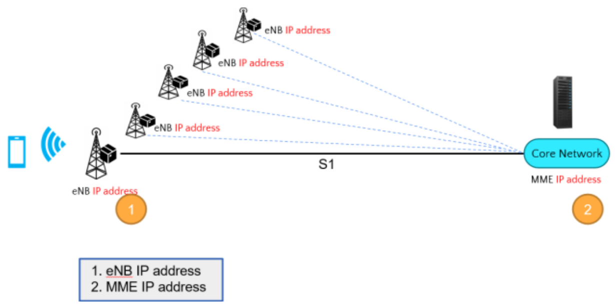


Figure 21. S1 interface, the interface between eNodeB and Core Network.

From figure 20 and 21, the problem identification shows that there's a database configuration mismatch between the IP address in the configuration file and the actual MME IP address.

F. eNodeB Corrective Actions

The core problem from previous troubleshooting step-by-step taken by the engineer shows that the problem is the misconfiguration of the MME database, the IP address is different. The corrective action for this case is to change the eNodeB configuration file located in the system with the correct IP address. This can be done via Vi editor or other editing tools to fix the problem of subscriber could not attach to the network.

III. Result and Discussion

The Operation, administration and maintenance of Radio Access Network [13] – Lab as a Service with the scenarios which can be used to develop human capitals is designed and already tested and implemented during Digital Talent Scholarships – Vocational School Graduate Academy [10]. It has successfully used as the Lab as a Service during the trainings and certifications. The lab is designed with fully cloud based and accessible remotely and can be used anytime according to the timeline for the training delivery as well as the certification process. Using the MobaXterm for the secure shell connection to each of the Virtual Machine [12] created as the complete set of Radio Access Network, Core Network because there is impossible to have only the Radio Access part without the complete set of the Network.

Regarding the participants of the trainings, they were equipped with laptop and internet connection, software installed (MobaXterm) and grouped in a team to perform the Operation, Administration and Maintenance works.

Each group has the access to one 4G simulator lab, they receive the IP address and the private key in order to have a secure connection through internet to the 4G Lab. The goal is to design and prepare a Lab as a Service in order that there's opportunity for the participants to have hands-on experiences as it is a generic solutions which can be implemented at any universities or institutions, To build their own simulation lab in 4G. Whether it is for a training hands-on from training center perspective, for research purpose from academic point of view or testing purpose from operator point of view. 4G is a user centric [5] network architecture.

Further discussion is needed to solve the challenges in upcoming technologies. Related to the cloud-based [7] solution Lab as a Service, one of the concern is the security of the Lab itself, and the accessibility, it supposed to be accessible for massive connections to the lab for each of the purpose of using the Lab. There should be further research on these based on the actual needs and possible innovation related to the infrastructures, especially the cloud.

IV. Conclusion

The Lab as a Service is designed for Operation, Administration, and Maintenance activities [18]. The software chosen is Open5GS which has two options for the core architecture; Open5GS 4G/5G NSA Core and Open5GS 5G SA Core. It is accessible from remote area as far as there is a good internet connection then the Lab as a Service is ready to use. There is room to add more scenarios to the existing ones in the future for trainings, research [16] or testing purposes by exploring the possibilities of software usage, modifications and customized designs.

Acknowledgment

The Lab as a Service has been used by ministry of ICT - Kominfo for the training and certification delivery during COVID-19 Pandemy, due to the increase of demand in having Radio Access Network Engineers to be able to support the needs of infrastructures installations all over Indonesia especially the 3T areas.

References

The references used in this paper is taken from internet, Journals and Conferences. The year of these references is from 2016 to 2023.

[1] Yati, R. (2023) Survei APJII: Pengguna internet di Indonesia tembus 215 Juta Orang, Bisnis.com. Available at: https://teknologi.bisnis.com/read/20230308/101/1635219/survei-apjii-pengguna-internet-di-indonesia-tembus-215-juta-orang (Accessed: 29 May 2023).

[2] Neto, F.J.D.S., et al. *Analysis for comparison of framework for 5G core implementation*. in *2021 International Conference on*

Information Science and Communications Technologies (ICISCT). 2021. IEEE.

[3] https://proserti.kominfo.go.id/4f0rm1n/files/pubreg/filedok_22.pdf Standard Kompetensi Kerja Nasional Indonesia (SKKNI) no. 633 Tahun 2016.

[4] https://mobaxterm.mobatek.net/download-home-edition.html MobaXterm software

[5] A. Sehgal and R. Agrawal, "QoS based network selection scheme for 4G systems," in *IEEE Transactions on Consumer Electronics*, vol. 56, no. 2, pp. 560-565, May 2010, doi: 10.1109/TCE.2010.5505970.

[6] Q. Jin, Q. Guo, M. Luo, Y. Zhang and W. Cai, "Research on High Performance 4G Wireless VPN for Smart Factory Based on Key Technologies of 5G Network Architecture," *2020 International Wireless Communications and Mobile Computing (IWCMC)*, Limassol, Cyprus, 2020, pp. 1443-1447, doi: 10.1109/IWCMC48107.2020.9148068

[7] J. Zhang, Z. Wu, W. Xie and F. Yang, "MEC Architectures in 4G and 5G Mobile Networks," *2018 10th International Conference on Wireless Communications and Signal Processing (WCSP)*, Hangzhou, China, 2018, pp. 1-5, doi: 10.1109/WCSP.2018.8555652.

[8] Zutin, D.G., et al. *Online lab infrastructure as a service: A new paradigm to simplify the development and deployment of online labs*. in *2016 13th International Conference on Remote Engineering and Virtual Instrumentation (REV)*. 2016.

[9] Raza, M.T., et al., *Highly Available Service Access Through Proactive Events Execution in LTE NFV*. IEEE Transactions on Network and Service Management, 2021. **18**(3): p. 2531-2544.

[10] https://digitalent.kominfo.go.id/program?akademi=VSGA

Digital Talent Scholarships - VSGA

[11] Z. Lin *et al*., "Remote Monitoring System Of Track Cleaning Vehicles Based On 4G-Network," *2020 IEEE International Conference on Networking, Sensing and Control (ICNSC)*, Nanjing, China, 2020, pp. 1-5, doi: 10.1109/ICNSC48988.2020.9238083.

[12] A. Ahmed, M. M. Khan and W. Ahmed, "Cloud based network management and control for building automation," *2016 19th International Multi-Topic Conference (INMIC)*, Islamabad, Pakistan, 2016, pp. 1-6, doi: 10.1109/INMIC.2016.7840123.

[13] A. Havolli, A. Maraj and L. Fetahu, "Cloud Radio Access Network for Next Generation Mobile Networks; practical implementation benefits," *2022 45th Jubilee International Convention on Information, Communication and Electronic Technology (MIPRO)*, Opatija, Croatia, 2022, pp. 449-454, doi: 10.23919/MIPRO55190.2022.9803365.

[14] N. K. Ardi and N. Joshi, "Poster Abstract: 5GHealthNet — A Cloud Based Framework for Faster and Authorized Access to Private Medical Records through 5G Wireless Network," *2016 IEEE/ACM Symposium on Edge Computing (SEC)*, Washington, DC, USA, 2016, pp. 89-90, doi: 10.1109/SEC.2016.19.

[15] L. Mamushiane, L. Mboweni, H. Kobo, M. Mudumbe, J. Mwangama and A. A. Lysko, "4G RAN Infrastructure Sharing by 5G Virtualized Mobile Network Operators: A Tutorial," *2021 IEEE AFRICON*, Arusha, Tanzania, United Republic of, 2021, pp. 1-7, doi: 10.1109/AFRICON51333.2021.9570937.

[16] J. Shin, Y. Shin and J. -G. Park, "Network Detection of Fake Base Station using Automatic Neighbour Relation in Self-Organizing Networks," *2022 13th International Conference on Information and Communication Technology Convergence (ICTC)*, Jeju Island, Korea, Republic of, 2022, pp. 968-970, doi: 10.1109/ICTC55196.2022.9952901.

[17] J. A. Figueira, P. Sebastião, F. Cercas and N. David, "Modelling and Simulation for Real Scenarios of 4G Mobile Communications Using Google Maps," *2013 UKSim 15th International Conference on Computer Modelling and Simulation*, Cambridge, UK, 2013, pp. 385-389, doi: 10.1109/UKSim.2013.106.

[18] M. E. Gonzalez, "A Generalized Packet Traffic Simulator for 4G Network Dimensioning Tools," *2007 IEEE 65th Vehicular Technology Conference - VTC2007-Spring*, Dublin, Ireland, 2007, pp. 1131-1136, doi: 10.1109/VETECS.2007.240.

[19] Míguez González, I., *Virtualized cellular networks with native cloud functions*. 2021.

[20] Lee, S., Open 5GS. GitHub Repository: https://github. *com/open5gs/open5gs, 2022. 5.*