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NETWORK PLANNING OF 5G USING ASSET TOOL

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ABSTRACT

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According to various resources Finland is ranked among the top 20 nations having the fastest internet in the world. The average internet speed is above 16Mbps. This is all because of the fast growth in technology with generations like 5G coming in full swing along with other Gs which are already there. 5G has aspiring targets, which includes excessive channel bandwidth, very high data rates, mobility is high, ultra-low latency, energy efficiency is high, large cell ranges and seamless connection density to name a few. Therefore, to cater to the above requirements the most important thing is planning of the network.

This is where the thesis comes in the picture, which is to design a fool proof 5G network and its optimization with the help of the tool called Asset. Network planning is an iterative process. This tool is used to plot various coverage simulations, traffic, and capacity predictions. The focus is studying the working of the Massive MIMO antenna techniques so that we can understand the impact of MIMO antenna in a particular area, also regarding the capacity and traffic. Also, studying the beam forming and how it helps in increasing the capacity, data throughput and improves the signal quality. There are various test scenarios which will help understand the above.

Keywords: 5G, Network planning, Optimization, Asset tool, Telecom, Communication System and Networks, Generations, Beamforming, Massive MIMO, 5G NR, Simulations, Traffic and coverage, Capacity.

The originality of this thesis has been checked using the Turnitin Originality Check service.

PREFACE

SISU – Imagine no limits

The thesis became my playground of imagination which taught me patience and kept me worked up in these bleak times of COVID and lockdown. With the thesis I completed the first part of the journey away from home and can prove to myself that anything and everything can be achieved with SISU by your side.

Therefore, I would like to thank first and foremost my parents for having confidence in me even when I didn't have, for pushing me continuously to extend my limits.

Then, I would like to thank Prof. Taneli Riihonen for helping and guiding me throughout the thesis.

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Tampere, June 2022

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LIST OF SYMBOLS AND ABBREVIATIONS

AAS	Advance Antenna System
AAU	Active Array Unit
CSI	Channel State Information
CSIRS	Channel State Information Reference Signal
DCI	Downlink Control Information
eMBB	Enhanced Mobile Broadband
FR 1	Frequency Range 1
FDMIMO	Full Dimensional MIMO
gNB	Next Generation node B
ISD	Inter Site Distance
KPI	Key Performance Indicator
LTE	Long Term Evolution
MIMO	Multiple Input Multiple Output
mMTC	Massive Machine Type Communication
MAC	Medium Access Control
NSA	Non Standalone
OFDM	Orthogonal Frequency Division Multiplexing
PRACH	Physical Random Access Channel
PSS	Primary Synchronization Signal
PBCH	Physical Broadcast Channel
PBCH DMRS	Physical Broadcast Channel Demodulation Reference Signal
PUSCH	Physical Uplink Shared Channel
PCI	Physical Cell ID
PDSCH	Physical Downlink Shared Channel
PRB	Physical Resource Block
RACH	Random Access Channel
RF	Radio Frequency
RxSL	Received Signal Level
RxS	Received Sensitivity
RMa	Rural Macrocell
RRU	Remote Radio Unit
RRC	Radio Resource Control
RB	Resource Block
RE	Resource Element
SSB	Synchronization Signal Block
SA	Standalone
SS-RSRP	Synchronization Signal Reference Signal Received Power
SS-SINR	Synchronization Signal to Noise Interference Ratio
SRS	Sounding Reference Signal
SSS	Secondary Synchronization Signal
SUL	Supplementary Uplink
Uma	Urban Macrocell
URLLC	Ultra Reliable Low Latency Communication
UE	User Equipment
5G NR	Fifth generation New Radio
3GPP	3 rd Generation Partnership Project

INTRODUCTION

5G has taken the world by storm. Is it true? 5G is still in its nascent stages. People lucky to have the 5G connection on their phone are trying to Figure out the difference between 5G connection and 4G. So, the question is what is 5G? How different is it from 4G?

Companies are talking about the communication network, which is reliable and resilient. Wireless communication is increasing and becoming stronger and is supposed to be accessible anytime and anywhere. There are lots and lots of applications for example, digitization, which is said to cover smart cities, smart homes, smart education, smart industry and many more. Then there is robotization, artificial intelligence, automation healthcare and e health which includes virtual healthcare and telepresence. For all these applications to come true, there is a need to strong foundation and that is where 5G and other future Gs are expected to lead.

5G is the fifth generation in cellular networks. Below figure depicts the history of cellular networks from first generation to fifth generation.

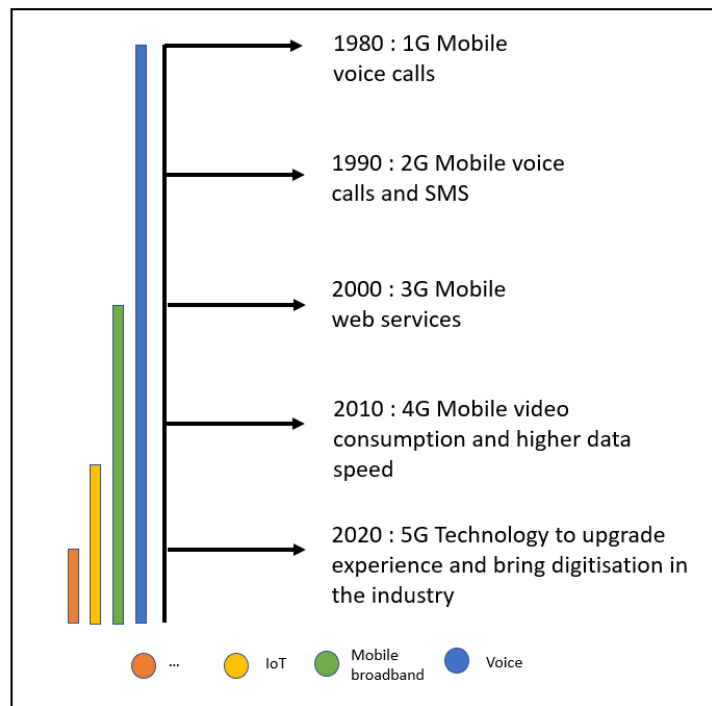


Figure 1.1 Evolution of cellular networks

The telephone industry had a huge impact on the telecommunication field, it changed the way we live, and work. There were many discoveries which were made and were interrelated just to name a few televisions, internet, computers, e-mail, online stock market. The timeline shows the 40-year advancement in the field of mobile technology. The cellular network has come a long way from the analog communication to the digital communication. There was SMSs and voice call earlier and now that has changed to high-speed data and video calls. Some of the very notifiable differences are the size of the mobile phones which has become smaller as the year passed. Surfing the net with the phone has become ubiquitous, downloading speed has increased, using social media with phone has also become very common. One can do everything and anything with the phone nowadays. 1G was first launched first by Nippon telegraph and Telephone in 1979 to the citizens of Tokyo and by 1984 it covered all over Japan. in 1983 it was launched in United States and Canada got the coverage in the mid-1980. 1G was very popular but also had its shortcomings for example, poor coverage, low sound quality. After 1G came 2G and was launched by Global System for Mobile Communication (GSM) in Finland in 1991. There was very visible progress which included improvement in sound quality, it also introduced text messages known as SMSs and multimedia messages. 2G downloading speed also improved to 0.2 Mbps during its lifetime. Then 3G came which was deployed by NTT DoCoMo in 2001 in Japan. It had four times better data transferring capabilities when compared to 2G with the downloading speed reaching to 2 Mbps on an average. With 3G there was increase in video streaming, chatting and live video chat. 4G is a huge improvement in the telecommunications industry which opened a lot many industries along with telecommunications industry. It has minimum speed of 12.5 Mbps, and many countries are still making use of it. It was first introduced in 2010 and since then has been growing exponentially with lots of applications. It has high quality video streaming, fast mobile web surfing, HD videos, online gaming, IoT applications to name a few. 5G is the latest development in the telecommunications industry. Few countries provide 5G network full-fledged whereas other developing countries are still in deployment of the technology. 4G had reached the saturation of providing the high-speed data transferring and there was need to for a faster network which led to the development of 5G. 5G has very low latency and improved bandwidth size. Low latency leads to higher download and upload speed. But all these technologies require deployment of the antenna and planning of the network. Therefore, this thesis is exactly what makes the technology a hit, that is studying the planning process of the telecommunications technology.

1.1 Motivation

It is very interesting to be working on a technology which is in its starting phase and 5G is in its starting phase. There are many things which are important to plan a network successfully. The below diagram is the one approach to it.

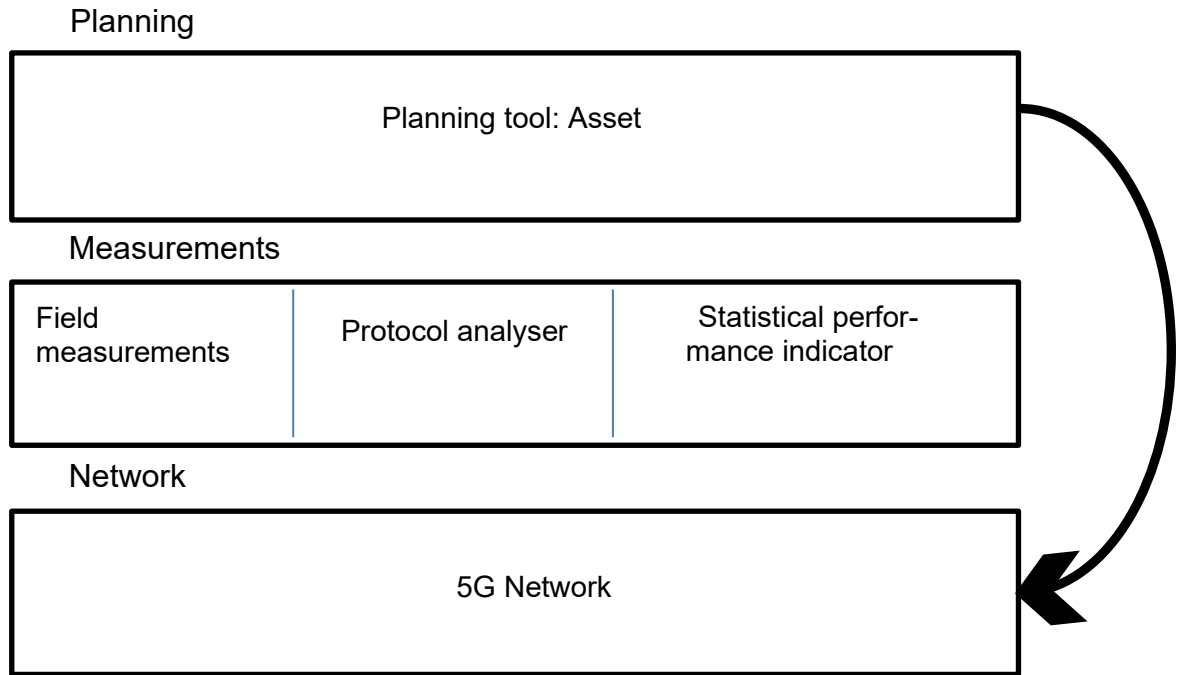


Figure 1.2 Planning of the network

From the telecom engineer who is in the planning and optimization field, there are steps which will lead you to plan the network effectively. In this thesis we are doing the coverage and capacity planning of the network selected. There are two dummy sites which are being used and are in the Helsinki region. So first important point is selection of the area for the installation of the base station. There is need to cover all the area and the increasing customer requirements as there is increasing user demands and is needed to provide satisfactory services, but deciding which area needs to be planned first. The regions can be divided into hotspot region, urban region, sub-urban, there is industrial region and village region, forest region and regions which are less populated but required for a ubiquitous coverage. 5G link budget is calculated for the designed network. This tells the total gain and loss in the network at the receiver. It is also very useful to decide which frequency band we are designing the network for. The parameters are also selected for a good coverage for example power control, noise interference, transition power, resource block allocation, user throughput, control channels, bearers and root sequence indicator planning to name a few. These parameters are set in the

RF planning tool to observe the working of the network with the defined parameters. After the values are being set in the RF planning tool the simulations are performed and the working of the planned network is seen. If the results are not quite satisfactory then again, the changes are made, and this can be done till we get the desired results from the planned network.

These are the planning part of the network. After the planning part there is measurement part of the network. This is done by installation of the designed network which was planned above or if the network is already planned then after some changes made for example in the antenna equipment. For the measurement part there is drive route which is prepared and the whole setup is prepared on the different needs for measurement. This is whether it is voice setup, data setup or both and for which technology. This setup is prepared, and the drive is carried out. Based on the setup the key performance indicators KPIs are being monitored. After the completion of the drive the results are checked of the planned network. Finally, the optimization of the network is done if the results obtained are not according to the planned network. These are the roughly stated out outline which are required for the successful planning of the network.

1.2 Research Questions

Based on the introduction and the motivation, there are some questions which are needed to be answered in this thesis. The questions can be about the planning, that is how accurately the planning of a network in a tool is mirrored in the field. The theoretical and the practical situations are always different. In the tool how the beam forming patterns are visible in the massive MIMO antenna? Studying the limitations of the 3.5 GHz, how is it affecting the field measurements?

1.3 Objectives

The main idea of this thesis is to learn the 5G planning simulations on the tool Asset. The objectives are defined as follows: The objective of this thesis is to make myself aware of the planning process of a network which in this case is 5G. The planning process was achieved mainly on the tool with two sites which were not put on air but was just for experimentation purposes. Through this process the coverage, signal quality the traffic simulations were done. The result of the two sites were impressive as the throughput looked enhanced by using the beam forming and the MIMO configurations.

Massive MIMO affects the user throughput significantly if we increase the number of antenna elements. It also provides high capacity and good performance for cell edge users. Beam forming is a technique which is used in Massive MIMO antennae. In beam forming the signal beam follows the device or the user, which is very similar to the way the people search something in the dark with the torch light on. In beamforming the device can be mobile or stationary. The massive MIMO antenna with more antenna elements leads to narrow beam and more concentrated energy.

1.4 Thesis structure

The thesis includes a total of 5 chapters. The first is the introduction which includes the motivation and objective behind the thesis.

Chapter 2 will tell us about the theoretical background of the 5G cellular network, different terms and various technologies which are used in 5G.

Chapter 3 concentrates on the planning part of the 5G network for example, link budget and various parameters.

Chapter 4 is all about tools, what are the various tools used in the market? Why are they required and what is its market standing?

Chapter 5 is about the simulations and results of the test scenarios.

Then there is in the end the conclusion.

2. 5G FUNDAMENTALS

There are in all five generations of cellular network in the last four decades. The one which is being in use is 4G and the one which is still in the research phase is the fifth generation. 5G is said to be the game changer. The design targets of 5G include high channel bandwidth, ultralow latency, high energy efficiency and extreme connection density. [33]5G is designed to achieve scalability of about 1000 billion devices, latency less than 1 ms, reliability to be greater or equal to 99.99999%, maximum throughput should be above 10 Gbps, mobility should be greater than equal to 500 km/hr and last but not the least locationing accuracy to be less than 1 m.

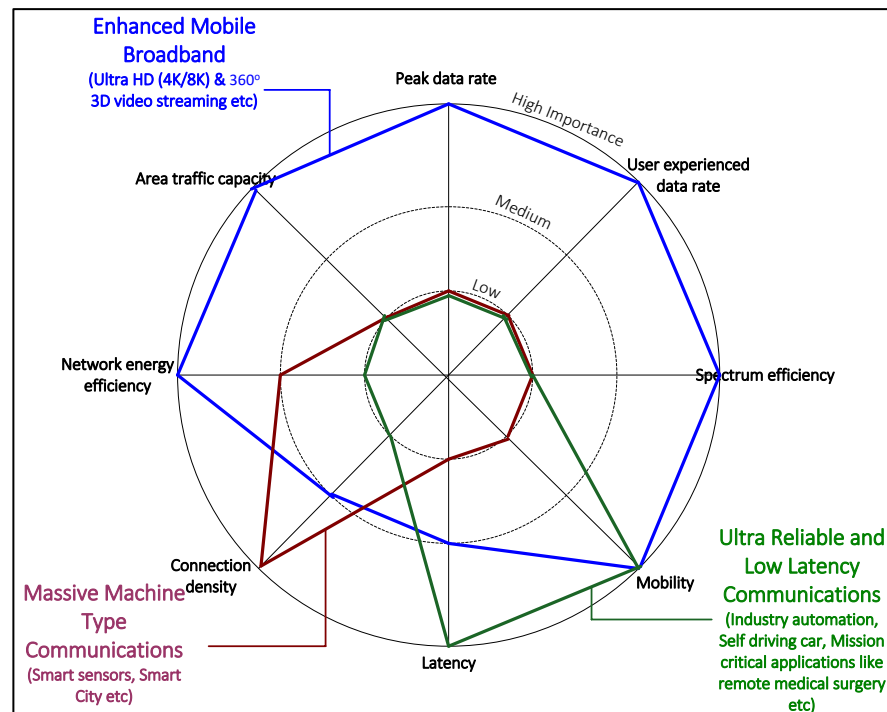


Figure 2.1 5G application wheel [33]

The above figure explains the importance of key features of the fifth generation in different usage scenarios. The technologies before 5G which are 2G, 3G and 4G support different set of use cases which is offering mobile data, be able to make voice and video calls and text messages services. So, these are the basic use cases of the technologies. If the customer wants higher data rate, that can also be achieved by using carrier aggregation where two or more frequency blocks can be assigned to one user. Therefore, for 5G there is requirement of new and advanced use cases in which many devices can be added together, and these use cases are namely eMBB which is enhanced mobile broadband, URLLC which is ultrareliable and low latency communication and mMTC

defined as massive machine type communication, they cover wide range of applications. eMBB demands peak data rate spectrum efficiency, there is requirement of high mobility, network energy efficiency, area traffic capacity and user experienced data rate. URLLC demands high mobility and low latency whereas mMTC requires very high connection density. One example of URLLC is self-driving vehicle in which the connection between the vehicle and the network requires real time communication with the network which means that latency must be very small. mMTC is part of the 3GPP Release 13/14 low power wide area technologies, which also includes NB-IoT. mMTC is a use case for the mass development of the IoT technology and devices. mMTC examples include home automation, sensors, and actuators to name a few.

The radio frequency in which 5G operates is also being used in smartphone, Wi-Fi networks and satellite communications, but a lot more technological advancements are done in it. With 5G network it is possible to download a full HD movie in seconds in mobile phones anywhere and everywhere, even in a crowded place, where the users are more. 5G is basically about connecting things anywhere and everywhere – constantly, without having any obstruction so that people can enjoy things in real time and also understand things in real time.

2.1 5G spectrum

As the technology increases so does the need to provide a wide range of applications ranging from extremes in coverage and capacity of 5G spectrum increases and is divided into three frequency ranges, low, medium, and high bands.

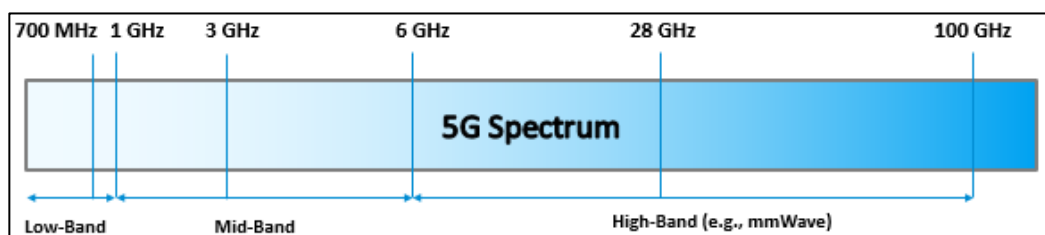


Figure 2.2 5G spectrum division [33]

Low band is the frequency ranges from 700 MHz to 1 GHz falls under this band. It is for deep indoor propagation and wide coverage. Then comes the mid band which is the frequency ranges from 1 GHz to 6 GHz falls under this band. This is for broadband services having ubiquitous footprint. The last one can be divided into high band which is the frequency ranges from 6 GHz to 100 GHz falls under this band. This is fit for eMBB applications and fixed wireless access services.

There are other frequency terms which are also used in 5G. Such as cmwave frequency and this is 330 GHz. The coverage is several hundreds of meters to kilometers and provides large throughput, macro coverage and support for high mobility. Another one is mmwave frequency which is 30 to 300 GHz. Since the frequency is high the wavelength is small and thus the coverage is tens of meters to 100 meters, but it provides high throughput which is only for the local area.

According to the 3GPP Release 15, the 5G frequencies are divided into two frequency ranges:

- Frequency range 1 (FR1) – Frequency range 1 are the ones which includes frequency ranges which are already present and the new bands below 6GHz.
- Frequency range 2 (FR2) – This consists of new bands from 24.2552.6 GHz.

The operating bands have also been defined by the 3GPP which corresponds to different frequency ranges for downlink and uplink. The bandwidth and subcarrier spacing is decided based on the range of the frequencies in which category it falls. The maximum bandwidth below 6 GHz is 100 MHz whereas in millimeter wave the range of the maximum bandwidth is 400 MHz. 5G has flexible scalability. There are some sub carriers spacing for example, 15 and 30 KHz which is used only below 6 GHz, and other which is 120 KHz is used only in millimeter wave range. The 60 KHz subcarrier spacing can be used in both below 6 GHz and millimeter wave range.

2.2 5G waveforms, numerology, and frame structure

Scalability	5G has scalable OFDM technology. Sub carrier spacing of 15, 30, 60, 120 and 240 KHz are available for varied deployments and applications.
Low latency	It has flexible slot structure.
Reliability	There is advanced channel coding. There are low density parity check codes for high reliability.
Beam forming	Massive MIMO and beam forming with more than 128 active antenna arrays for high-capacity gains

Figure 2.3 5G NR Key components

5G NR makes use of CPOFDM for DL and UL. In UL it also makes use of DFTs OFDM. OFDM is defined as orthogonal frequency division multiplexing. It is a technology where a wide frequency band is split into smaller frequencies and carries data onto each

of these subcarriers. The split frequency is called as subcarrier. This is called as frequency division because of the transmission of the data on each of the subcarriers and is done simultaneously. This is one kind of multiplexing. The OFDM works in a way that the band is divided into multiple sub carriers in such a way that in the frequency domain each sampling point which is there it has a correspondence of one carrier having a non-zero value and the rest of the sub carriers have zero value at sampling point. This is known as orthogonal which is defined as multiple subcarriers coexisting together but are all independent and does not influence each other. This way OFDM utilizes the given frequency wisely. But for orthogonality to exist there is need to maintain the space between the sub carriers. In time domain there are two signals, and the situation is ideal. But if the first symbol in the signal got delayed a little bit, then the ending part of the first symbol will overlap with the following symbol time and interference the next symbol. This kind of interference is called as ISI inter symbol interference. To resolve this issue there is need to add the gap between the symbols so that there won't be any interference with the next symbol even when there is a delay in the symbol. In this gap there is copied part of a signal from the end and paste it in the gap. This copied portion pretended at the beginning is called as cyclic prefix CP. The main purpose of cyclic prefix is reduce ISI. The CP thus acts as a guard which protects against the interference from previously transmitted symbols.

CPOFDM [36] is called as cyclic prefix orthogonal frequency division multiplexing. In CPOFDM there is variable subcarrier spacing termed as numerology. This means it can make use of 15 kHz, 30 kHz, 60 kHz and 120 kHz. When there is a change in the sub-carrier spacing there is also change in the cyclic prefix duration per symbol. CPOFDM makes use of the (de)modulation implementation among all the multicarrier waveforms. It employs a rectangular pulse shape, which is to combat inter symbol interference in a multipath channel. The CP refers to the cyclic extension of an OFDM symbol. If the CP is chosen to be greater than the delay spread of the channel, than the received OFDM signal does not suffer from any ISI. In practice, CPOFDM modulator is implemented using computationally efficient fast Fourier transform (FFT).

DFTs OFDM is known as direct Fourier transform spread OFDM and is a SC single carrier which is like a transmission scheme. If it is combined with OFDM it leads to significant flexibility for a mobile communication system like 5G. This is described as SCFDMA. SCFDMA's transmission processes is very similar to OFDMA. For every user, the sequence of bits which are transmitted are mapped to a complex constellation of symbols which are for example BPSK, QPSK. After the mapping process transmitters i.e. users are provided with different Fourier coefficients. This assignment is than performed in mapping and demapping blocks. The receiver side to receive the user signal

consists of many blocks which are one demapping block, one detection block and one IDFT block. The guard intervals which are known as CP are introduced between the blocks of symbols just like in OFDM, for the sole purpose of eliminating the inter symbol interference from time spreading.

Scalable OFDM numerology has been introduced in 5G NR to support diverse spectrum bands, which means it has scalable subcarrier spacing along with the cyclic prefix which is either normal or extended.[31]

Table 2.1 5G 38.211 subcarrier spacing and numerology table

μ	$\Delta f = 2^u \cdot 15$ [kHz]	Cyclic prefix
0	15	Normal
1	30	Normal
2	60	Normal, Extended
3	120	Normal
4	240	Normal

Each numerology is mentioned as “u” which can be seen from the table above. Sub carrier spacing is provided in the second column with the formula in which scaling is done by the power of 2 and keeping “u=0” [1] and hence ranges from 15, 30 to 240 kHz. The multiple numerology means the radio frame structure will be different. But the length of one radio frame and subframe remains the same i.e. 10 ms and 1 ms respectively.

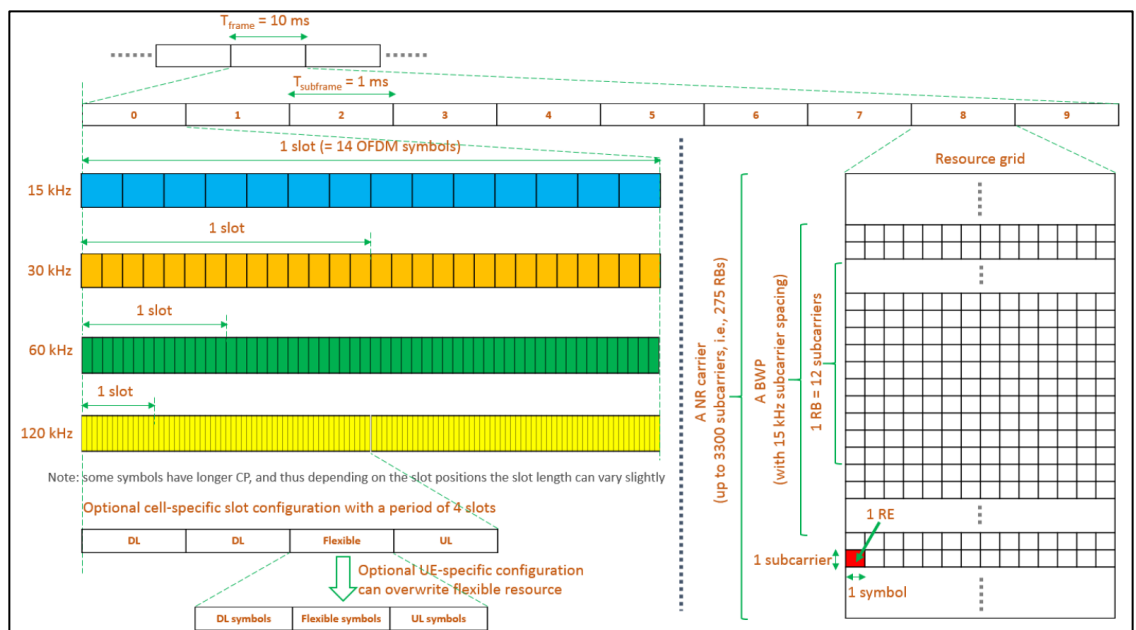


Figure 2.4 5G frame structure [1]

From the above Figure for every sub carrier spacing, there are different number of slots which are present within one sub frame. For example, for numerology 0 there is only one slot which means there are only 10 slots in the radio frame. [14] The OFDM symbols present are 14 within 1 slot and the subcarrier spacing is 15 kHz. The resource grid of 5G NR is like LTE, but the difference is the physical dimensions which are sub-carrier spacing, number of OFDM symbols within a radio frame is different or depends on the numerology used. [3]

The waveform as OFDM is defined with cyclic prefix in 5G NR. There is decrease in the guard band for the waveform which in turn helps in assigning much larger number of resources within the carrier bandwidth, for example, 106 PRBs in 20 MHz instead of 100 PRBs in LTE.

2.3 Massive MIMO

Massive multiple input multiple output (MIMO) is defined as an antenna array which is using massive amount of antenna. Now how many antenna elements make a massive MIMO depends on how the receiver algorithm or equalizer is designed. The smallest is 2×2 which is used in the LTE system.

The name massive MIMO because 5G uses high frequencies for example, mmWave signals. High frequency meaning small wavelength and smaller single antenna, therefore smaller aperture (the area for receiving energy). To overcome this on the receiver side we need large number of antennae on the transmitter side. This can also be achieved by increasing receiver or transmitter antenna gain. The gains can be increased by design, but another way is to increase the number of antennae. Therefore, exactly there is need of massive MIMO. It is also known as largescale MIMO (LS MIMO). There are various advantages of massive MIMO which are, the capacity increases by 10 times and radiated energy efficiency increases in the order of 100. When building massive MIMO, it is inexpensive and there is requirement of low power consumption. Massive MIMO helps in the reduction of latency. It also provides good coverage. There is also good penetration of RF beams which in turn leads to improvement of SINR and indoor coverage. Massive MIMO helps in reducing severe fading of the mmWave signals, it also provides wireless backhaul and reduces the interference in dense networks.

In massive MIMO the energy which is transferred by the antenna array focuses on very narrow area, which means very concentrated beams. This leads to the concept of beam forming and beam steering.

Massive MIMO relies on spatial multiplexing. The base station is equipped with channel state information in both uplink and downlink side and spatial multiplexing depends

on this. Signal pilots are sent in the uplink by the terminal. [27] The pilot helps in determining channel estimate of each terminal. Pilot waveforms are sent to the terminals by the base stations, then the terminal estimates the channel, quantize it and feedback it to base station. There are many slots required in Massive MIMO. Number of base station antennas increases the number of channel estimates and increases for each terminal which in term needs hundred times more uplink slots to feedback channel responses to the base station. [17] Massive MIMO technology depends on the phase coherent signals from all antennas at the base station.

The capacity in massive MIMO can be increased by spatial multiplexing technique. The increase in number of antennas improves the radiated energy efficient, and this leads to the concentration of energy in the small regions in the space. The beam of the massive MIMO work in such a way that the emitted rays from the antenna towards the UE will be added constructively at the intended terminal's location and destructively elsewhere. [28] Zero forcing is used between the terminals to cancel the interference.

Massive MIMO makes use of inexpensive amplifiers with respect to expensive amplifiers. Thus, this is the one advantage of massive MIMO systems which can be put together with the help of low power and less costly components.

2.3.1 FD MIMO

FD MIMO stands for full dimension MIMO. Full dimension MIMO antenna means the system which forms the beam in both horizontal and vertical direction so that it can cover anywhere in 3D space. FD MIMO uses active antenna system (AAS). Active antenna systems allow huge number of antenna elements which will be brought together with feasible base stations form factors. There are three different features to FD MIMO. [28] Firstly, there are certain amount of antenna which are supported within BS form factor has increased and this is because the structure of the antenna arrays is 2D planar structure. Secondly, the traditional azimuth dimensions can be obtained by the 2D arrangement of active antenna elements. Thirdly, the implementation of FDMIMO architecture follows the hybrid digital analog implementation where the multiuser MIMO precoding stage is being implemented in the basement and there is elevation beamforming which is done in the analog domain.

The AAS system in FDMIMO is required to change the beam concentration in one direction and the radiation pattern which is being directed in a particular defined area. [37] This is done by amplitude and phase shift which is applied to each antenna element for the beamforming to work and is controlled by the power amplifier which is directly connected to the antenna element. The transceivers in a 2D array are arranged and

mapped to a group of antenna elements. These antenna elements are arranged in vertical direction and this provides the capability to for adaptive electronic beamforming to the elevation plane along with the conventional azimuth plane. This leads to electrical downtilt feature. This feature in AAS system helps in forming the vertical radiation pattern. This 3D modelling is known as elevation beamforming. The elevation beamforming provides more directed beams to large number of users and thus helps in increasing throughput and coverage.

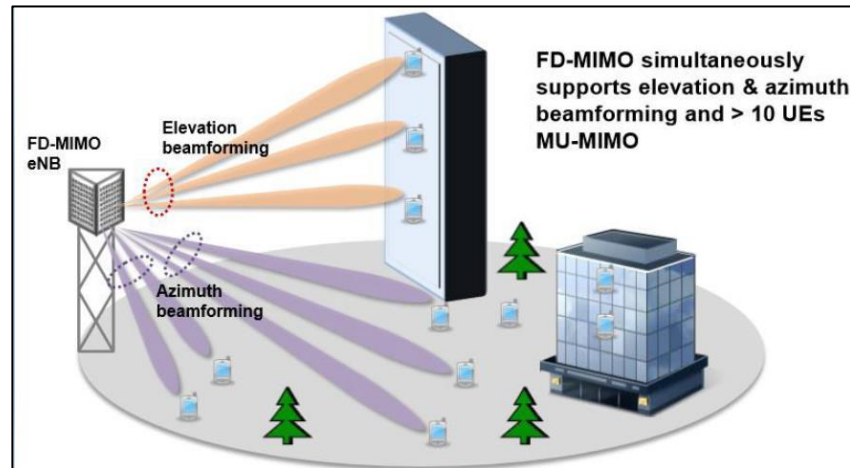


Figure 2.5 FD MIMO [33]

FD MIMO is a rectangular array. It can be formed of any rectangular matrix. It supports antenna arrays with up to 32 elements for less than 6 GHz frequency. In this spatial resolution increases as number of eNB antennae. There is narrow beam transmission with little MU interference. The very important question which arises is how to model antenna beam pattern? In 3GPP TR 36.873, there is given the basic mathematical model which tells the direction and shape of the beam which will be coming from the antenna system.

2.4 Beamforming

Beamforming simply put means forming of beams, which is basically a method to form the antenna radiation pattern, as shown in the Figure 2.8. Beamforming is required to provide the signal strength of the radiation pattern in the direction of the UE where it will be strongest, and in other places it will be weak. One more way of forming the beam, different from one mentioned above and is using the property of interference of the multiple waves. When there is in phase multiple wave interference the amplitude of the interfered wave gets bigger and when there is out of phase multiple wave interference the amplitude of the interfered waves cancels each other. This way constructive interference and destructive interference takes place. Therefore, when there is constructive interference, it forms the beam to be pointed at a specific direction. The beam can be formed

by multiple array antennae. The antennae can be aligned in many ways, but the simplest way is to align the antennae along the line to form the beam. The greater number of antennae elements leads to sharper beam. Multiple antennas are used to control the direction of the beam wave by appropriately weighting the magnitude and phase of individual antenna signals in array of various antennas.

Initial access meaning a sequence of process between UE and gNB so that UE can acquire uplink synchronization and obtain specified ID for the radio access communication. This process which is the initial access is known as RACH process which is Random Access Channel. First message from UE to gNB when the power is on. It's not complete random, it depends on timing, frequency location and possible identification. The main purpose of RACH is achieved UL synchronization between UE and gNB. The next is obtain the resource for message 3 for example RRC connection request. RACH is required for beamforming and beam management. Physical random access channel sequences are Zadoff Chu based sequence. There are two different preamble lengths long sequence and short sequence. Long sequence is $L=839$. This is for < 6 GHz and sub carrier spacing and bandwidth is 1.25 kHz and 5 kHz. Short sequence is $L=139$ and this is intended for > 6 GHz which is basically for beam sweeping. This can be used in both below and above 6 GHz. The PRACH sequence is detected by the scheduler implementation which makes sufficient space depending on the cell size. RACH resources are based on RACH slots repeated with RACH configuration period, the RACH periodicity ranges from 10 ms to 160 ms. RACH are categorised into two parts contention based and non-contention based. Contention based RACH procedure is as follows, UE to network there is RACH preamble sent which consists to RARNTI and L2/L3 messages. Then the network sends random access response which is timing advance and T_CRNTI and UL grants for L2/L3 messages to the UE. The UE then responds to the network via L2/L3 messages and asks for early contention resolution. The contention free procedure is defined when network sends RACH preamble assignment to UE. The UE then responds with the L2/L3 messages. The last step is network sending the random-access response which includes timing advance and layer messages to UE.

Beamforming includes initial access or beam sweeping and beam management. The initial access procedure has the way by which the device initially finds the cell when it is in the coverage area. This means device is in idle state or inactive state and accesses the network. This procedure is done during the handover as well and in the connected state. In the connected state the procedure is to request the resources for UL transmission or to re-establish UL synchronisation.

In beam forming it is difficult to have multiple UEs in single transmission unless the UEs are located close to each other. For this there is need for managing the beams for

the multiple devices which are scattered in all the directions. This is known as beam management. Beam management is very important during two processes first is during the RACH process and second is during the after the call connection process. During the RACH process there is beam sweeping by gNB in which gNB sweeps beam by using different DL beam for each SSB. The beam selection by UE is it selects the best beam from gNB and then informs the system by using PRACH resource which is mapped to each DL beam. Now during the connected mode, the steps are transmission/reception beam selection and beam change. These procedures are all based on the CSI measurements.

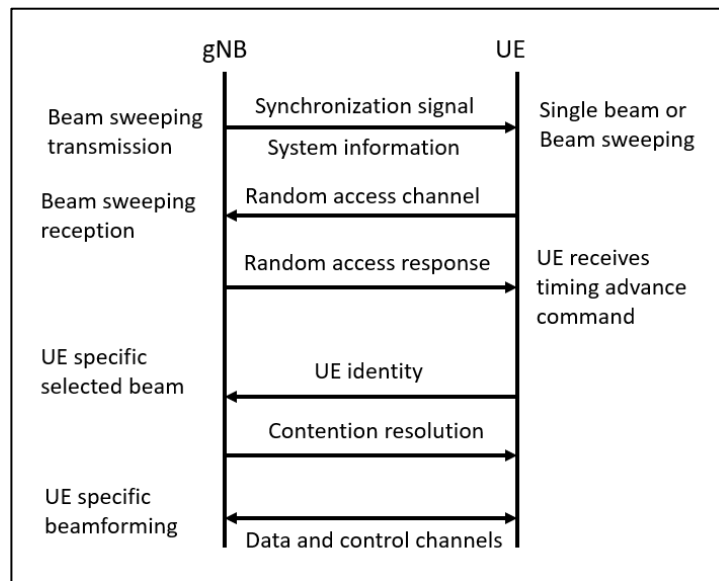


Figure 2.6 Beamforming method

The above Figure states the entire procedure of beam forming. The initial access procedure for beam forming is beam sweeping transmission, which is from gNB to UE. There is synchronization signal SS Block sent. System information is also sent which is the basic information for all UEs. It is cell coverage and UE wise coverage. RACH process takes place from UE to gNB and is called beam sweeping reception. There is open loop beamforming and closed loop beamforming. The beam can be formed by making use of the property of interference of multiple waves. There are "in phase" and "out of phase" interference. The "in phase" or constructive interference is when multiple waves interfere at "in phase" and the amplitude gets bigger. The opposite happens in the "out of phase" scenario, the amplitude cancels the interfered waves, and this is called as destructive interference. In constructive interference the beam that is formed is pointed in a particular direction. Beams are formed by using antenna array.

In the beam forming the main question which arises is where to point the beam? This can be divided into two parts, one when transmitting and other when receiving. When

transmitting case includes, the gNB or UE must transmit the signal in the direction that can reach the receiver with the best signal quality. This can be Figure out by gNB by constantly measuring the quality of the specific reference signal of various beams from UE. Then gNB decides the strongest signal quality. UE does the same but with various beams coming from gNB. The reference signals can be sometimes SSB, or it can also be CSIRS. When receiving which means that gNB or UE must tune their receivers in a way that they can receive the best signal quality from the transmitter. The reference signal for gNB while receiving the signal quality from UE is in the form of CSI report. The reference signal for UE is SRS signal quality.

Beam management [8] includes the following phases, which have been explained above. The phases are defined as beam sweeping, beam measurements, beam determination, beam reporting and finally beam failure recovery. Beam sweeping works on a operation of covering a spatial area with beams transmitted and or received during a time interval in a predetermined way. Beam sweeping is defined periodically for downlink and covers cell search and detection. It also helps in MIB acquisition and beam detection and measurements. Beam measurements are for transmitters or UEs to measure characteristics of received beamformed signals. Beam determination is for transmitters or UEs to select its own Tx/Rx beams. Beam reporting is for UE to report information of beamformed signals to the gNB which is based on beam management.

2.5 5G NR SS Block

SSB is defined as synchronisation signal block. Synchronisation/PBCH block and the components are:

Synchronisation signal – PSS (Primary synchronisation signal), SSS (Secondary synchronisation signal)

PSS which is defined as primary synchronisation signal. It is a specific physical layer signal that is used for radio frame synchronization. It is mapped to 127 active sub carriers around the centre of SSB. It is used for downlink frame synchronization, one of the most important points is, it defines the physical cell ID. It is derived from 127 m sequence which is MLS maximum length sequence. The m sequence which is used to drive the sequence comes from LFSR sequence (linear feedback shift register). LFSR works as a shift register in which if one or two inputs is linearly combined and then the feedback is sent to the input value. Therefore, the output is basically repeating itself. The speciality of m sequence is it provides the longest nonrepeating sequence for every number.

SSS is defined as secondary synchronisation signal. It is very similar to PSS, but it is mapped to 127 active sub carriers around the lower end of the system bandwidth ie.

subcarrier 80 to 206. NR SSS does not vary with the subframe at which it is transmitted. The centre frequency of PSS/SSS is aligned with the centre frequency of PBCH. There are three different PSS 0,1 and 2 and 336 SSS sequence which gives of total 1008 physical layer cell id. The physical cell id is given by the formula:

$$N_{ID}^{cell} = 3N_{ID}^1 + N_{ID}^2,$$

where, N_{ID}^2 is PSS carrying the physical layer identity $\{0,1,2\}$

PSS sequence with generator polynomial $g(x) = x^7 + x^4 + 1$ and 3 cyclic shifts (0,43,86) are used to generate the three PSS signals.

SSS carries the physical cell identity group which is $N_{ID}^1 = \{0,1,\dots,335\}$ The generator model for SSS is $g_0(x) = x^7 + x^4 + 1$ and $g_1(x) = x^7 + x + 1$

PBCH – PBCH DMRS and PBCH data PBCH makes use of the same antenna port as PSS and SSS in the SS block. The single antenna port transmission scheme is used which is called the precoder cycling. The channel coding scheme used by PBCH is polar code. PBCH is used to transmit minimum system information. The remaining minimum system information is transmitted through physical downlink shared channel (PDSCH).

5G has varying subcarrier spacing and thus the time domain and frequency domain position are different.

Beam sweeping is defined by the SSB, which is implemented by changing beam direction for each SSB transmission. There are many SSBs which are transmitted with certain level, and the SSBs can be identified by SSB index which is the unique number. It is transmitted in a specific beam in a certain direction. There are multiple UEs which are placed randomly. UE then measures the signal strength of every SSB for a period. After keep on measuring the signal, the UE selects the strongest signal strength SSB and this is the one it latches to.

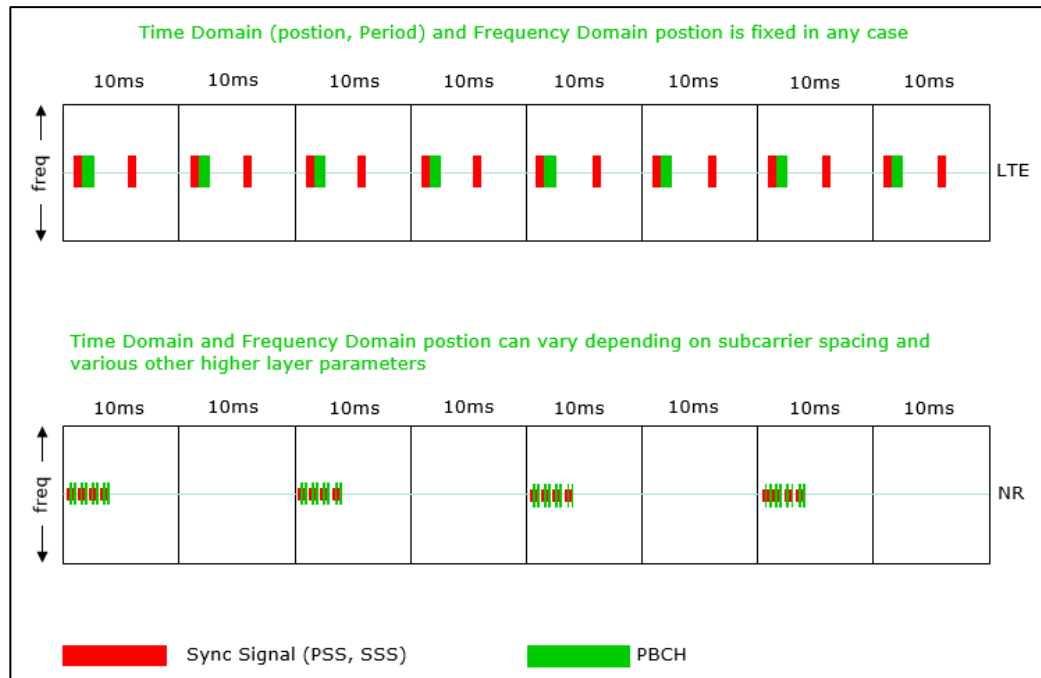


Figure 2.7 SSB 4G and 5G [14]

The number of different beams depends on the sub carrier spacing and the numerology. SSB time index is provided in two parts i.e. implicit part encoded by scrambling and explicit part in the PBCH payload. There are 8 different scrambling patterns which are used, and they are mapped to eight different SS block time indices. This is sufficient for < 6GHz (FR1) operation. The minimum component for carrier bandwidth can be defined by the PSS, SSS and PBCH transmission (SSB). If it is < 6 GHz i.e. falls in FR1 and the subcarrier spacing is 15 kHz then the bandwidth is 5 MHz and if the subcarrier spacing is 30 kHz it is 10 MHz. For > 6 GHz i.e. FR2 if the subcarrier spacing is 120 kHz or 240 kHz the bandwidth is 50 MHz or 100 MHz respectively.

3. 5G NETWORK PLANNING

Network planning is an iterative process. But why network planning is required? There is constant increase in the communication technology and along with it there is constant increase in the radio network, because of which the task of network planning and its optimization is required. The radio resource is limited whereas the number of subscribers is increasing and to cater that need there is increase in network operators which are operating within the limited frequency spectrum. Deployment of a network is also along with time is super expensive. Therefore, there is required the use of automated software and algorithm which can help in tackling those tasks.

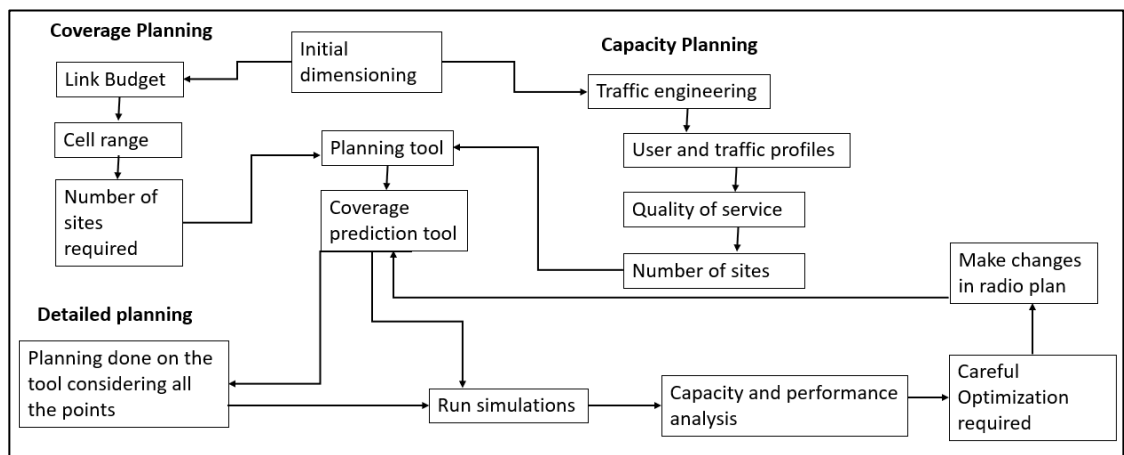


Figure 3.1 Total planning

The above figure is the depiction of overall planning. The whole designing is divided into three parts roughly, which are coverage planning, capacity planning and detailed planning. Coverage planning means till where a user equipment can get the signal uninterrupted. The requirement for this is link budget calculations, cell range calculations which is for how many kilometers or meters or miles the range should be. For the uninterrupted coverage number of site requirement calculations, initial dimensioning and these parameters are then fed to the planning tool. The capacity planning is the user throughput which is how good a user can use the mobile data. Capacity includes traffic, this also describes to how many users can be connected to a site. The quality of service also comes in the picture. The detailed planning phase is running the simulations on the RF planning tool, implementation and drive test measurements and optimization if required of the network.

The points which are to be considered while designing are many. They are antenna model which consists of the physical aspects for example height, azimuth, and tilts. The frequency on which it is going to operate. Bandwidth is one of the important parameters,

clutter, site location for example, in a hotspot, suburban area, rural or an industrial area. Checking the antenna configuration if it supports MIMO and till how much, 8T8R, 32T32R or 64T64R. Making calculations for the cell serving range and area by using link budget.

The RF planning also includes along with the abovementioned points the provision of the required capacity, along with the frequency what will be the optimum usage of the available frequency requirement, minimum number of sites which will be required, making sure the easy and smooth expansion of the network in future and of the coverage.

The planning process basically starts with the input from the customers. They put their requirements, characteristics, and constraints. Then it is done on the RF planning tool virtually. After which the planned system is implemented because the assumptions which were made during planning needs validation, and thus optimization is required. Therefore, the whole process is in the following steps which is capacity planning, coverage planning, parameter planning and last is optimization. For coverage the Link budget is very important.

3.1 5G Link budget

Link budget is defined as calculation from source to destination of the power loss and gain. There is input and output energy balance. As there are devices connected to each other. There is energy loss or power loss in some devices and in some devices, there is energy gain as signal flows through them.[19] This is from transmitter which goes through the communication mediums such as radio waves, cables, optical fibre, or waveguide to the receiver. The losses are attenuation which are caused because of antenna gains, feedline losses or there is amplification of the signal in the receiver or any repeaters through which the signal passes. This complete flow of energy calculation is called as link budget. By having link budget, we can understand radio channel status whether it is pass or fail and also cell radius. Link budget is important because it helps in ensuring whether the information which is received by the receiver is understood properly or not with an adequate amount of signal to noise ratio. In its simplest form the link budget can be given as:

$$\text{Received power (dBm)} = \text{transmitted power (dBm)} + \text{gains (dB)} - \text{losses (dB)}$$

3.1.15Glinkbudget

5G link budget is used for designing and dimensioning of the network. Technically link budget is defined as the calculation of total gain and loss in the given system to conclude the received signal level (RxSL) at the receiver. The received signal level is compared to the receiver sensitivity (RxS) to check if the channel status is failing or passing. For example, if RxSL calculated is 77 dBm and RxS is 93 link status is pass. There is UL

and DL link budget which is calculated separately. RxS depends on the thermal noise, NF and SINR. [13] SINR is an important factor in 5G, higher its values mean better modulation, path loss is lower and thus cell radius is smaller, but the disadvantage is greater number of 5G base stations are required. There are building losses or log normal fading losses which is also called shadowing, in car user losses, in building users or building walls as the signal must pass through it.

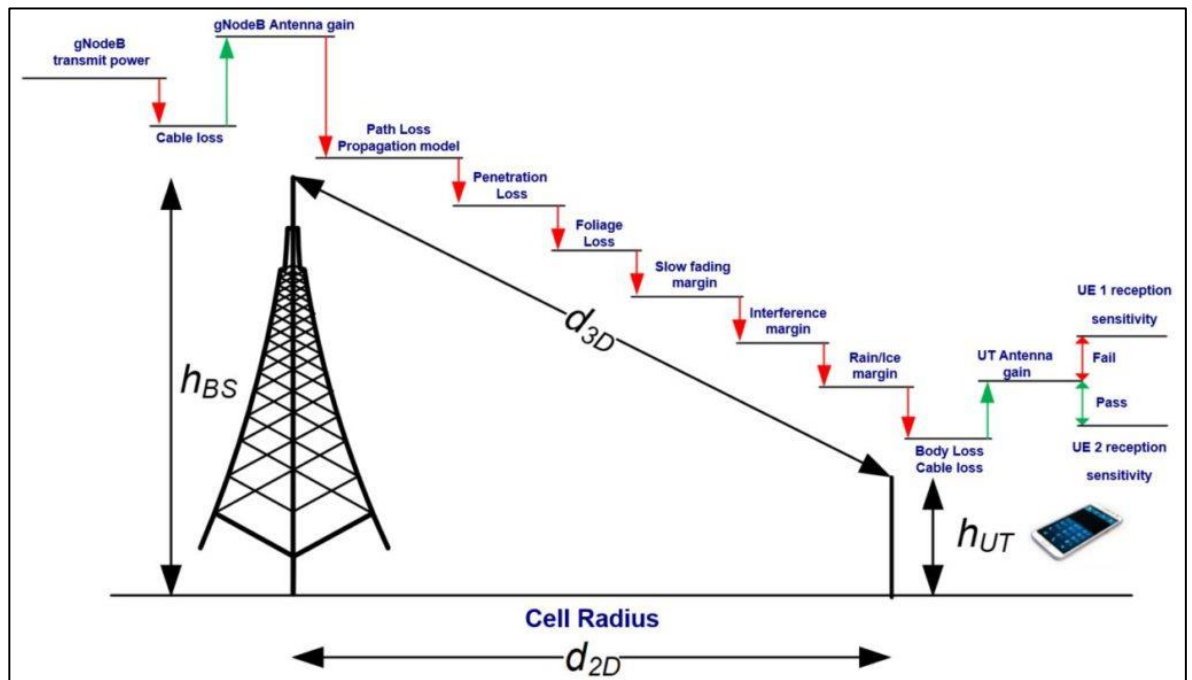


Figure 3.2 5G Link Budget [32]

The output of a link budget is many. They are, it gives information of the cell radius. How many base stations are required, so tells about their number. The capacity and throughput at the cell edge.

To calculate 5G link budget the parameters which should be known, are power, antenna gain and at what frequency it is going to operate. The cell edge throughput required, radio type whether it is massive MIMO unit or RRU, then the clutter, body losses, propagation model, bandwidth are some of the important parameters which are needed. The more the cell edge throughput (Mbps) the smaller the cell radius, if the clutter is urban. If it is rural then greater cell radius as there is less losses.

The major difference between 4G and 5G link budget is the path loss calculation. In 5G path loss are calculated using suitable propagation models because they give accurate path loss and real user received signal strength. The path loss models are defined in the 3GPP TR 38.901, and they are, rural macrocell (RMA) pathloss model, urban macrocell (UMa) pathloss model. There is statistical pathloss model which is mostly used by

vendors or operators. This is based on the real drive test measurements. The path loss formula helps us to calculate the distance or cell radius of gNB. These are helpful in calculating the gNB footprint when site planning is done. The path loss is given as:

$$\text{Path loss} = 28.0 + 22 * \log_{10} (d) + 20 \log_{10} (fc)$$

From the above formula it can be found that to calculate it there is requirement of “d” which is the distance between transmitter and receiver cell radius and also there is “fc” centre frequency. If the cell radius is maximum cell range the path loss will be maximum allowed path loss. Path loss leads to calculation of the received signal level which can be then compared to the receiver sensitivity. Receiver sensitivity depends on various factors for example, thermal noise power in dBm, noise Figure in dB, demodulation threshold SINR in dB. The most important factor in path loss calculation is the SINR and this means if the value of SINR value is higher which means better modulation the path loss is lower and therefore cell radius is smaller and thus a greater number of 5G base stations are required.

$$\begin{aligned} \text{Link Budget}_{\text{Signal level at Receiver}} = & \text{TransmitPower}_{\text{TX Bandwidth}} + \text{AntennaGain}_{\text{TX}} - \text{CableLoss}_{\text{TX}} + \\ & \text{AntennaGain}_{\text{RX}} - \text{CableLoss}_{\text{RX}} - \text{PathLoss}_{\text{propagationModel}} - \text{PenetrationLoss}_{\text{dB}} - \text{FoliageLoss}_{\text{dB}} - \\ & \text{BodyLoss}_{\text{dB}} - \text{InterferenceMargin}_{\text{dB}} - \text{RainIceMargin}_{\text{dB}} - \text{SlowFadingMargin}_{\text{dB}} - \\ & \text{PenetrationLoss}_{\text{indoor}} - \text{Attenuation}_{\text{indoor}} \end{aligned}$$

* $\text{TransmitPower}_{\text{TX Bandwidth}}$ – part of NodeB or UE TX Power, used for current data transmission.

Figure 3.3 5G Link Budget formula [32]

The difference between 4G and 5G link budget are for the feeder losses RRUs are used with external antenna feeder loss in 4G. In 5G AAUs are used without external antenna feeder loss and RRUs are used with external antenna feeder loss. In 4G there is a single antenna which is being associated with the single transmission and the gain is like that of the physical antenna. In 5G there is massive MIMO antenna array, which is associated with multiple transmissions, where one transmission corresponds to multiple physical antennae. Propagation model which is used for 4G link budget is COST231HATA. For 5G the propagation models are UMa/RMa model which are defined in 3GPP TR 36.873 and Umi model in 3GPP TR 38.901. The penetration loss is relatively low in 4G link budget and there is higher frequency band and penetration loss. There is rain attenuation, tree fading and body block loss in 5G link budget whereas they are not there in 4G link budget. The interference margin is large in 4G. The massive MIMO beam has interference suppression effect therefore interference is low for 5G. These are the differences which can be observed between 4G and 5G link budget.

The link budget helps in knowing the cell radius and due to which we can find the square area coverage of one base station. And thus, finding it for the entire region.

There is 5G coverage planning and 5G capacity planning which are explained in the coming sections. Link budget is part of the coverage planning.

3.2 5G Coverage Planning

The need for coverage planning arises from the need to provide the ubiquitous coverage, which means indoors and outdoors. There is need to locate the hotspots for example city centre, malls, residential area, industrial area, urban, suburban, and rural. The below picture is a simple way of putting the coverage planning. For coverage planning few requirements are site selection for base station, there is locating area and includes radio resource management requirements and there is frequency planning requirement as well.

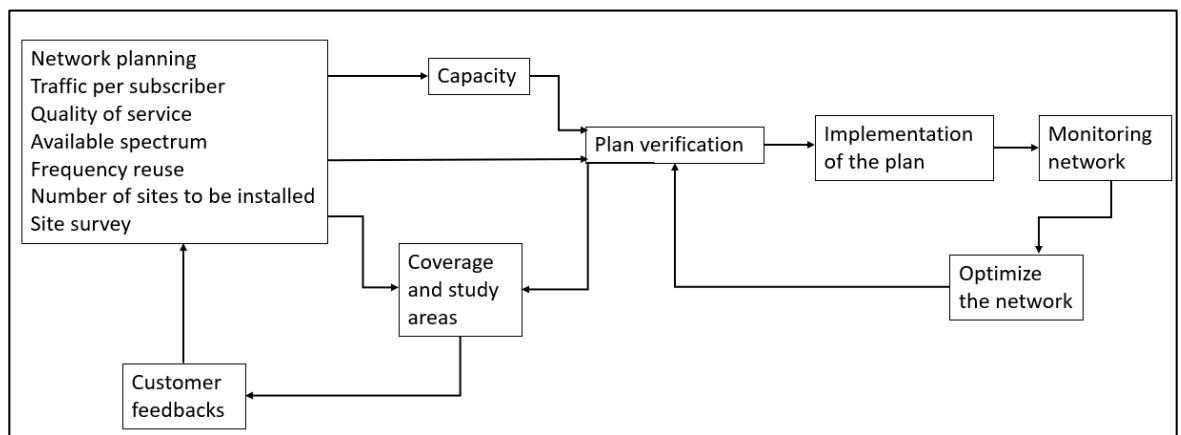


Figure 3.4 Coverage Planning

Base station planning is used to cater to the ever-increasing user demands and be able to provide good coverage and services. Number of base stations and where they should be placed are required for coverage and capacity planning. The base stations are in the areas where the good signal strength can be provided. There also needs to be considered signal to interference ratio when planning the sites. There is frequency assignment which should be considered as well, but initially it is when the network is planned for the first time, for example 2G network. In 2G because of the high site density and limited spectrum resources availability frequency was allocated carefully so that interference can be minimized. During the planning of the network in 2G for this problem the frequency hopping and dynamic channel location were used as a solution. Then there came frequency reuse factor which is used in 3G. In LTE and 5G the frequency reuse problem was resolved by designing the spectrum into large number of the sub carriers

which are orthogonal to each other. This is all part of the coverage planning and in coverage planning the target is calculate the coverage prediction for all the base stations, to tune a radio propagation model. Inputs required are the gains and the losses i.e. the link budget, frequency band, BTS location, antenna height and azimuth. Planning of the network, how much traffic a site can handle and also users and the quality of the service or the throughput, availability of the spectrum is also included in the coverage planning. There is site and plan verification which is done followed by the implementation of the plan, monitoring the planned network and optimization of the network which is a important part of the whole process.

The 5G architecture has two different modes, NSA, and SA mode [34]. NSA is Non standalone mode. In this mode the gNB is integrated with the already available LTE EPC. Therefore, when the gNB are installed, they are connected to the already available EPCs. NSA tends to the control signalling of 5G radio network to the 4G core. The second mode is known as SA mode which is Standalone mode. In this mode there is deployment of gNB with the available 5G core network, which is the counterpart for the EPC. SA connects to the 5G radio network directly to the 5G core network and the control signalling does not depend on 4G network at all. Therefore, there is coverage planning required for both modes. The Figure below shows the two modes.

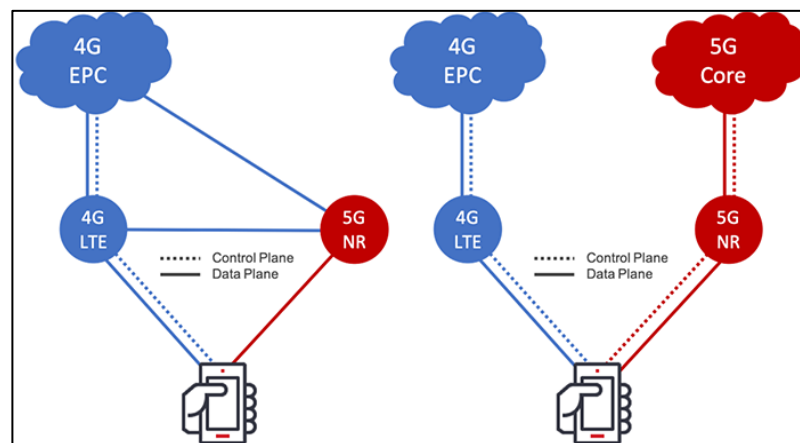


Figure 3.5 NSA and SA modes [34]

In 3GPP TR 21.915 both NSA and SA deployment factors are defined. In NSA only 4G services are supported, but it has capacity offered by 5G new radio. NSA is called as “E-UTRAN Dual connectivity” or “Architecture option 3”. In the NSA mode there are various novelties which are not present because NR will be implemented only where 4G/LTE network exist. [26] The various novelties are for example, network slicing, QoS treatments, flexibility in edge computing and the general extensibility of the 5G core. The advantage to NSA 5G is there is remarkable increase in the bandwidth capacity and

network throughput. Another advantage is there is flexibility in the function of the user plane provided by the gateways (SGW and PGW) of the EPC core. In SA architecture, there is use of virtual network functions which will help in the architecture even to the end users.

Link budget is calculated for the signal level at receiver. Initial planning parameters are which frequency band to use. 5G frequencies are a mixture of TDD and FDD and SUL which is supplementary uplink. The cell desired coverage is taken into consideration, as this will affect several factors of planning for example, interference, path loss and distribution of users during the simulations. There are two scenarios which are considered when this parameter is to be considered. The first one is FR1 if the frequency $f_c < 6$ GHz because in this the desired coverage will be considered for the wide beam gains of the sector. This is the scenario without beam forming. In case 2 FR2 if the frequency $f_c > 6$ GHz the desired coverage will be considered for the narrow beam gains of the beam forming functionality. This is with the beam forming. There is also needed to decide power control. This is important parameter for initial planning of the network. This is defined as the initial power level that the 5G gNB receiver needs to receive per resource block.

For 5G uplink planning there is need to consider UL power, UL noise and UL interference. UL noise is considered per resource block. The noise Figure generally to be considered is less i.e. around 2.3 dB. Noise Figure is the sign of the degradation of the signal to noise in a system which is caused due to noise generated or present in the system. If the noise Figure is less than the system performance is better and there is less signal to noise degradation. This is generally provided by the vendor RRU or AAU unit.

UL interference is calculated by using the SINR formula. The intercell interference depends on the cell coverage, network topology and inter site distance ISD. The intracell interference is also calculated, this depends on vendor proprietary scheduler capability, mMIMO AAU antenna elements and sub array structure. The sub array capabilities define the beam separation. The more the antenna elements the narrower the antenna beams, thus the better separation and less intracell interference.

For downlink planning also there is DL power, DL noise and DL interference which is required.

3.3 5G Capacity Planning

Capacity planning is defined as the maximum number of users which can fit in a network. In this, the target is to define the number of carriers or channels which are at each cell, also to divide the traffic channels between different technologies. The requirements are traffic amount, density, and distribution, which is the exact location of traffic hotspots.

The first is resource block allocation for downlink and uplink. Resource allocation defines the way in which the scheduler allocates resource blocks for each transmission. For NR there are three types of resource allocation block, they are: type 0, type 1 and dynamic switch. The resource block type is determined by the RRC layer message or the DCI format. For type 0 the consecutive RBs are grouped together in RBGs which is resource block groups and then there is allocation of PUSCH/PDSCH for multiple RBs. For type 1 there is resource allocation parameter which is defined by parameters like RB_Start, DCI, number of consecutive RBs within a specific bandwidth part. Dynamic switch is defined as whether to use type 0 or type 1 and this is determined by DCI at the time of each transmission.

There is also transport block size selection. Transport block is a packet of data which is passed between the MAC and physical layers. It is done in both the directions, upwards i.e., at receiver and downwards at the transmitter. It is mapped to PDSCH for the transfer across the air interface. 3GPP has defined the algorithm in the steps, step 1 is where UE defines the number of REs which are allocated for PDSCH within a PRB. Then there is estimate intermediate number of information bits. For the capacity planning there is user throughput defined. It is completely dependent on the vendor scheduler proprietary software also the vendor hardware performance. The user throughput is dependent on the drive test analysis and regression algorithm to obtain real network statistics, extracting RB throughput versus SINR. The services like QCI are also considered. After user throughput there is cell throughput defined as well.

Network planning is very important for any technology to succeed and follows various parameters. There is coverage, capacity, quality, cost efficient infrastructure and quality of service planning. This leads to minimum number of base stations sites, antenna height and other details which are considered as well.

4. NETWORK PLANNING TOOLS

Network planning is one of the important parts in the complete telecommunication process. To help the successful planning of the network there are many RF planning tools which are used. RF planning or radio frequency network planning is the process in which radio frequencies are allocated in a planned way to get maximum coverage.

4.1 Requirement of Planning tool

The study of the tool is important due to various reasons, some of which are listed. Proper planning of the network is required because mobile users are very demanding and change the service according to the best plan which they get. Planning tools and other data analytics helps to see these issues or customer experience for the operators to help them in better optimization solutions. RF planning tools provide the coverage analysis, traffic analysis through various simulations so that the existing network's coverage gaps and other shortcomings can be identified and resolved into the planning process and right from the start.[22] The real-world information can be obtained through drive tests and is known to be the best solution to build the rough network environment.

Planning tools use automation to simplify the rigorous process of network investigation, spectrum analysis, quality requirement parameters, RF path planning and allocation of RF resources in an optimum manner. [21] This helps in the reduction of the overall cost and hours spent on analysis. RF planning tool also helps with troubleshooting of the network. Path loss can be identified and addressed in ideal deployment scenarios. As the mobile generations are increasing a proper wireless network design tool is required to help plan the network efficiently. As the network moves from 3G to 4G to 5G the planning tools also upgrade and offers more options and advantages for the design and planning. The RF planning tools provide multitudes of benefits for network service providers.

4.2 Available RF planning tool

There is big list [20] of RF planning tool which are available in the market. Some of them can be named as Mentum Planet, Mentum CellPlanner, Forsk Atoll, ASSET, Celplan, Broadband Planner, WinProp, Vsoft Probe, EDX Wireless, TAP, Astrix, x – Wizard, Overture, siBwave, CRCCOVLAB, FUN.

The abovementioned tools are for network planning and designing. Along with the planning tool there is requirement of propagation engines, automation tools, microwave tools and drive test tools for the complete network planning package. The network technology for which they provide planning are GSM, WCDMA, LTE, 5G, Wi-Fi, WiMAX to name a few.

The tools help in achieving the best possible network performance, which will enhance the network capabilities. Every tool has some different configurations ranging from google earth visualisation features, studying the different propagation models for example, Okamura hata model, cost hata, Longley rice models to heat maps studying. These tools can also be called as measurement-based prediction tools as along with other functions they also help in predicting the radio coverage almost accurately of any type of wireless network.

4.3 Introduction to Asset

The tool which I have used for the network planning is Asset tool by Teoco. It is Teoco's market leading radio planning tool. [23] It provides RF coverage, capacity, cell parameter and neighbour planning for wireless and mobile cellular networks. It is a software product for planning of various multi technology wireless networks across GSM, UMTS, LTE, 5G. There are many benefits of this tool, and the key ones are described as advanced network modelling where it makes use of GEO, PM, CM and marketing inputs and also has multi height prediction. The Asset tool has extensive 5G capabilities which are 5G NR modelling involving complex antenna arrays. This tool also comes with highly automated features which can be used for site placements, PCI planning, RACH planning, neighbour planning, and network optimization.

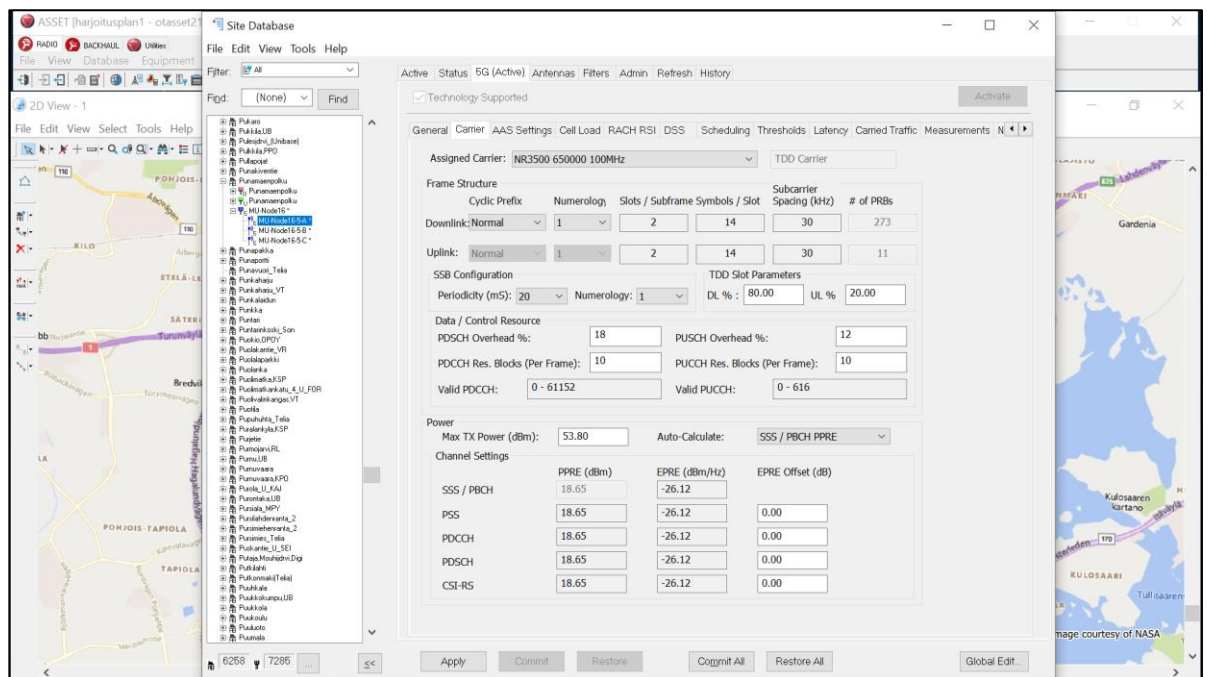


Figure 4.1 Asset working environment

All the RF planning tool which has been mentioned above have been upgraded with new features for all the upcoming technologies and so does Asset tool. With the latest version of Asset which is Asset V10.0 there are many new features added for 5G. The main features which have been focused are based on the planning requirement. For example, mmWave propagation and environment modelling, there is also beam switching antenna modelling, 5G data model (gNodeB and cells) and multi tech capacity simulation which means 2G/3G/4G/5G.

Asset radio includes network modelling, LTE/VoLTE planning, 5G planning, capacity analysis and geolocation support. Network modelling has 2G, 3G,4G and 5G modelling and also supports inter technology modelling. The coverage analysis is done using the Monte Carlo simulations. Geolocation provides the support of the geolocated traffic and performance maps which helps in planning.

5G advanced radio planning modelling has many new features too. They are beam switching, beamforming, carrier sharing with LTE, massive MIMO and 3D traffic modelling. In beam switching it can include up to 256 beams per antenna. FD MIMO is supported in Asset. It helps in selecting the best beam for each location according to the simulations.

Beamforming is based on 3GPP 38.901 based antenna modelling. RSRP and SINR improvement. Interference on gNodeB level or cluster level. Massive MIMO features Asset model to be based on the RF propagation path from gNodeB to UE.

Asset NR key features are NR frequency band, NR frame, NR carrier, NR gNodeB and NR cell.

NR frequency band feature has detailed implementation of 3GPP 38.104 requirements. There are predefined 3GPP NR bands, it also has TDD/FDD duplexing. There is capability to the end user to add new user defined bands. There is also 7.5KHz optional frequency offset for central carrier frequency.

NR frame supports 3GPP average UL and DL overhead based on user defined values. There is resource allocation for PDCCH and user for control traffic dimensioning. NR carrier supports NR frame, NR frequency band pre carrier. There is attenuation also defined which is based on various functions, capability to model interference between narrowband and wideband carriers. NR gNodeB has the carrier defined, carrier aggregation defined. NR cell is basically defining all the above mentioned 5G parameter design.

4.4 General parameters

Asset has different parameters which are required for the design of a network such as base station, cell meters according to the technology which is used for planning.

The antenna or the base station is defined by the geographical area where it should be placed. Transmitters means all the equipment which are used to generate the radio waves, for transmitting or receiving the data with the use of an antenna. For the site to be planned there is list of various antenna model, the mechanical tilts, the azimuth, number of antennae used in transmission and reception.

The various cell level parameters which Asset has are:

- Carrier – This tells which frequency band to be used. Also it has the bandwidth.
- Max Power – It defines the maximum transmission power.
- Min SSRSRP – It is defined as the minimum SSRSRP required for a user to be successfully connected to the network.
- Numerology – It defines the numerology of the 5G network which is flexible.
- MIMO users (UL and DL) – The number of MIMO antenna elements.
- Noise Figure – The indication of the degradation of signal to noise in a system. It should be low.
- Frame structure – It is about the cyclic prefix to be used, the numerology and the sub carrier frame.
- Data and control resources – PUSCH and PDSCH overhead percentages, PDCCH and PUCCH resource blocks per frame.
- AAS settings – SUMIMO and MUMIMO DL and UL settings along with switched beam configuration which involves the SSB beams.
- Carrier settings – There is carrier setting as in which frequency band is used, carrier aggregation is allowed or not and the carried traffic.
- Cellular antenna – It is to decide the antenna patterns, the basic electrical tilt, mechanical tilts, and azimuth information along with the beam set.
- Multi technology – It is to decide which technology to use 2G, 3G, 4G or 5G.

There is a template available in which all the above mentioned parameters have a default values set by Asset. We can change the template by the desired values when we are planning a network. The 5G NR radio equipment defines radio bearers and bearer selection ranges.

4.4.1 Traffic parameters

The traffic parameters are same for all the radio technologies in Asset. It defines the number of users, their mobility, the terminals which they use, their environment where

they are located, which is the clutter idea, whether it is urban, rural, industrial or suburban.

Services like voice, internet, broadband are defined in Asset.

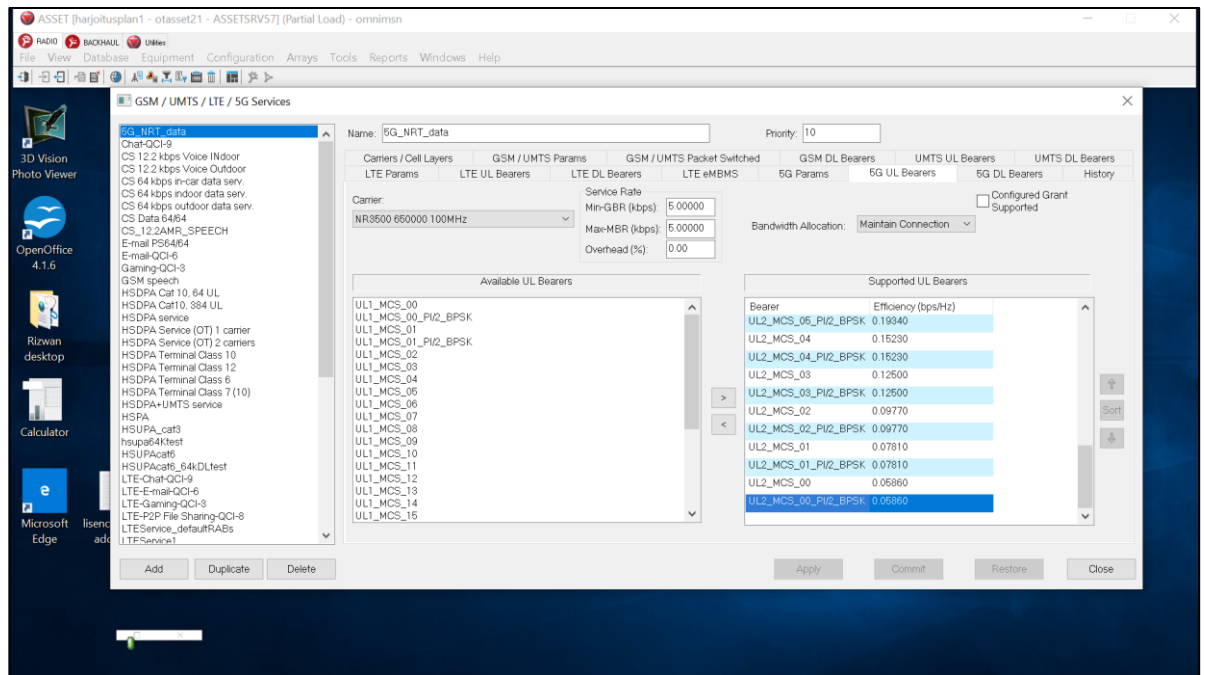


Figure 4.2 Asset 5G environment

In 5G NR the information about receiver mobility is required to determine which bearer threshold to use. There is a huge list of bearers are present.

4.4.2 Beamforming parameters

There is geometry-based antenna modelling in which there is beam switching. This is done using the simulator, no dynamic radiation pattern is available. Various propagation modelling is available. For the beam forming MYRAID is there. The requirements are number of concurrent users, RSRP and SINR improvement. Beam forming also requires terrain height. The main goals for beam forming are maximum RSRP per UE, maximum SINR per cell and maximum bits/s/Hz.

Beam switching is also done in Asset. It selects the best beam for each location under simulation.

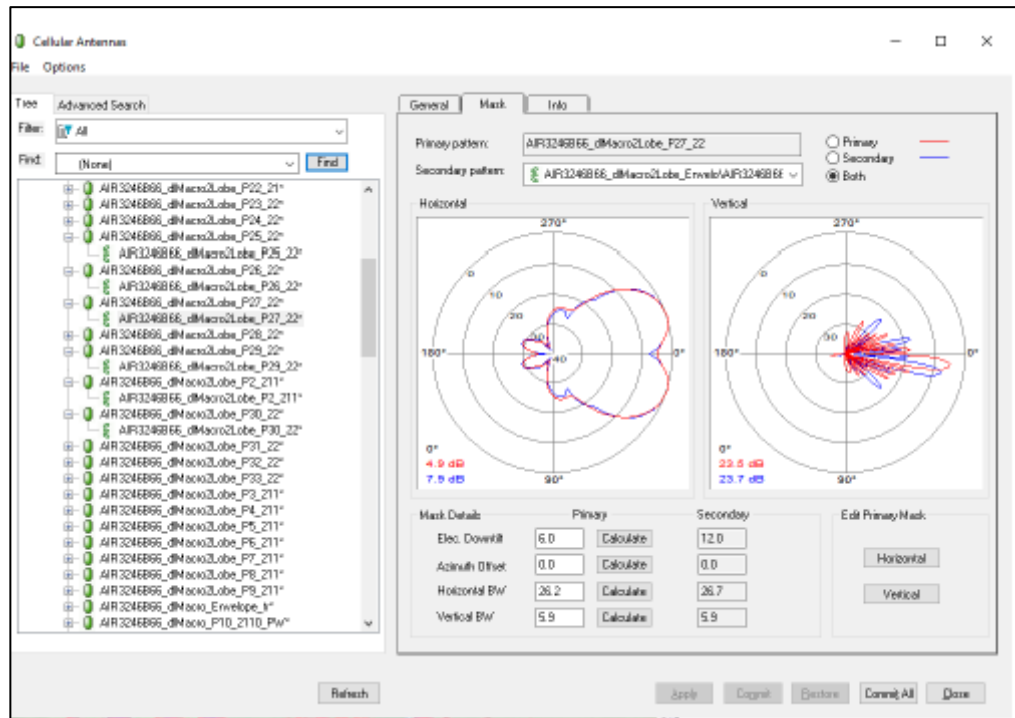


Figure 4.3 Asset 5G beam switching

There are multiple beam sets in an antenna. One can choose the patterns which are suitable for a particular 5G cell by creating and assigning a beam set at the logical level antenna. There is also control SSB and traffic patterns defined. There is fast determination of beam-to-beam interference.

There are many different features which are there in the Asset tool for example, dynamic spectrum sharing which is used to allow the same carrier to be used for 4G and 5G with the option guaranteed and shared spectrum segments. There is 5G neighbour planning, which is critical for seamless mobility, maintaining high data rates, and minimizing interference. There is also option for the drive tests to be uploaded and trace call records for tuning of propagation models for improving coverage predictions. There is multi height support as well, which is during the traffic modelling which it supports all arrays at multiple receiver heights. There is also RACH RSI planner which is for RSI planning and optimization. PCI planner also which is neighbours with the same PCI, with same PSS, antenna allocated, neighbours with same SSS and PCI confusion.

Asset is a complete tool for designing of the network and its optimization.

4.5 Use cases of Asset Tool

There is various use [5] cases for the Asset tool. First for example is the workflow integration.

In this workflow integration there is explanation of how a workflow is designed. There must be the synchronization between CM and Asset. The planning must be based on the accurate network data. There must be automated output of coverage arrays. The user base must be greater than 200. There is need for multiple managed service providers and vendors.

The second use case is regarding the synchronizing site design system and asset. In this firstly, there is need for creating the site, which is selecting the antennas, defining the RF configuration, and verifying coverage. This detailed information is then transferred to site design system. The site design system also includes physical site design for example, brackets, cables, connectors, diplexers. After the design is complete it is then updated in the Asset with all the changes which are made by the site design team.

Another use case is automatic coverage generation. In this there is prediction generation, coverage check which is then requested for any updated coverage arrays. Then finally publish the updated coverage maps.

5. SIMULATIONS AND RESULTS

Simulation is defined as the modelling of the network in order to study what exactly will occur in the field. Therefore, we studied the network planning by simulations which were performed on the RF designing and network planning tool called Asset. The thesis is done on two sites and study of the Asset tool [5] extensively. Its parameters are checked, and features are studied. This tool was chosen since the company uses this tool for planning and optimization. Many iterations were performed on the tool with the two sites, to understand all the results for example, coverage simulations, traffic simulations, capacity simulations and interference tables, neighbour planning was also checked.

5.1 Test scenarios

For studying various features various test scenarios were planned and tested for planning of the network. They are Massive MIMO application i.e. testing with normal antenna elements on one or two sites and then applying it to many sites. Beamforming which can be understood while applying Massive MIMO solutions. The different test scenario is varying the transmission power by increasing or decreasing them. Also testing by changing different parameters in the tool. For example, transmission power, required SSRSRP range and required SSRSRQ range, SINR gains and noise Figure. gNodeB parameter, cell parameters and carrier parameters and bearers. As the thesis was on the understanding of the 5G implementation on the actual field therefore studying the 5G frame structures and multiple frequency bands and various flexible numerologies present in the tool. Along with the parametric changes also making the physical changes in the antenna height calculation methods, by using effective method average, relative slope and knife-edge. The various 5G new features for example dynamic spectrum sharing enabled and disabled check, network slicing and checking switched beam or FD beamforming also included in the test scenarios. Since the tool already supports older version of technologies for example 4G, 3G and 2G therefore testing the 5G deployment of the network alongside 4G and seeing how it impacts or improves the network and most importantly the throughput which decreases. The other key performance indicators like SINR and RSRP. The SINR traffic decreases. The coverage prediction is one of the important simulations in the various scenario of studying the deployment of 5G in the network, which also has the traffic simulations and capacity simulations. Another possible test case scenario is the path loss study while building the network, by having receiver height fixed say 1.5 m versus the changing receiver height. When studying the Massive MIMO and beamforming, its gain can also be studied in terms of SS-RSRP level, PDSCH level and

PDSCH SINR level. Modulation scheme will also be studied along with beamforming and number of different beams.

5.2 Actual scenario

The circled are two sites in the Helsinki area. The clutter is suburban. The distance between the two sites is not more than 1 km. The area is having quite a good traffic. The physical parameters are defined in the Asset tool. The antenna which was placed is Ericsson AIR3239 and was also tested using Huawei antenna, as a comparison. The below pictures are taken from Google Earth. It is one of the most common tools used in the telecom industry for various purposes for example, positioning of the site, studying the geographical area, clutter identification, for marking the drive routes, studying the demography which helps in placement of the site by identifying the hotspots and elevation of the area.

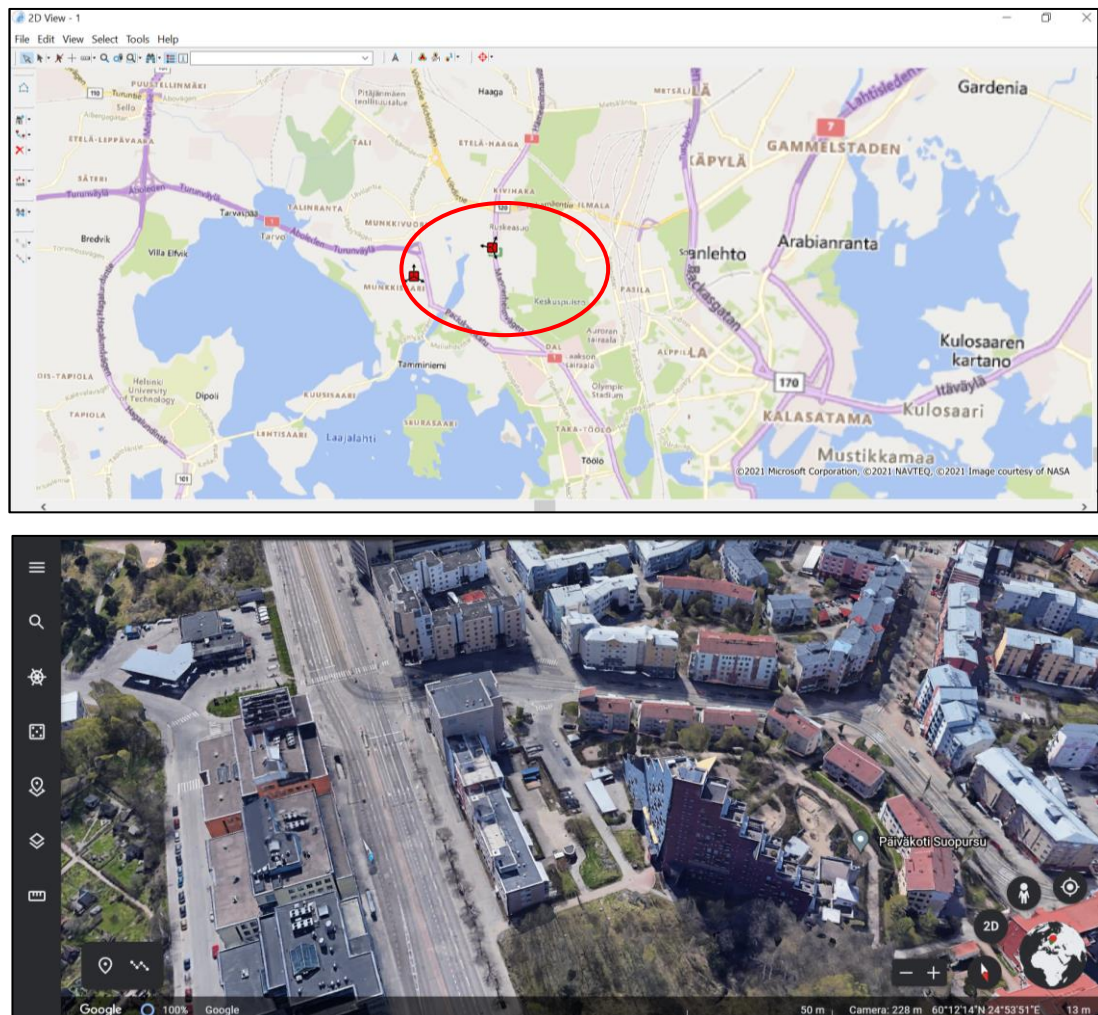


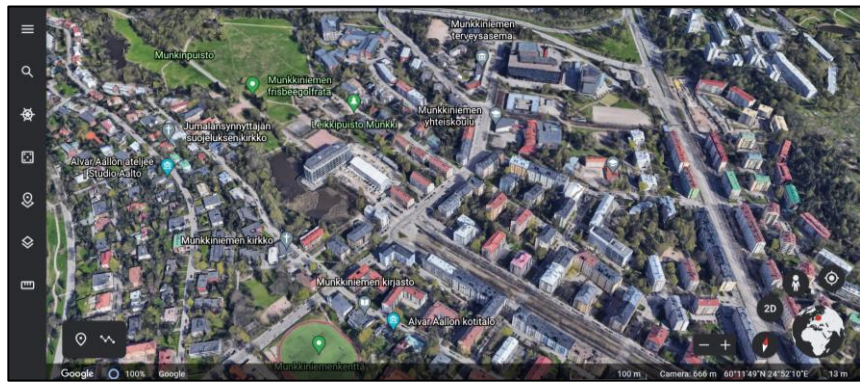
Figure 5.1 Antenna placement and location and physical details

Site Database

Filter: All

Find: (None) Find

Index	Absolute	Units	X	Y	Device ID	Azimuth	Height - Inv (m)	Height - Pred Offset (m)	Height - Pred (m)	Mech.Downtilt	Tv
1	1	E	0	0	K742215_214	20	26.00	0.00	26.00	0.0	0.0
3	3	E	0	0	K742215_214	280	26.00	0.00	26.00	0.0	0.0
4	4	D	0.00000000	0.00000000	K 741794 (18)	20	26.00	0.00	26.00	3.0	0.0
6	6	D	0.00000000	0.00000000	K 741794 (18)	280	26.00	0.00	26.00	3.0	0.0
7	7	E	0	0	AAU5313_03	20	25.00	0.00	25.00	3.0	0.0
8	8	E	0	0	AAU5313_03	160	25.00	0.00	25.00	3.0	0.0
9	9	E	0	0	AAU5313_03	280	25.00	0.00	25.00	3.0	0.0
10	10	E	0	0	AIR3239_B78	20	25.00	0.00	25.00	5.0	0.0
11	11	E	0	0	AIR3239_B78	160	25.00	0.00	25.00	5.0	0.0
12	12	E	0	0	AIR3239_B78	280	25.00	0.00	25.00	5.0	0.0
2	2	E	0	0	K742215_214	160	23.00	0.00	23.00	0.0	0.0
5	5	D	0.00000000	0.00000000	K 741794 (18)	160	23.00	0.00	23.00	3.0	0.0



Site Database

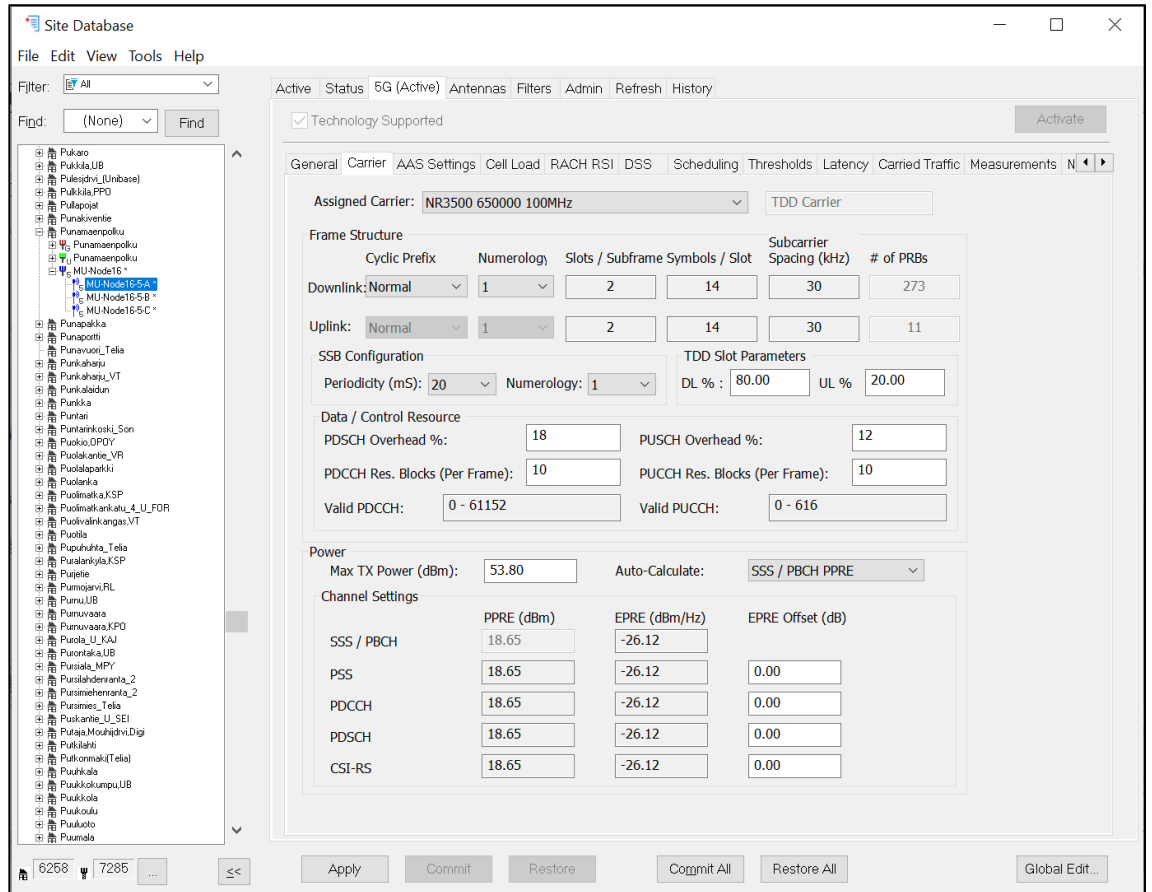
Filter: All

Find: (None) Find

Index	Absolute	Units	X	Y	Device ID	Azimuth	Height - Inv (m)	Height - Pred Offset (m)	Height - Pred (m)	Mech.Downtilt	Tv
4	4	E	0	0	AIR3239_B78	0	25.00	0.00	25.00	5.0	0.0
5	5	E	0	0	AIR3239_B78	120	25.00	0.00	25.00	3.0	0.0
6	6	E	0	0	AIR3239_B78	240	25.00	0.00	25.00	3.0	0.0
1	1	D	0.00000000	0.00000000	K 739490_V	85	10.00	0.00	10.00	10.0	0.0
2	2	D	0.00000000	0.00000000	K 739490_V	200	10.00	0.00	10.00	15.0	0.0
3	3	D	0.00000000	0.00000000	K 739490_V	355	10.00	0.00	10.00	15.0	0.0

Figure 5.2 Second Antenna placement and location and physical details

The parameters changes which were done in the Asset tool are defined with the screenshots below. The changes are done for both the antennae. The changes are frequency band selection, antenna selection [23], MIMO configuration selection, power level and carrier selection of 5G.



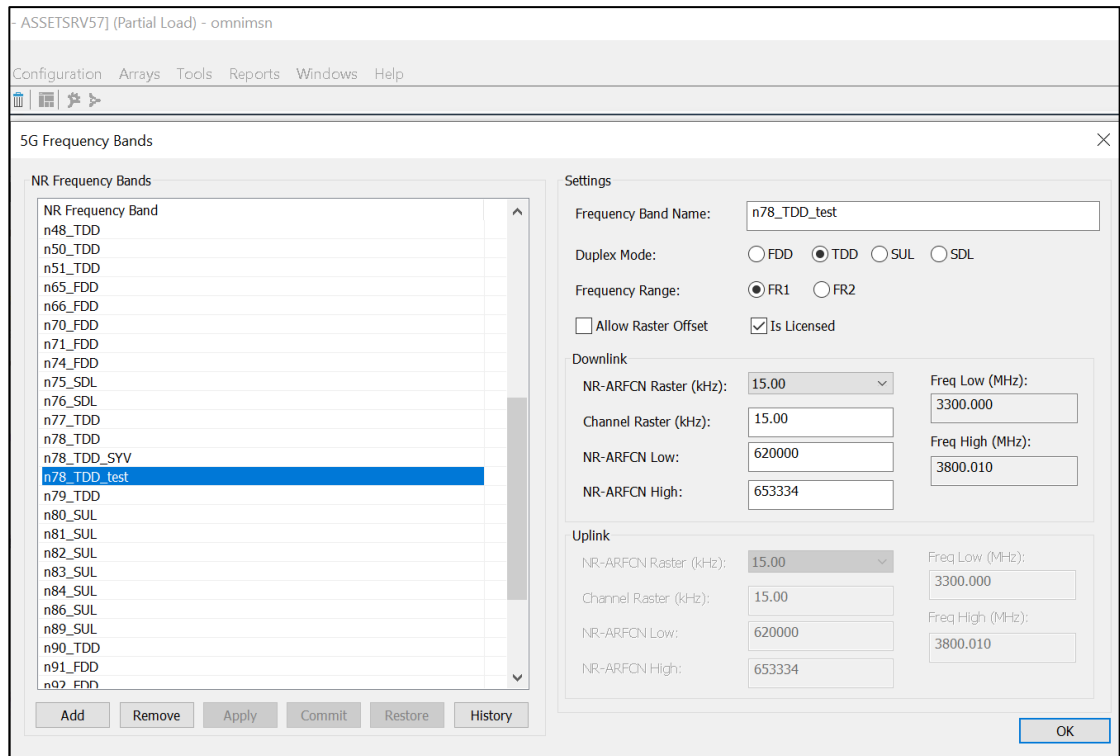


Figure 5.3 Parametric changes

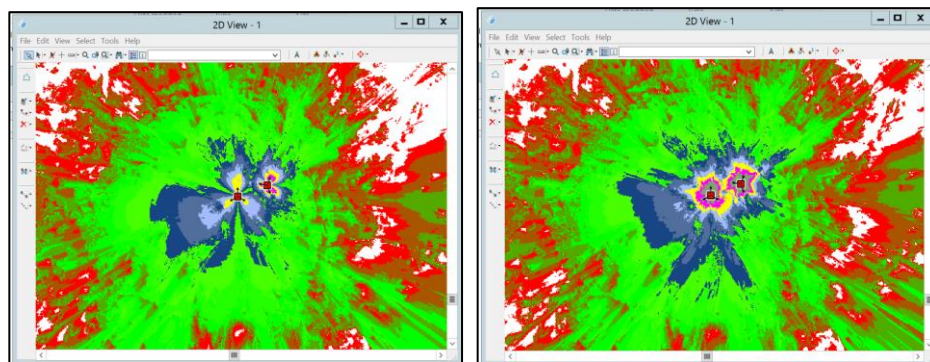


Figure 5.4 Huawei and Ericsson antennae

This is the antenna comparison by keeping all the parameters same just studying the antenna difference, in order to find which, one is more effective. The parameter is SINR, clearly Huawei antenna has less coverage than Ericsson antenna. This is PDSCHSINR. Beam set for Huawei has 1 pattern for control beam, and 1 pattern for traffic beam whereas Ericsson has 7 control beams defined. These are 32T32R antennae.

5.3 Test cases and results

Table 5.1 Test cases scenarios

Parameters	1 st case	2 nd case	3 rd case
Antenna	AIR3239	AIR3239	AIR3239
SUMIMO	2T2R	32T32R	32T32R
Carrier	3.5 GHz	3.5 GHz	3.5 GHz
Bandwidth	100 MHz	100 MHz	100 MHz
CP	Normal	Normal	Normal
Noise Figure	2.5 dB	5 dB	2 dB
Maximum Transmission Power	200 W	20 W	40 W
Terminals	1000	1000	1000

The above mentioned is the table of the test cases which were considered for simulations. In the second and third case the data rates with 5G UL and DL bearers service rate were also considered with minimum GBR as 15 kbps and overhead as 20%. Overhead means the processing time required for the codes for error checking and control of transmission. In the 3rd case decoupling and carrier aggregation were enabled.

The simulations results are:

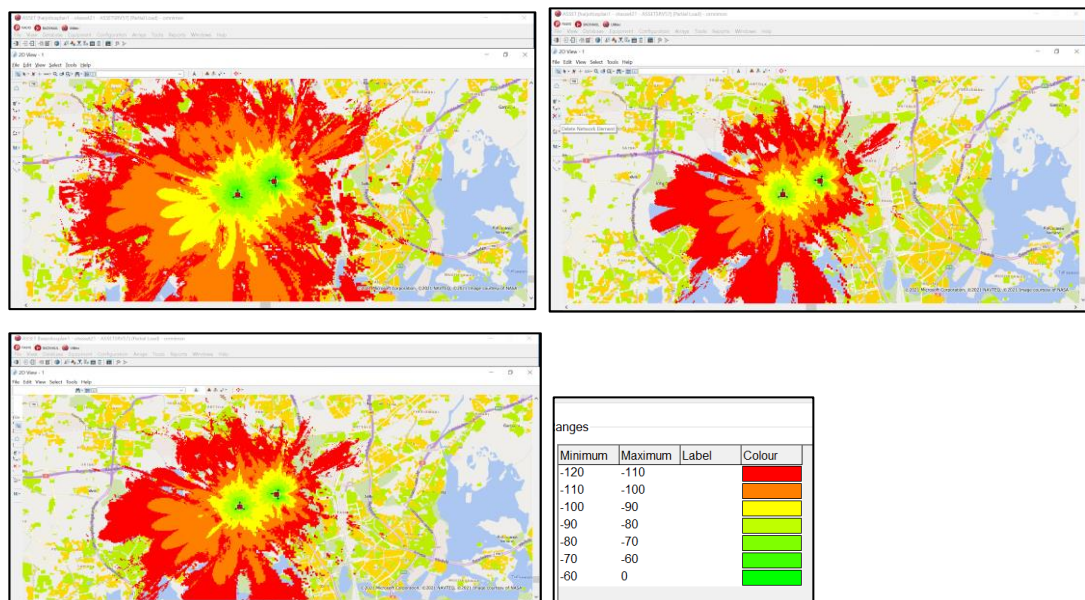


Figure 5.5 SSRSRP for 200, 20 and 40 Watts case respectively

It can be seen from the above figure that SS-RSRP has decreased around the site with decreasing power.

SS-RSRP [11] is defined as the linear average of the received secondary synchronization signal levels. These signals are specific to each cell are transmitting using the source elements. In **SS-RSRP ≥ 80 dBm** is the strongest signal which gives maximum data speeds. ≤ 100 dBm is the worst signal or no connection at all. **SS-RSRP** defines the cell selection procedure, cell reselection, handover, and power control signals. In 5G RSRP is measured in layer 1 and layer 3. Layer 1 measurements are for beam switching and layer 3 are used for cell reselection and handover.

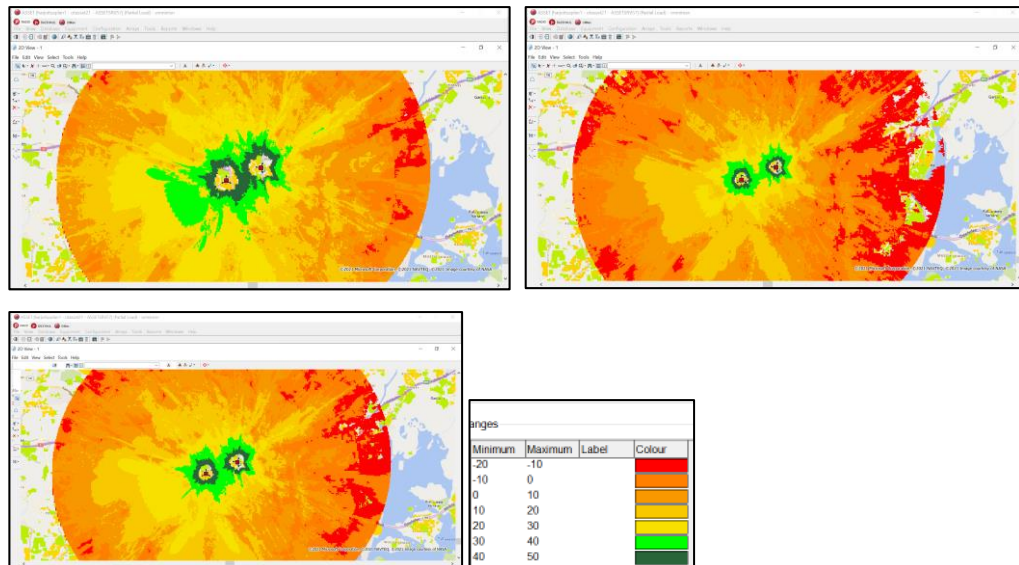


Figure 5.6 PDSCH SINR for 200, 20 and 40 Watts case respectively

The 20 W case shows the poor PDSCH SINR for the first site, but that is because that area is falling in the no zone of the site and the noise Figure has been increased. Therefore, with increased noise Figure the system performance decreases. In the 200 W case the noise Figure is 2.5 dB and for 40 W it is 2 dB.

PDSCH [14] is physical data shared channel. It carries the user data in the physical downlink channel. It is also used for paging information and random-access response message. To read the data PDSCH [35] requires DCI from PDCCH which is physical downlink control channel. It makes use of LDPC (Low density parity check) code which is basically error correcting code and is used for encoding of the data. NR supports up to 256 QAM modulation scheme. The performance of the block error rate depends on the channel quality between the base station and the receiver.

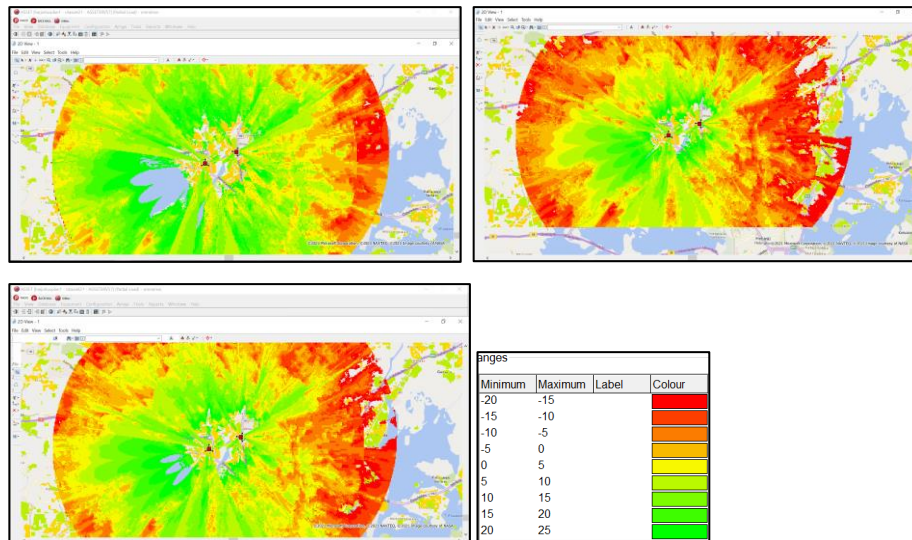


Figure 5.7 SS-SINR for 200, 20 and 40 Watts case respectively

The SS SINR is bad for 20 W case the reason is noise Figure increased to 5 dB. But for 40 W the SS SINR is bad maybe because of the transmission power cause the noise Figure in this is 2 dB.

SS-SINR [11] is synchronization signal to noise and interference ratio.[11] This is defined as linear average over the power contribution (in Watts) of the resource elements carrying the SSS divided by the linear average of the noise and interference power. **≥ 20 dB SINR** is excellent. It is a strong signal which gives maximum data speed. **≤ 0 dB SINR** is lost connection. SSSINR provides accurate information of the network coverage and quality.

SINR, RSRP, RSRQ, these are very important KPIs in terms of signal strength of the network and they differ according to the different service modes. There are many different factors which influence these KPIs for example, what is the traffic load in the area, if the antenna load is full in terms of physical resource blocks, are there any competing networks nearby, physical hindrances like, mountains, dense vegetation, buildings, what is the weather type. The above mentioned KPIs are important for the successful data connection and functioning of the network. These KPIs are also very crucial in deciding the cell selection, cell reselection, handover, and power control parameters as well of the network.

CONCLUSION

The technology is growing very fast, there is R&D going on for 6G in Oulu, Finland and also other parts of the world, which is the future. But this thesis was about the network planning of the 5G network. 5G network planning is a continuous process and is being implemented in various parts of the world. Since, I am in Finland, the country has embraced 5G, and the implementation is still under way. While planning, various things are to be kept in mind, for example, most importantly by deciding the area where exactly we are going to install the new antenna, the coverage, and the capacity implementation, which can be decided by deciding various physical parameters antenna height, azimuth, electrical and mechanical tilts. There were some test scenarios made to study the massive MIMO working the beam forming working and the 5G network working in general. The thesis was done on the two virtual sites with lots of permutation combination done in the settings. The conclusions with respect to beam forming are that the throughput can be increased if we increase the number of beams due to which the users can be benefited from a dedicated beam. Another way of increasing the throughput will be increasing the number of antenna elements which will increase the directivity and the gain of the beam. There is a huge difference seen with beam forming and without beam forming, that with beam forming various users were benefited when they were distributed vertically. The conclusion regarding the massive MIMO was in Asset there are three different transmit diversity: they are single user MIMO (SUMIMO), multiuser MIMO (MUMIMO) and transmit diversity. The simulation results are showing the most important KPIs which are SSRSRP, SSSINR and PDSCHSINR to name a few. For future reference, the study of the tool is still going on and exploring various path loss features and different new features of the millimeter wave study. Also, the antenna which were deployed and provided the desired throughput and user requirement is under way. This tool Asset which is a RF planning software tool various parameter related to traffic, user conditions and radio access technology are being tested to improve the results which were obtained.

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