FACULTY OF INFORMATION TECHNOLOGY AND ELECTRICAL ENGINEERING
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MASTER'S THESIS

USER EQUIPMENT ROTATION SYSTEM INTEGRATION FOR FREQUENCY RANGE 2 TEST ENVIRONMENT

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ABSTRACT

This thesis work was done for MediaTek Wireless Finland Oy, and it was carried out in the laboratory premises of the company. The work investigated wireless communication, and especially its latest fifth generation mobile communication technology (5G). The purpose of the thesis work was to design and implement a completely new test environment with an integrated a rotation system, which can rotate a device under test. The rotation system can rotate the test device horizontally in three different positions, allowing the device to rotate more than 180 degrees about its axis. In the completed test environment, various measurements and tests were performed, and those test cases can provide information about a performance of the device under research. Those test measurements focused on determining which of the antenna groups of the User equipment (UE) were active during those tests.

The test environment was utilizing a Frequency Range 2 (FR2) and a Non-Standalone (NSA) technology, which allowed to use millimeter wave (mmWave) technology during different test cases. The three main antenna groups used by the UE could receive those mmWave signals and performed measurements provided information on which of these antenna groups were active during the measurements. The environment was implemented in an Electro Magnetic Chamber (EMC) laboratory room and the UE rotation system was built in that same room. As part of the work, a Python script was made which can manage the controlling of the rotating system.

Five separate test cases were performed in the work. In addition to the active antenna of the device, the tests performed in the work also measured the ability of the test device to utilize wireless network which was used in that test environment. This wireless network used 5G technology, so the related 5G theory and the theory which was needed to perform the tests was explored.

The implementation of the test cases and the results obtained from those cases were documented and analyzed. Those analyzes were utilized in the research and development of the test environment. Based on the test results, it can be briefly stated that all the mmWave antenna groups of the device were active during the tests, and the change of the active antenna took place depending on the position of the UE. Those antenna groups were active one at a time. In addition, a change in the active antenna was affected on the performance of the test device. At the end of the work, it was also considered how successful the work was and what improvements could be made to the measurements or the test environment in the future. This environment can also be integrated into the company's testing plan.

Key words: FR2, NSA, 5G, mmWave, laboratory measurement.

Nyberg S. (2021) Testilaitetta pyörittävän systeemin integroiminen FR2-testiympäristöön. Oulun yliopisto, tieto- ja sähkötekniikan tiedekunta, elektroniikan ja tietoliikennetekniikan tutkinto-ohjelma. Diplomityö, 52 s.

TIIVISTELMÄ

Tämä diplomityö tehtiin MediaTek Wireless Finland Oy:lle ja se suoritettiin yrityksen tarjoamissa laboratoriotiloissa. Työssä tutkittiin langatonta tietoliikennettä ja erityisesti 5G-teknologiaa. Kyseisessä työssä suunniteltiin ja rakennettiin täysin uusi testiympäristö, johon integroitiin tutkittavaa testilaitetta pyörittävä järjestelmä. Se pystyi pyörittämään testattavaa laitetta vaakasuunnassa kolmessa eri asennossa, jolloin laitetta voitiin pyörittää yli 180 astetta oman akselinsa ympäri. Kun testiympäristö oli rakennettu valmiiksi, siinä tehtiin erilaisia mittauksia, joiden avulla kerättiin tietoa testilaitteen suorituskyvystä. Kyseisissä mittauksissa keskityttiin tutkimaan, mitkä testilaitteen antenniryhmistä olivat aktiivisina mittauksen aikana.

Testiympäristössä hyödynnettiin FR2-teknologiaa ja NSA-teknologiaa, jotka mahdollistivat millimetrisignaalien käyttämisen mittauksissa. Kolme pääantenniryhmää operoivat millimetriaaltojen avulla ja suoritettavien mittausten sekä testien tulisi antaa tietoa siitä, mitkä kyseistä antenniryhmistä ovat aktiivisia kunkin mittauksen aikana. Tutkimusympäristö toteutettiin laboratoriotilojen sähkömagneettisessa kammiossa, jonne antenniryhmiä pyörittävä laite rakennettiin. Osana käytännön työtä luotiin Python-ohjelmointikielellä komentojono, jonka avulla testilaitetta pyörittävää järjestelmää pystyttiin hallitsemaan.

Työssä suoritettiin viisi erillistä testiä. Laitteen aktiivisen antennin lisäksi testit mittasivat myös laitteen kykyä hyödyntää testiympäristössä käytettävää langatonta verkkoa ja itse testilaitteen toimintakykyä. Ympäristössä käytetty verkko hyödynsi viidennen sukupolven matkaviestintätekniikkaa, joten myös siihen liittyvää teoriaa sekä suoritettavien mittausten kannalta oleellista teoriaa käytiin työssä läpi.

Testien toteuttaminen ja niistä saadut tulokset dokumentoitiin sekä analysoitiin. Näitä analyyseja hyödynnettiin testiympäristön tutkimuksessa ja kehittämisessä. Testeistä saatujen tulosten perusteella voitiin lyhyesti todeta aktiivisten antenniryhmien vaihtuvan riippuen testilaitteen asennosta. Kyseiset antenniryhmät olivat aktiivisena yksi kerrallaan. Aktiivisen antennin muutoksella oli myös vaikutusta laitteen suorituskykyyn. Työn lopussa tarkasteltiin sitä, kuinka hyvin työ onnistui, ja mitä parannuksia mittauksiin tai testiympäristöön voitaisiin tehdä tulevaisuudessa. Kyseinen testiympäristö on mahdollista integroida osaksi yrityksen testaussuunnitelmaa.

Avainsanat: FR2, NSA, 5G, millimetriaalto, laboratoriomittaus

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FOREWORD

Probably for many authors of the thesis work, the foreword section is mainly a formality, where author can thank the important parties involved in the work and studies. For me, however, this section comes straight from my heart. I want to thank my supervisor Pekka Kyösti and second examiner Tuomo Hänninen for academic vision, guidance, and assistance which greatly assisted me in carrying out this thesis work. I would like to thank the entire Mediatek Wireless Finland Oy organization and especially my own team for the opportunity to do this work and gain useful work experience from undisputed professionals in the wireless communication field. Inside my own team, special thanks for team leader Esa Viitanen, technical supervisor Risto Paatelma, co-worker Tomi Rahkola and laboratory support Risto Juuti.

This work completes my journey in electronics and communications engineering degree program and along that journey I have had the honor of meeting some great people who have helped me on my journey to achieve my goals. I want to thank all my friends who have been involved in this journey. Thank you for the memorable moments both in studies and in free time.

I have always considered myself the privileged, because being born into a wonderful family. I want to thank my whole family and loved ones very much for their support and help throughout my life and studies. I wish I could have been a positive role model for my two younger brothers, and I want to thank them for everything. Many thanks to my mother for being able to believe me, being always supportive and encouraging on the academic path. Also, many thanks to my father for teaching me a practical skill and a good and relentless attitude for the life. I also want to thank my dear girlfriend Mandi for her support and all the wonderful moments I have had with you. I had to experience a tragedy in the summer of 2019 when my father passed away unexpectedly. I want to dedicate this work for his memory, because I feel he has always been proud to my studies for a master's degree in engineering.

Finally, I want to thank myself. Thank me for being able to work hard, believe in myself, the courage to approach a woman who would later become my girlfriend, stay awake at nights working and sometimes partying, to develop myself, and continue even in difficult moments. The future is full of opportunities.

Oulu, September 24, 2021

Sami Nyberg

LIST OF ABBREVIATIONS AND SYMBOLS

1G	First generation mobile communication technology
2G	Second generation mobile communication technology
3D	Three-dimensional
3G	Third generation mobile communication technology
3GPP	3rd Generation Partnership Project
4G	Fourth generation mobile communication technology
5G	Fifth generation mobile communication technology
5GCN	5G Core Network
ADCs	Analog-to-digital Convertors
AMF	Authentication and Mobility Functions
EHF	Extremely High Frequency
EM	Electro-magnetic
EMC	Electro-magnetic Chamber
EN-DC	E-UTRA-NR Dual Connectivity
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
ETSI	European Telecommunications Standards Institute
EPC	Evolved Packet Core
DACs	Digital-to-analog Convertors
DL	Downlink
FDD	Frequency-Division Duplexing
FR1	Frequency Range 1
FR2	Frequency Range 2
gNB	Next Generation Node B
GSM	Global System for Mobile
IC	Integrated Circuit
IP	Internet Protocol
IPv4	Internet Protocol Version 4
IPv6	Internet Protocol Version 6
ITU	International Telecommunication Union
L1	Layer 1
LOS	Line-of-sight
LTE	Long Term Evolution
mmWave	Millimetre Wave
ng-eNB	Next Generation Evolved Node B
NR	New Radio
NSA	Non-Standalone
OFDMA	Orthogonal Frequency-Division Multiplexing
OTA	Over-the-air
PC	Personal Computer
PDU	Protocol Data Unit
QoS	Quality of Service
RACH	Random Access Channel
RAN	Radio Access Network
RF	Radio Frequency
RRM	Radio Resource Management
RSRP	Reference Signal Receive Power

RSSI	Received Signal Strength Indicator
SA	Standalone
SDO	Standards Developing Organizations
SDL	Supplemental Downlink
SMF	Session Management Functions
SNR	Signal-to-noise Ration
SOC	System on a chip
SUL	Supplemental Uplink
TDD	Time-Division Duplexing
UE	User Equipment
UL	Uplink
UPF	User Plane Functions
WCDMA	Wideband Code Division Multiple Access
cm	Centimetre
Gbps	Gigabits per second
GHz	Giga Hertz
kg	kilogram
Mbps	Megabits per second
ms	Millisecond
m	Metre
V	Voltage
°	Degree

1. INTRODUCTION

The wireless communication technology and mobile communication technology have been developing for decades and that development will not end. The development of mobile communication has been divided different generations. If those generations are placed on the timeline, that timeline would be from 1980s to the present day and would include five different generations of mobile communication technology [1]. Each generation has offered new features and technologies for the wireless communications and without that development the world would be a very different.

The first of those generations was set in the 1980s and created the beginning for the development of mobile communication technology. The first generation of mobile communications is known as 1G and is based on a wireless analogue data transmission. Only voice was transmitted in this way wirelessly. This technology was made available to ordinary people for the first time. The next generation of mobile communication was set in the 1990s. The second generation of mobile communication is known as 2G and in that generation data also could be transmitted digitally using a radio link. The most important standard of second generation was the Global System for Mobile communications (GSM), which enabled data services. In the beginning of 2000s third generation of mobile communication was introduced to the world. That generation is known as 3G, and it offered great development towards first-class mobile broadband. This enabled to consumers to have wireless and fast internet access. The fourth generation of mobile communication or 4G can be placed in 2010s and is better known as a Long-Term Evolution (LTE). The LTE improved some 3G features, including higher transfer rates, and efficiency. This has been made possible by using more advanced multi-antenna technologies and orthogonal frequency-division multiplexing (OFDM). The current generation that is still being developing is the fifth generation of mobile communication technology or 5G and this thesis work will focus on this technology. Figure 1 will demonstrate how the different mobile communication generations are located in the timeline from the 1980s to the 2020s. [1]

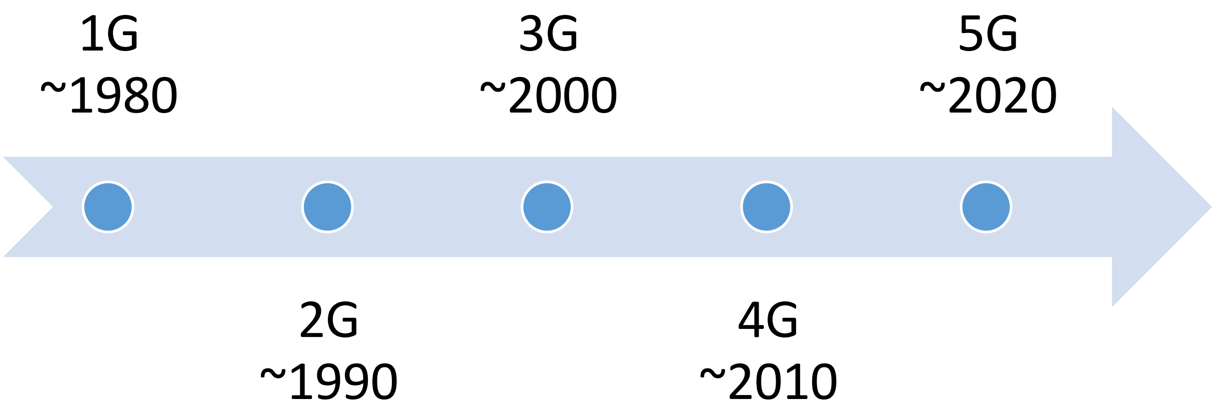

Figure 1. Mobile communication generations from the 1980s to the 2020s.

These days almost everyone owns a device which uses wireless communications technology and one of the most common is a smartphone. Figure 2 shows how the number of smartphone users has grown over the last ten years.

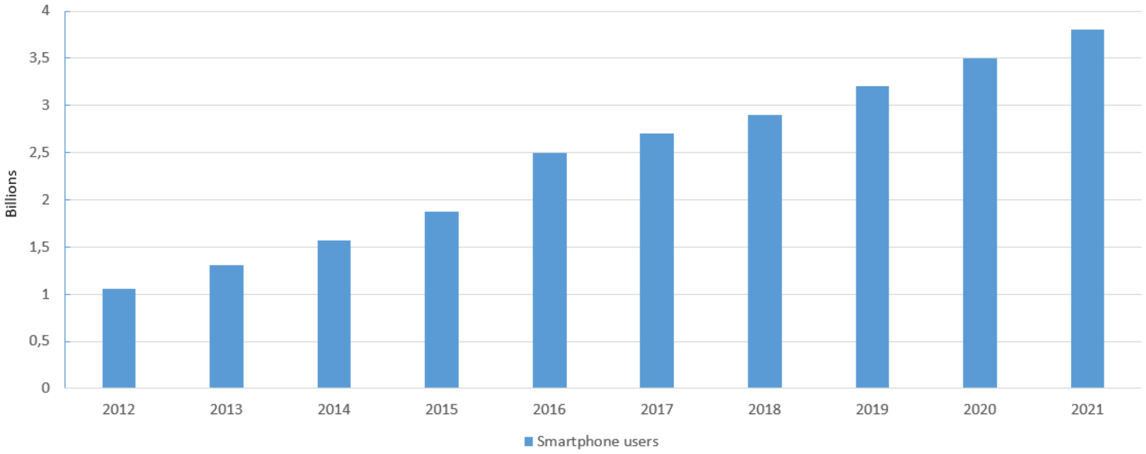

Figure 2. The number of smartphone users from 2012 to 2021. [2]

Figure 2 shows that during the last ten years, the number of smartphone users has almost quadrupled. For example, in 2012 there were about 1.06 billion smartphone users and at the moment those users were about 3.8 billion. People transfer and receiver more and more data every day, so people's need for faster, more reliable, and less delayed connections also growing continuously. This partly explains why there is desire to develop mobile communication technology better generation after generation. The large number of smartphone users have created a large market area where many companies compete internationally. [2]

The research and development of mobile communication technology and devices required a lot of academic knowledge, expertise, and familiarization, but also often practical testing and laboratory work. The device should perform under laboratory conditions flawlessly before it reaches commercial distribution. Such devices usually contain a variety of hardware and software components, and the functionality of those components is very important. Due to the large number of components and properties, test must be performed to examine even very specific functions. For example, test can measure device performance, throughput, network latency or network capacity [3]. In addition to laboratory conditions, tests and measurements are also performed against live networks and are also performed in collaboration with various technology companies and telecom operators. Both additions require very precise technical specifications for both the systems under test and the methods by which the tests are carried out.

This thesis work will demonstrate and document how to integrate new element into the laboratory test environment. The user equipment (UE) will be integrated into a fifth generation test environment which will consist of a Nokia base station (BS) and a separate servomotor which can rotate the UE around it axis. The combination of UE and rotator will form a new element for the test environment under research and the name of this element is UE rotation system. The 5G base station will use frequency range 2 (FR2) and non-standalone (NSA) technologies and the test measurements in this environment are over-the-air (OTA) tests. The UE under research is a 5G smartphone with a microchip manufactured by a MediaTek Wireless Oy. The UE rotation system and base station are placed in a laboratory room, which is an electro-magnetic chamber (EMC). The control of UE rotation system will be implemented by using a separate python script and doing this script is part of practical work. Minimum requirement is to rotate UE 180 degree (°) around its axis horizontally, but also vertical rotation is desirable. Rotating the UE in the test environment gives information about how that effects its performance. The UE performance can be measured in the test setup using a variety of different measurements and these measurement results should be interpreted and evaluated. The UE under research contains three main FR2 antenna groups and this work focuses on exploring which of these antennas are active when the UE is rotating. In real life, the user's device can be in rotating or moving while connected to the 5G network. In addition, the connected signal may be blocked by the user's hand or other obstacles, but despite that, the UE should be able to function properly. For those reasons, the UE must be a feature to change the active antenna. The research questions could be canning the UE rotation system be integrated on the FR2 test environment successfully, how the performance of the UE will change when UE is rotating in that test environment and how this rotation will affect for the active antenna selection.

Since the measurements will use the 5G UE and the 5G test environment, basic knowledge of those technologies is needed. The next chapter will focus the basic technical features, standards, and benefits about 5G technology. The basic theory of those will help to understand the diversity and potential of that technology. The third chapter will introduce the main technologies used in the test environment and will also open the most important feature of the equipment and environment under study. The most important aspects of the environment, the test UE and the measurements are FR2, NSA and the selection of the active antenna. The fourth chapter documents how the test environment is designed and built. In addition, this chapter also provides more detailed information about the different parts and components of the test environment. The fifth chapter will focus on tests and measurements what will be used to examine the performance of the UE in that test environment. This chapter describes the implementation of the measurements, but also presents and interprets the measurement results. The sixth and final main chapter will consider and evaluate how the test measurements and the work were successful.

2. 5G TECHNOLOGY, ARCHITECTURE AND COMPONENTS

Second chapter of thesis work gives knowledge about the 5G technology, standardisation, architecture and main component. Basic understanding about those technologies will give knowledge and append understanding how test environment are worked in this situation. The necessary parts that will be reviewed includes: 5G standardization, benefits, requirements, 5G network, architecture, and New Radio (NR) interface.

2.1. Standardization

Many organizations are involved in 5G technology standardization. In the field of mobile communication technology this means the creation of standards, regulations, and technical specifications. When these requirements are followed, the research and development of a large entity is much clearer. The parties involved in that work can be divided into three different groups. Those groups are the Standards Developing Organizations (SDOs), regulatory administrators and bodies, and industry forums. [1]

The SDOs agree and develop on standards for mobile communication technology and systems. Those technical standards make possible for industry to develop and produce products that are standardized and compatible with other industrial companies. The SDOs exist globally, internationally, and nationally. One of the best known and most important SDO is the Third Generation Partnership Project (3GPP). The 3GPP is global standardization organization made up of seven national and regional SDOs. As an example, the European Telecommunications Standards Institute (ETSI) is one of those. The 3GPP is created the technical specifications of 5G technology, NR interface, LTE and WCDMA (Wideband Code Division Multiple Access). [1]

The regulatory administrators and bodies are organizations administered by the government. Those organizations set legal and regulatory requirements for operating, selling, and deploying the mobile communication systems and products. Those organizations as well control use of the radio frequency (RF) spectrum and follow mobile operators that those will use specific frequency range. As an example, the International Telecommunication Union (ITU) is handled spectrum regulation on a global level. [1]

Industry forms are groups administered by the industry. In the mobile communication technology industry, those are repeatedly led by mobile operators. Those groups are responsible for lobbying and promoting for specific technologies. It is good to understand how and by whom the standardization of this new technology will be carried out, as the information created by these standardization organizations will be used in this thesis work. [1]

2.2. The requirements and benefits

The standardization and development of 5G technology aims certain functional requirements and benefits that the technology should provide to customers. These requirements can be divided into eight different categories as shown in Figure 3. The 5G technology will make possible 10 Gigabits per second (Gbps) data transmission in real network and further provides a round trip latency of less than 1 millisecond (ms). It is possible to connect many devices simultaneously in the 5G network in a specific area. In addition, 5G network should be very reliable, always available, and complete coverage. Practically customers should be able to connect to the network wirelessly from anytime or anywhere in unit area. In these days, the development of technology must pay attention to state of being environmentally friendly and longevity of products. These are also listed in the requirements and benefits of 5G technology. At the end of this thesis work, it is possible to compare test results with some of these benefits and requirements. At least there are some reverence values to which it is possible to compare. Rather, those provide a concrete example of the potential of that technology. [4]

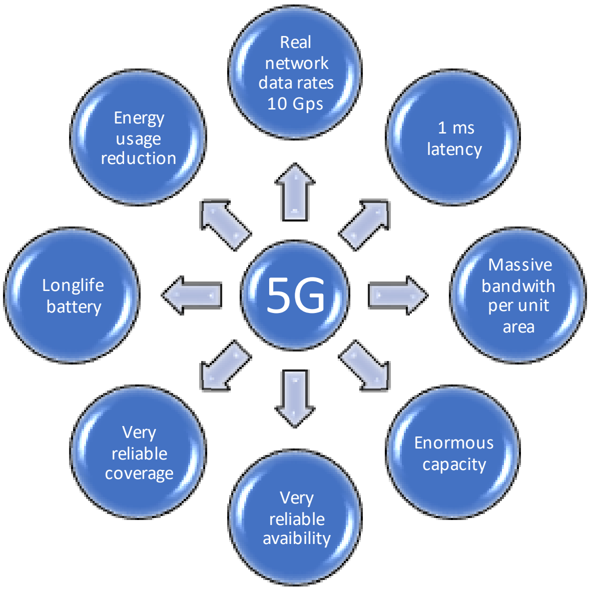

Figure 3. The requirements and benefits of 5G technology.

2.3. 5G Network, architecture, and NR interface

The technology under research includes many important components, architecture, and technologies, but this section will focus at a basic level on few key technologies and topics which are important for 5G system network and architecture. The 5G system shortly can consist with a 5G core network (5GCN) and 5G radio access network (RAN). The 5GCN contains various functional components as authentication and mobility functions (AMF), session management functions (SMF) and user plane functions (UPF). The 5G RAN contains next generation evolved Node B (ng-eNB) or next generation Node B (gNB). The gNB offers control plane protocol and user plane protocol conclusions to the UE. The ng-eNB offers those same protocols, but on Evolved Universal Terrestrial Radio Access Network (E-UTRAN) side. It should be noted that gNB and ng-eNB can be classified protocol anchors, that when these terms will be used the focus is the protocol layer viewpoint. When using a term 5G base station, then focus is the RF resources and hardware and how those are related to radio connectivity. [5]

Next, the components and functions presented above will be examined in more detail. Figure 4 will show how functions and components split between 5GCN and 5G RAN. It should be noted that those functions are researched from a high-level viewpoint. The figure 4 shows, that 5G RAN and more specifically its components gNB or ng-eNB host many different functions. These functions include, for example, radio connection control, inter-cell radio resource management (RRM) and connection mobility. Radio connection control will handle connection setup and release, but also can control UE connection state. Inter-cell RRM will allow the UE to discover different neighbour cells and inquire about best serving cell. In addition, during the handover decision it support the network. Connection mobility will support connected mode and idle mode in the case of intra cell handover positions. [5]

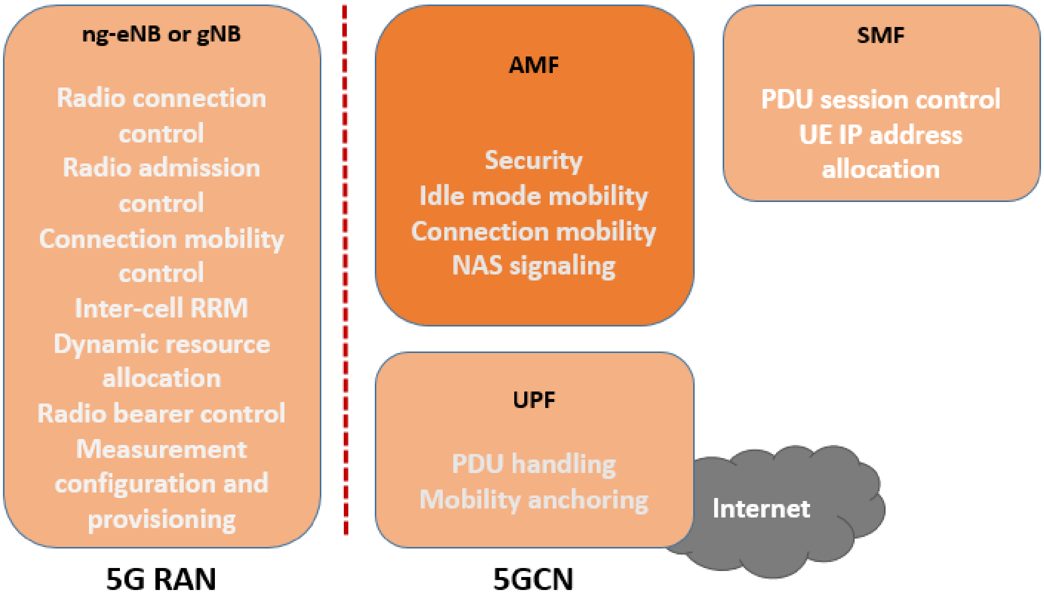

Figure 4. 5GCN and 5G RAN components and functions.

The 5GCN and more specifically AMF, UPF and SMF also host many different functions shown in figure 4. This group includes, for example, security, protocol data unit (PDU) handling and UE internet protocol (IP) address allocation. Looking at PDU handling from the user plane perspective, it will allow packet routing, quality of service (QoS) handling and forwarding. 5G technology can be classified a packet-switched network model. UE IP address location will make possibility to support data reception and route data packets. The 5G technology will support internet protocol version 4 (IPv4) and internet protocol version 6 (IPv6) addressing. [5]

Some of these functions are also utilized in this thesis work. For example, the QoS and the UE IP address allocation allow the test device and environment to work in 5G network. The QoS function will for example the function can monitor the quality of the received signal and affect which of the antennas of the device under study is most useful to be active [5]. For the thesis work perspective, the 5G theory needs to be limited only to the most relevant technologies what the test environment, the device, and the measurements will utilize. The next chapter will present those relevant technologies, but it should be remembered that at a certain level, even those relevant technologies take advantage of the functions discussed in this chapter. This section gives a perspective on how extensive and multi-level the 5G technology is.

3. RELEVANT TECHNOLOGIES

This chapter is an overview of components and specific technologies which are relevant for the test environment and the UE. The focus is to try limit the theory of these relevant technologies to briefly but also accurate. The necessary parts that will be reviewed includes Non-Standalone (NSA) and Standalone (SA), frequency range 1 (FR1), frequency range 2 (FR2), millimetre wave (mmWave) and beamforming.

3.1. Non-Standalone and Standalone

The UE can be connected in two different scenarios or methods to the 5G wireless technology and 5G NR interface. Those connectivity scenarios are NSA and SA. The NSA connectivity scenario is used in the future test environment, but SA scenario is also briefly reviewed in this chapter. The NSA and the SA connectivity methods are illustrated in Figure 5. [6]

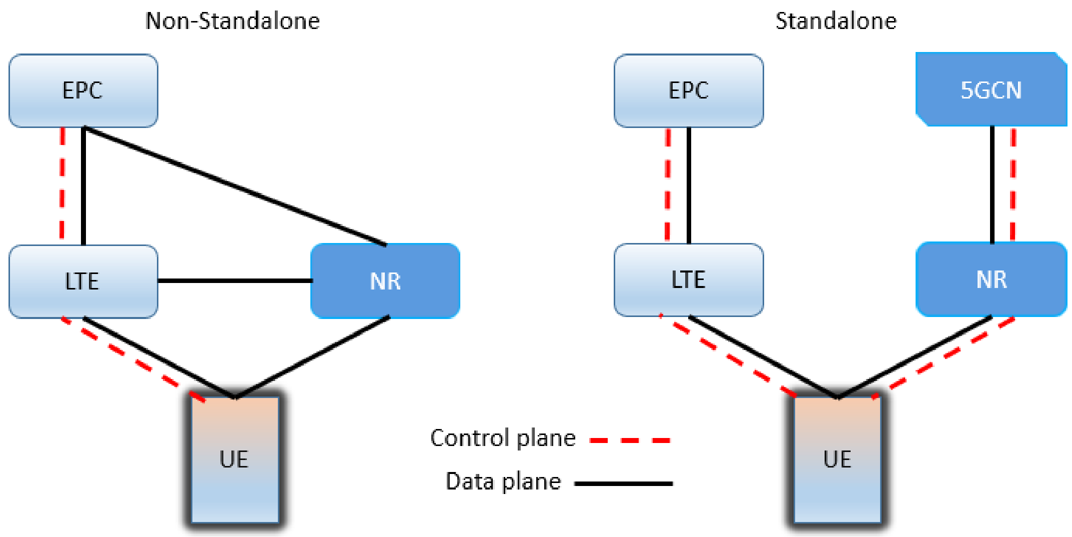

Figure 5. The Non-Standalone and the Standalone connectivity scenarios.

The NSA connectivity architecture uses NR interface and 5G RAN in conjunction with existent Evolved Packed Core (EPC) infrastructure and LTE. In this way, without replacing network NR technology is available. In this method, the LTE services are only supported, but at the same time benefits of 5G NR can be exploit. Figure 5 shows relationships between the components of NSA and SA architectures and in addition control and data planes. According to 3GPP, this architecture is also known "Architecture Option 3" or "E-UTRA-NR Dual Connectivity (EN-DC)". [6]

In the SA connectivity architecture, the NR interface is connected to the only 5GCN. In this scenario full set of 5G technology performance is supported. In addition to this, as shown in the Figure 5, the UE has also the possibility to use LTE connection as backup opportunity. The test environment will use the BS, which can support NSA technology. [6]

3.2. Frequency Spectrum

The frequencies used in the wireless 5G technology are divided in two specific frequency ranges. This classification has been made by the 3GPP and those frequency bands are the frequency range 1 (FR1) and the frequency range 2 (FR2). The FR1 is classified into frequency bands from 4.1 Gigahertz (GHz) to 7.125 GHz. This frequency range is used for focusing and carrying the most of the 5G mobile communication technology traffic. The FR2 is classified into frequency bands from 24.25 GHz to 52.6 GHz and this frequency range is focused and used more on a wireless communication where needed capability of a very high data range, but the data transfer will execute short-range. [7]

The following tables will show how these frequency ranges are divided into different bands, what is the name of the band, uplink (UL) bandwidth, downlink (DL) bandwidth and used duplex mode. Table 1 will show bands of FR1 and table 2 bands of FR2.

Table 1. FR1 Frequency bands

Band	Uplink [GHz]	Downlink [GHz]	Duplex Mode
n1	1.92- 1.989	2.11- 2.17	FDD
n2	1.85- 1.91	1.93- 1.99	FDD
n3	1.171- 1.785	1.805- 1.88	FDD
n5	0.824- 0.849	0.869- 0.894	FDD
n7	2.5- 2.67	2.62- 2.69	FDD
n8	0.88- 0.915	0.925- 0.96	FDD
n20	0.832- 0.862	0.719- 0.821	FDD
n28	0.703- 0.748	0.758- 0.803	FDD
n66	1.71- 1.78	2.11- 2.2	FDD
n70	1.695- 1.71	1.995- 2.02	FDD
n71	0.663- 0.698	0.617- 0.652	FDD
n74	1.427- 1.47	1.475- 1.518	FDD
n75	---	1.432- 1.517	SDL
n76	---	1.427- 1.432	SDL
n38	2.57- 2.62	2.57- 2.62	TDD
n41	2.469- 2.69	2.469- 2.69	TDD
n50	1.431- 1.517	1.431- 1.517	TDD
n51	1.427- 1.432	1.427- 1.432	TDD
n77	3.3- 3.42	3.3- 3.42	TDD
n78	3.3- 3.8	3.3- 3.8	TDD
n79	4.4- 5	4.4- 5	TDD
n80	1.171- 1.785	---	SUL
n81	0.88- 0.915	---	SUL
n82	0.832- 0.862	---	SUL
n83	0.703- 0.748	---	SUL
n84	1.92- 1.98	---	SUL

Table 2. FR2 Frequency bands

Band	Uplink [GHz]	Downlink [GHz]	Duplex mode
n257	26.5- 29.5	26.5- 29.5	TDD
n258	24.25-27.5	24.25-27.5	TDD
n259	39.5-43.5	39.5-43.5	TDD
n260	37.0- 41.0	37.0- 41.0	TDD
n261	27.5- 28.35	27.5- 28.35	TDD

The duplexing modes in those tables are time division duplexing (TDD), frequency division duplexing (FDD), supplemental uplink (SUL) and supplemental downlink (SDL). In these tables, the values for UP and DL frequency spectrum are given in Gigahertz. If those frequencies are compared with, for example, frequencies used in LTE technology, then it is noticed that those 5G frequencies are even ten times higher than LTE frequencies. It is good to note, that the higher frequencies are more susceptible for propagation losses. The signal that propagates at FR2 frequencies is also known as millimetre waves or extremely high frequency (EHF). The test environment will use the BS, which support FR2 technology and mmWaves. [7]

3.3. Beamforming

Because the measurements will made in the OTA test environment, it is good to know how the wireless signal propagates in that system. The signal is transmitted by using the millimeter waves. The mmWaves offers a gigantic bandwidth, but on the other hand it increases technical challenges. For example, shadowing, penetration, and propagation losses are significantly reducing the efficient coverage. Despites those technical challenges, the mmWave base stations can be used and exploited in a high capacity and a small cell connectivity case. [8]

Since the mmWaves are sensitive to different technical challenges and earlier mentioned losses, it is important to be able to direct millimeter wave antennas sensibly using the beamforming and beam managment. In short it means that the antenna beams are effectively directed in a specific area, direction, or the receiving device. When antenna will use some beamforming method, then the radiation pattern of antenna can be directed the specific area much more energy efficient and controlled than without the beamforming. Figure 6 shows how the beamformed antenna array differs from the conventional antenna array.

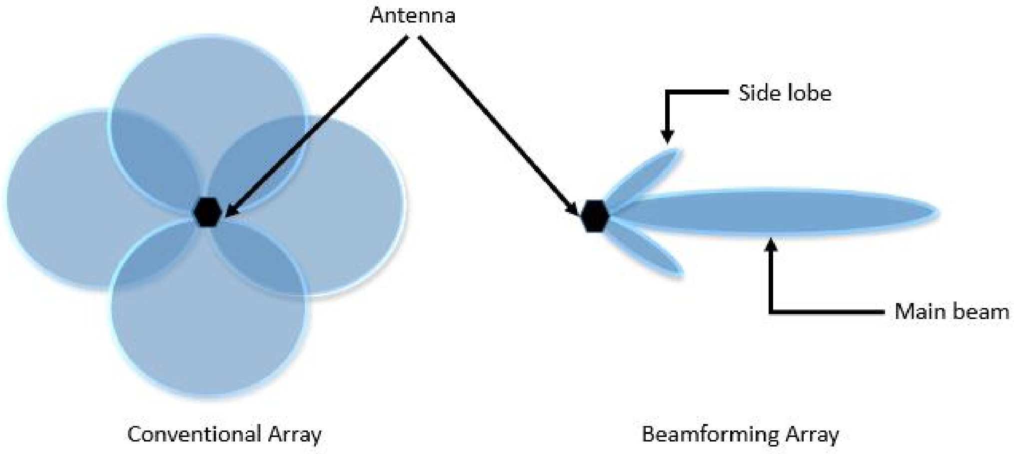

Figure 6. The conventional array versus the beamforming array.

Figure 6 shows that the radiation pattern of the conventional array antenna is evenly distributed around the antenna, but when the antenna uses beamforming, the radiation pattern of the antenna can be directed in a specific direction and additional an antenna gain is obtained at the same time. The high antenna gain is one of the biggest factors which can be used to compensate large propagation losses caused by the mmWaves. For this reason, use of beamforming is mandatory in the mmWave environment. [9]

Three different beamforming methods will be introduced next. These methods are an analog beamforming, a digital beamforming, and a hybrid beamforming. A digital precoding is required for the digital beamforming and this precoding method will multiply a specific coefficient to the baseband signal which has been modulated. This digital precoding method has been done with every RF chain and requires separate blocks to convert information from digital to analog and from again analog to digital. That kind of analog-to-digital convertors (ADCs) and digital-to-analog convertors (DACs) are commonly used in digital communication. For the analog beamforming a complex coefficient will be applied to manipulate the RF signals. This enables a controlling of variable gain amplifiers and phase shifters, which perform beamforming. The digital beamforming method can offer better performance and flexibility but will increase also complexity. The analog beamforming method is simpler but also effective architecture when beamforming will be focusing to create the high beamforming gains for a many different antennas. The analog beamforming is less flexible compared to the digital beamforming. The hybrid beamforming combines benefits of analog and digital beamforming in transmitter and receiver sides. This architecture will use the analog beamforming to increase the sharpness and gain of the beams, and the digital beamforming will increase the flexibility. [10]

The beamforming is managed and controlled by the beam management. The beam management will handle for example these four operations: a beam measurement, a beam sweeping, a beam reporting and a beam determination. The beam measurement will measure the estimated signal quality from the received signal. The beam sweeping will take care, that the reception and transmission of beams in a set of directions and pre-specified intervals will cover a specific area. The beam reporting will monitor quality of the received beamformed signals and will report this information forward. The beam determination will determinate optimal set of beams, which it can modify and set to be fully beamformed and directed. The best beam is selected by the UE and the selection can be based on for example signal-to-noise ratio (SNR) or reference signal receive power (RSRP) measurement. The beam reporting will again collect information with the property of the beamformed signal and decisions what was done when the signal was beamformed in the previous phase. [11]

3.4. Active antenna of UE

As noted in previous chapters, the FR2, the NSA and the beamforming architectures are all very important parts of this work. Those architectures contain many pros and cons. Especially using of the mmWave signals creates different challenges which makes for example the beamforming an increasingly important part of the 5G NR wireless systems. The 5G UE under research use several receiver and transmitter antennas, and for future tests it is essential to know which of those antennas are active and how the active antennas are selected. [12]

One of the most challenging part when a new 5G devices are designed and developed are how to integrate the mmWave antenna groups to the device under design. In this case, it must be taken into account different properties of the device such as a limited power capacity, a strict design and materials used in manufacture. In addition, the most of designed 5G devices have thin frame and metallic casing, so the physical size of the wireless 5G communication module and antenna groups should be also miniaturized. [13]

It can be clearly stated that antennas are one of the key components in different wireless systems. One important design goal for active antennas is that antennas have high gain, which will reduce the power used to transfer data and increase the link budget at the same time. In addition, the antennas should be able to receive and transmit signal in any position. For example, the UE user's hand or head may block the transmitted or received signal. 5G devices will often use multiple antenna groups for avoid such a scenario. By using several antenna groups, it is possible to ensure that the radiation pattern of the antennas extends to all sides of the device. When placing a group of multiple antennas in the device, should be careful, so that neighboring antennas do not interfere negative with each other. [14, 15]

The intended system of active steering antenna can be divided on three different parts: the active antenna, a controller and switch integrated circuits (IC). The software of the device under research will control a system on a chip (SOC) to add in real time data for QoS to the controller of active antennas. Using this data from the SOC, the controller of active antenna will decide active settings of switch on device under research. Components of active antenna are switched in right order to modify the features of the antenna which will be active. Those components include, for example inductors, capacitors, and other antenna elements. [14]

The test environment will operate by using the mmWave signals and the wireless communication range of this environment is short. As mentioned earlier the antenna groups must have the high gain, which will compensate propagation loses. The gain of antenna is one of the key variables that influence active antenna selection. Next chapter will introduce more variables, which can affect the selection of active antenna. [16]

The selection of active antenna includes many different variables and parameters which are modified for the test device under research. In the future test cases a specific test tool will be used to find these parameters and values. The threshold or limit values of certain variables and parameters have been modified from the device under research and exceedingly over or falling below these limit values will made the UE change the active antenna. When selecting the best active antenna from the three mmWave antennas, UE will observe those threshold values and try to find the best active antenna. Figure 7 will show how beams and gains of the antenna groups will depend by the position and rotation of the device under research. The active antennas are named AIM0, AIM1 and AIM2 in Figure 7.

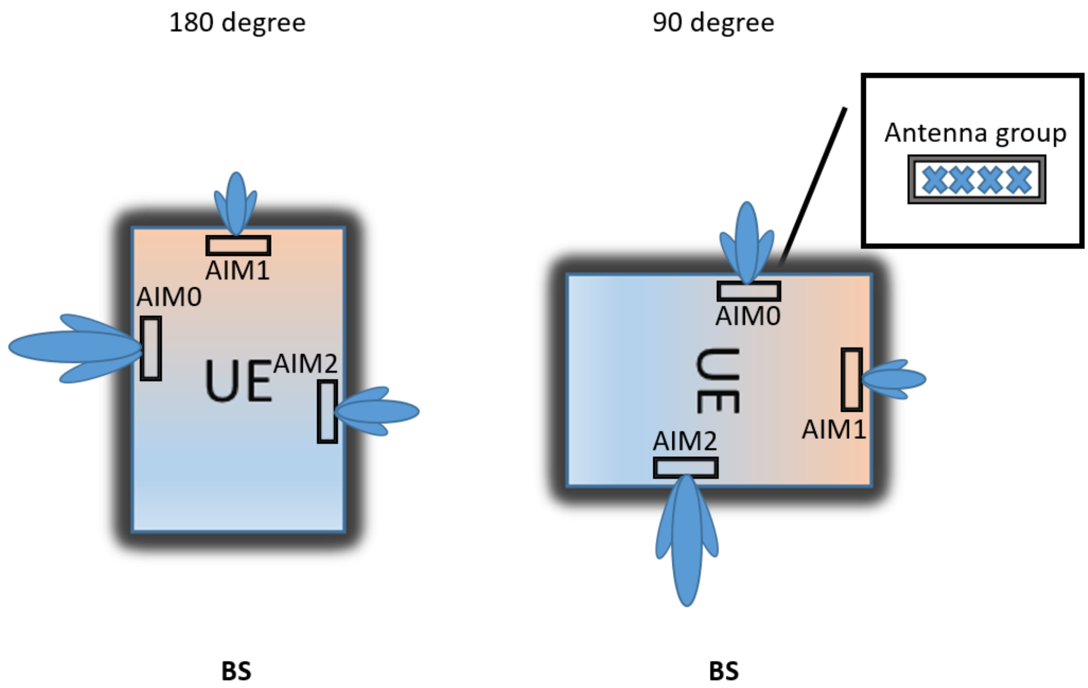

Figure 7. Beams and gains of the different antenna groups on the different positions of the UE.

Figure 7 shows that when the UE will be rotating in different positions, then at the same time values which will affect the active antenna selection will change. One of the mmWave antenna groups then has the strongest beam capable of receiving the signal. As a result, that certain mmWave antennas is the best choice for the active antenna. Because some of these parameters and variables are secret, it is not possible to describe these parameters and variables very detailed or present exact values. However, examples can be given of how these parameters generally influence about the selection of the active antenna.

One of those variables are the received signal strength indicator (RSSI) value, which is used as a help in determining the active antenna. Shortly, the RSSI value will provide information about signal strength of the propagating radio waves in real time. It is affected by various environmental factors such as reflections, temperature, shadowing, multipath propagation, moisture, and signal blocking obstacles. The effect of these factors should be considered when future test cases will be analyzed. [16]

4. TEST ENVIRONMENT

Fourth chapter of the thesis work will be focusing about the test environment and used test equipment. This chapter will give briefly but accurate information about the different parts of that test environment. The design and implementation of the environment is also documented in this section.

4.1. Design and implementation

The introduction explained what kind of test environment is being planned and this section will be telling more specific about the design, layout, and implementation of that environment. Figure 8 will show how the test environment will be implemented and what components it contains. Design of the test environment is quite simple. An isolated EMC laboratory room is placed a test personal computer (PC), the 5G UE, the 5G BS and a servomotor which can rotate the UE rotation system.

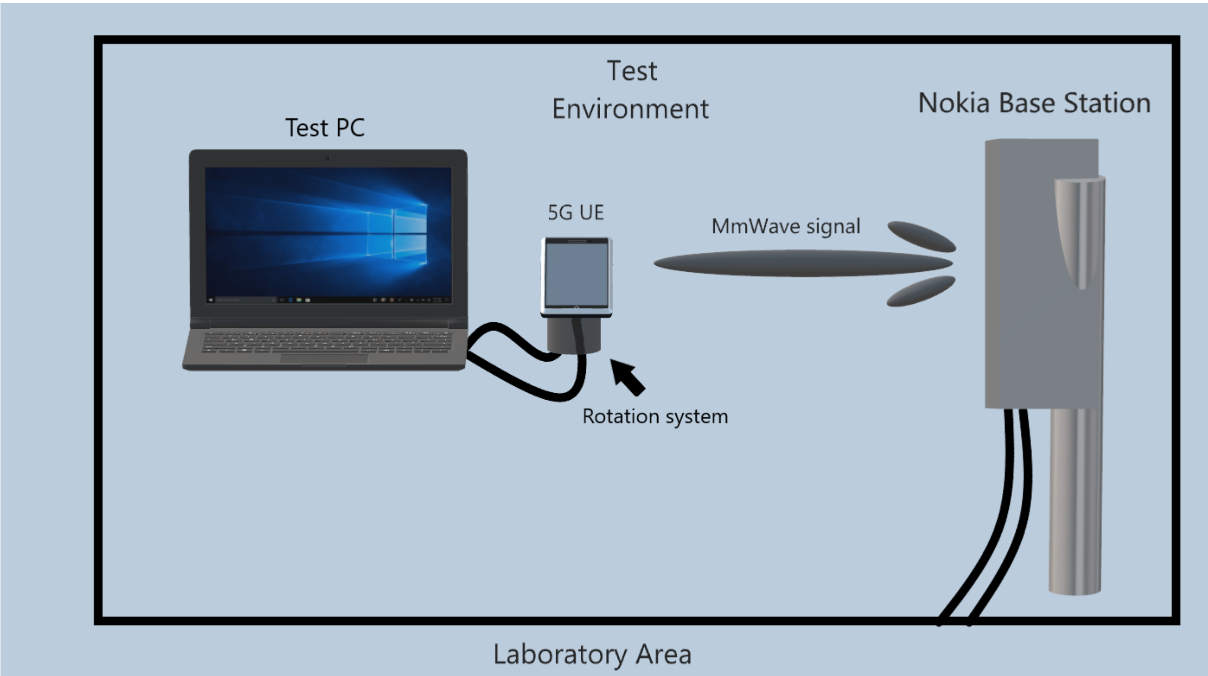

Figure 8. The test environment implementation.

The UE under research is connected to the test PC and controlling of the rotation system, the UE and the test cases are handled with this PC. This setup is built in the EMC laboratory room. The BS is installed in this laboratory room and its control is managed by a separate PC. As mentioned earlier, the BS supports the FR2 and the NSA technology. There are already a couple of different FR2 devices in that EMC room, but the BS will be directed to the 5G device under research. Can be assumed that other FR2 devices in this EMC room have very little effect on the 5G UE under test and research. Once all tests have been completed and the test results reviewed, one can consider whether other devices have any effect on the tests. Figure 9 shows layout of the laboratory room and exposes important dimensions. Distance between the UE rotation system and the BS is about 1.5 meters (m). As mentioned earlier, the laboratory room is the EMC room, so external electromagnetic signals should not affect in-room testing. The laboratory area is about 2.0 m wide and 3.0 m long.

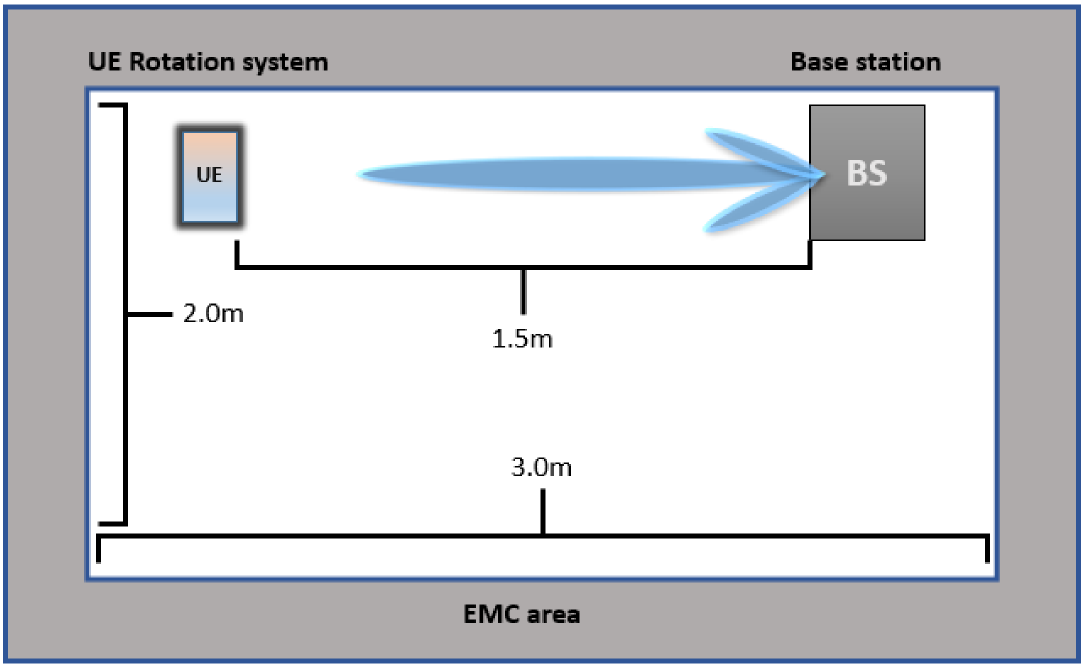

Figure 9. The laboratory area layout.

The UE rotation system will be implemented with the servomotor and the servo controller connected to each other. The servomotor can rotate the UE over 180 degrees around it axis horizontally. Figure 10 will show implementation and design of the rotation system. The UE can be connected to the servomotor using a jig made with a 3D printer. The servo controller is connected to the servomotor, which can be used to handle the UE rotation system by the self-implemented python script. In the future, this rotation system can be integrated, for example, into a linear actuator which is also capable of moving the 5G UE linearly towards or away from the BS. In the future UE rotation system can be added also more servomotors when the rotation positions can be increased also vertical directions. However, this work is limited to examining the effects of the 5G device rotation on its performance only in the horizontal direction.

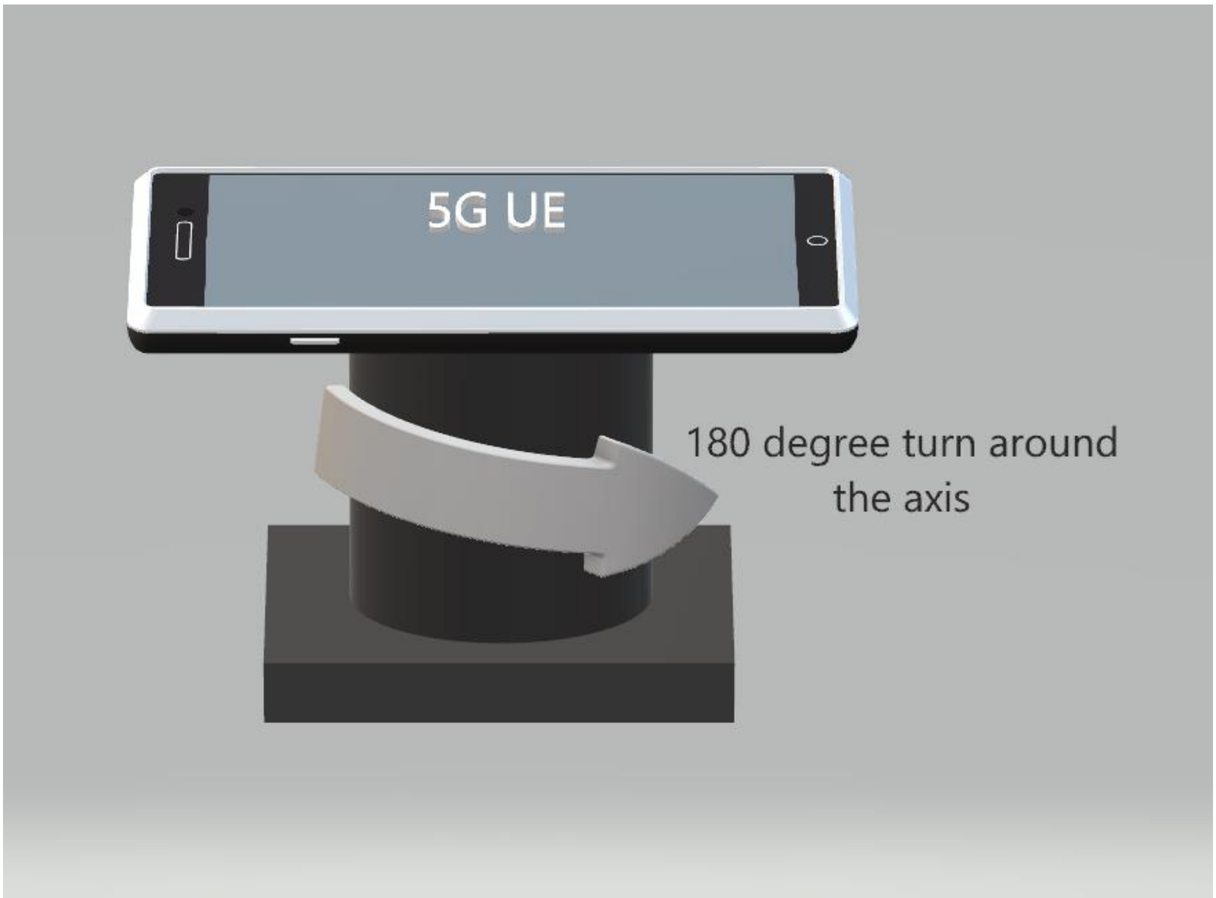

Figure 10. The implementation of the rotation system.

4.2. Parts of test environment

The design and the implementation of the test environment has been completed, so this section will describe and provide more detailed information about the most important parts of the test environment. These test components or parts are the laboratory area, the BS, the UE under research and the rotation system itself. The aim is to document the technical data and intended use of the various components as well as possible, so that the test environment and the future test measurements can be repeated by others if necessary.

4.2.1. Laboratory area

Mediatek Wireless Finland Oy office in Oulu has a large laboratory area with several separate laboratory rooms. The test environment is in the isolated EMC laboratory room with the FR2 base station which can transmitting the mmWave signal. The distance between the UE rotation system and the BS is about 1.5 m. The room is not lined with non-absorbent material, but it is the isolated chamber with metallic shielding. Figure 11 shows the completed UE rotation system with one servomotor. The figure 11 also shows the trajectory of the system, where three different positions are marked to different colors. When system will use one servomotor the test

UE can be rotated between 0, 90 and 180 degrees. The system is taped to the table, but in the future, it will be screwed to the stand which is designed for the UE rotation system.

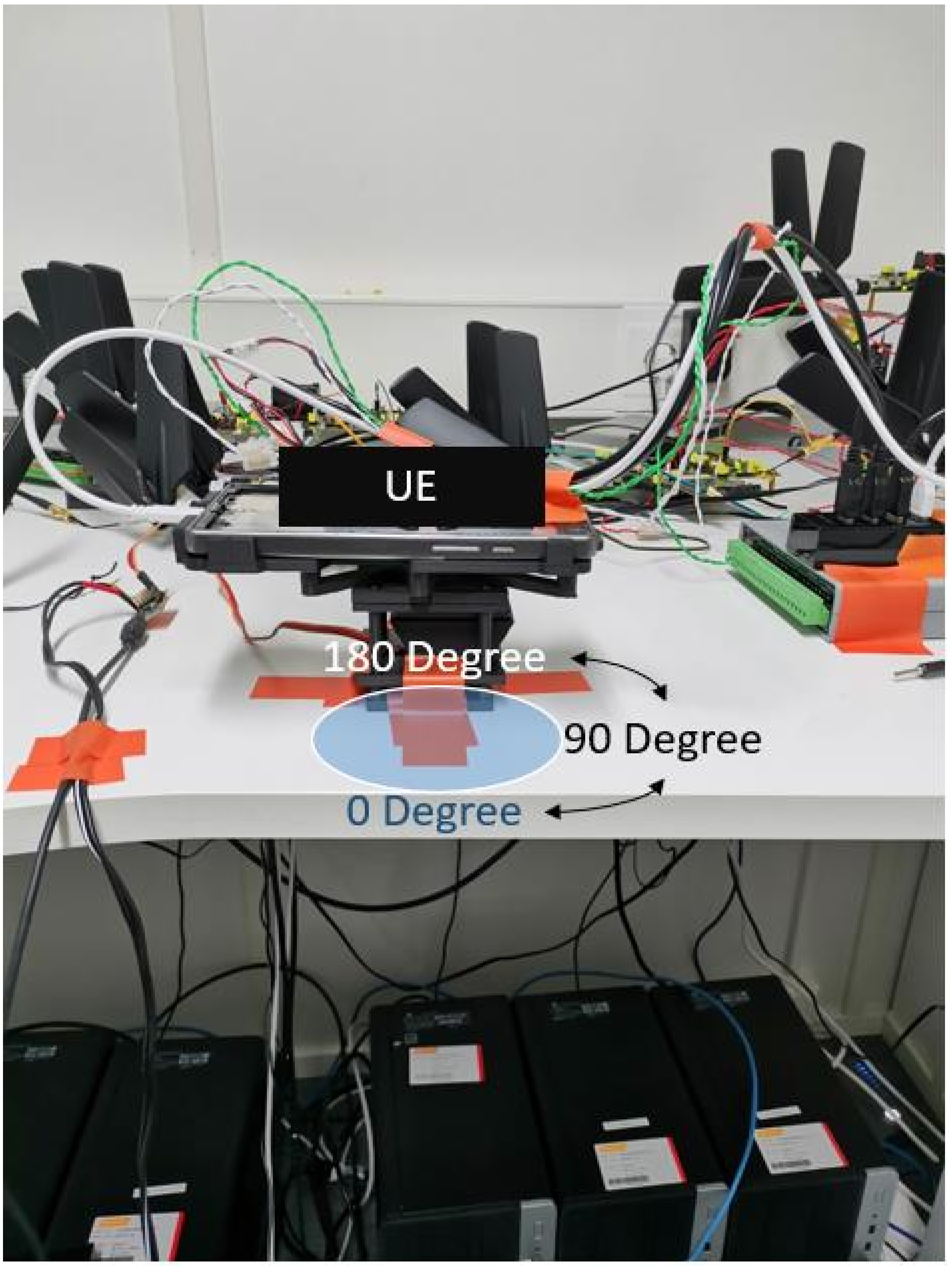

Figure 11. The completed UE rotation system with one servomotor.

4.2.2. Base station

The test measurements are performed against a Nokia base station which is configured for those test cases. The BS is NR NSA base station, and it operates using FR2 frequencies. More specifically, the used NR FR2 cell is the n261 cell with LTE anchor cell b2. Figure 12 shows the UE rotation system and BS. The distance between those is about 1.5 meters and the base station should have a line-of-sight (LOS) view with the test device. A test subscriber identity module (SIM) card is configured for the BS and one SIM card is initially used in that environment. However, another SIM card can be also added to the device under research if necessary.

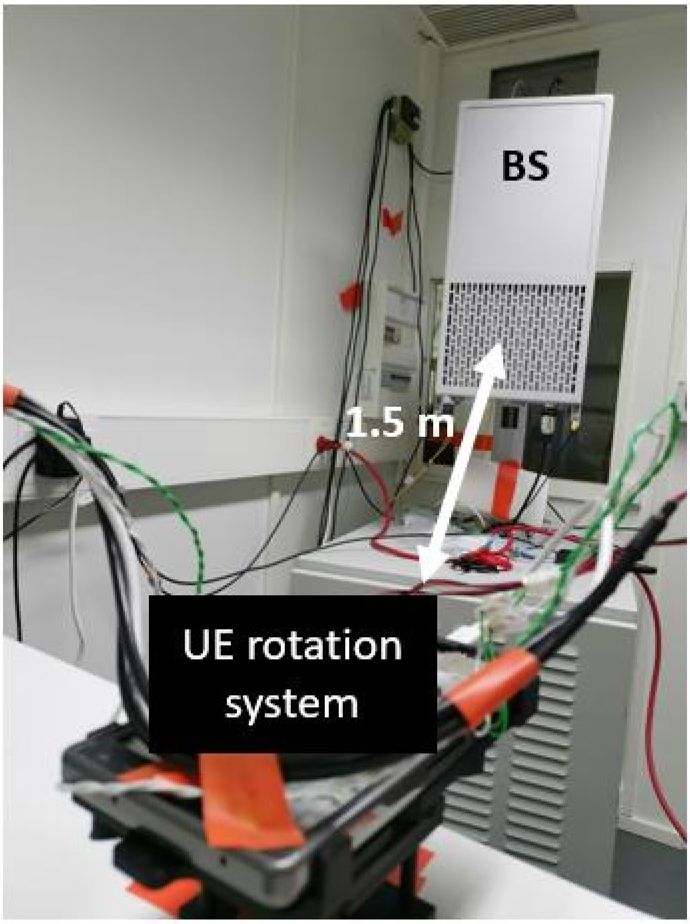

Figure 12. The UE rotation system and the BS.

4.2.3. User equipment

The test UE is a 5G smartphone with a Mediatek's microchip. The more specific technical specifications of the smartphone are not relevant for the test measurements, but it is still good to note how the mmWave antennas of UE are placed on it. The figure 13 will show the UE FR2 antenna layout. As can be seen from the figure 13 the test device has three separate mmWave antenna groups and these groups are located on the left and right side of the device as well as one on the top of the device. The antenna groups are named as shown: AIM0, AIM1 and AIM2. Because the antennas are used on FR2 frequencies, their physical size is very small. The size of a single antenna is even less than fourth of a centimeter in both horizontal and vertical direction. As the UE also includes other important components, this should be considered when designing and positioning the UE antenna groups. In addition, a separate external antennas can also be connected to the test UE.

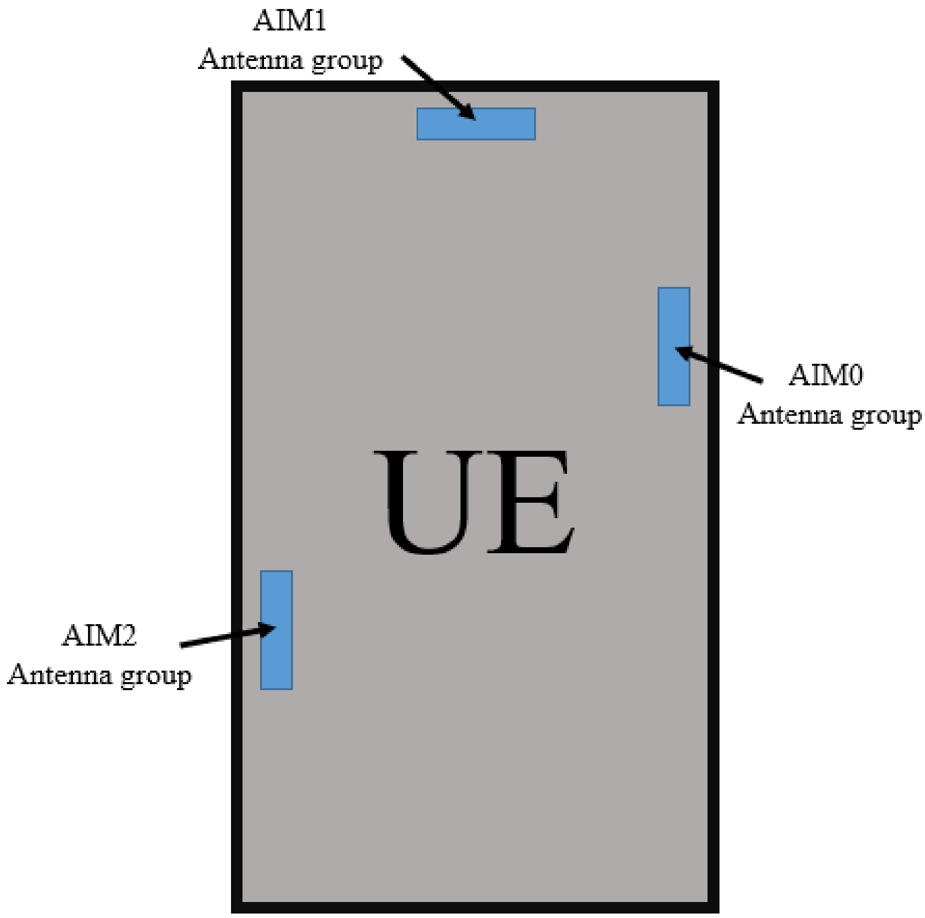

Figure 13. The UE FR2 antenna groups layout.

4.2.4. UE rotation system

As before mentioned, the UE rotation system will be simply composed with one servomotor and this servomotor can rotate over 180 degrees around it axis horizontally. More specifically, the UE rotation system will consist of the servomotor, a jig made with a three-dimensional (3D) printer and the servo controller which handle controlling of the rotation system.

The KST MS825 helicopter servo is used as the servomotor of the rotation system because it allows movement of more than 180 degrees, which is not always the main feature in similar servomotors. The Pololu Micro Maestro 6 is used an USB servo controller and that controller can control multiple servomotors. With using the 3D printer, the servomotor jig was printed for the servomotor, so it stays firmly in place and the test UE can be attached to this jig. Risto Juuti helped design and print this jig for the servo motor and UE. Risto also handled the selection and ordering of components for the UE rotation system. Figure 14 shows the 3D modeling of the jig which is designed for the servomotor. This model was used also in the rotation system. The test device can be attached to top of the servomotor jig. Servomotor can be added inside the jig shown in Figure 14 by opening the jig lid and screwing it back into place.

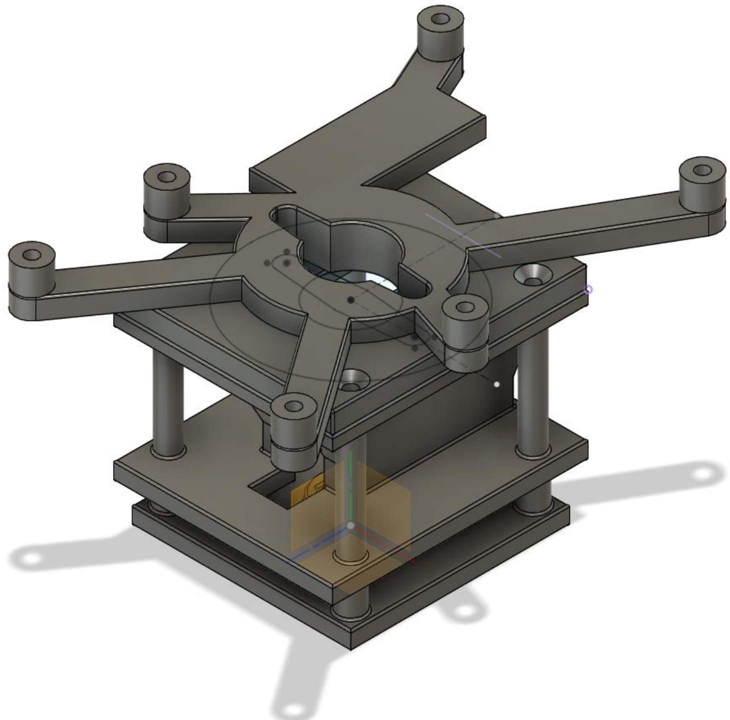

Figure 14. The 3D model for the servomotor jig.

The servomotor can be handled by using the Pololu micro maestro 6 controller, either by using a specific Pololu controller application or by using a programming language. In this work, a simple Python script made for controlling the servomotor, and this is documented more detailed in chapter 4.3.1. The servo controller has six different channels where can be connected different servomotors, power supplies or sensors. The different channels are named 0 to 5, so that channel 0 is reserved for power supply. Other channels can be used for servomotors and sensors. The controller will use channel 5 for the servomotor leaving the other channels free. The controller has connected to the test PC using USB mini-B cable. Most important variables what control can handle are speed, position, and acceleration. [17]

The UE rotation system is designed with one servomotor which is assembled on the 3D servo jig. The test UE will be connected onto this same jig. The KST servomotors were chosen for that test environment as they allow more than 180 degrees of rotation. KST MS825 servomotors will operate on 6.0 voltage (V), which gives them torque of 25 kilograms (Kg) per centimeter (cm) [18]. Figure 15 shows the completed system with one servomotor and servo controller. Figure 15 is focused on the controller itself with an orange circle. One power supply and servomotor are connected to channels 0 and 5.

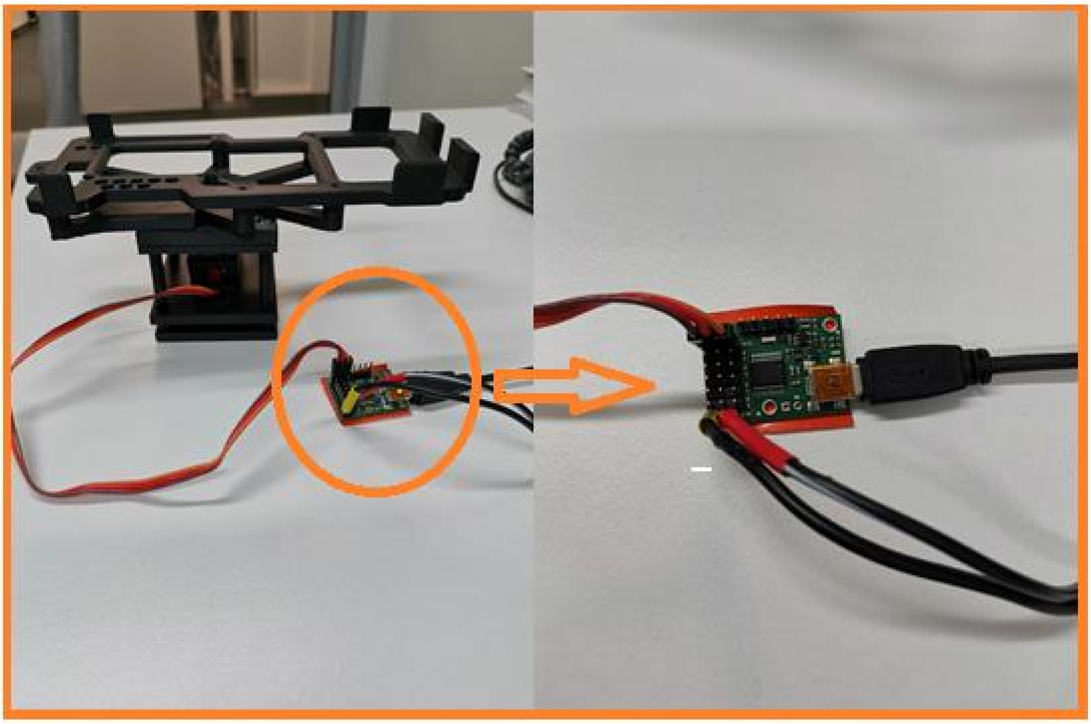

Figure 15. The completed UE rotation system with the Pololu Micro maestro 6 servo controller and the KST MS825 servomotor.

4.3. Software and test cases

After looking at the most important elements of the test environment, this chapter can focus on the test software and the test cases. The test software refers to the Python script used to control the UE rotation system. Five different test cases will be implemented in the test measurements and those cases are briefly described in this chapter.

4.3.1. UE rotation system software

The Python script was developed to control the servo controller and servomotor as part of the practical work. It was decided to use Python as the programming language in the script, but it could have been implemented in other programming languages as well. There was a pre-built Maestro Python class for the servo controller, which contains various functions related to the operation of the controller and servomotors [17, 19]. The UE rotation system script will use the different functions of that class. Both of those scripts can be found in Appendices 1 and 2.

The UE rotation system script made for the system itself is simple. There are 4 main functions that will affect activity of servomotor: position, acceleration, speed, and active channel. The script is encoded in 3 different positions into where the servomotor can be moved. Speed, positions, and acceleration are set to certain constant values in the script and these values can be changed if necessary. Figure 16 documents the main elements of the Python script and open their activities.

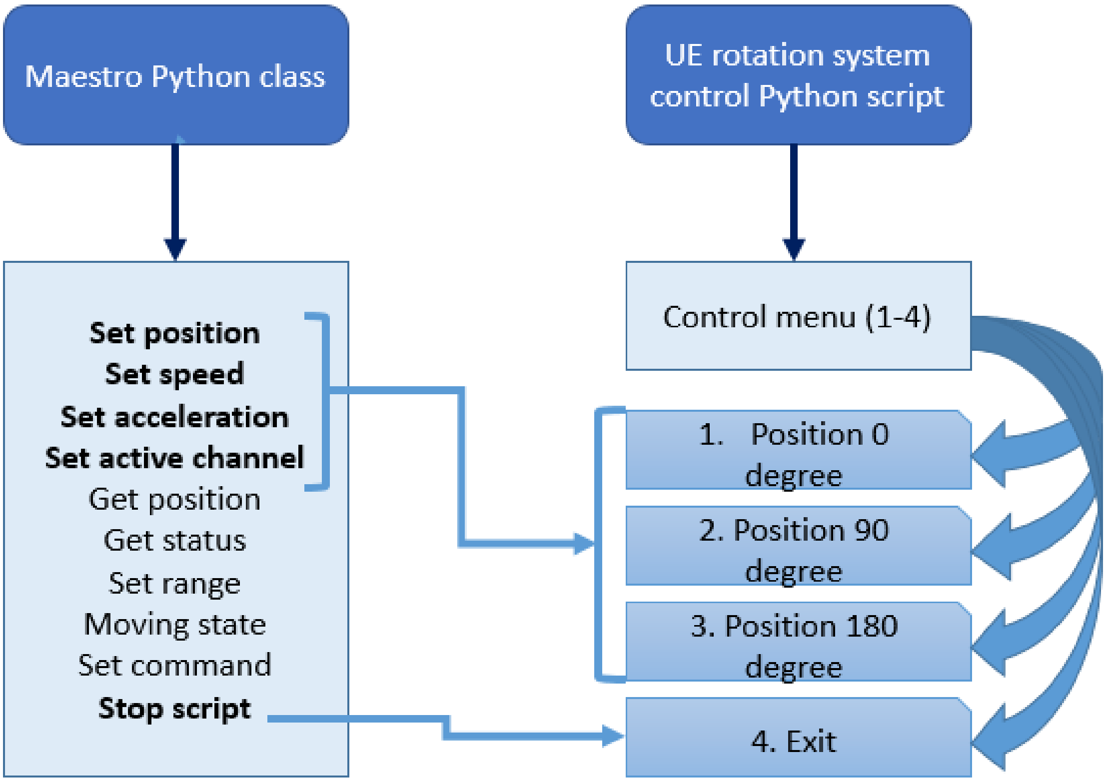

Figure 16. The main elements of the UE rotation system control Python script.

The Maestro python class contains various functions that can be used with the UE rotation system control script. The most important of those functions are set speed, set acceleration, set active channel, and stop script. The selection of a specific position is done using the UE rotation system control script. The control menu can be selected from options 1 to 4. Options 1 to 3 will set servomotor target position and option 4 will stop the script. Position, speed, acceleration, and active channel is stored as constant values for variables in scripts. For example, all three positions have the same acceleration and speed. If necessary, these variables can be changed in the scripts or other functions can be add from the Maestro class to the UE rotation system control script.

4.3.2. Test cases

The UE rotation system has been integrated into the FR2 test environment, let's get familiar with the different measurements and tests cases. The possibilities for different test cases are numerous, but for this thesis work, the most useful test cases are shown in Table 3. This table summarizes the main test cases and describes those tests realization briefly. In almost all cases, the UE under research is compared as it stays in place and rotates around it axis. In other words, the servomotor spins it 180 degree or holds it in place during each test. Each test case also focuses on examining which mmWave antenna groups of the UE is active. The special testing tool is used to investigate all test cases, and this testing tool will also save the necessary measurement data. The measurement data will be presented in the form of figures or tables. In the future, also other test cases may be used for this test environment.

Table 3. Different test cases

Test case:	Realization:	Note:
Attach and detach	In every different position the UE will do attach and detach to the 5G network.	In every different position the testing tool will check which mmWave antenna group is active.
The active antenna group selection when the UE is rotating.	The UE will be rotating when it is attached to the network. After that the UE will make detach to the network. The UE will be rotating in all three different positions.	The testing tool will be checking which mmWave antenna group is active during the rotation.
Ping	In each different positions the UE will do 15 second ping test against the BS. After that UE will do also 15 second ping test at the same time when the UE rotation system is rotating between different positions.	In each different positions the testing tool will check which mmWave antenna group is active. Testing the active antenna group is in progress while the UE is rotating.
UL data transfer	In each different positions the UE will do the 15 second UL data transfer test. After that the UE will do also the 15 second UL data transfer test at the same time when the UE rotation system is rotating between different positions.	In each different positions the testing tool will check which mmWave antenna group is active. Testing the active antenna groups is in progress while the UE is rotating.
AIM1 active antenna group test	During first four test AIM1 antenna is not active, so this test will confirm which positions of the UE the AIM1 antenna group is active.	In each different positions the testing tool will check which mmWave antenna groups is active. The aim is focus on the activity of AIM1 antenna group.

Because the focus is found which antenna groups are active, figure 17 will show mmWave antenna locations in different rotation positions in first four test cases. This figure 17 also indicates the direction in where the BS is located. It is good to note that in each position, one antenna is closest to the BS and have line-of-sight (LOS) against the BS. Figure 18 will show last test case scenario where the UE is placed in different way to the rotation system and will demonstrate where active antenna groups and BS are in different positions.

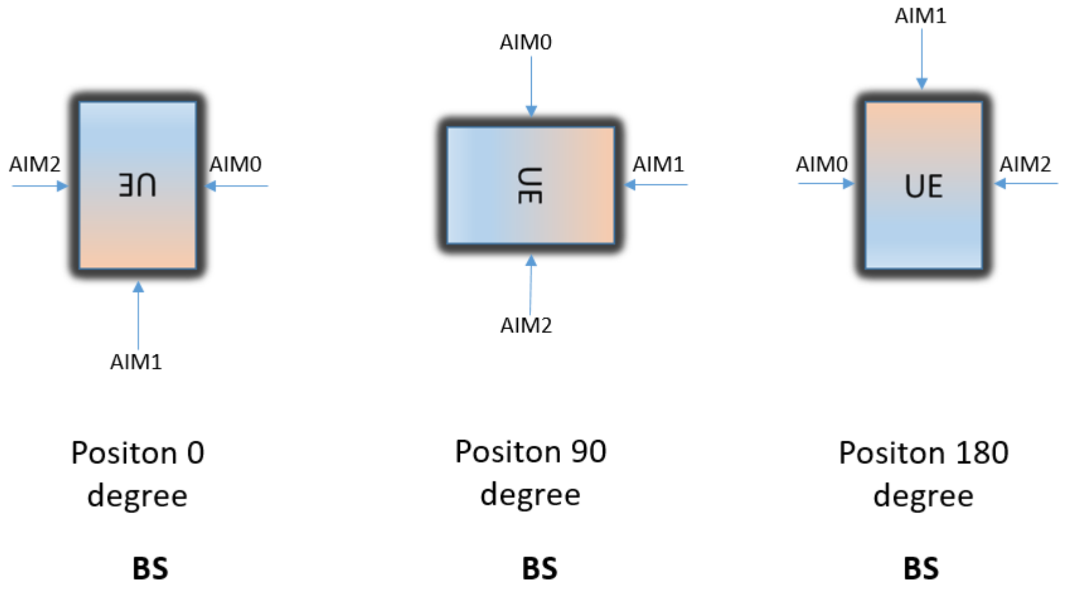

Figure 17. The mmWave antenna group's locations of UE in different rotation positions during the first four test cases.

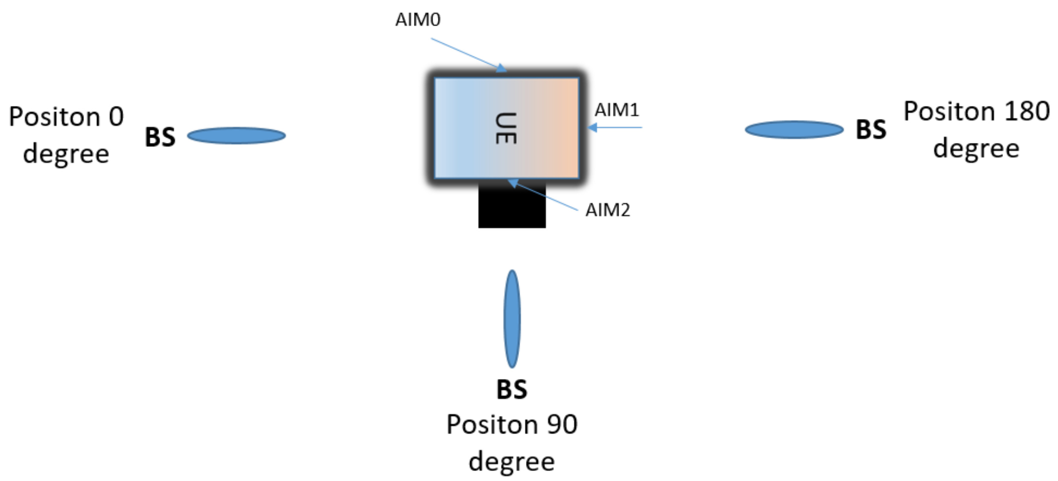

Figure 18. The mmWave antenna group's locations of UE in different rotation positions during the last test case.

5. TEST RESULTS.

Fifth chapter of thesis work will be focusing about the documentation of test cases and gives measurement results of these cases. The test results will be presented in the form of figures and tables. After the results are presented, these test results are also analyzed.

5.1. Attach and detach

The first test case will be basic attach and detach test, where the UE will attach and detach to the 5G network in different test positions 0, 90 and 180 degrees. At each test position, the test PC with the testing tool will be looking at which mmWave antenna is active. The active antenna will be found by checking layer 1 (L1) trace window and using specific command. The 5G network attach and detach will be using specific functions and commands which are not opened in more detailed in this work. The testing tool will be checking can the UE find the FR2 cell and can it connect successfully to the 5G network. The results of this test case are summarized in Table 4. This test measurement will also serve a reference measurement of which antenna should be active in each test positions.

Table 4. Attach and detach test case

Position	Active mmWave antenna group	The 5G network connection was successful (LTE cell + FR2cell)
0 degrees	AIM2	Yes (b2 + n261)
90 degrees	AIM2	Yes (b2 + n261)
180 degrees	AIM0	Yes (b2 + n261)

During these different positions the active antennas are AIM2 and AIM0. In every position the UE can make attach to the 5G network successfully and finds the cells b2 and n261. In this case b2 is the LTE anchor cell and n261 is the FR2 cell, which confirm that the BS is using the NSA technology. It is good to notice, that the AIM1 antenna is not active at during those three test positions. When the UE is in position 0 and 90 degree the active antenna seems to be AIM2, but when the device is in the position 180 degree the active antenna seems to be AIM0. The test was repeated a few times without any change in the result.

The main consideration for this case is to note that the test device can find the desired LTE and NR cells during different test positions. In the positions 0 and 180 degree the active antenna is on the left side of test device, but in the position 90 degree the active antenna is the in terms of the nearest antenna group by looking the BS side and has the LOS connection to that BS. According to the assumption made in the previous chapter, the AIM1 antenna is oriented so that when the UE is in that position in the rotation system, the AIM1 antenna group is not active.

The testing tool gives the information of specific variables for different antenna groups and those variables will affect the selection of the active antenna. Those variables varied during the measurements. However, exact variable values cannot be given for these measurements because the test equipment is the property of the company and is still under development.

5.2. Active antenna selection when UE is rotating

The second test case will be active antenna selection when the UE is rotating. In that case the UE will be rotating in four different ways. First test run the UE will attach to the network and start rotation from position 0 degree to position 180 degrees. After every test run the UE will detach from the network. Second test run the UE will attach to network and start rotation from 180 degrees position and end rotation to 0 degrees position. Third and fourth test runs the UE will attach to the network and start rotation from 90 degrees position. In third test run it end rotation to the 0 degrees position and fourth test runt it ends rotation to the 180 degrees position. The results of this test case are summarized in Table 5. Table 5 will show the direction of rotation, which antenna groups are active, will active antenna change during rotation and can the UE make connection to the 5G network successfully.

Table 5. Active antenna selection when the UE is moving

Rotation from the starting position to the ending position	Active mmWave antenna group during rotation	Active mmWave antenna group will change.	The 5G network connection was successful (LTE cell + FR2cell)
0 degrees → 180 degrees	AIM2 → AIM0	Yes	Yes (b2 + n261)
180 degrees → 0 degrees	AIM0 → AIM2	Yes	Yes (b2 + n261)
90 degrees → 0 degrees	AIM2	No	Yes (b2 + n261)
90 degrees → 180 degrees	AIM2 → AIM0	Yes	Yes (b2 + n261)

During the rotation active antenna will change except during rotation from 90 degree to 0 degree. Depending on the start of rotation, the UE uses either AIM0 or AIM2 as the active antenna, and it follows the results of the first test case. Also, during those test, the AIM1 antenna group is not active with any test runs. The UE can be connected to the 5G network regardless of the rotation. That test was repeated a few times, and there was change in the results. With some test runs the active antenna did not change during rotation, but most of the runs active antenna change happened.

The most interesting consideration in those test runs was that the active antenna changes when the UE rotates from positions 90 degree to 180 degree, but not when it rotates from positions 90 degree to 0 degree. In addition, the change also happens as the UE rotates whole 180 degrees regardless of the starting position. Looking at the values obtained from the test tool, it is observed that the active antenna changes after the UE has rotated in the rotation system a little over 90 degrees position.

Based on this case, it is observed that the active antenna changes during to the rotation of the UE rotation system. The change of the active antenna seems to take place when the UE has passed the position 90 degrees and is rotating towards the position 180 degrees. When the system begins to rotation from the position of 180 degree, the change in the active antenna occurs before the position of 90 degree.

5.3. Ping

The third test case will be ping test where the UE is rotating and stays place in different test positions. In that case the UE will ping data to the ping target which will be the test environment BS. Ping test is one of the most used test cases which can give information about reachability and availability of the IP networks host. In ping test, the data packet is sent to the host address and the host address responds by sending the data packet back. The test measures how long it took for the data packet to loop through to the host of the IP network and from there back to the device that is sending that data packet. In addition, test will also check was the IP host able to successfully send this data packet back to the device. [20]

The ping test will take 15 seconds and the UE will ping to the target address always every second. The UE will ping to the target address in 5 different ways. For the first three measurement runs, the UE is in place at each test position. With the last two measurement runs, the UE will be rotating between test positions 0 and 180 degree. After every test run, the UE will make detach from the network and after new test run attach again to the 5G network. The results of this test case are documented in Table 6 and Figure 19. Table 6 will show which antenna is active in each measurement run and Figure 19 will show ping test as a paragraph, where the x-axis shows the concrete time of measurement in seconds and the y-axis shows the latency of the ping test in milliseconds (ms).

Table 6. Ping test

The UE position during the ping test	Active mmWave antenna group.	Active mmWave antenna group will change.	The 5G network connection was successful (LTE cell + FR2cell).
0 degrees	AIM2	No	Yes (b2 + n261)
90 degrees	AIM2	No	Yes (b2 + n261)
180 degrees	AIM0	No	Yes (b2 + n261)
0 degrees → 180 degrees	AIM2 → AIM0	No	Yes (b2 + n261)
180 degrees → 0 degrees	AIM0 → AIM2	Yes	Yes (b2 + n261)

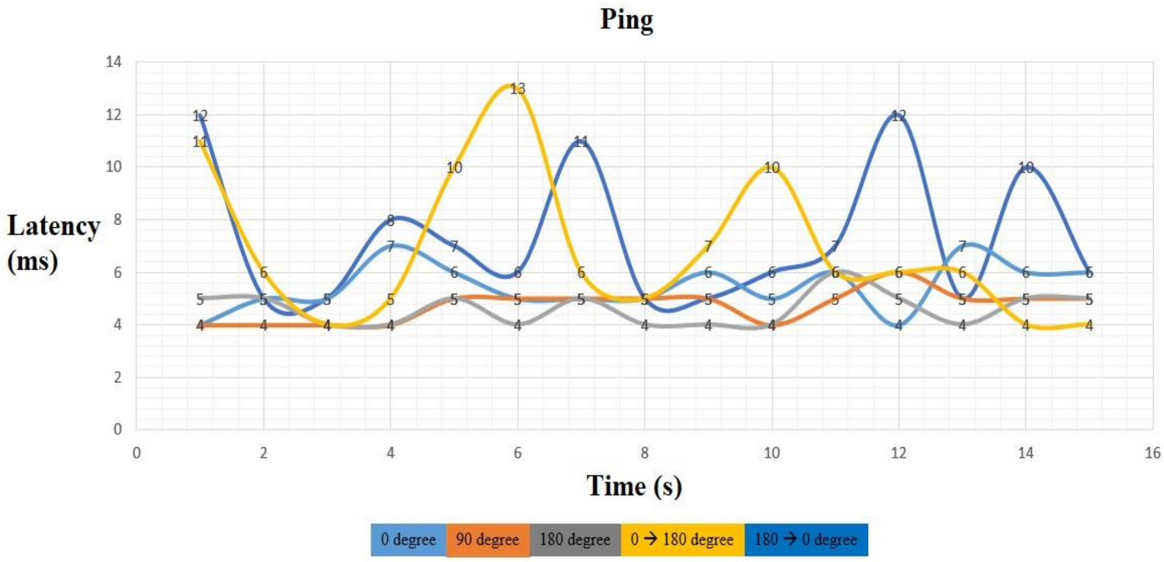

Figure 19. The ping test paragraph.

Table 6 shows that the test result is like the previous test cases, but this time the active antenna changes during the UE rotation from the position 180 degree to 0 degree. Still at all tests positions the UE can connected to the network, but now the rotation of the UE causes the active antenna to change from AIM0 to AIM2. Figure 19 shows the result of the ping test at the different position by using different colors in paragraph. When the UE stays one place in three different test positions, the ping test latency varies from 4 ms to 7 ms. As the UE rotates during the test runs, the change is larger. As the UE rotates from 0 degree to 180 degree, the results vary between 4 ms to 13 ms and in the other direction between 5 ms to 12 ms. That test case was repeated a few times, but the test results have not been averaged. In addition, there is no change in active antenna in every test run.

The test results show that the ping latency values vary less when the UE does not rotate and stays in place at the specific test positions. When the UE rotates during the test, the variation of the ping test latency values is at a higher interval. The test device rotates 180 degrees for about 15 seconds and the rotation system will start moving at the same time as the ping test itself will start. Based on this case, it is found that the rotation of the device and the change of the active antenna have a small effect on the performance of the UE, and it can be said that the ping test results are better when the UE is not in rotating. The active antenna change is not detected with each test run, but it occurs almost every time when the system rotates.

5.4. UL data transfer

The fourth test case will be the UL data transfer test when the UE is rotating and stays place in different test positions. The realization of that test case is very similar to the previous one. In that case the UE only transfer UL data to the test environment BS. When the UE use the UL data transmission, it will transfer a certain amount of data to the target, which in this case is the BS [21]. Each measurement run will take 15 seconds and the UE will transfer data to the target always every second. The results of this test case are documented in Table 7 and Figure 20. Table 7 will show same parameters as Table 7 and Figure 20 will show the UL data transfer test as a paragraph, where the x-axis shows the concrete time of measurement in seconds and the y-axis the transferred UL data in megabits per second (Mbps). The UL data was transferred 200 Mbps during the test. Before each test position change was made detach and attach to the network. This test case was repeated also a few times, but the results have not been averaged.

Table 7. The UL data transfer test

The UE position during the UL data transfer test.	Active mmWave antenna group.	Active mmWave antenna group will change.	The 5G network connection was successful (LTE cell + FR2cell)
0 degree	AIM2	No	Yes (b2 + n261)
90 degrees	AIM2	No	Yes (b2 + n261)
180 degrees	AIM0	No	Yes (b2 + n261)
0 degree → 180 degrees	AIM2 → AIM0	Yes	Yes (b2 + n261)
180 degrees → 0 degree	AIM0 → AIM2	Yes	Yes (b2 + n261)

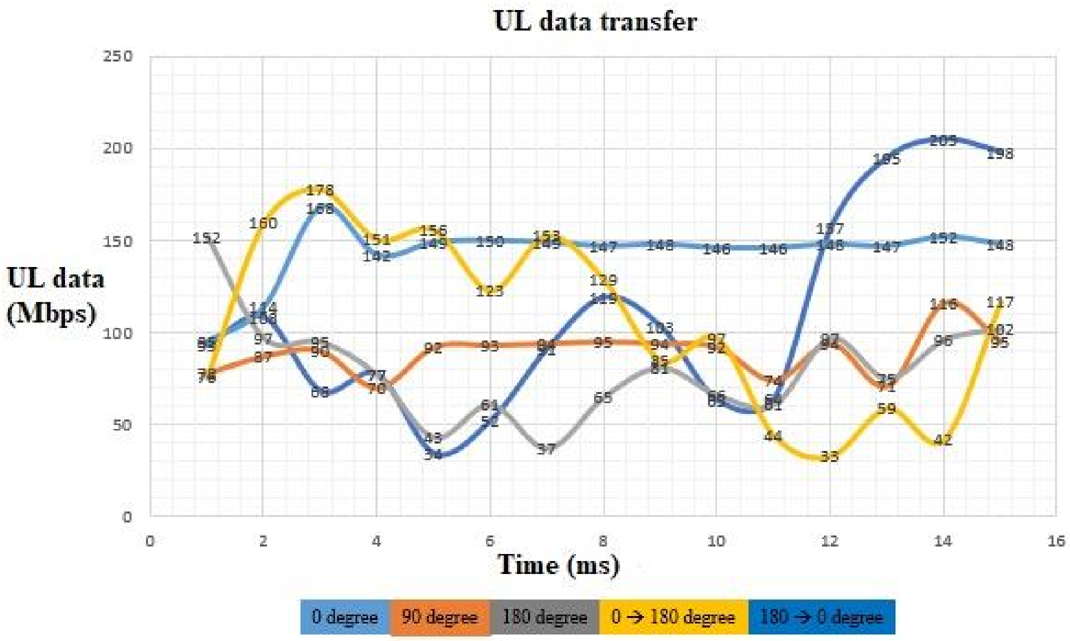

Figure 20. The UL data transfer test paragraph.

The selection of the active antenna seems to follow the same pattern as in the previous test cases, but this time the active antenna also changes when rotating from position 0 degree to position 180 degrees. Also, during this test case, the AIM1 was once seen as the active antenna. Figure 20 shows the UL data transferred during this case, and paragraphs of different colours represent data transfer at different positions. The paragraph show that the transmitted data varies depending on the position or rotation. For example, in the test position 0 degree the UL data transfer is smooth except for a small increase at the beginning of the test.

When the UE rotates, the UL data transmission variation is the largest and the active antenna group changes during the test run. The UE rotates from the position 0 to the position 180, the data transfer is beginning of the test run high and after 7 second it will start to decrease. The situation is reversed when the direction of rotation is also reversed. This Figure 20 shows that at the position 0 degree the highest UL data transmission is obtained with the AIM2 active antenna. During the test runs, the UL data transfer maximum value was 205 Mbps and minimum value was 34 Mbps.

Based on test runs, the highest UL data transmissions are achieved when the active antenna group is AIM2. When the test system rotates, it is detected that the active antenna changes affect the UL data transfer rate so that the transfer rates with the AIM2 antenna group are higher than with the AIM0 antenna. Also, when the UE stays in one place with the active antenna AIM2, the transmission speeds are higher than with the AIM0. This test shows that depending on the rotation, position and active antenna of the UE, there is an effect on the performance of the test device.

5.5. AIM1 active antenna test

Based on previously test cases, it was found that the AIM1 antenna was not active in those cases, expected momentarily expect just once. Because of that information, as a final test, the AIM1 active antenna test is performed by turning the UE of rotation system in the different direction. Figure 21 will demonstrate how UE is connected to the rotation system. The AIM1 antenna group is located at the top of the test device, in which case, connecting the device to the system as shown in the Figure 21 would give more information about which directions the AIM1 antenna is active. In this test the rotation system is also moved to the three test positions mentioned above. This test was also intended to be included in test cases because, in many cases, the customer uses the test device as shown in Figure 21.

This test case will show when the AIM1 antenna group is active when UE is rotated in test positions 0, 90 and 180 degrees. This case also demonstrates that the UE can be placed in the rotation system in different ways. The results of the test runs are summarized in Table 8 at the same way as in the previous test cases. Whenever the UE is rotated to the different position, UE will do first detach and attach to the 5G network. No data is transferred during the test runs and the active antenna information was checked by using same testing tool as previously cases.

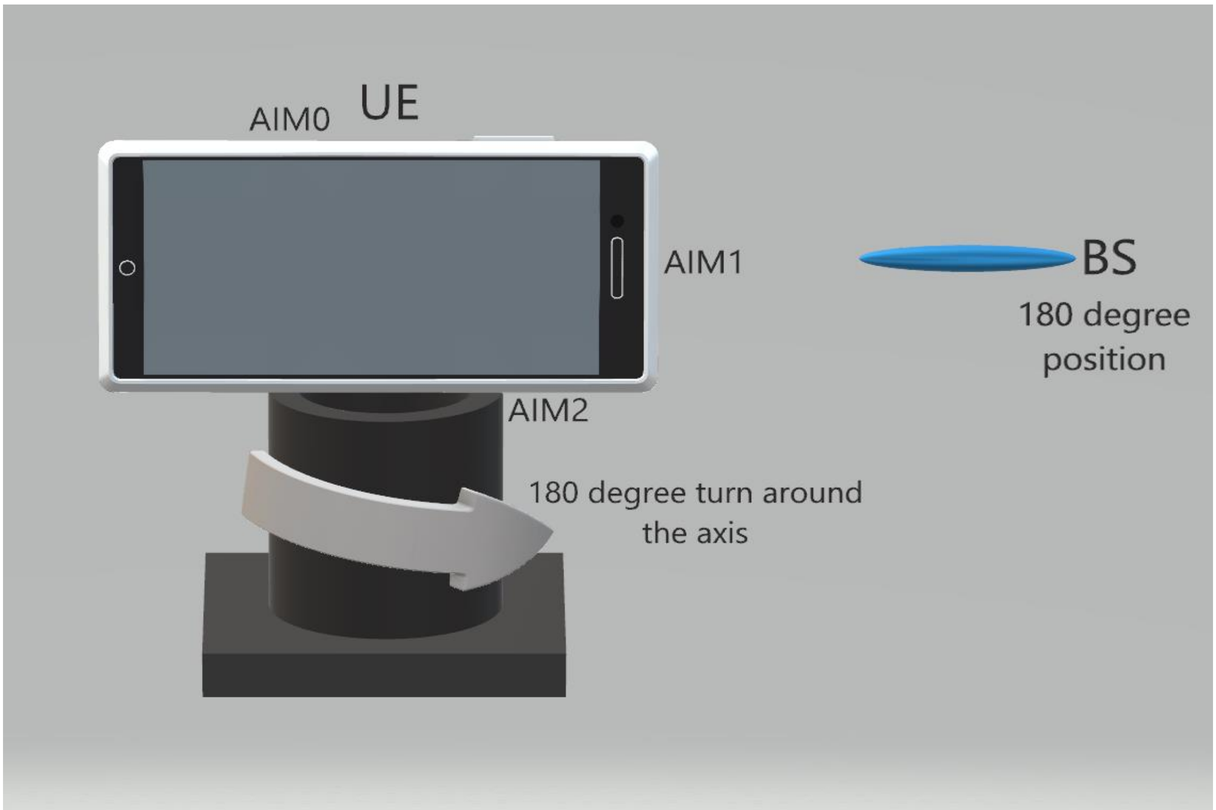

Figure 21. The UE rotation system test setup during the final test case.

Table 8. The AIM1 active antenna test

UE position during DL data transfer test	Active MmWave antennas	Active MmWave antenna will change.	5G network connection was successful (LTE cell + FR2cell)
0 degrees	AIM2	No	Yes (b2 + n261)
90 degrees	AIM2 OR AIM1	Yes	Yes (b2 + n261)
180 degrees	AIM1	No	Yes (b2 + n261)
0 degrees → 180 degrees	AIM2 → AIM1	Yes	Yes (b2 + n261)
180 degrees → 0 degrees	AIM1 → AIM2	Yes	Yes (b2 + n261)

It can be seen from Table 8 that test positions 90 and 180 degrees AIM1 is the active antenna group and positions 0 and 90 degrees AIM2 is the active antenna group. This measurement was repeated several times and at position 90 degree the active antenna varied between AIM1 and AIM2. When the UE rotates from position 0 degrees to position 180 degrees, the active antenna array changes from AIM2 to AIM1. When the direction of rotation is opposite, the active antenna changes from AIM1 to AIM2. The AIM0 antenna group was not active during the last test runs. It is good to note that at position 180 degree the AIM1 antenna has the LOS connection to the BS. The active antenna change does not happen every test run, but that change happens almost every time. The 5G network was found without problems in all test positions during the final test case.

Based on those test runs, it can be stated that the AIM1 antenna group is active in certain positions with the test device placed as shown in Figure 21. Based on this case, it is noticed that in the 90 degrees position the active antenna varies depending on the test run. This observation is reminiscent of the result of the first test cases where it was observed that the active antenna changes when the UE rotates slightly over the 90 degrees position. When looking testing tool, the variables which will affect the selection of the active antenna also vary slightly at the 90 degrees test position. Since the BS of the test environment is directed to the rotation system in the same way in each test, it is possible to compare the results of this case with previous test results even in this case the UE is set differently in the rotation system.

6. DISCUSSION

This section discusses how well the test environment, and the UE rotation system were implemented. It considers the correctness of the final test results and analysis of tests. Chapter 6 also considers how the work progressed, can the test environment be utilized in the future and what could have been improved.

6.1. Test environment functionality and performance

The rotation system integration for the FR2 test environment was successfully. The rotation system will work with one servomotor which allows it to over 180 degrees rotation around it axis. In all the test cases the UE rotation system was assembled against the table and the rotation was horizontal. The test UE can be installed in that system in two different ways as shown in the previous chapters. For future test cases it is possible to also install second servomotor or other components in the rotation system. The test position of the device under research can also be changed by modifying the script made for the system. These follow-up actions can be added when the system is deployed in the company’s test plan.

Assembling the system and creating the Python script to move it were successfully. The script can be modified, if some tester wants to add more servomotors, change the speed or acceleration of rotation. While the script is simple, it allows almost anyone to modify it easily. Some features could have been added to the UE rotation system script, for example to the control menu could be able to set a certain speed or acceleration values of the servomotor. Because the test cases are compared with each other, these values were constant, so there was no need for that addition.

Analysis of the tests showed that the UE can connect to the 5G network and find the FR2 cell and LTE anchor cell. In addition, the test tool detects that the UE changes the active antenna when it is in the different test position, but that change does not always happen as the UE rotates. When the laboratory area is the EMC room, the walls of the laboratory room reflect and shadow the mmWave signal. The test environment could be improved by lining the degraded walls with a material that reduces signal reflections.

Mainly, the design and functionality of the test environment was implemented as expected. However, with the above considerations and more careful design, the test environment could be better. The creation of a new test environment is partly empirical, so the creation of that test environment provided information that can be utilized in the future. The work also had partially predetermined restrictions and requirements, for example, with the laboratory area, which were followed in this work.

After the measurements, it can be stated that the work was successful. Answers to the desired research questions regarding the test environment, active antenna selection, and how that will influence the performance of the UE were found. The results obtained from the test cases can be utilized in the development and research of the company's products. It is still good to note that a lot of different improvements could have been made to the work that have already been highlighted, with which the test results and the environment itself could have been improved. Those improvements can be added as the test environment is utilized in the future.

6.2. Consider about the test results

A total of 5 different test cases were performed on the implemented test environment and the rotation system, which provide information about this environment and the performance of the UE. The results of the tests were collected by using tables and paragraphs and the results were reviewed with brief analyzes after each case. This section examines in more detail the information provided by these tests and considers the validation and correctness of the test measurements. The tests focused on the selection of the active antenna of the device and its effect on the performance of the test device.

As mentioned earlier, there were empirical features in the tests and measurements, as completely that kind of measurements had not been performed before. On the other hand, this work wanted to implement the new environment from which to gather new information. The results serve this purpose and the various test cases are documented in such a way that, if necessary, those measurements can also be repeated by a different tester. When measurements were taken, several test runs would be required in each test case to obtain the most reliable test result, and those results should have been averaged at the end of every case. This was considered when presenting and analyzing the test results. For each case, an attempt was made to present the results of the test runs which would be most relevant for this thesis work.

The measurements focused on selecting the active antenna group of the test UE. The device under research had three different antenna groups which can handle the reception and transmission of the mmWave signal at FR2 frequencies. The test cases were selected so that each of those antenna groups were examined, and it was found from the test runs that all of those antenna groups were active when the UE rotates in the different test positions. Those antenna groups were not active at the same time. The active antenna selection depended on the position in which the UE was placed in the rotation system. In addition, as the test system rotated, the active antenna changed almost always during this rotation. The position and rotation of the UE influence the selection of the active antenna. The change in the active antenna also had the effect on the performance of the device under test. The values obtained in the tests were slightly better with the device stationary than in rotation.

The base station itself is directed to the test system in the same way for all measurements, so that the effect of the measurements on the performance of the UE can be compared with each other. All three antenna groups were active on certain test cases, in addition values which effect to selection of the active antenna were varied during those tests. This is probably explained by the fact that in the different test position the BS directs the test with environmental reflections and shadings to the test device so that the signal strength what active antenna will receive depends to the position of the test device. In addition, the tests found that the active antenna changed frequently when the device moved slightly over the 90 degrees position, with the antenna probably having the best sight of the BS.

As mentioned earlier, the choice of active antenna is affected by several different variables and thresholds. Exact values for these variables cannot be reported in this work. However, the test device can be assumed to have certain limit values when the active antenna is selected again. Those variable limits are affected by the position of the test device relative to the BS. In some test measurements, those variables varied slightly over a short period of time, leaving no time for the active antenna change. As those threshold values are internal information of the company, it will be possible to find out the exact limit values from the measurements and the documents concerning the test device. Those threshold values could be compared the measurements made in the test environment. This test environment and the test UE are also suitable for more challenging measurements such as a stress test or maximum throughput. The number of test cases was decided to be limited to the 5 different cases.

6.3. Integration in the test plan of company

In the future, that test environment will be able to integrate into the company's test plan but should be considering the improvements previously considered. When the test environment is added to the overnight automated testing, the number of test cases can be also increased. When a new software which can control microchip of the UE is flashed on the test device under research every day, a lot of asserts can be found during those tests. Other test devices of company can also be added to the UE rotation system, as the jig of the rotation system can be easily modified to attach new test equipment. In addition, also extra servomotors can be added this system, which will improve UE rotation. Can be expect, that the rotation system of this work can also be utilized in other test environments in the future, for example by modifying it in the linear actuator with guide which can move the test UE in a distance direction relative to the BS.

7. SUMMARY

At the beginning of the thesis work, the relevant technologies and the theory used in the test environment and measurements were introduced. Those sections introducing for example the basics of the 5G, the benefits and requirements of that technology, the NSA technology, the FR2 frequencies, and factors influencing active antenna selection. Those theory sections were the most focused on the last three sections, because those were the most relevant for the implementation and design of the test environment and the test measurements. The BS in the test environment utilizes the NSA and the FR2 technology, so it uses a certain frequency range for wireless communication and needs the LTE anchor cell to support the 5G cell. The tests, on the other hand, focus on the mmWave active antenna selection feature of the test device under research.

After the necessary theory, the practical part of the work was started, which included the design and implementation of the new test environment. This environment used the FR2 and the NSA technology, and the test measurements focused on the selection of the active antenna of the test device when the device will rotate in the test environment. The test UE was the smartphone that utilizes the 5G technology and is also able to utilize wireless communication with using mmWaves. The device has the three main FR2 antenna groups, which will use that communication technology. For the control of the UE rotation system the Python script was created. The test device would be able to rotate in the environment under research between three different test positions and the UE can rotate more than 180 degrees about its axis horizontally.

Once the test environment had been successfully built, the different test measurements can be started in that environment. In total of 5 different test cases were performed in this work, which provided information about the performance of the test UE and the selection of the active antenna. All tests focused on how the rotation of the device affects the selection of the active antenna. Each test case was documented, and the test results were presented using tables and figures.

The analysis of the results shown that the UE rotation affecting the performance of the device and the active antenna vary depending on the position of the test UE. The test device was able to work well on the 5G network, with each test run. Despite the change of the active mmWave antenna group, the connection to the 5G network remained good in all test cases. The test measurements were found to be successful, and the data obtained from them can be used in the future to improve the equipment under test and the test environment itself. However, when considering the correctness of the tests, several improvements were noted that could be used to improve the test environment and measurements. At the end of the work, it was decided that that test environment could be utilized in the company's test plan.

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9. APPENDICES

Appendix 1 UE rotation system control python script

Appendix 2 Maestro python class [19]

Appendix 3 Opinnäytetyön julkaisusopimus FI Sami Nyberg

Appendix 1 UE rotation system control python script

```

## UE rotation system control menu (c) Sami Nyberg

import sys
import maestro
import time

servo = maestro.Controller('COM19')     #Add right com port of servo sensor

def print_menu():
    print(" ")
    print("____________________UE ROTATION SYSTEM_______________________")
    print("[                                                            ] ")
    print("[ 1. Set UE rotaion system to vertical positon 0 degrees     ]")
    print("[ 2. Set UE rotaion system to vertical positon 90 degrees    ]")
    print("[ 3. Set UE rotaion system to vertical positon 180 degrees   ]")
    print("[ 4. Exit                                                    ]")
    print("[____________________________________________________________]")
    print(" ")

loop=True

while loop:          ## While loop which will keep going until loop = False

    while loop:
        print_menu()     ## UE rotation system menu
        try:
            selection = (input("Set position for UE rotation system [1-4]: "))
            selection = int(selection)
            break
        except ValueError:
            print("NOTE: Please enter number [1-4]: ")

    if selection==1:
        print ("1. Set UE rotaion system to positon 0 degrees")
        time.sleep(3)
        servo.setAccel(5,0)         #set servo 5 acceleration to 0
        servo.setSpeed(5,5)         #set speed of servo 5
        servo.setTarget(5,2200)     #set servo to move to center position
        servo.stopScript()

    elif selection==2:
        print ("2. Set UE rotaion system to positon 90 degrees")
        time.sleep(3)
        servo.setAccel(5,0)         #set servo 5 acceleration to 0
        servo.setSpeed(5,5)        #set speed of servo 5
        servo.setTarget(5,5880)     #set servo to move to center position
        servo.stopScript()

    elif selection==3:
        print ("3. Set UE rotaion system to positon 180 degrees")
        time.sleep(3)
        servo.setAccel(5,0)         #set servo 5 acceleration to 0
        servo.setSpeed(5,5)        #set speed of servo 5
        servo.setTarget(5,9560)     #set servo to move to center position
        servo.stopScript()

    elif selection==4:
        print ("Exit")
        servo.stopScript()
        loop=False # This will make the while loop to end as not value of loop is set to False

    elif selection !=  selection:
        print("NOTE: Please enter number [1-4]: ")
```

Appendix 2 Maestro python class [19]

```
#
#---------------------------
# Maestro Servo Controller
#---------------------------
#


import serial
from sys import version_info

PY2 = version_info[0] == 2   #Running Python 2.x?

class Controller:

    def __init__(self,ttyStr='/dev/ttyACM0',device=0x0c):
        # Open the command port
        self.usb = serial.Serial(ttyStr)
        # Command lead-in and device number are sent for each Pololu serial command.
        self.PololuCmd = chr(0xaa) + chr(device)
        # Track target position for each servo. The function isMoving() will
        # use the Target vs Current servo position to determine if movement is
        # occuring.  Upto 24 servos on a Maestro, (0-23). Targets start at 0.
        self.Targets = [0] * 24
        # Servo minimum and maximum targets can be restricted to protect components.
        self.Mins = [0] * 24
        self.Maxs = [0] * 24

    # Cleanup by closing USB serial port
    def close(self):
        self.usb.close()

    # Send a Pololu command out the serial port
    def sendCmd(self, cmd):
        cmdStr = self.PololuCmd + cmd
        if PY2:
            self.usb.write(cmdStr)
        else:
            self.usb.write(bytes(cmdStr,'latin-1'))

```

```
    # Set channels min and max value range.  Use this as a safety to protect
    # from accidentally moving outside known safe parameters. A setting of 0
    # allows unrestricted movement.
    #
    # ***Note that the Maestro itself is configured to limit the range of servo travel
    # which has precedence over these values.  Use the Maestro Control Center to configure
    # ranges that are saved to the controller.  Use setRange for software controllable ranges.
    def setRange(self, chan, min, max):
        self.Mins[chan] = min
        self.Maxs[chan] = max

    # Return Minimum channel range value
    def getMin(self, chan):
        return self.Mins[chan]

    # Return Maximum channel range value
    def getMax(self, chan):
        return self.Maxs[chan]

    # Set channel to a specified target value.  Servo will begin moving based
    # on Speed and Acceleration parameters previously set.
    # Target values will be constrained within Min and Max range, if set.
    # For servos, target represents the pulse width in of quarter-microseconds
    # Servo center is at 1500 microseconds, or 6000 quarter-microseconds
    # Typcially valid servo range is 3000 to 9000 quarter-microseconds
    # If channel is configured for digital output, values < 6000 = Low ouput
    def setTarget(self, chan, target):
        # if Min is defined and Target is below, force to Min
        if self.Mins[chan] > 0 and target < self.Mins[chan]:
            target = self.Mins[chan]
        # if Max is defined and Target is above, force to Max
        if self.Maxs[chan] > 0 and target > self.Maxs[chan]:
            target = self.Maxs[chan]
        #
        lsb = target & 0x7f #7 bits for least significant byte
        msb = (target >> 7) & 0x7f #shift 7 and take next 7 bits for msb
        cmd = chr(0x04) + chr(chan) + chr(lsb) + chr(msb)
        self.sendCmd(cmd)
        # Record Target value
        self.Targets[chan] = target
```

```

    # Set speed of channel
    # Speed is measured as 0.25microseconds/10milliseconds
    # For the standard 1ms pulse width change to move a servo between extremes, a speed
    # of 1 will take 1 minute, and a speed of 60 would take 1 second.
    # Speed of 0 is unrestricted.
    def setSpeed(self, chan, speed):
        lsb = speed & 0x7f #7 bits for least significant byte
        msb = (speed >> 7) & 0x7f #shift 7 and take next 7 bits for msb
        cmd = chr(0x07) + chr(chan) + chr(lsb) + chr(msb)
        self.sendCmd(cmd)

    # Set acceleration of channel
    # This provide soft starts and finishes when servo moves to target position.
    # Valid values are from 0 to 255. 0=unrestricted, 1 is slowest start.
    # A value of 1 will take the servo about 3s to move between 1ms to 2ms range.
    def setAccel(self, chan, accel):
        lsb = accel & 0x7f #7 bits for least significant byte
        msb = (accel >> 7) & 0x7f #shift 7 and take next 7 bits for msb
        cmd = chr(0x09) + chr(chan) + chr(lsb) + chr(msb)
        self.sendCmd(cmd)

    # Get the current position of the device on the specified channel
    # The result is returned in a measure of quarter-microseconds, which mirrors
    # the Target parameter of setTarget.
    # This is not reading the true servo position, but the last target position sent
    # to the servo. If the Speed is set to below the top speed of the servo, then
    # the position result will align well with the acutal servo position, assuming
    # it is not stalled or slowed.
    def getPosition(self, chan):
        cmd = chr(0x10) + chr(chan)
        self.sendCmd(cmd)
        lsb = ord(self.usb.read())
        msb = ord(self.usb.read())
        return (msb << 8) + lsb
```

```python

    # Test to see if a servo has reached the set target position.  This only provides
    # useful results if the Speed parameter is set slower than the maximum speed of
    # the servo.  Servo range must be defined first using setRange. See setRange comment.
    #
    # ***Note if target position goes outside of Maestro's allowable range for the
    # channel, then the target can never be reached, so it will appear to always be
    # moving to the target.
    def isMoving(self, chan):
        if self.Targets[chan] > 0:
            if self.getPosition(chan) != self.Targets[chan]:
                return True
        return False

    # Have all servo outputs reached their targets? This is useful only if Speed and/or
    # Acceleration have been set on one or more of the channels. Returns True or False.
    # Not available with Micro Maestro.
    def getMovingState(self):
        cmd = chr(0x13)
        self.sendCmd(cmd)
        if self.usb.read() == chr(0):
            return False
        else:
            return True

    # Run a Maestro Script subroutine in the currently active script. Scripts can
    # have multiple subroutines, which get numbered sequentially from 0 on up. Code your
    # Maestro subroutine to either infinitely loop, or just end (return is not valid).
    def runScriptSub(self, subNumber):
        cmd = chr(0x27) + chr(subNumber)
        # can pass a param with command 0x28
        # cmd = chr(0x28) + chr(subNumber) + chr(lsb) + chr(msb)
        self.sendCmd(cmd)

    # Stop the current Maestro Script
    def stopScript(self):
        cmd = chr(0x24)
        self.sendCmd(cmd)
```

Appendix 3 Opinnäytetyön julkaisusopimus FI Sami Nyberg

Opinnäytetyön julkaisusopimus

Opinnäytetyöt ovat julkisia, joten hyväksytyn opinnäytetyön elektroninen versio tiivistelmineen tulee olemaan selailtavissa ja tulostettavissa Oulun yliopiston kirjastossa ja arkistossa. Opinnäytteen tekijä voi sen lisäksi valita, haluaako hän opinnäytteensä myös avoimeen tietoverkkoon.

(•) Haluan, että opinnäytteeni tiivistelmineen on selailtavissa, tulostettavissa ja tallennettavissa myös avoimesti verkossa. Opinnäytetyö saa pysyvän urn-osoitteen, jota voi jakaa, ja siihen voi viitata.

( ) En halua, että opinnäytteeni on myös julkisesti verkossa. Ainoastaan opinnäytetyön metatiedot tallennetaan Jultika-julkaisuarkistoon ilman työn kokotekstiä. Opinnäytetyön kokoteksti on luettavissa kirjaston toimipaikoissa e-gradutyöasemilla.

Tekijä tallentaa opinnäytetyön sähköiseen opinnäytejärjestelmään järjestelmän edellyttämässä muodossa.

Opinnäytetyön tekijänoikeudet

Opinnäytetyön tekijänoikeudet kuuluvat tekijälle. Tekijä vastaa itse opinnäytetyön sisällöstä ja oikeuksistaan siihen ja vakuuttaa, että hänellä on kuvien, taulukoiden tai muun aineiston käyttöön tarvittavat oikeudet. Mahdollisista kolmansien osapuolien vaateista vastaa tekijä. Opinnäytetyöhön ei saa sisällyttää tietoja, jotka ovat viranomaisten toiminnan julkisuudesta annetun lain (621/199) nojalla salassa pidettäviä.

Opinnäytetyön lisensointi

Valitse, mitä oikeuksia annat opinnäytetyösi lukijoille. Oulun yliopiston vastuullisen tutkimuksen julistus suosittelee opinnäytetyön avointa julkaisemista CC-BY 4.0 -lisenssillä. CC-BY 4.0 -lisensoitua teosta saa kopioida, levittää, esittää ja muuttaa vapaasti, myös kaupallisiin tarkoituksiin. Tekijän nimi on aina mainittava asianmukaisesti eikä tekijän nimeä, kuvaa tai logoa saa muuttaa. CC BY on yleisin avoimien sisältöjen lisenssi ja se on erittäin tehokas tapa saada paljon lukijoita tai yleisöä. Lisenssillä varustettua aineistoa voi esimerkiksi käyttää opetuksessa, kunhan tekijä mainitaan.

(•) Kaikki oikeudet pidätetään. Opinnäytetyön yksityiskäyttö on sallittu.

( ) CC BY 4.0 (Nimeä 4.0 Kansainvälinen). Tieto lisenssistä on liitettynä opinnäytteen kansilehteen.

Suostumus plagioinnintunnistukseen (Turnitin)

(•) Suostun, että työni tallentuu plagiaatintunnistusjärjestelmän tietokantaan. Turnitin Similarity –järjestelmä sijaitsee EU:n alueella. Työtäni verrataan tietokannan muihin dokumentteihin, sähköisiin tiedejulkaisuihin, hakuteoksiin ja avoimen internetin tietosisältöihin. Oulun yliopistolla on myös oikeus siirtää työni toiseen tallennuspaikkaan plagioinnintunnistusjärjestelmän vaihtuessa.

( ) En anna suostumustani opinnäytetyöni tallennukseen TurnItIn Similarity –plagiaatintunnistusjärjeslmän tietokantaan.

Suostumus plagioinnintunnistukseen (Urkund)

Olen lukenut Urkund-sopimuksen (https://libguides.oulu.fi/opinnaytteet/urkund) ja

◉ antanut luvan opinnäytteeni lähettämiseen analysoitavaksi ja tallennettavaksi Urkund-järjestelmään.

○ en ole antanut lupaa opinnäytteeni lähettämiseen analysoitavaksi ja tallennettavaksi Urkund-järjestelmään.

Oulun yliopiston vastuut

Oulun yliopisto huolehtii opinnäytetyön rekisteröimisestä kirjastoluetteloihin ja tarjoaa pääsyn opinnäytetyöhön tekijän tekemien valintojen mukaan. Oulun yliopisto julkaisee tekijänoikeuden alaisen aineiston käyttöoikeuksiin liittyvän huomautuksen palvelun yhteydessä. Oulun yliopistolla on oikeus arkistoida opinnäytetyö tarkoituksenmukaisena pitämällään tavalla, ja sillä on lisäksi tarvittaessa oikeus muuttaa opinnäytetyön tallennusmuotoa pitkäaikaisen säilyttämisen varmistamiseksi.

Oulun yliopisto ei suorita tekijälle korvausta opinnäytetyön käytöstä. Oulun yliopisto ja tekijä eivät peri yleisöltä maksua tai korvausta opinnäytetyön verkkokäytöstä.

☑ Olen tutustunut yllä mainittuihin ehtoihin ja hyväksyn ne.

Opiskelijan nimi: Sami Nyberg

Tiedekunta ja tutkinto-ohjelma: Tietojenkäsittely ja tietoliikenne, Elektroniikka ja tietoliikennetekniikka

Opinnäytetyön otsikko (suomi/eng): Testilaitetta pyörittävän systeemin integroiminen FR2-testiympäristöön. / User equipment rotation system integration for Frequency Range 2 test environment.

Opinnäytetyön ohjaaja(t): Risto Paatelmaa

Opinnäytetyön tarkastaja(t): Pekka Kyösti ja Tuomo Hänninen

Opinnäytetyön hyväksyjä(t): Pekka Kyösti ja Tuomo Hänninen

Kurssikoodi: 521998S

Opinnäytetyön tyyppi (kandintyö/pro-gradu/DI-työ): DI-työ

Tutkinto-ohjelma: Elektroniikka ja tietoliikennetekniikka

Ala: Diplomi-insinööri (Tietoliikennetekniikka)

Tiedekunta: Tietojenkäsittely ja tietoliikenne

Hyväksymispäivämäärä: 5.11.2021

Allekirjoitus: Sami Nyberg