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Channel Emulator Automation for OTA Testing

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ABSTRACT

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The aim of the thesis was to get a better understanding on theory of channel emulation, implement test automation support for a channel emulator and integrate that automation to existing test automation software. Theory part of the thesis briefly covers what is 5G and channel emulation.

The automation provided by the thesis enables tester to run test cases much faster and makes the testing less complex. This provides more accurate test results and a base for implementing further test automation cases for running multiple tests with different test scenarios, even during the night-time.

Keywords: 5G, Channel Emulation, Automation

ABBREVIATIONS

3GPP	3rd Generation Partnership Project
5G	5th generation mobile network
ADB	Android Debug Bridge
ATE	Automatic Test Equipment
BTS	Base Transceiver Station
CDL	Clustered Delay Line
DUT	Device Under Testing
GCM	Geometric Channel Modeling
LOS	Line-Of-Sight
MIMO	Multiple-Input and Multiple-Output
MPAC	Multi Probe Anechoic Chamber
NLOS	Non-Line-Of-Sight
NR	New radio
OTA	Over the Air
PAS	Power Angular Spectrum
PBCH	Physical Broadcast Channel
PSS	Primary Synchronization Signal
RRU	Remote Radio Unit
SCPI	Standard Commands for Programmable Instruments
SS	Synchronization Signal
SSS	Secondary Synchronization Signal
TDL	Tapped Delay Line
UE	User Equipment
UMa	Urban Macro
VISA	Virtual Instrument Software Architecture

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1 INTRODUCTION

Nokia in 2022, is a company that develops and manufactures networking and telecommunications equipment. In Finland Nokia has three different campuses, Espoo campus that is also Nokia's headquarters, Tampere campus, and Oulu. Oulu campus has a long history in researching, developing and manufacturing radio technology. This long history is the reason for its nickname "Home of Radio". OTAVA laboratory in Oulu campus is a laboratory that focuses on Over the Air (OTA) testing with state-of-the-art OTA environments and equipment.

Over the Air testing means that the signal is transmitted and received over the air. OTA testing needs to be done in an anechoic chamber that prevents reflections from occurring. Anechoic chamber also isolates the testing environment from the outside world preventing transmitted signals from interfering with e.g., real 5G base stations in the same frequency range.

End-to-end in 5G testing means, that along with the 5G base station a real user equipment (UE) will be part of the testing. End-to-end testing is the only way to test the systems as they are intended to be operated. Without end-to-end testing capabilities many of the software and hardware issues would be leaked to the real base stations in the field and it would have a negative impact on the end-user's experience.

Key for testing 5G NR base stations real performance in laboratory conditions is to mimic real-life conditions and bring that to an OTA environment. This can be achieved with a channel emulator with a correct channel model in a properly built environment with end-to-end (E2E) testing capability. Environments with channel emulation capability are expensive, so the number of environments can be low due to the high costs. Automation is the key for getting the utilization rate high and getting the most out of the environment. End to end testing consists of using multiple different equipment and software that needs to be handled manually and without the automation this is a time-consuming process. Automation makes this whole end-to-end testing more streamlined and helps the testers dramatically.

Automation support made during the thesis allows testers without any extensive knowledge of channel emulation to run the tests. The integration to already existing test automation software brings the complexity down and makes the testing more approachable without the previously needed knowledge. Testers who have had previous experience with the test automation software would now be able to run tests in these channel emulator environments with just a quick training. Ability to bring channel emulator testing complexity down means that the testing will no more be dependent on the few people that have the knowledge, but others will then be able to support them as needed.

The goal for the thesis is to automate testing process for channel emulator environments and get more familiar with channel emulation in general. Getting more knowledge about channel emulation will help planning and developing of testing activities related to channel emulator environments. The channel emulator used during this thesis work is Keysight's Propsim FS16 channel emulator and the automation part is written in Python using open-source libraries.

Chapter two covers briefly what is 5G and beamforming which is widely used in 5G. Chapter three explains the following concepts: what is channel emulation, what are the channel characteristics and how they affect the channel, channel modelling for 5G, and how channel emulation works in over the air environments. Chapter four is about how the automation and the integration of the automation was done. The overall conclusion of the thesis is presented in the last chapter.

2 5G NR

5G NR is the fifth generation of cellular networks. 5G differences from 4G by bringing faster speeds, lower latency and greater bandwidth. (Nokia 2021, 3.) These are the main enablers for three different often talked use cases (Figure 1.) for 5G NR: enhanced mobile broadband (eMBB), massive machine-type communication (mMTC), and ultra-reliable and low latency communication (URLLC) (Dahlman, Parkvall & Skold 2018, Chapter 1.2.1).

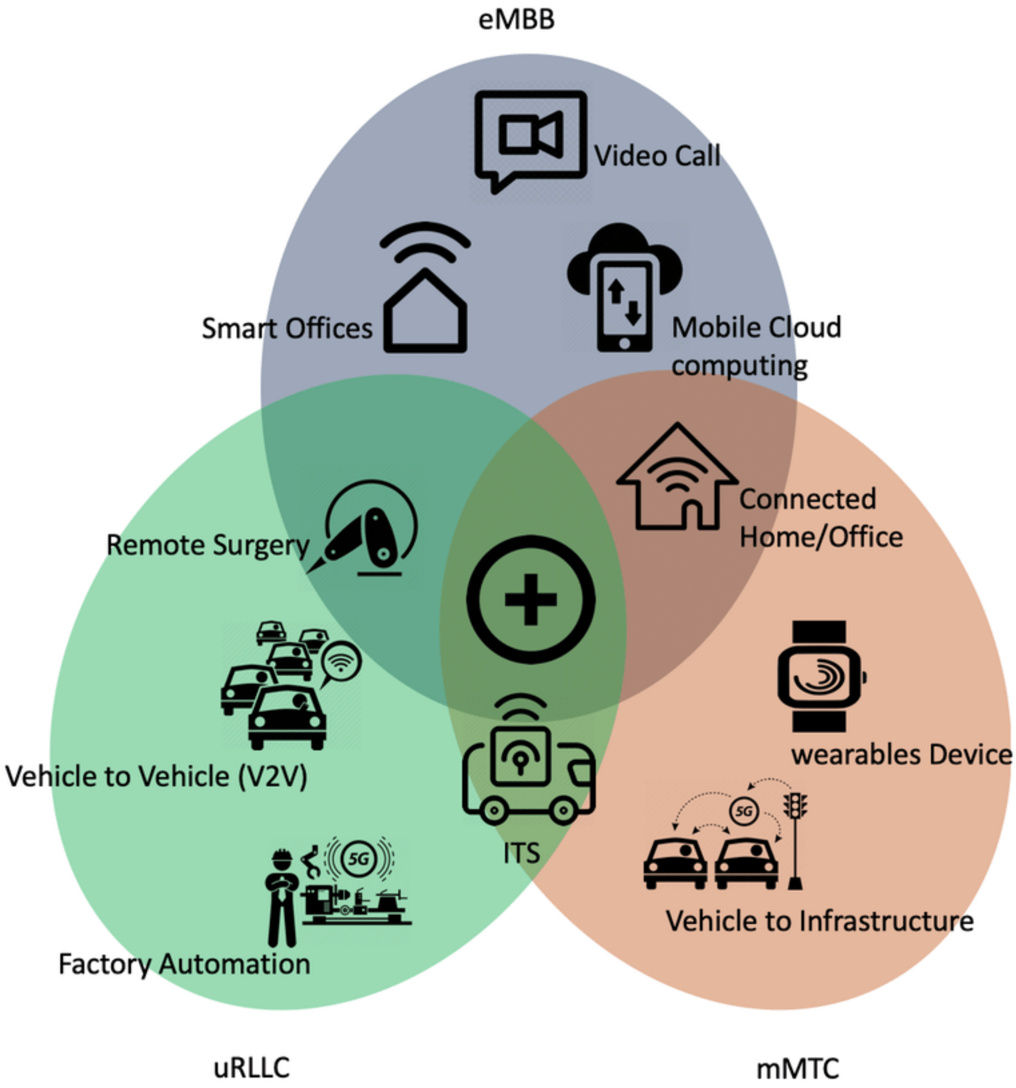

Figure 1. 5G NR use cases. (Barzegar 2020)

2.1 Beamforming

Beamforming is a way to manipulate an antenna arrays radiation pattern by changing the RF signal phases for an antenna element. Adjusting antenna arrays signal path phases individually we can adjust the angle and shape of the transmitted beam. In Figure 2 we can see that by increasing the phase of the other side of antenna array and lowering the phase on the opposite side of the array we are able to adjust the angle of the beam. (Hamdy 2020, 2, 10.)

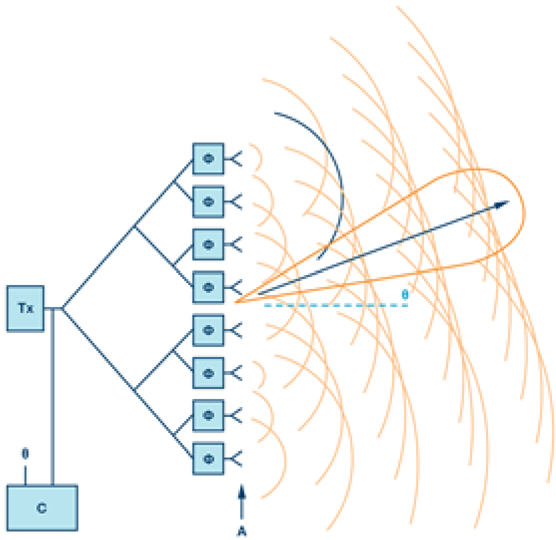

Figure 2. Antenna element phases effect on beam angle (Benson 2019, Phased Array Technology)

This can be achieved with three different techniques: analog beamforming, digital beamforming, and hybrid beamforming. Analog beamforming uses phase shifters to alter the signal phases, digital beamforming changes the signal phases in the baseband, and hybrid beamforming is then a mix of analog and digital beamforming. (Hamdy 2020, 11 - 12.)

In 5G beamforming is used e.g., for synchronization signals. These synchronization signals (PSS, SSS, and PBCH) are embedded in SS blocks, that are then mapped to certain angular directions. When compared to LTE, 5G synchronization signals have better SNR due to beamforming gain as in LTE these signals are not steerable. (Hamdy 2020, 2 - 3.)

3 CHANNEL EMULATION

As radio technology has evolved the devices have become more advanced and are using complex methods to achieve the best performance and spectrum efficiency. Increasement of complexity puts more challenge to be able to test the devices in close to real life scenarios for testing the device performance. When RF signal is transmitted from an antenna it is traveling through some medium, this medium can be referred as a channel. (Braun & Dersch 1991, 1.) Channel emulation with a correct channel model provides a way to bring real life scenarios to lab environments (Spirent 2018, 1).

Figure 3. LOS signal propagation channel between the BTS and UE

3.1 Channel Characteristics

There are three main factors that influence the channel on radio signal transmission the most: path loss, shadow fading, and multi-path fading. Signal propagation can also be divided to three different factors: reflection, diffraction, and scattering. (Jun 2014, 1.)

3.1.1 Path loss, Shadowing & Fast Fading – Impact on Radio Channel

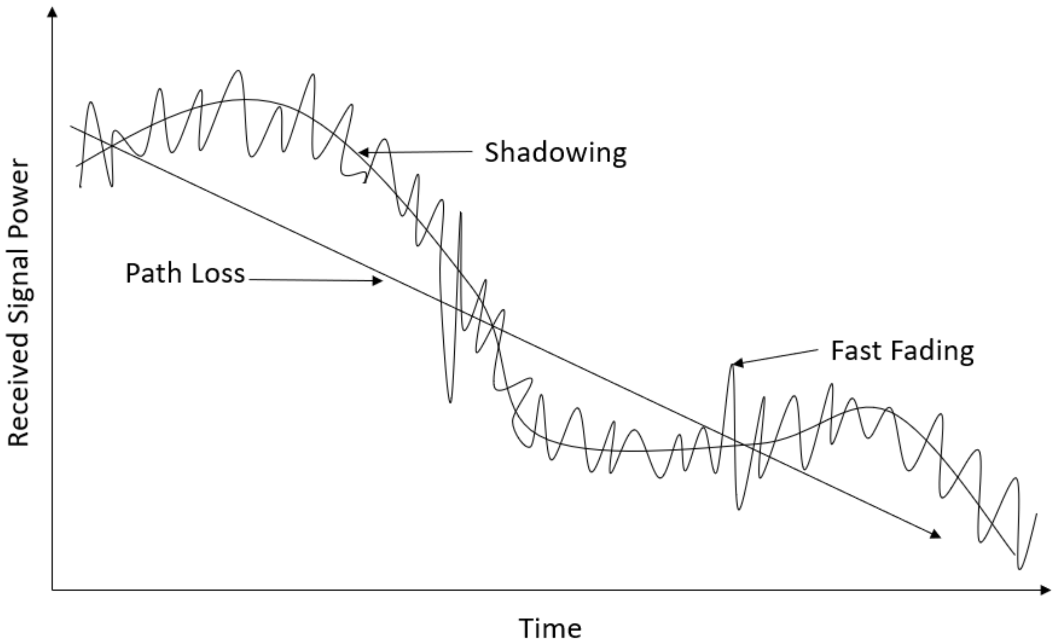

Figure 4. Effects of path loss, shadowing and fast fading on received signal power.

Path loss means transmission loss that is a function of the distance between the UE and the BTS. Shadow fading, also known as slow fading, means the slow signal level changes due to the obstacles of the environment, e.g., buildings. Multi-path fading, also known as fast fading, means fast signal level changes that come from multi-path scattering of the signal. (Jun 2014, 1 - 2.)

3.1.2 Signal Propagation in Radio Channel

Signal can be transmitted to the end user by LOS and NLOS as seen in Figure 5. There are three main NLOS ways for the signal to reach the end user: reflection, diffraction, and scattering. (Figure 5.) These different NLOS ways for the signal propagation are then causing small scale fading effects on the signal power. Small scale fading is caused by the NLOS signals coming at slightly different times with random amplitudes, phases, and angles. When all these sum up the signal will get distorted by the fading. Small scale fading can then also be separated to flat fading, frequency selective fading, fast fading, and slow fading. They all have slightly different ways of forming. (Jun 2014, 1 - 3.)

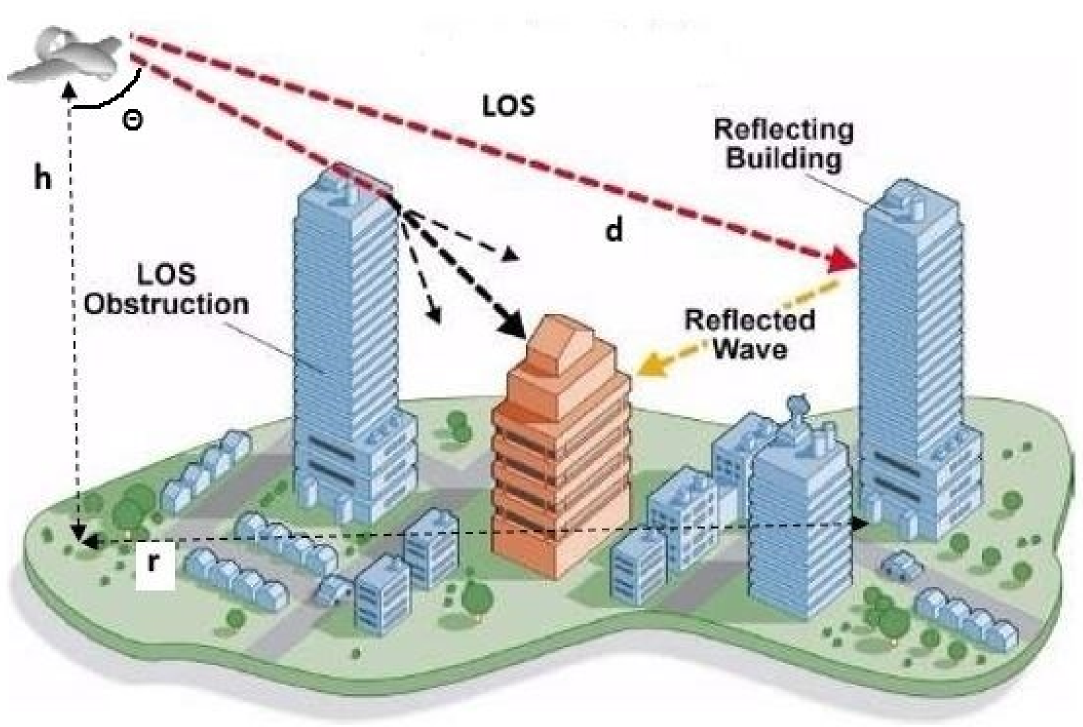

Figure 5. LOS and NLOS propagation (Sharma et al. 2018, 1)

3.2 Channel Model for 5G

When talking about channel models, it is a way to represent a channel with certain characteristics as explained in chapter 3.1. This channel model can then be taken into use with a channel emulator which can then emulate the channel characteristics over time for the test environment in use.

There are two mainly used methods for characterization of channels: Tapped Delay Line (TDL) modelling and Geometry-based Stochastic Channel Model (GSCM). Channel model introduced for 5G by 3GPP is based on GSCM. Main differences between GSCM and TDL is that GSCM has the effects of the antenna array and angular information of the propagation paths considered. (Kyösti 2018, 30 - 31.)

The channel model used for 5G by 3GPP specification is called Clustered Delay Line (CDL). Clusters in CDL consist of rays and each individual cluster contains following parameters with different values: delay, power (dB), Angle Of Departure (AOD), Angle Of Arrival (AOA), Zenith AOD (ZOD), and Zenith AOA (ZOA). All clusters in one channel model have then the same per-cluster parameters with the same values that are: Azimuth angle Spread of Departure (ASD), Azimuth angle Spread of Arrival (ASA), Zenith angle Spread of Departure (ZSD), Zenith angle Spread of Arrival (ZSA), and Cross-Polarization Power Ratio (XPR). (3GPP 2022, Chapter 7.7.1.) In Figure 6 is an example channel model with CDL-C NLOS channel. This same channel model was then emulated, and emulation was run with a real UE in Figure 7. From these two figures we can see similar fading effects as in Figure 4.

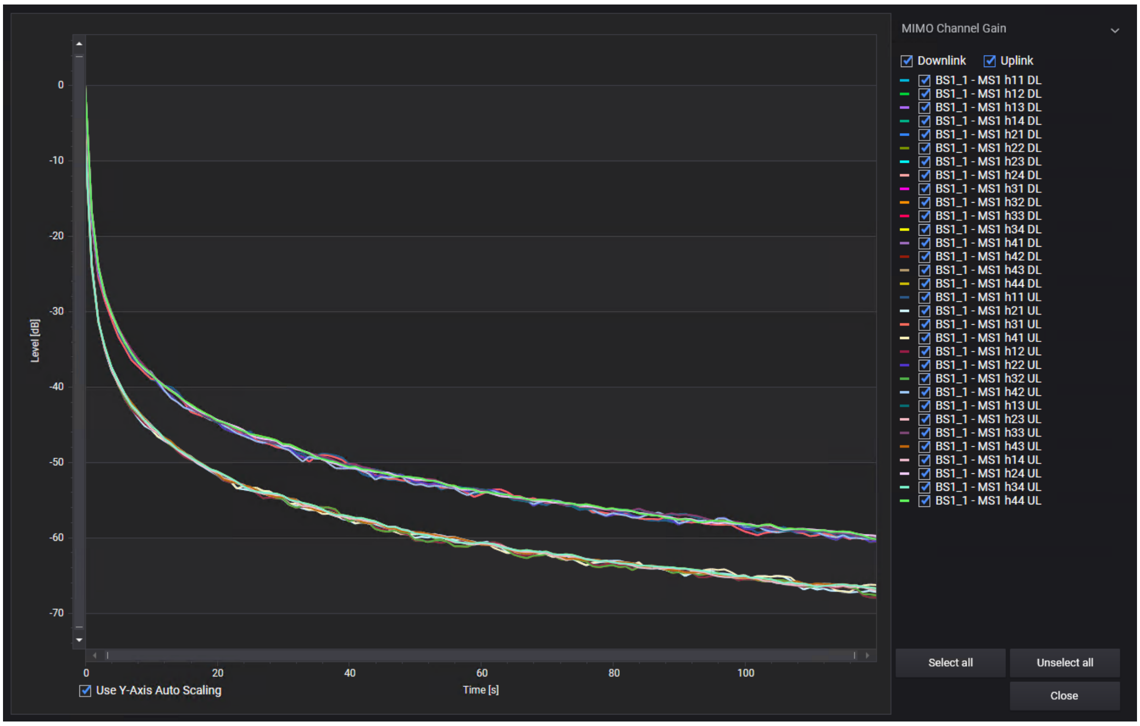

Figure 6. GCM tool output for UMa CDL-C NLOS channel with individual MIMO channel gains over time

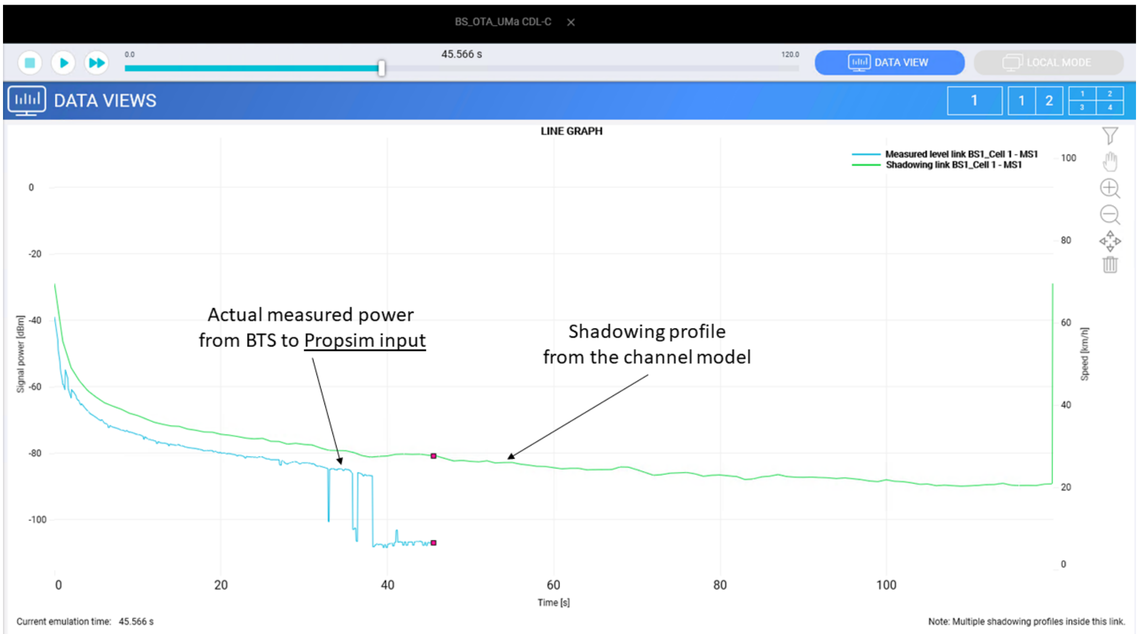

Figure 7. Example of realised channel model emulation using a 5G BTS and a real UE

3.3 Channel Emulation in OTA Environments

5G radios are using massive MIMO antenna arrays and are more compact in build, which brings more challenges for testing the products (Dahlman, Parkvall & Skold 2018, Chapter 3.2). This complexity brings also challenges for testing 5G radios with fading environments and thus OTA radiated testing is required and conducted testing is not possible. OTA radiated testing vs conducted testing brings one benefit, that the DUT's antenna arrays characteristics are taken then into account, and it makes the testing environment more realistic. (Kyösti et al. 2018, 1.)

Kyösti et al. (2018, 2) suggests that multiprobe anechoic chamber (MPAC) is the most suitable OTA testing method for electrically large 5G devices (massive MIMO radios). Suitable MPAC details to test all DUT's in LOS and NLOS channel models based on the simulations, without environment getting too complex, are: range length 1m, eight active probes, elevation sector 30°, and probe panel (Figure 8) spacing 7.5°. With this kind of configuration, the variation distance of the PAS remains low enough for both LOS and NLOS channel models. (Kyösti et al. 2018, 7 - 11.)

Figure 8. Example of a multi probe panel with +/- 45° cross polarised probes

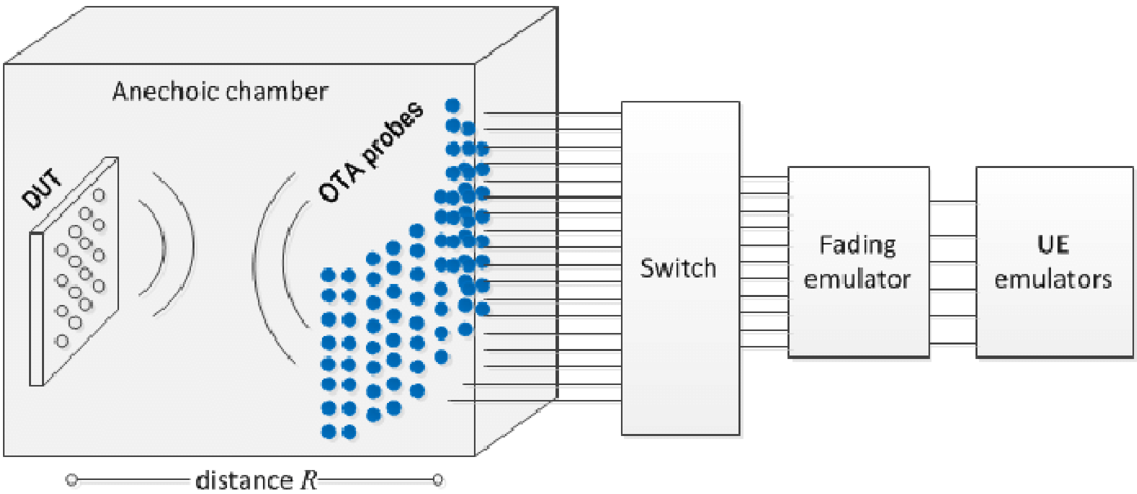

Figure 9. The MPAC test environment (Kyösti et al. 2018, 4)

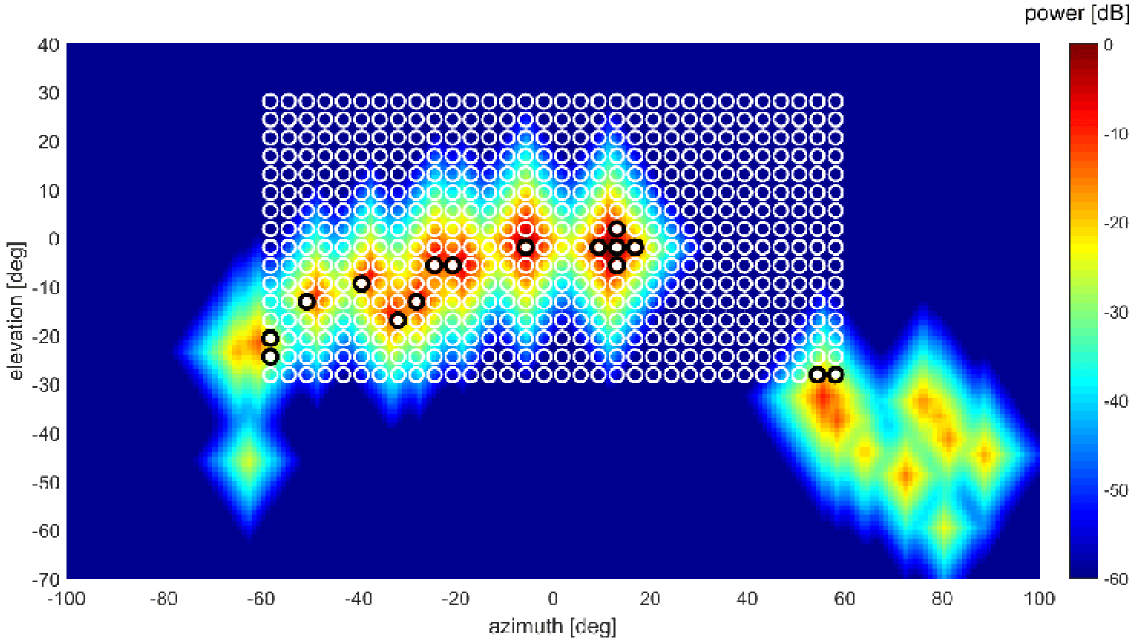

Figure 10. Reference PAS of NLOS CDL-C channel model with ideal probe locations. (Kyösti et al. 2018, 5)

4 IMPLEMENTATION

4.1 Connection to the Channel Emulator

The Propsim channel emulator can be operated remotely by ATE remote control interface. This interface can handle common SCPI commands that are widely used when controlling measurement devices remotely. (Keysight 2020, 3.)

As the used device is only connected through LAN cable to one dedicated PC, port forwarding was needed for the communications port (3334 for Propsim) to enable test automation software to access the channel emulator.
In windows PC this was done through PowerShell with one command (Figure 3).

```
netsh interface portproxy add v4tov4 listenport=3334 connectaddress=<propsim_IP_address> connectport=3334
```

Figure 11: Port forwarding with netsh

This allowed the test automation software to connect to the dedicated PC and the dedicated PC would then forward the SCPI commands from port 3334 to Propsim's port 3334.

4.2 VISA Connection

VISA is an interface for controlling devices programmatically (Agilent Technologies 2005, 9). In this case as the test automation is based on Python programming language the VISA connection was also handled by Python. Open-source package PyVISA and PyVISA-py for Python was used for handling the VISA connection. As Propsim is using socket interface for remote control the connection with PyVISA was initialized similarly as in Figure 4. After this the communication with the device by using write, read or query commands was possible.

```
import pyvisa

# "@py" specifies that we are using PyVISA-py as the VISA backend
rm = pyvisa.ResourceManager("@py")

# For socket connection we need to change the read_termination parameter
my_device = rm.open_reasource("TCPIP::propsim_IP_address::3334::SOCKET", read_termination="\n")

my_device.query("*IDN?")
```

Figure 12. Initializing connection with PyVISA library

4.3 Controlling the Propsim

When controlling measurement devices with SCPI commands, it is easier for the programmer if a library containing all the needed commands is available. There were not any libraries available for Propsim in the organization as this was a new addition to the test automation, so a command library was created.

Example snippet from the library in Figure 5. The messenger is a VISA connection handler done similarly as example in Figure 4. The function "run_emulation" will load the wanted channel emulation file and right after that command we will wait for that operation to complete with "*OPC?" query.

```python

class Propsim:
    def __init__(self, messenger) -> None:
        self.messenger = messenger

    def wait_operation(self):
        """ Wait operation to be completed. """
        self.messenger.query("*OPC?")

    def run_emulation(self, file):
        """ Load channel emulation file to use. """
        self.messenger.write(f"CALC:FILT:FILE {file}")
        self.wait_operation()

```

Figure 13. Example of Propsim command library functions

4.4 Integration to Existing Test Automation

Implementation made to control the Propsim automatically can be run as a service in the used test automation framework. This service was made into a docker image that can then be taken into use, when necessary, by the test automation software.

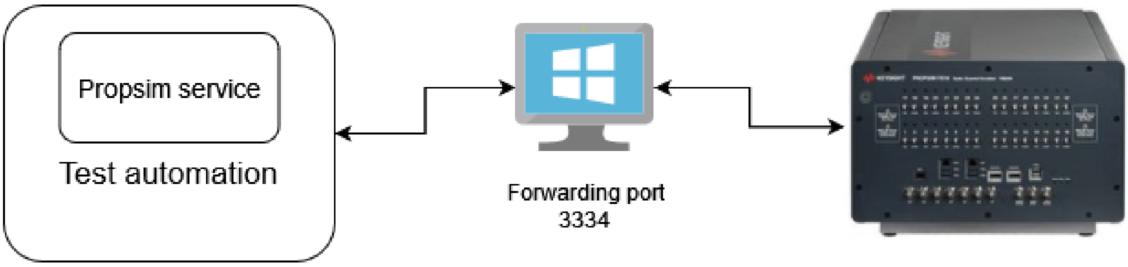

Figure 14. Diagram of the Propsim automation setup

4.5 Testing

The test automation software that this implementation was integrated has different test cases that are then used for testing specific things. Testing with Propsim also needed a test case to allow testing to begin.

The test case can be broken down to three main phases: set up, test steps, and tear down (Figure 15).

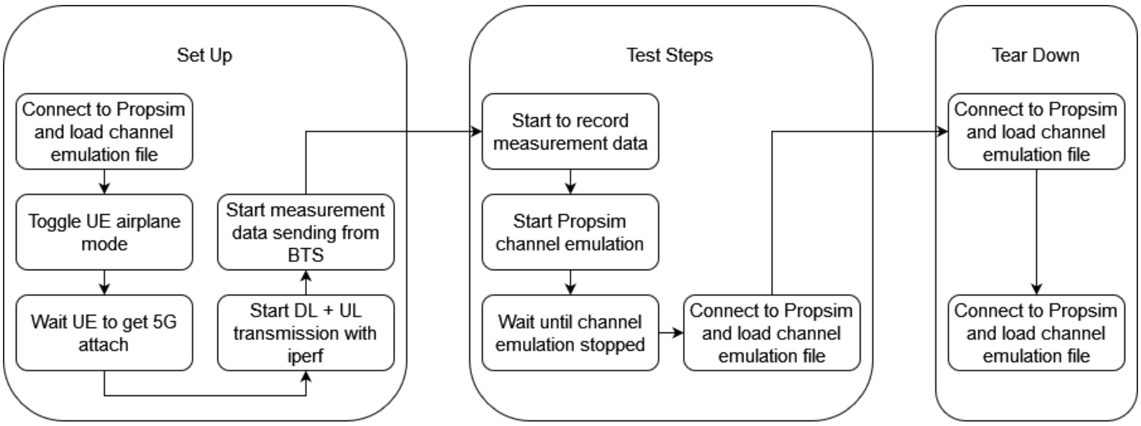

Figure 15. Different phases of the test case

In set up phase first thing is to connect to the Propsim and then load the wanted emulation file. After loading the emulation file, UE airplane mode will be toggled to get the UE to attach to the 5G network. After the UE has the connection iperf data transmission will be started to downlink and uplink directions. Test steps are to start gathering measurement logs, start the emulation playback, wait for the emulation to finish, and then stop logging of the measurement data. In the tear down phase the previously loaded emulation can be closed if wanted, previously started iperf data transmissions will be stopped, and data logging from BTS will be stopped.

5 CONCLUSION

The goal of the thesis was to get a further understanding of channel emulation and then implement a support for automating testing with a channel emulator.

Further understanding of channel emulation and OTA environment impacts on it was achieved. In the future, this knowledge helps to develop the use of channel emulator through different test scenarios. In addition to this, thesis also provides a better understanding of what can be tested and the different needs that should be considered while using channel emulator in OTA environments.

The implemented test automation helps the testers to achieve better results by making the testing automated. One of the benefits of this automation is, that all test runs are repeated the same way. The repeatability will make the test result comparison easier and the probability of human error decreases. When doing the testing with channel emulators, the repeatability is one of the most crucial things because all test runs should be comparable to each other. Without the repeatability, testing and comparing the test results would be labour intensive. Therefore, the automation does not only decrease the probability of human error made during the testing but also improves the work efficiency.

Improvements for the test automation are needed. The implementation of this thesis enables only the automation to run each test case separately. Next steps would be to further improve this automation by enabling robot testing. This robot testing method would increase the efficiency by omitting the manual work phases from the process.

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