5G Micro-Cell Deployment in Coexistence with Fixed Services

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ABSTRACT OF THE
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This study deals with the coexistence between 5G networks and Fixed Services (FS), where fixed links (FL) is one application that is considered. To meet the demanding requirements of 5G systems, it is expected that 5G systems will require spectrum in high frequency bands. Most likely, these systems will have to share spectrum with fixed services. This thesis assesses the mutual interference between a micro-cell deployment and the fixed link, and examines the feasibility of the coexistence based on the interference requirements. The results indicate that the downlink (DL) interference that 5G generates towards the fixed link, surpasses the protection criteria for primary-secondary sharing in a co-channel case. However, the interference generated by the uplink (UL) transmission of the 5G system stays below the required threshold when an antenna array composed of 16 elements is used. In downlink (DL) communication, coexistence conditions were improved when lower transmit power was used. Thus, coexistence could be feasible in case the micro-layer was used only in UL. Frequency Division Duplexing (FDD) systems could be used in 5G communication systems to enable this feature.

Keywords: 5G, co-existence, fixed link spectrum, interference, sharing

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Khaled Matyas Abdallah

Abbreviations

AOSA	array of sub-arrays
BS	base station
CSO	cell selection offset
dBi	dB isotropic, antenna gain compared to a hypothetical isotropic antenna
DL	downlink
EIRP	effective isotropic radiated power
FDD	frequency division duplexing
FL	fixed link
FS	fixed service
ISD	inter-site distance
ITU	International Telecommunication Union
LTE	Long Term Evolution
MS	mobile station
RL	reference load
RSRP	Reference Signal Received Power
UD	user distribution
UE	user equipment
UL	uplink
5G	fifth generation of cellular communication systems

Contents

Chapter 1

Introduction

The radio-frequency spectrum is a limited resource that is essential for communication infrastructures. In recent years, a remarkable growth in mobile data traffic has been observed, and obviously this trend will continue in the future. New services, technologies and applications are emerging that will contribute to the increasing traffic passing through the cellular networks. As an example, one can consider machine-to-machine communication (M2M) that most probably will use the cellular network for its ubiquitous and robust coverage. This will result in unprecedented growth of traffic generated by users, devices and new types of services. Over half a billion (526 million) mobile devices and connections were added in 2013 and the overall mobile data traffic is expected to grow to 15.9 exabytes per month by 2018, nearly an 11-fold increase over 2013 [1]. According to the UMTS traffic forecasts [2] for the year of 2020; mobile traffic will exceed 800MB per subscriber leading to 130 exabits (1018) of data per year for some operators. Our current communication systems will fail to handle such a huge demand of traffic generating from people to people, people to machine and machine to machine communication. Thus, the need for massive capacity and massive connectivity is triggered.

There is a direct correlation between the bandwidth of a signal and the achievable data rate. Hence, to achieve significantly increased data rates for mobile broadband, such as the preliminary figures currently being discussed (10Gbit/s in specific scenarios such as indoor and dense outdoor environments [3]), much higher bandwidths are expected to be needed, and for example, channel bandwidths of several hundred MHz are being discussed within the ITU-R [4][5]. Frequency bands above 6 GHz, where spectrum allocation is less fragmented, present a more realistic opportunity to meet these requirements than bands below 6 GHz. However, a challenge within these higher bands is the coexistence with already existing radio services, including fixed services, military systems, radars, and satellite services are operating. An example of FSS system in higher frequencies is the UKSAT-10 FSS system, which was launched in early 2007, has a uplink frequency band is ranging from 29:5 GHz to 30 GHz and a downlink frequency band ranging from 19.7 GHz to 20.2 GHz [6]. Another example is the FSS application in the cognitive radio for satellite communications (CoRaSat) project [7], which uses 10.7 -12.75 GHz as downlink and 12.75 13.25, 13.75 14.5 GHz as uplink.

Thus, there is a need to study the possibility for coexistence between these services and the cellular network. This coexistence will mainly depend on the interference generated by the cellular network towards the fixed services and on the interference generated by the fixed service towards the cellular network.

This thesis work is dedicated to study 5G micro base station deployment scenarios in coexistence with point-to-point fixed links in dense urban environments.

1.1 Wireless Communication in Higher Frequencies

The studies on communication at higher frequency bands and the properties of millimeter waves are ongoing. Solutions and ideas to tackle the drawbacks of higher frequency waves are developed every day.

Generally, as one moves to higher frequencies, the transmission range gets shorter (from the range of kilometers to the range of hundreds of meters). In addition to that, signals are unable to penetrate walls easily. However, antenna size that is proportional to the wavelength gets smaller, allowing more antennas to be packed into devices. These larger arrays of antennas allow supporting directional beams towards the users and compensating the difficult propagation conditions.

1.1.1 Previous Work and Research Gap

Recent studies demonstrate the feasibility of millimeter wave mobile communications using multiple antenna arrays in conjunction with adaptive beamforming in order to compensate for propagation losses at high frequencies [8]. In addition, several measurements and capacity studies performed in New York City at 28GHz and 73 GHz in [9] show that even in non-line of sight scenarios strong signals could be detected 100 to 200 m from the base station and spatial multiplexing can be supported.

The coexistence study carried out in [10], considers a macro outdoor deployment. The results verify that by using beamforming, the interference at the fixed link can be reduced. However, for the co-channel coexistence scenarios, even for low traffic conditions the interference level at the fixed receiver was exceeded. Coexistence was found possible for the adjacent channel case with low traffic. Another interesting finding of [10], was that the interference created by the fixed link towards the 5G network was negligible in comparison to the interference that was generated internally by the network.

Most of the proposals to counteract surpassing the allowed interference threshold include the separation distance [11][12]. The separation distance is an area around the fixed service where no deployment of base stations is permitted. This safety region is used to protect the fixed link from experiencing interference level higher than the allowed thresholds. Furthermore, some schemes are also developed to try to minimize these separation distances [13]. In [12], the interference at the fixed service receiver is studied in both the uplink and downlink communication of a 5G small cell system. The simulations were performed through varying the separation distances from 0-30 Km as well as assigning different orientations to the fixed link receiver between 0 to 180°.

The studies mentioned above consider macro-base station deployment with separation distances from the fixed link. However, they don't specify the effect of these exclusion zones on the throughput of the cellular network. In addition to that, coexistence with micro-base station deployment in a heterogeneous network has not been studied yet.

1.2 Thesis Purpose

The main purpose of this thesis is to take the next step towards gaining a better understanding of the spectrum sharing capabilities in the future cellular network by investigating the following:

- The possibility of having micro-cell deployment in coexistence with the fixed services and observing the performance of the cellular network
- Improvements in performance for coexistence by increasing the number of elements used for beamforming in the antenna arrays
- The major factors that affect the interference at the fixed link, like antenna transmit power, traffic carried by the micro-layer etc..

This thesis project will answer the question:"what are the major parameters affecting the coexistence possibility of fixed links and 5G micro-cell deployment in a heterogeneous network?".

1.2.1 Benefits, Ethics and Sustainability

The use of directional transmission between the base station and a mobile device reduces signal interference, and which might account for the reduction in energy use we are seeing. When establishing a direct link and suppressing interference, one can send data at higher rates for a given transmission energy level. Therefore, throughput per unit energy increases hence energy efficiency improves. Energy efficiency is very important here as well because of the growth in the number of users and devices; and efficiency should be considered with any new standard. However, due to the time constraint of the project these factors will not be studied in the thesis project.

Ethically, no problems occur for this study

1.3 Methodology

This project uses an Experimental research approach [14]. Simulations are carried out to investigate the impact of the factors stated in section 1.2. All the simulations are carried out using an internal Ericsson state-of the-art simulator. The radio access network (RAN) simulator is written in Matlab [15]. The simulation results will then be analyzed and conclusions will be formed. Hence, the goal and contribution of this thesis project is to study another scenario for coexistence and check the extent of its feasibility. Considering the purpose of this project, and the fact of dealing with variables (transmit power, deployment density and beamforming) where one variable is manipulated while the rest are fixed, this method was preferred over other methods. The other methods would include the non-experimental research method, the descriptive research method, analytical research method, fundamental research method, conceptual research method and empirical research method are not as suitable to examine the system performance in context of this thesis.

1.3.1 Simulation

The methodology of the simulation is represented in figure 1.1. The process starts by setting the main parameters of the simulations, like the network setup, propagation model, and traffic loads. Based on those parameters the map is loaded and the total assigned traffic is distributed among the users. Propagation losses and gain matrices between every user and base station node is calculated so that the every user could be assigned to a serving cell. The next step is calculating the Signal to Interference-Noise Ratio (SINR) and throughput of every user for the different assigned traffic loads. Finally, the results relevant to the study are extracted and post processed

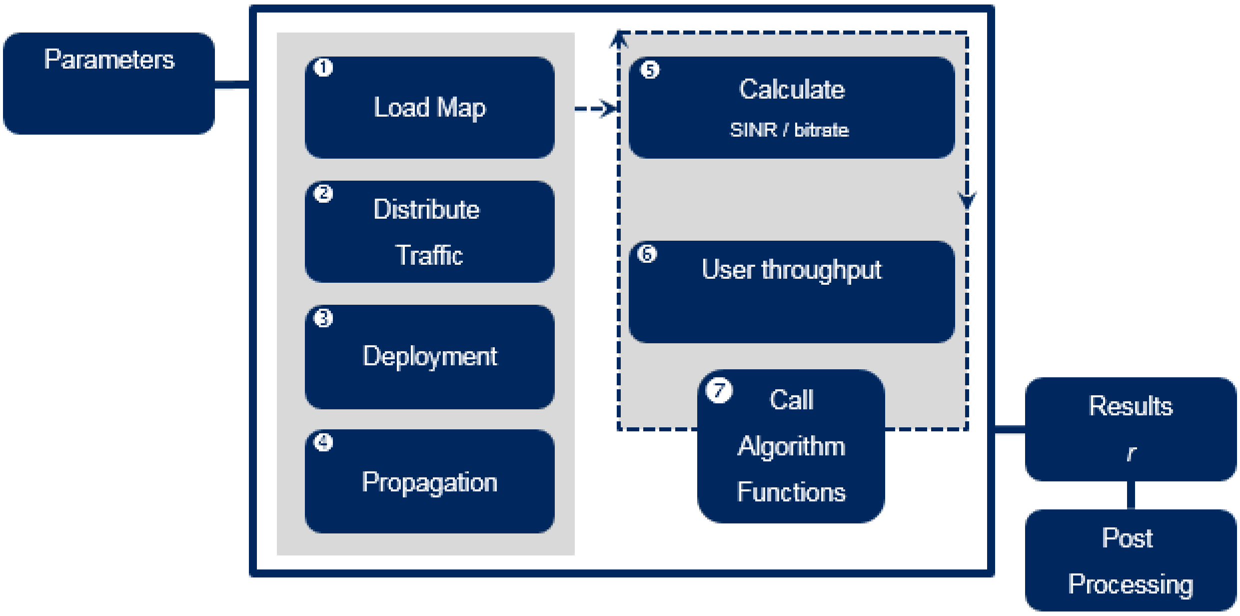

Figure 1.1: Ericsson Internal Simulator

1.4 Thesis Outline

The rest of the thesis is organised as follows: Chapter 2 describes the deployment of the network and presents some of the basic parameters used. Chapter 3 presents the interference scenarios considered in this study, as well as the interference and throughput calculations that are used as metrics in the evaluation of the results. In Chapter 4 the simulation setup is where the different parameters studied are discussed. This chapter also describes the different simulation cases. Finally, Chapters 5,6 and 7 present and discusses the results giving the conclusions of this thesis.

Chapter 2

System Model and Network Layout

This Chapter provides a description of the considered scenario, and the components of the networks considered.

2.1 Propagation Environment

The deployment of micro-cells to create heterogeneous networks will be used by future networks to enhance coverage and quality of service for certain hotspots [16]. These hotspots could be transportation hubs, shopping streets or markets or any location where high capacity demands occur.

2.1.1 Map

Figure 2.1 shows the used city model, that was created to resemble an Asian city with an area of 2x2 km^2. The city consists of 1442 buildings with their heights ranging from 16m to 144m. The central part of the map contains high rise buildings, generating more traffic when compared to the surrounding part of the map. The distribution of building types in the center area is around 60% old and 40% new. The terms old and new are used to refer to the material the buildings were constructed of. The old buildings are made of 80% concrete and 20% standard glass, whereas the new buildings are built with 10% concrete and 90% Infrared Reflective Glass.

2.1.2 Propagation Model

The model is based on ray tracing for site specific 3D modelling taking into account the actual building environment for path loss. Stochastic azimuth angle spread is added to both, a single selected above building path, and to a second selected around building path. Angle spread in elevation domain is partly stochastic and partly deterministic.

In order to approximate losses due to buildings, the following equations were used [10]:

- loss through a standard glass window:

  $L_1(dB) = 0.2 \times f + 2$

- loss through a coated glass window:

  $L_1(dB) = 0.3 \times f + 23$

- loss through a concrete wall:

  $L_1(dB) = 4 \times f + 5$

where f is the frequency in GHz

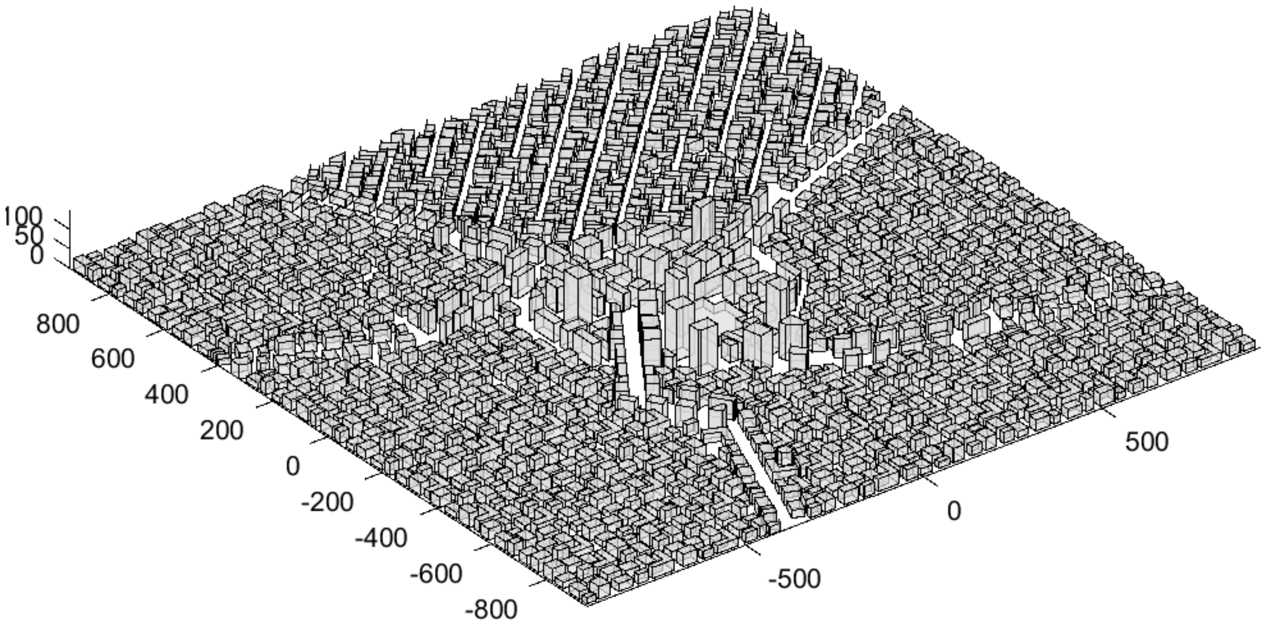

Figure 2.1: City model used for evaluations, similar to an Asian City

2.2 5G Heterogeneous Network Model

The heterogeneous network is modelled as four layers:

1. User Layer
2. Center Macro-cell Layer
3. Surrounding Macro-cell Layer
4. Micro-cell Layer

The features that render the network to be 5G are the combinations of LTE features and 5G ones (i.e., beamforming, multi-antenna, and operation at higher frequencies). Figure 2.2 shows the deployment of the base stations on the map. The carried traffic that will be offloaded between the serving layers (Macro and Micro) will be analyzed. Hence, the characteristics of all the layers are presented in the following subsections.

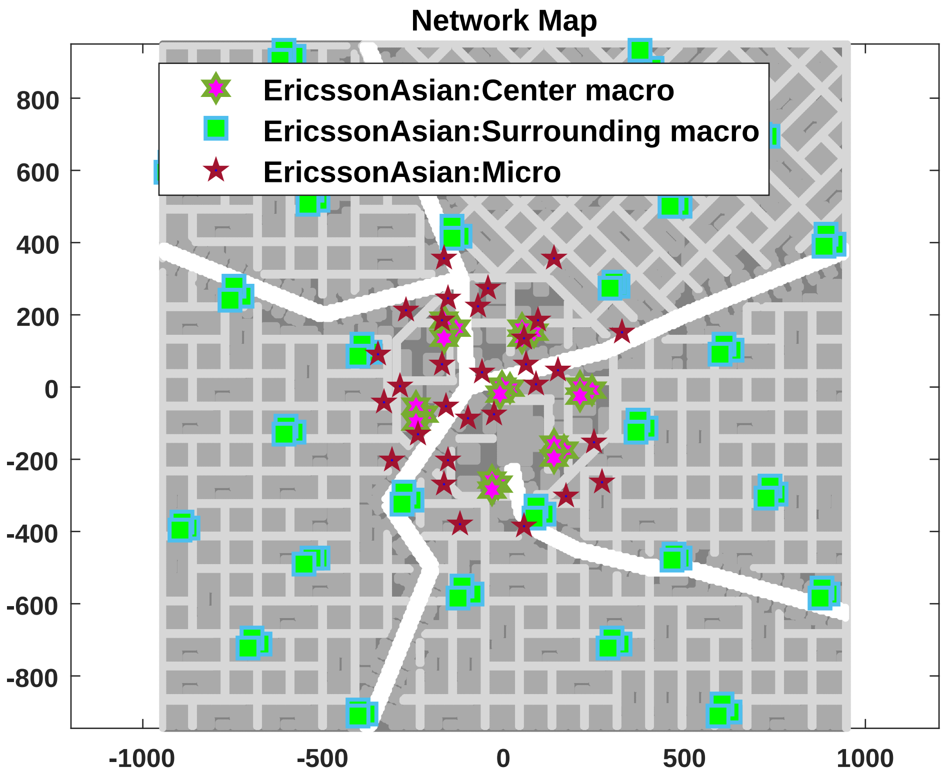

Figure 2.2: Heterogeneous network base station deployment

2.2.1 User Deployment (Layer 1)

Throughout the study, two different user deployments were considered. The obtained results of the simulations were then compared.

- A uniform all outdoor distribution (UD1).
- A map-height biased distribution with a ratio of 80:20 of indoor to outdoor users (UD2).

In both cases the number of users was kept to 3000 UEs. A more detailed explanation for choosing these 2 types of user distributions will be discussed in Chaper 4.

Every UE was equipped with 2 systems, LTE and 5G. The parameters for both systems can be seen in Table 2.1. The choice of the presented parameters was based on [10] and Metis Use Case 1, Dense Urban Information Society [17] [1]

Parameter	**LTE System**	**5G System**
Operating Frequency (GHz)	0.9	28
System Bandwidth (MHz)	10	60
UE Height*	1.5m	1.5m
UL max Power (Watt)*	0.2	0.2
System Highest Modulation	16 QAM	64 QAM
Thermal Noise (dBm/MHz)	-114	-114
Noise Figure (dB)*	9	9

Table 2.1: Shows the parameters assigned to LTE and 5G systems of the user equipment

2.2.2 Macro Base Station Deployment (Layers 2 and 3)

The macro layers form the LTE network. The network consists of a center macro layer (layer 2) with 7 base stations (21 cells), and a surrounding macro layer (layer 3) with 28 base stations (84 cells). The center macro layer is more dense with an inter site distance(ISD) of 200m, whereas the surrounding macro layer has an ISD=400m. Based on [10][17] the parameters for the macro base stations are presented in table 2.2.

2.2.3 Micro Base Station Deployment (Layer 4)

The micro layer consists of 30 base stations deployed to enhance the coverage of the macro base stations in the central area of the city. The exact position of the micro-cell base stations were fixed throughout the whole study. As was the

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[1] The parameters marked with a * were based on the METIS use case

Parameter	**Macro Layer**
Operating Frequency (GHz)	0.9
System Bandwidth (MHz)*	10
Deployment	3m above rooftop on roof edge
Max Tx Power (Watt)*	40
Max Antenna Gain (dBi)*	17
System Highest Modulation	64 QAM
Thermal Noise (dBm/MHz)	-114
Noise Figure (dB)	2

Table 2.2: Macro base stations' parameters

case for the previous layers, the parameters of layer 4 are based on [10][17] and are presented in table 2.3.

Parameter	**Micro Layer**
Operating Frequency (GHz)	28
System Bandwidth (MHz)	60
Deployment	5m above ground on buildings
Max Antenna Element Gain (dBi)	5.3
System Highest Modulation	64 QAM
Thermal Noise (dBm/MHz)	-114
Noise Figure (dB)	8

Table 2.3: Micro base stations' parameters

In addition to these characteristics, beamforming was applied at the micro base station antennas. With this said, the 5G micro cells and uisers are modelled by:

- The higher frequency band of 28 GHz used by the second system of the UEs and the Micro base stations.
- The 60 MHz bandwidth used by micro-cells serving the second system of the users.
- Beamforming applied for Uplink and Downlink at the micro base stations.

Beamfroming

One of the main advantages of operating at higher frequencies, is that as the carrier frequency gets higher the antenna elements get smaller. This means that more elements could be packed into smaller antennas. Due to higher path loss at high frequencies it is important to have larger antenna arrays to compensate for that loss. This study utilized UE-specific beamforming. The base station will select the beam with the highest gain toward a specific UE. 5G micro-base station will use a maximum size of 8x1 (vertical x horizontal) antenna array of sub arrays (AOSA), see figure 2.3. The parameters for constructing the antenna are presented in table 2.4. Dual polarization is assumed that results in having twice as many beams as antenna elements in each direction. The radiation pattern of the antenna can be seen in figure 2.4.

Horizontal element spacing	0.52λ
Vertical element spacing	0.52λ
Max Tx Power (Watt)	18.5
Max Antenna Gain (dBi)	12
Max number of elements	8 dual polarized

Table 2.4: Beamforming parameters

2.3 Fixed Service Model

This study considers one application of fixed services; fixed radio links (FL). FL provide point-to point (P-P) or point-to-multipoint (P-MP) communication

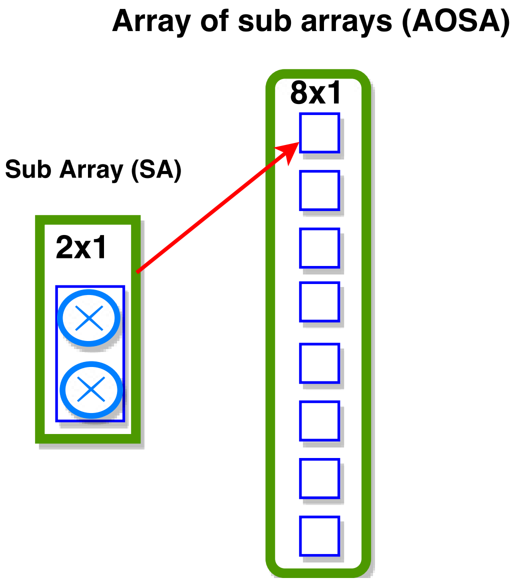

Figure 2.3: AOSA 8x1 configuration

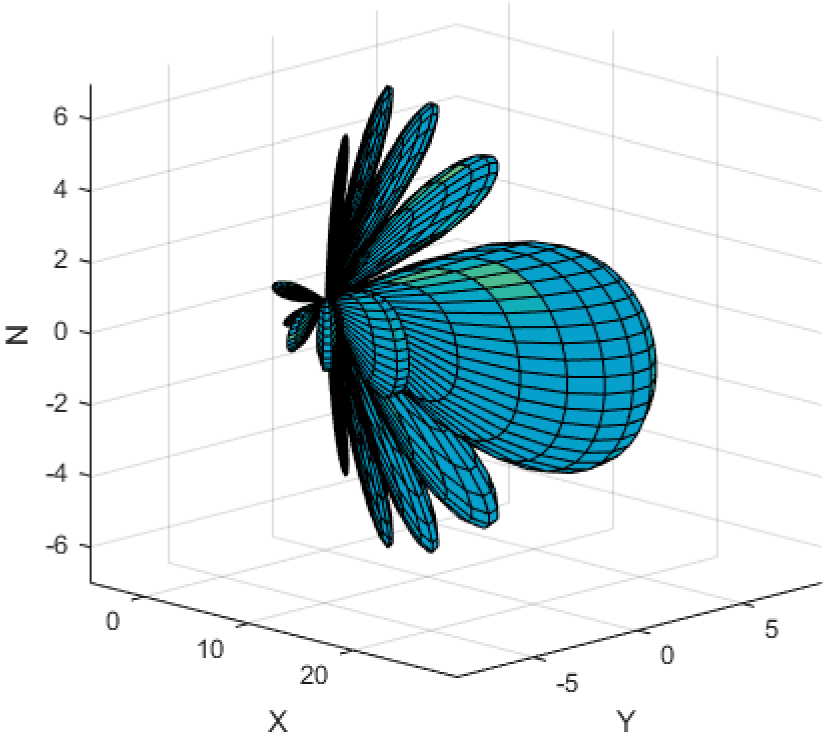

Figure 2.4: 5G Beamforming antenna pattern of an 8x1 AOSA

for voice, data or video transmission. Typical users for fixed links are mobile operators (mobile network infrastructure), corporate users (connecting remote premises) and private users (customer access to PSTN or other networks). The fixed link is modeled using a single dish antenna pointing towards another dish antenna in a line-of-sight point to point communication.

The parameters based on [18] used to simulate the fixed link are presented in table 2.5. A significant parameter to highlight is the maximum allowed interference at the fixed link.

2.3.1 Fixed Link Antenna Pattern

Figure 2.5 show the fixed link antenna pattern based on [20] current model restricted to diameter/wavelength less than or equal to 100 MHz. Increasing the diameter of the dish antenna will render the beam width narrower and increases the antenna gain. Hence, having a larger dish size would reduce the amount of interference captured at the fixed link. In order to get a more conservative view on the interference levels, the dish size was fixed to 0.3m throughout this study.

Parameter	
Operating Frequency (GHz)	28
System Bandwidth (MHz)	60
Antenna Type	0.3m Dish
Antenna Height (m)	35
System Modulation (m)	64 QAM
TX Power Density (dBm/MHz)	17
Antenna main beam gain (dBi)	31.5 according to [19]
I/N(dB)	**-10**
Thermal Noise (dBm/MHz)	-114
Noise Figure (dB)	4
Maximum Co-channel interference threshold (dBm/MHz)	**-120**[2]

Table 2.5: Parameters of the fixed link based on [18]

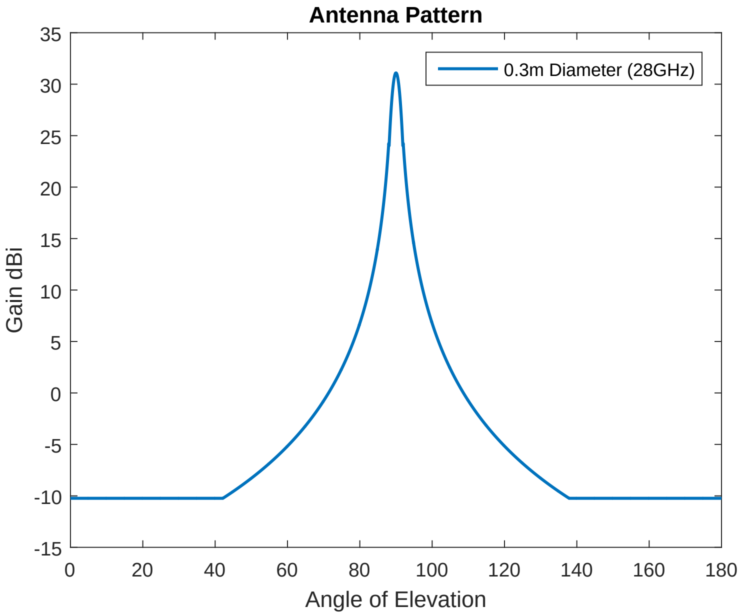

Figure 2.5: Fixed Link Antenna Pattern

Chapter 3

Interference

In this study two inter-network interference cases were considered. The first case is the study of the interference generated by the DL of the 5G network at the fixed link dishes 5G DL-to-FL. The second is the interference generated by the UL of the 5G network at the fixed link dishes 5G UL-to-FL.

3.1 5G DL-to-FL

In this case, the aggregated interference from all BSs to the fixed link dishes is of interest. $I_{(i,k)}$ is defined as the individual downlink interference (in dB), i.e. every single interference to a FL receiver k antenna generated by the transmission from cellular BS i to its associated MS j,

$$I_{(i,k)} = P_i + G_i(\phi, \theta) - L_{(i,k)} + G_k(\phi^*, \theta^*)$$

where, P_i is the transmit power from BS i, $G_i(\phi, \theta)$ is antenna gain to the receiver antenna of the FL generated by the transmission from BS i to its associated MSs. In addition, $G_k(\phi^*, \theta^*)$ is the antenna gain of FL receiver antenna generated by the transmission from BS i to its associated MS. The azimuth angles ϕ and ϕ^* and the elevation angles θ and θ^* are explained in figure 3.1. $L_{(i,k)}$ are the propagation losses from BS i to FL receiver antenna k. The aggregate interference is the sum of the individual interferences for all active connections.

3.2 5G UL-to-FL

In this case, the aggregated interference from all MSs to the fixed link dishes is of interest. $I_{(j,k)}$ is defined as the individual uplink interference (in dB), i.e. every single interference to a FL receiver k antenna generated by the transmission from cellular MS j to its associated BS i,

$$I_{(j,k)} = P_j + G_j - L_{(j,k)} + G_k(\phi^*, \theta^*)$$

where, P_j is the transmit power from MS j. Note that uplink transmit power control is applied. G_i is antenna gain to the receiver antenna of the FL generated by the transmission from MS j to its associated BS, assumed to be

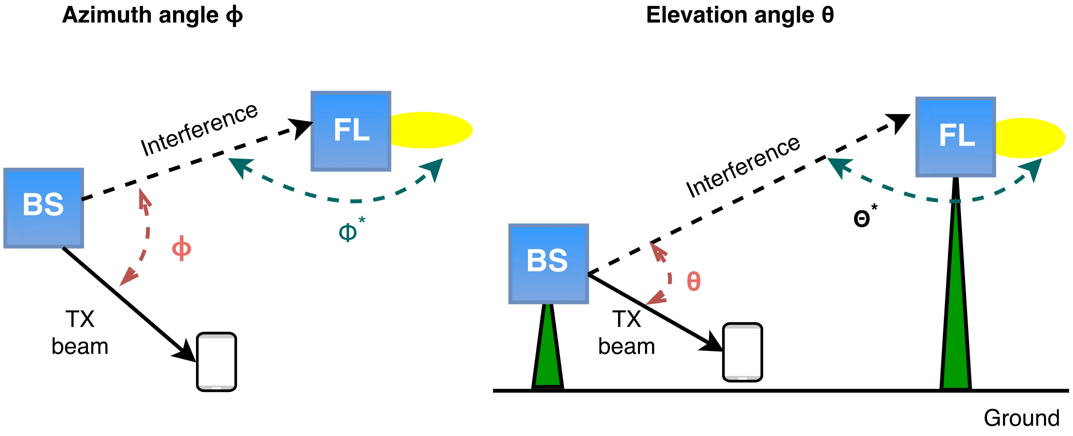

Figure 3.1: Representation of the azimuth and elevation angles at an FL receiver antenna.

omnidirectional, i.e. 0 dBi. $G_k(\phi^*, \theta^*)$ and $L_{(i,k)}$ were defined in the previous section. The aggregate interference is the sum of the individual interferences for all active connections.

3.3 Interference Threshold

To evaluate the level of interference at the fixed link, the maximum interference threshold I_{thr} calculated below was set based on the parameter $I/N = -10dB$ [18]. This value of interference level relative to receiver thermal noise floor results in a 0.5dB degradation in the carrier to noise ratio of the fixed link.

$$I_{thr} = ReceiverThermalNoiseFloor + I/N$$

where,

$$ReceiverThermalNoiseFloor = ThermalNoise + NF$$

and,

$$ThermalNoise = K * T * B$$

having,

- $K = 1.38 * 10^{-23}$, Boltzmann Constant
- $T = 288$, is the temperature in Kelvin
- $B = 10^6$, is the Bandwidth in Hz
- $NF = 4dB$, is the Noise figure of the receiver

Hence, the values normalized over 1 MHz are,

$$ReceiverThermalNoiseFloor = -110dBm/MHz$$

$$I_{thr} = -120dBm/MHz$$

3.4 SINR and Throughput

In the simulator used, a signal to interference plus noise ratio (SINR) is determined for a number of time samples, for each user position, as the ratio between the received signal power and the sum of inter-cell interference contributions from other active cells and noise. As mentioned, the SINR for a given user (bin) and time sample depends on the inter-cell interference. For downlink:

$$SINR_{b,t} = \frac{g_{b,c(b)}P_{c(b)}}{\sigma^2 + \sum_{c \neq s(b)} U_{c,t} g_{b,c(b)} P_{c(b)}}$$

where s(b) is the cell associated with bin b, P_c is the transmit power of cell c, $g_{b,c}$ is the pathgain between cell c and bin b and $U_{c,t} \in [0,1]$ is a random variable with $\Pr(U_{c,t} = 1) = u_c$. u_c is the utilization of cell c determined by summing up contributions from the bins associated with the cell, which is the ratio of the offered traffic to the bit rate of the bin. The SINR is then mapped to the data rates. Throughput is defined as the number of successfully served bits per second that is a function of the "bit rate after dropped traffic" and the time of waiting active users in the queue.

3.5 Evaluation Criteria

Three evaluation criteria have been assumed, to compare cases of strict and more relaxed conditions. For the relaxed criteria, the interference to noise ratio threshold should not be exceeded 90% of the time. However, the coexistence criteria based on the strict criteria is that the interference to noise ratio threshold should be met 99% if the time. In this study, a middle value of 95% was also considered to compare the experiments descried in Chapter 4.

Chapter 4

Experimental Design

This chapter is dedicated to explain the cases that were simulated and the parameters that were changed to obtain more intuitive results.

4.1 Traffic Loads

The simulator models active users that the systems sees at a given time, not the subscribers. An equal buffer model was used, where a variable fraction of the subscribers are active simultaneously. The offered traffic (service demand) is clearly specified and must be served. The total traffic demand was assumed to be 10 bps/m^2 and 5 bps/m^2, for downlink and uplink respectively. With the map having a valid size of 1900x1900 m^2, the total offered traffics are:

$$\begin{aligned}\text{Total Traffic Volume} &= \text{traffic volume per m}^2 * \text{ valid map size}\\ &= 36.1 \text{ Mbps for } \textbf{downlink} \text{ and,}\\ &= 18.05 \text{ Mbps for } \textbf{uplink}\end{aligned}$$

The traffic loads were varied throughout the simulations to examine their effect on the interference levels at the fixed link and the user's throughput. For that purpose, the above calculated *Total Traffic Volume* will be referred to as *Reference Load*(RL). Multiples of the Reference Load that were used in the study are presented in table 4.1.

Multiples of Reference Load	Downlink (Mbps)	Uplink (Mbps)
2xRL	72.2	36.1
4xRL	144.4	72.2
8xRL	288.8	144.4
10xRL	361	180.5
40xRL	1444	722
60xRL	2166	1083

Table 4.1: Traffic Loads used

4.2 Experiment 1. Map Sampling

The central area of the map, containing the micro-base station deployment was sampled in an attempt to study the interference conditions at the Fixed Link and generalize it over the whole map without being limited to a few positions. From the set of positions that were used in the sampling process, the pair (facing sites) of positions experiencing the worst interference would be selected for further studies. The sampling process was carried out with the parameters specified in Chapter 2 with an AOSA of 8x1.

Both, uplink and downlink interference were measured at a total of 104 positions within the central area. Figure 4.1 shows an example of a deployment considered in the sampling process. The simulations for every point consisted of taking 25 snapshots for two high network loads. For every snapshot different interferes were selected.

To ensure that the results only depended on the deployment of the fixed links, some parameters had to be fixed for all the 104 samples:

- User Deployment
- Height of the Fixed link above the ground
- Traffic carried by the Micro-Base stations

In addition to that, some measures were also taken to increase the traffic passing through the micro Layer:

- Cell Selection Offset for the micro-cells.

These key factors are explained separately in the following sections.

4.2.1 User Distribution (UD1)

A uniform user deployment was chosen to make sure that the 5G network will behave in the exact same way for all simulations. All users were deployed outdoors to increase the traffic served by the 28 GHz system. By doing that,

- The users are closer to the micro-cell antennas
- The advantage of the macro base stations(operating at lower frequencies) of having lower wall penetration losses to their signals has no effect.
- The case of having users deployed at higher floors is excluded.

4.2.2 Traffic Carried by Micro-Cells

The traffic carried by the micro-cells was increased as much as possible to study its effect on the interference generated at the fixed link. That was done through choosing the user deployment and setting a high traffic load to the network to get more traffic offloaded to the micro-cell layer. For the sampling process the extreme cases of 40xRL 60xRL were used.

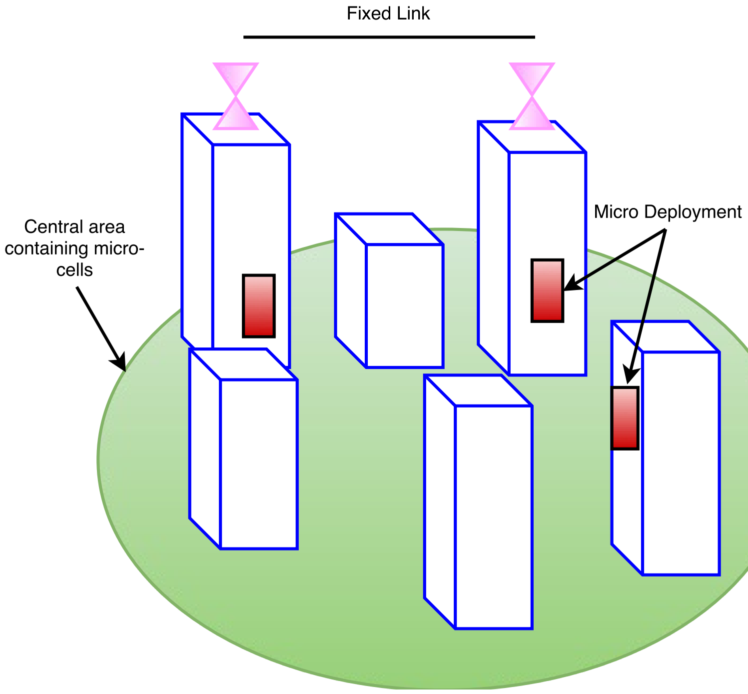

Figure 4.1: Example of the sampled area

4.2.3 Cell Selection Offset

In the case of the Heterogeneous Network deployment, described in Chapter 2. The macro base stations have a higher transmission power than that of the micro base stations. Thus the coverage of the macro cells is much larger than the coverage of micro cells which results in a small number of users being served by the small cell. In typical macro cell networks, the UE cell selection is based on Reference Signal Received Power (RSRP) measurements. The UE chooses the eNB that offers the highest RSRP, and connects to it [21]. Applying this criteria to the Heterogeneous Network Scenario studied in this thesis would lead to having the macro base stations carrying most of the offered traffic and leaving the micro base stations underutilized.

To account for this imbalance, the range of the micro cells has to be expanded by adding a positive bias called Cell Selection Offset to the RSRP measured from the micro-cells [22]. Thus increasing the footprint of the micro layer and making it more appealing to UEs within the extended range (see Figure 4.3). In order to push as many users as possible to the micro layer, the CSO parameter was set to a maximum of 9 dB for a worst case scenario study.

4.3 Experiment 2. Worst Case Position

After the sampling process, the interference values captured from the fixed link were compared and the position that experienced the worst case of interference

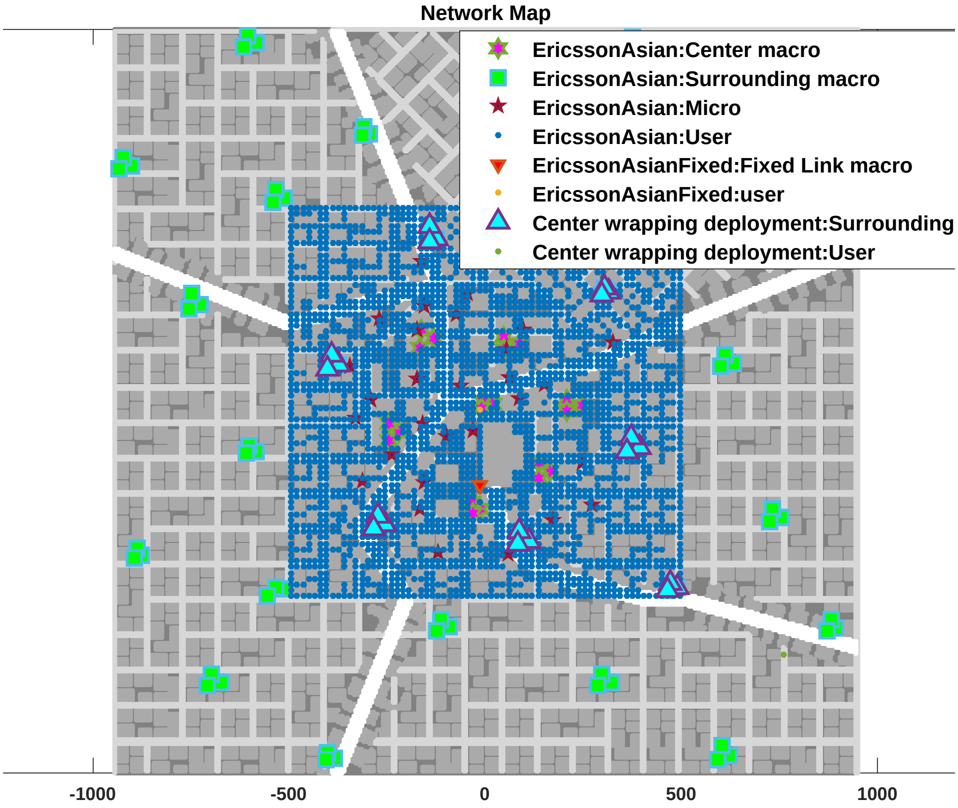

Figure 4.2: Uniform outdoor user distribution

was selected. Further studies were carried out at that position, with network loads that are more realistic than the extreme cases that were simulated for during the sampling process.

4.3.1 Impact of Fixed Link Deployment

The impact of the fixed link on the performance of the 5G network was examined. Interference from the fixed link to the 5G system was compared with the intra-cell interference generated before the presence of the fixed link.

4.3.2 Experiment 3. Antenna Array Effects

The effect of beamforming was studied at the worst case position. This was done by comparing two antenna array configurations of different antenna elements. Two antenna configurations were compared.

- Configuration 1: 2 x 1 array of sub-arrays (4 elements)
- Configuration 2: 8 x 1 array of sub-arrays (16 elements)

In both configurations a maximum EIRP of 60 dBm was used.

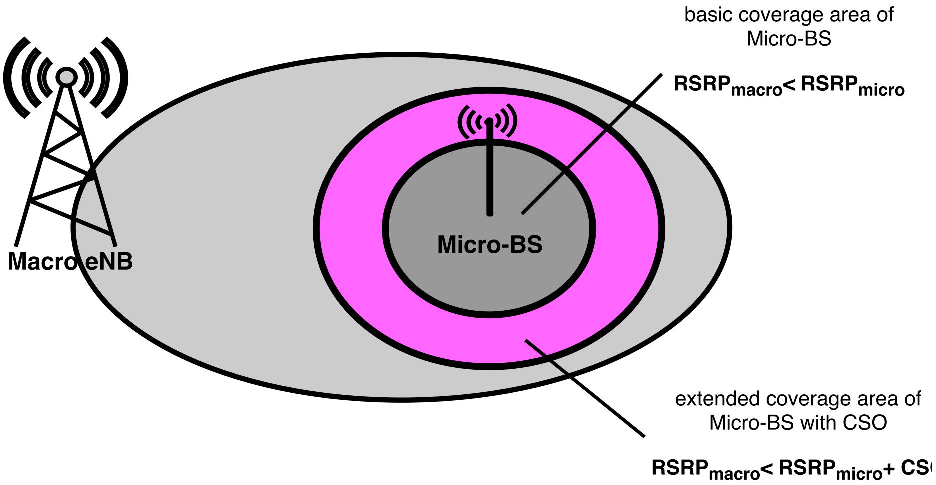

Figure 4.3: Cell Selection Offset

4.3.3 Experiment 4. Maximum allowed EIRP for Micro Layer Antennas

The maximum downlink power of micro cell base stations is controlled through the maximum allowed Effective Isotropic Radiated Power (EIRP).

EIRP$_{max}(dBm) = P_{Tx}(dBm) + G_{max}(dB) - FL(dB)$ Where,

- P_{Tx} is the maximum transmit power measured at the connector of the RF equipment
- G_{max} is the maximum beamforming gain of the antenna
- FL is the feeder loss

4.4 Experiment 5. Decreased Traffic Served by Micro Layer

In this section a scenario when the micro cells carry less traffic is considered. Achieving that by conducting the following changes:

- The cell selection offset was decreased to 3dB
- A new user distribution was used

4.4.1 User Distribution (UD 2)

Part of creating a scenario that fits an everyday situation was done by adjusting the user distribution. A uniform distribution was still used, however, indoor users in addition to users on higher floors were allowed. A ratio of 80/20 of indoor to outdoor users is assumed. That means that the users are concentrated at the center of the map where the high rise buildings are deployed. Intuitively, buildings with more floors will contain more users.

Chapter 5

Simulation Results

In this chapter the simulation results for the scenarios discussed in Chapter 4 are presented. This chapter is then followed by the discussion chapter where the results are discussed.

5.1 Sampled Map Statistics

In the simulations the fixed link receiver moves in 104 different positions (for an antenna size of 0.3 m). Figure 5.1 and Figure 5.2 shows the collection of the statistics on all the positions for Uplink and Downlink interferences respectively. Tables 5.1 and 5.2 show the percentage of traffic served by each layer. The position that was contributing with the worst values of interference was chosen to conduct more experiments. This position will be referred to as "worst case position".

Percentage of Carried Traffic Case UL, Served Traffic: 650 Mbps - 805 Mbps		
	LOAD 5 (40 times RL)	**LOAD 6 (60 times RL))**
Central Macro Layer	19%	16.9%
Surrounding Macro Layer	44.4%	38.7%
Micro Layer	36.6%	44.4%

Table 5.1: Traffic carried by layers in uplink

Percentage of Carried Traffic Case DL Served Traffic: 945 Mbps - 1191 Mbps		
	LOAD 5 (40 times RL)	**LOAD 6 (60 times RL)**
Central Macro Layer	13.9%	11.2%
Surrounding Macro Layer	35.64%	38.7%
Micro Layer	50.45%	60.1%

Table 5.2: Traffic carried by layers in downlink

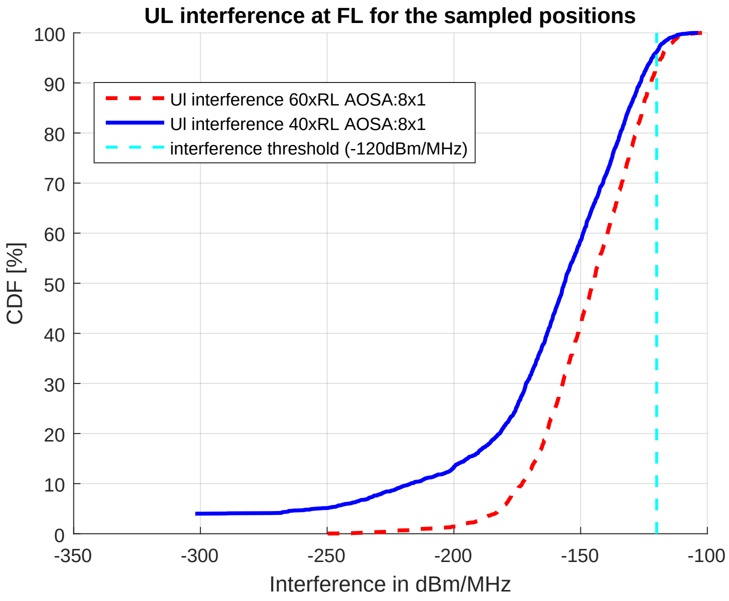

Figure 5.1: Gathered statistics for UL interference with EIRP=60dBm for micro base stations.

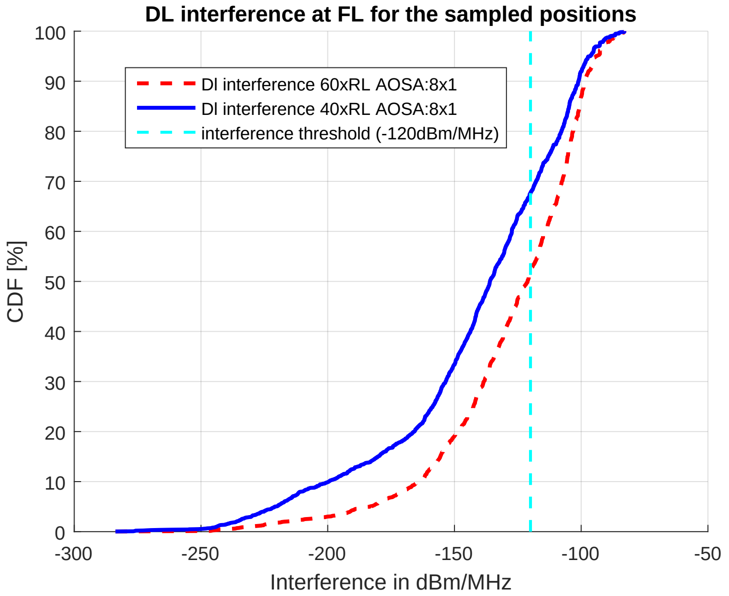

Figure 5.2: Gathered statistics for DL interference with EIRP=60dBm for micro base stations.

As it can be observed from the two figures 5.1 and 5.2, the interference threshold is exceeded for both uplink and downlink for a significant percentage of time. However, as it can be seen in tables 5.1 and 5.2, the micro layer is carrying the majority of traffic for both loads. It is thus called an extreme case where approximately 50% of the offered traffic was actually served.

5.2 Worst Case Position

The cdf of the interference generated at the fixed links at the worst case position was simulated for different loads. The results are shown in figures 5.3 and 5.4, for uplink and downlink respectively. Lower loads were used than the initial extreme loads used for sampling in order to be able to observe the effect of these loads on the users. This effect is shown in tables 5.3 and 5.4 through the 5^{th} percentile of the user throughput.The simulation were done for 4 loads. All the offered traffic was served:

- Central Macro Layer serving : 18.8% of the traffic
- Surrounding Macro Layer serving : 48.2% of the traffic
- Micro Layer serving : 33% of the traffic

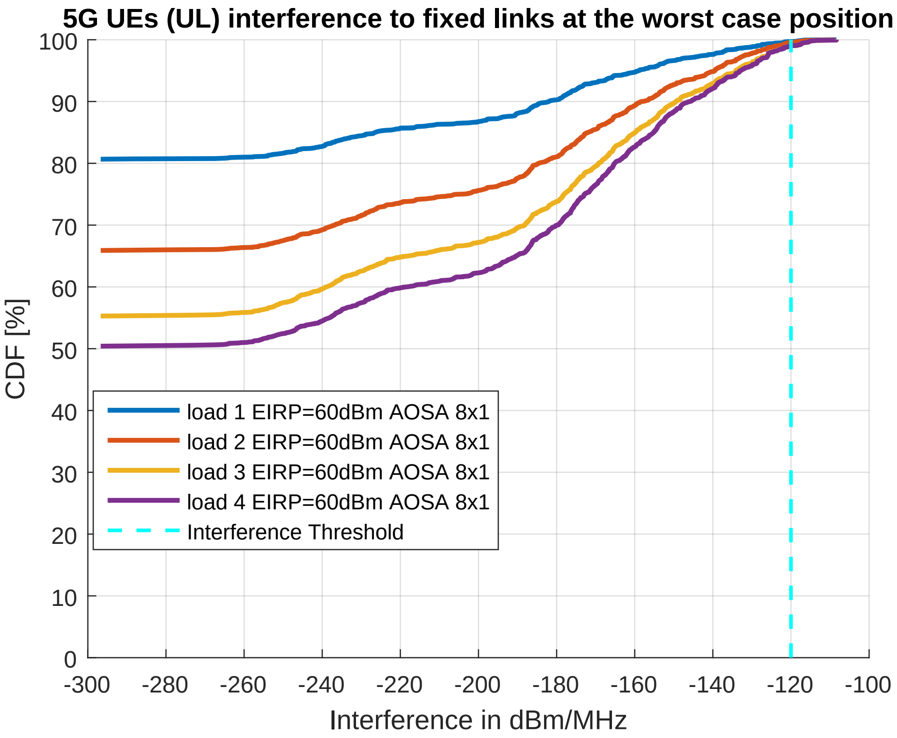

Figure 5.3: CDF of UL interference generated at the fixed link for different loads

FL Position (-15,-20,35)-(-15,-210,35) / AOSA 8x1 / EIRP=60dBm /UL				
Load	**All Layers (Mbps)**	**Micro layer (Mbps)**	**Center Macro Layer (Mbps)**	**Surrounding Macro Layer (Mbps)**
Load1 (2xRL)	19.6	26.389	19.4	19.154
Load2 (4xRL)	18.56	25.757	18.25	10.88
Load3 (8xRL)	10.02	24.735	9.7	9.63
Load4 (10xRL)	9.455	24.397	9.1	9.06

Table 5.3: The 5^{th} percentile throughput of UE for different loads in UL

In this experiment we can observe that for both uplink and downlink as the traffic loads increase the interference conditions at the fixed link get worse. It is noticeable that the traffic carried by the micro layer is still high compared to that carried by the central macro layer. As the loads increase the throughput of the worst case UE decreases due to the fact of having a longer queue time in addition to experiencing worse SINR due to having more intra-cell interference resulting from the higher activity of the nodes.

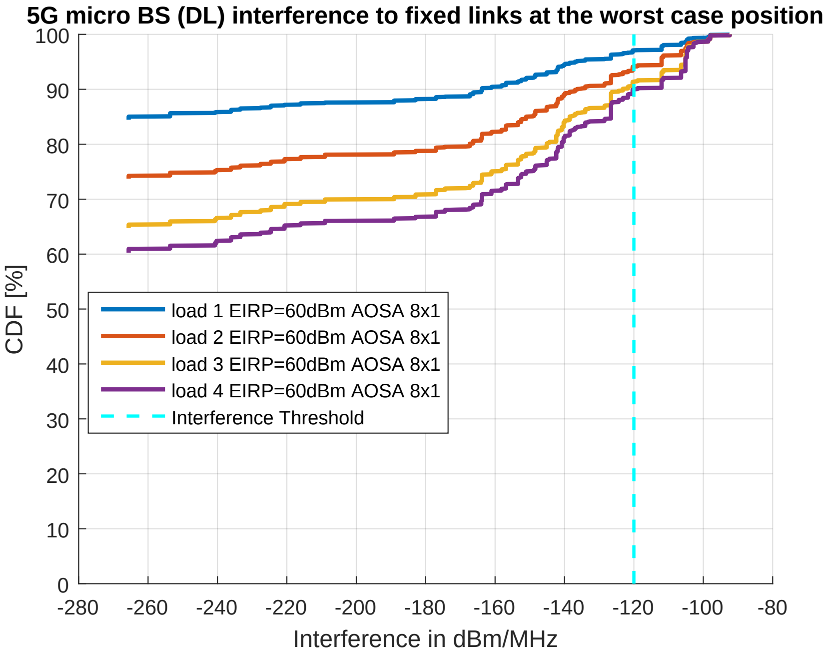

Figure 5.4: CDF of DL interference generated at the fixed link for different loads

FL Position (-15,-20,35)-(-15,-210,35) / AOSA 8x1 / EIRP=60dBm /DL				
Load	**All Layers (Mbps)**	**Micro layer (Mbps)**	**Center Macro Layer (Mbps)**	**Surrounding Macro Layer (Mbps)**
Load1 (2xRL)	13.309	98.12	11.29	12.629
Load2 (4xRL)	11.37	96.66	9.31	10.605
Load3 (8xRL)	7.4723	93.607	6.16	6.74
Load4 (10xRL)	5.84	92.22	4.73	5.19

Table 5.4: The 5^{th} percentile throughput of UE for different loads in DL

5.3 Impact of Fixed Link Deployment

The impact of the inter-network interference (interference from fixed link to 5G network) was studied by comparing the interference generated with and without the deployment of the fixed link (only 1 fixed link). The cdf curves of the downlink interference was chosen to be presented in figure 5.5. The figure is a ”zoomed in” version of the original plot, that was done to point out the part where the two curves differ. As observed the fixed link generates negligible interference as compared to the internal interference generated by the 5G network.

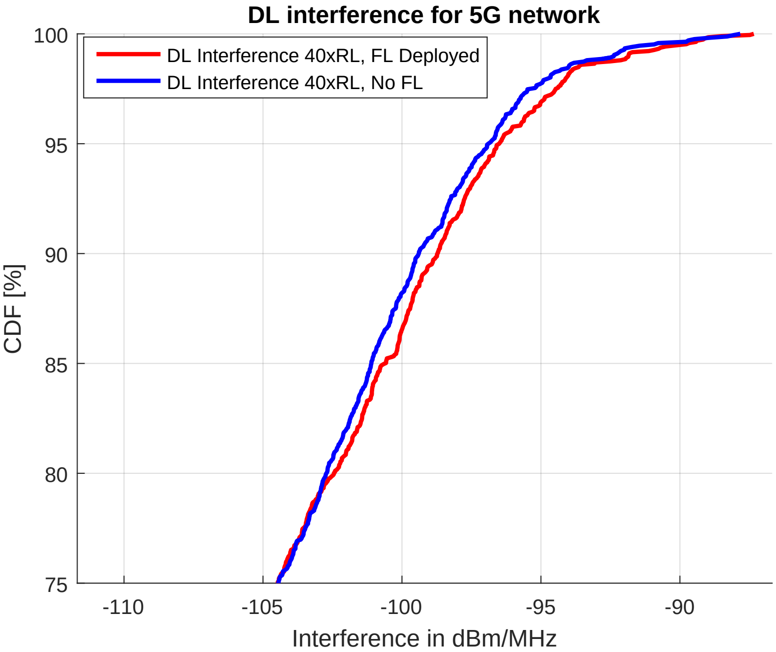

Figure 5.5: CDF of UL interference generated at the fixed link for different number of antenna elements

5.4 Antenna Array Effects

The two antenna configurations used in this experiment had the following maximum gains: AOSA 2x1=6.0206 dB and AOSA 8x1=12.0412 dB. Figures 5.6 and 5.7 show the interference generated at the fixed link for the two configuration, in uplink and downlink respectively. In addition to that, the effect of using different antenna arrays on the user equipment can be observed through the 5^{th} percentile of user throughput in tables 5.5 and 5.6. The simulation results are shown in figures 5.6 and 5.7. The effects of using different antenna arrays on the users are compared in tables 5.5 and 5.6 through the 5^{th} percentile of the throughput. All the offered traffic was served with AOSA 2x1:

- Central Macro Layer serving : 19.5% of the traffic
- Surrounding Macro Layer serving : 50.5% of the traffic
- Micro Layer serving : 30% of the traffic

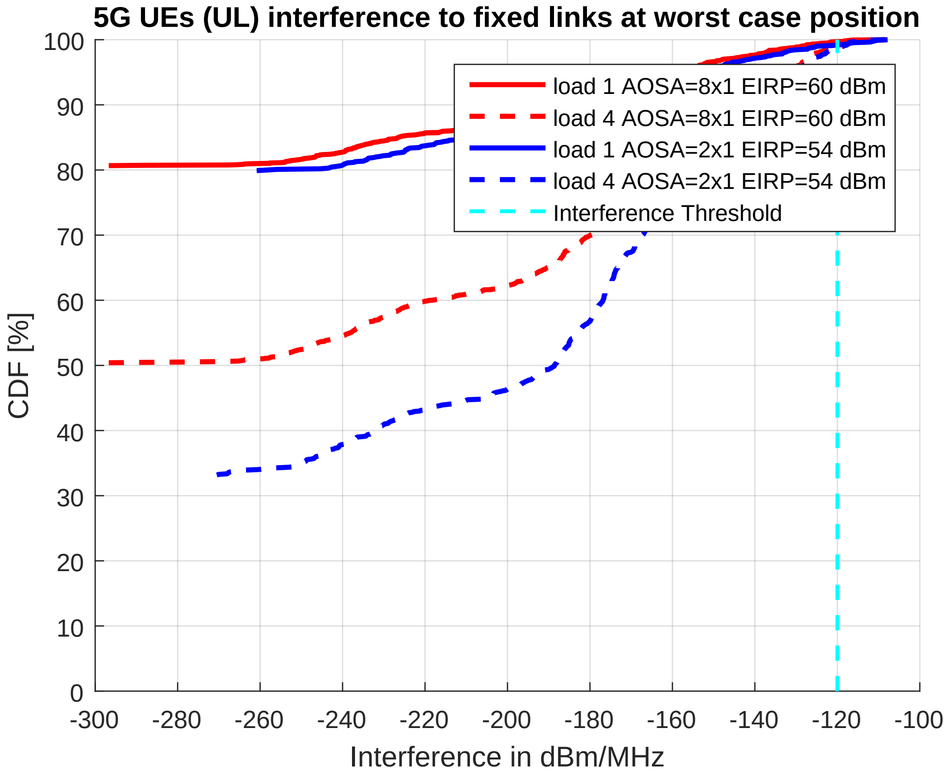

Figure 5.6: CDF of UL interference generated at the fixed link for different number of antenna elements

It can be noticed from figures 5.6 and 5.7 that by having lower number of antenna elements in the antenna array the interference at the fixed link becomes worse (especialy for higher loads). The micro cell antenna transmit beam becomes wider and more traffic is served through the micro layer. The throughput

Worst Case FL Position/AOSA 2x1 vs 8x1/EIRP 60dBm/UL				
Load	**All Layers (Mbps)**	**Micro layer (Mbps)**	**Center Macro Layer (Mbps)**	**Surrounding Macro Layer (Mbps)**
Load1 (2xRL) AOSA 2x1	19.4	25.09	19.437	19.175
Load1 (2xRL) AOSA 8x1	19.6	26.389	19.4	19.154
Load4 (10xRL) AOSA 2x1	13.2	23.170	9.223	9.222
Load4 (10xRL) AOSA 8x1	9.28	24.397	8.95	9.06

Table 5.5: The 5^{th} percentile throughput of UE for different number of antenna elements in the antenna array in UL

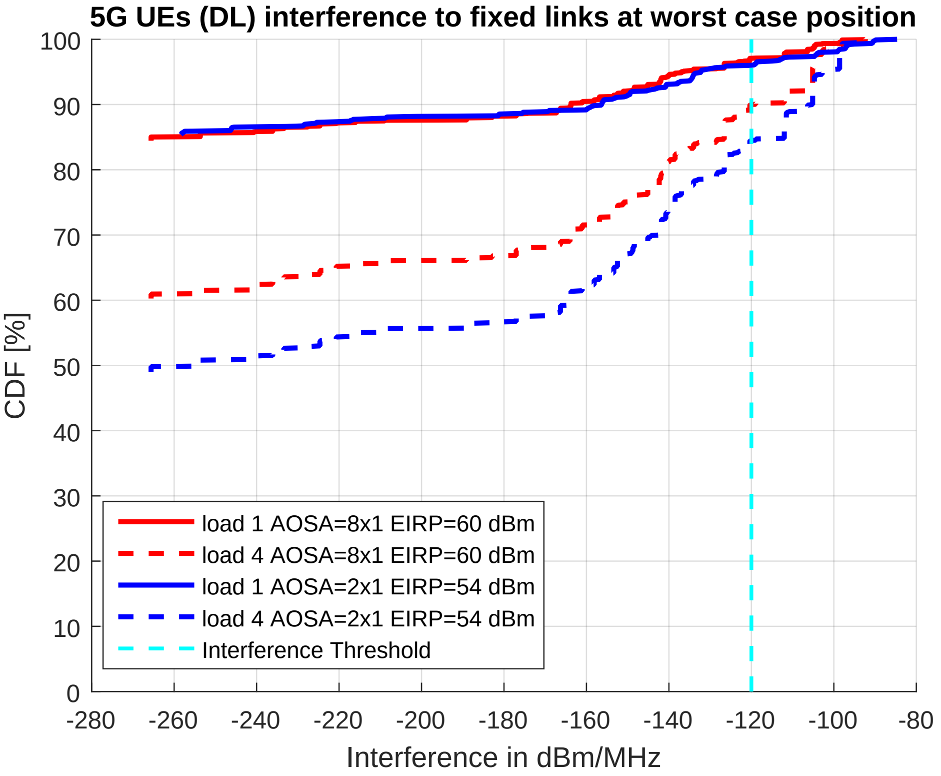

Figure 5.7: CDF of DL interference generated at the fixed link for different number of antenna elements

Worst Case FL Position/AOSA 2x1 vs 8x1/EIRP 60dBm/DL				
Load	**All Layers (Mbps)**	**Micro layer (Mbps)**	**Center Macro Layer (Mbps)**	**Surrounding Macro Layer (Mbps)**
Load1 (2xRL) AOSA 2x1	13.2	96.5	11.26	12.579
Load1 (2xRL) AOSA 8x1	13.309	98.12	11.29	12.629
Load4 (10xRL) AOSA 2x1	5.448	86.48	4.474	4.905
Load4 (10xRL) AOSA 8x1	9.455	92.227	9.1	9.06

Table 5.6: The 5^{th} percentile throughput of UE for different number of antenna elements in the antenna array in DL

of the users is affected quite significantly due to the beam being less directive and generating more inter-cell interference.

5.5 Reduced Micro-Base Station EIRP

The maximum allowed EIRP of the micro layer antennas was reduced to 40dBm while keeping the number of elements of the antenna array unchanged (AOSA 8x1). A comparison of the generated interference at the fixed link for the two values of maximum allowed EIRP, 40 and 60 dBm, is presented in figures 5.8 and 5.9 (UL and DL respectively). In tables 5.7 and 5.8 the effect of the decreased maximum EIRP can be observed on the user throughput. The percentage of traffic carried by the layers for all loads:

- Central Macro Layer serving : 23.3% of the traffic
- Surrounding Macro Layer serving : 57.4% of the traffic
- Micro Layer serving : 19.3% of the traffic

As a consequence of decreased EIRP, less traffic is served by the micro layer than compared to previous experiments. The served traffic in the DL is causing less interference to the fixed link but that comes at the cost of having lower throughput for the UEs associated with the micro layer. The simulator uses DL RSRP measurements to associate users to their corresponding base stations, thus the results in UL are also affected.

5.6 User Distribution Case 2 ((UD 2)

In this experiment, all the parameters were kept the same as for the experiment described in Section 5.2 of this chapter. However, users were also deployed

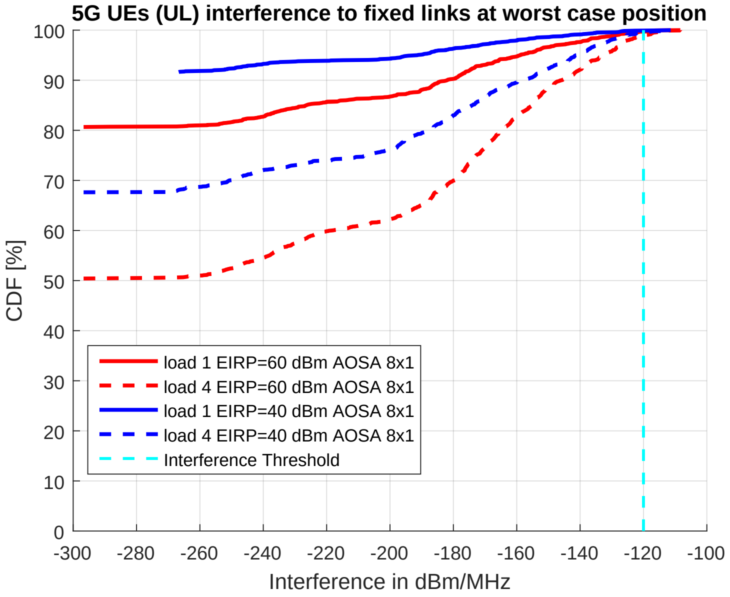

Figure 5.8: CDF of UL interference generated at the fixed link for different allowed maximum EIRPs

indoors, and the cell selection offset parameter of the micro-cells was decreased to 3dB. These changes influenced the amount of traffic carried by every layer:

- Central Macro Layer serving : 40.5% of the traffic
- Surrounding Macro Layer serving : 50% of the traffic

Worst Case FL Position / AOSA 8x1/ EIRP 40dBm vs 60dBm /UL				
Load	**All Layers (Mbps)**	**Micro layer (Mbps)**	**Center Macro Layer (Mbps)**	**Surrounding Macro Layer (Mbps)**
Load1 (2xRL) EIRP=40dBm	19.299	74.009	19.187	18.951
Load1 (2xRL) EIRP=60dBm	13.309	26.389	19.4	19.154
Load4 (10xRL) EIRP=40dBm	8.581	72.577	8.248	8.333
Load4 (10xRL) EIRP=60dBm	9.455	24.397	9.1	9.06

Table 5.7: Effect of loads and micro-base station antenna configuration on UE throughput in UL

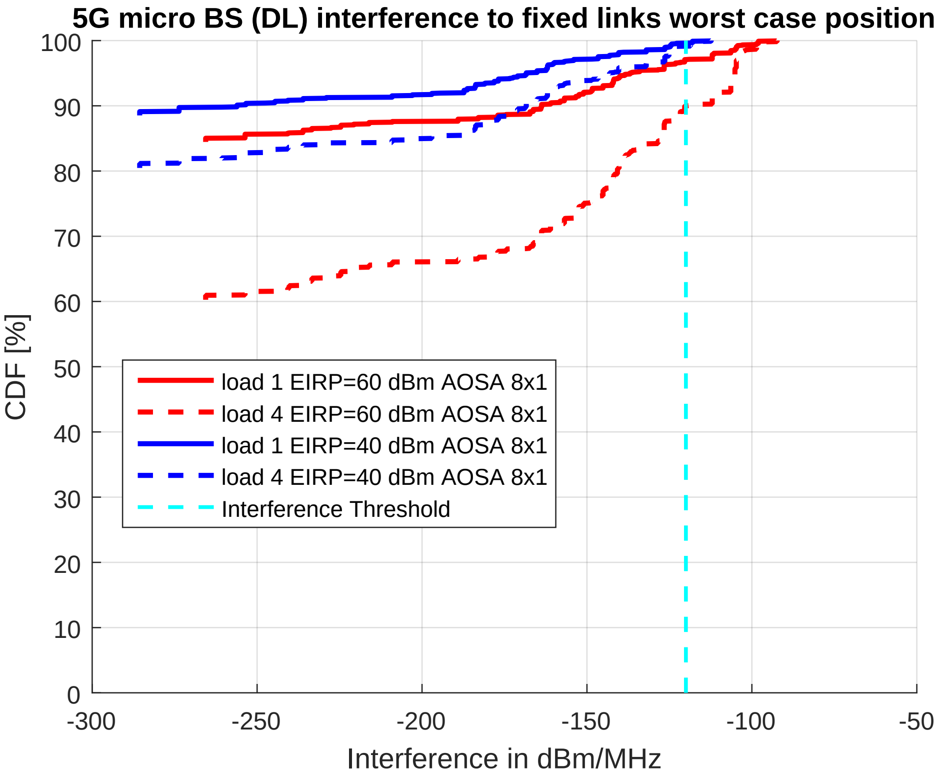

Figure 5.9: CDF of DL interference generated at the fixed link for different allowed maximum EIRPs

Worst Case Fl Position / AOSA 8x1 / EIRP 40dBm vs 60dBm /DL				
Load	**All Layers (Mbps)**	**Micro layer (Mbps)**	**Center Macro Layer (Mbps)**	**Surrounding Macro Layer (Mbps)**
Load1 (2xRL) EIRP=40dBm	12.188	83.74	10.712	12.629
Load1 (2xRL) EIRP=60dBm	13.309	98.12	11.29	19.154
Load4 (10xRL) EIRP=40dBm	3.605	53.178	2.99	3.445
Load4 (10xRL) EIRP=60dBm	5.8425	92.2201	4.73	5.19

Table 5.8: The 5^{th} percentile throughput of UE for different allowed EIRP of the micro layer in DL

- Micro Layer serving : 9.5% of the traffic

Figures 5.10 and 5.11 present a comparison of this experiment (UL and DL respectively) to that of outdoor distribution only referred to as UD 1 in the legend of the plots. Similarly to the previous sections, tables 5.9 and 5.10 show the user throughput in UL and DL respectively.

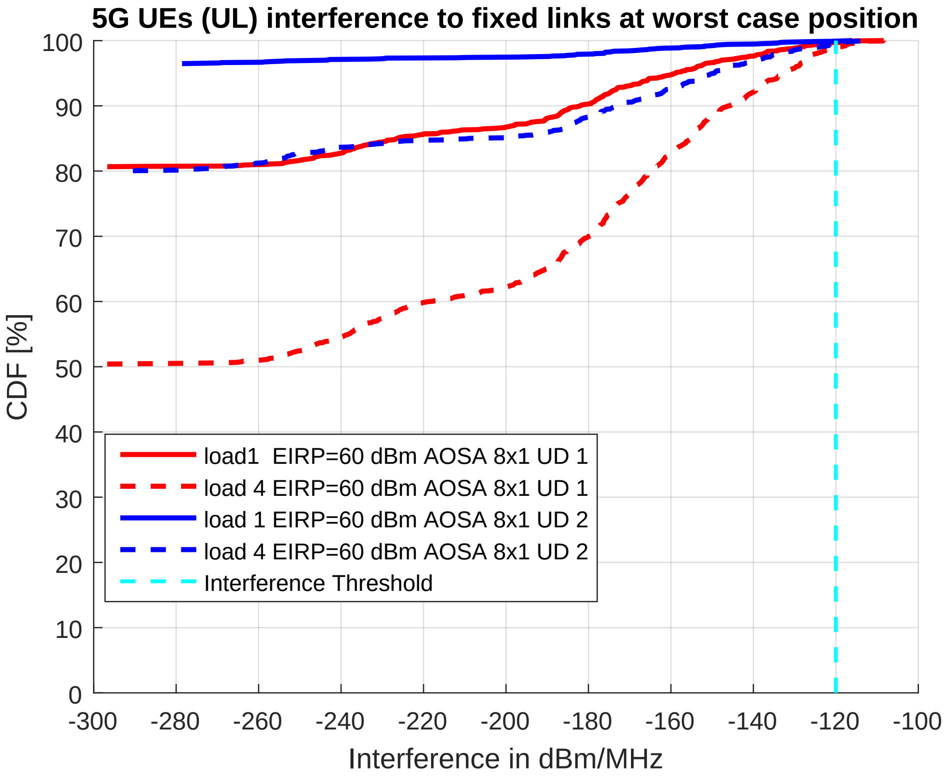

Figure 5.10: CDF of UL interference generated at the fixed link for different user distributions

Applying the new user distribution and decreasing the Cell Selection Offset, meant that less traffic was served by the micro layer. By allowing indoor deployment of user nodes, the users were deployed at higher floors at the central area of the map, making them too far from the micro base stations. In addition to that, the macro base stations had an advantage of using lower frequency than the micro layer, making wall penetration easier. As a result, the interference at the fixed link decreased significantly. The price for that was an expected decreased UE throughput.

FL Position (-15,-210,35)(-15,-20,35) / AOSA 8x1 / EIRP 60dBm /UL				
Load	**All Layers (Mbps)**	**Micro layer (Mbps)**	**Center Macro Layer (Mbps)**	**Surrounding Macro Layer (Mbps)**
Load1 (2xRL) UC 2	11.218	36.855	9.9548	12.099
Load1 (2xRL) UC 1	13.309	26.389	19.4	19.154
Load4 (10xRL) UC 2	2.191	36.682	0.5874	4.809
Load4 (10xRL) UC 1	9.455	24.397	9.1	9.06

Table 5.9: The 5^{th} percentile throughput of UE for different user distributions in UL

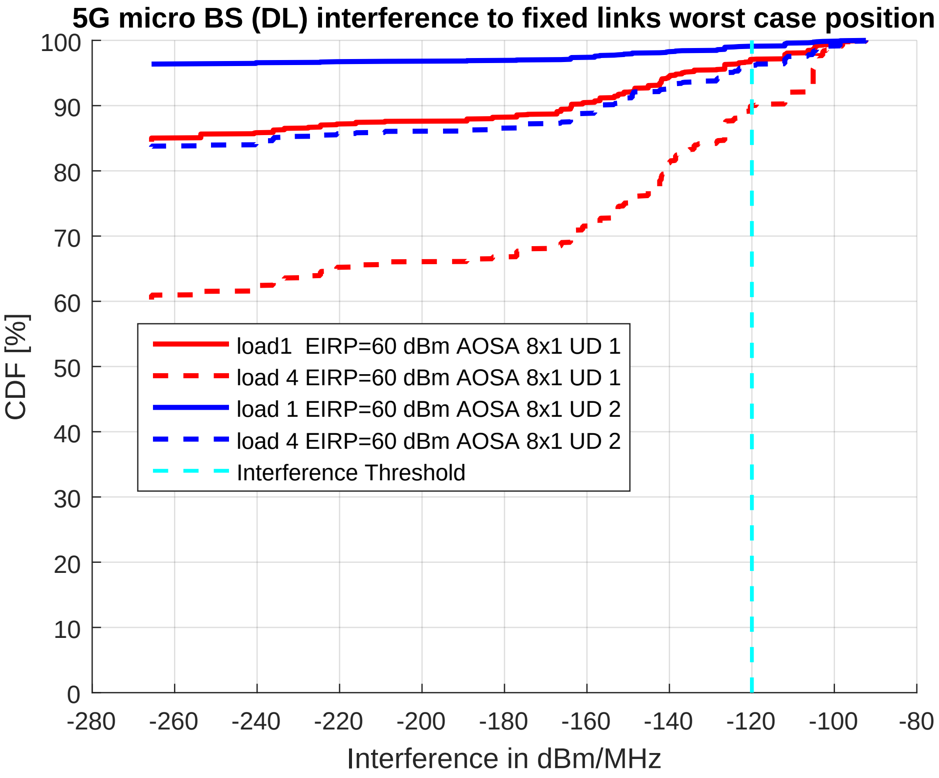

Figure 5.11: CDF of DL interference generated at the fixed link for different user distributions

FL Position (-15,-210,35)(-15,-20,35) / AOSA 8x1 / EIRP 60dBm /DL				
Load	5^{th} **percentile of UE throughput (Mbps)**	5^{th} **percentile of UE throughput (Mbps)**	5^{th} **percentile of UE throughput (Mbps)**	5^{th} **percentile of UE throughput (Mbps)**
Load1 (2xRL) UD 2	9.1203	98.953	7.973	10.145
Load1 (2xRL) UD 1	13.309	98.12	11.29	19.154
Load4 (10xRL) UD 2	0	92.603	0	0.089
Load4 (10xRL) UD 1	5.8425	92.2201	4.73	5.19

Table 5.10: The 5^{th} percentile throughput of UE for different user distributions in DL

Chapter 6

Conclusions and Future Work

In this chapter the conclusion of the results obtained will be presented.

6.1 Interference Related Conclusions

To reach the conclusion for the study three criteria were considered:

- Strict sharing criteria: interference below threshold for 99% of the time [18]
- Relaxed sharing criteria: interference below threshold for 90 % of the time [18]
- Middle value: interference below threshold for 95 % of the time (assumed for comparison)

Figures 6.1 and 6.2 summarize the results (for uplink and downlink respectively) of the experiments presented in Chapter 5. As it can be observed that strict criteria is only satisfied with low EIRP or for the UD2 with low load. The more relaxed sharing criteria was satisfied for all the uplink cases and for downlink scenarios of low load. It was also satisfied for for DL of low EIRP and for UD2 when higher loads were used. The middle criteria was met for systems with low load or with low EIRP. Based on these observations, it is clear that threshold criteria is difficult to achieve, which makes coexistence difficult. However, in case that the micro cells would only be used for uplink in a Frequency Division Duplexing (FDD system), or the traffic load carried by the micro-cells would be controlled; strict coexistence would be possible.

6.2 UE Throughput Trends

The trend in the UE throughput can be observed through figures 6.3 and 6.4 that represent the change in percentage of the 5^{th} percentile of the user throughput in the micro layer, as compared to the AOSA 2x1 experiment. From the figures it can be seen, that by increasing the number of antenna elements in the micro base station antenna (AOSA 8x1) would improve the UE throughput as well as decrease the interference generated at the fixed link. A trade off can be observed between having lower interference at the fixed link and the UE throughput in DL for the EIRP 40 dBm experiment. For the same experiment in UL, an increased UE throughput can be observed as the users have better SINR conditions, considering that there is less inter-cell interference (less traffic carried by the micros) and that the worst case UE is closer to access point. For the UD2 experiment, an improvement in UE throughput for both UL and DL can be observed. In addition to that, this experiment has better interference conditions at the FL; this coming at the expense of the amount of traffic carried by the micro layer.

6.3 Future Work

In order to further investigate the effects of beamforming, antenna arrays of larger sizes in terms of antenna elements could be used. In addition to that, a scenario that includes more fixed links operating at the same time could be studied to examine the effects on the 5G network's performance.

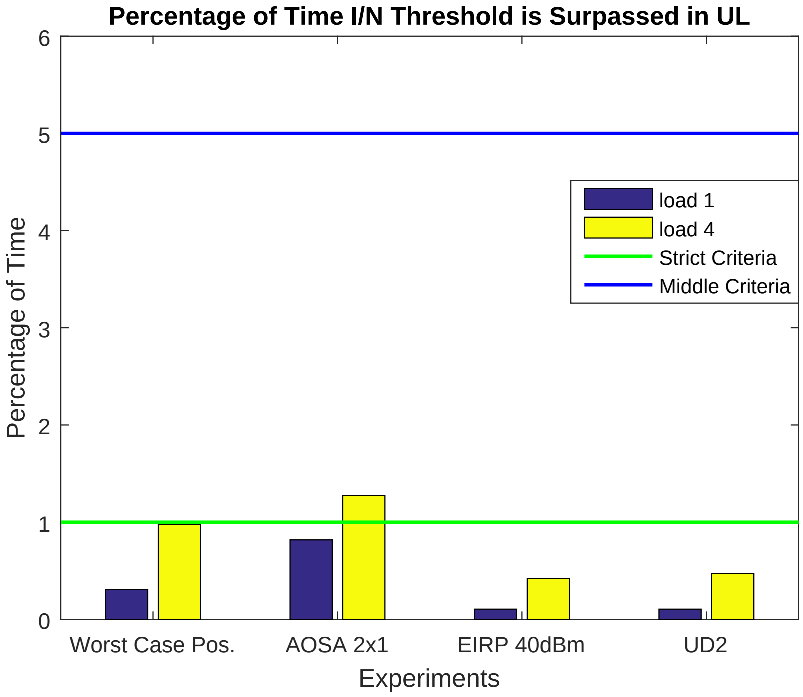

Figure 6.1: Showing the percentage of time for which every experiment crosses the I/N threshold for UL

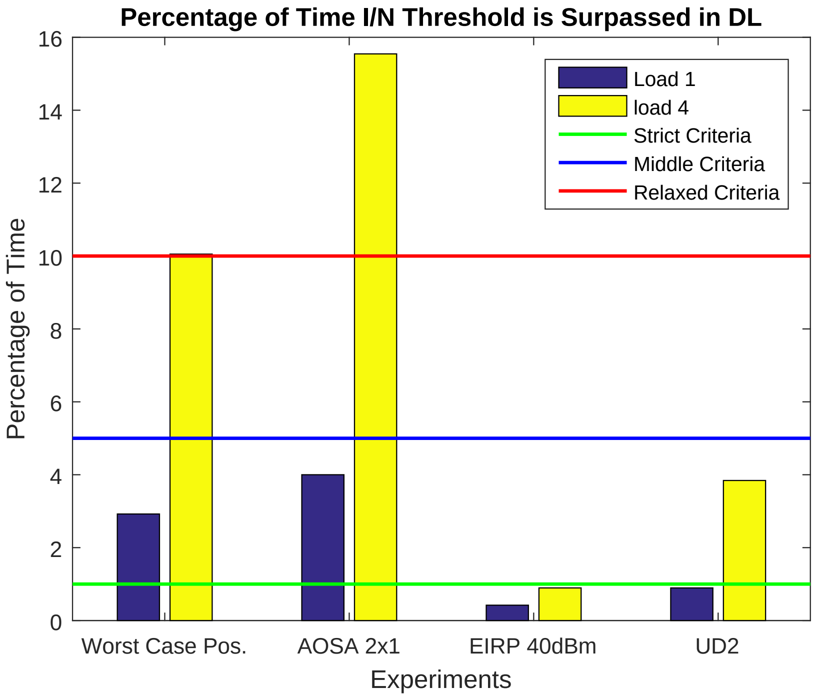

Figure 6.2: Showing the percentage of time for which every experiment crosses the I/N threshold for DL

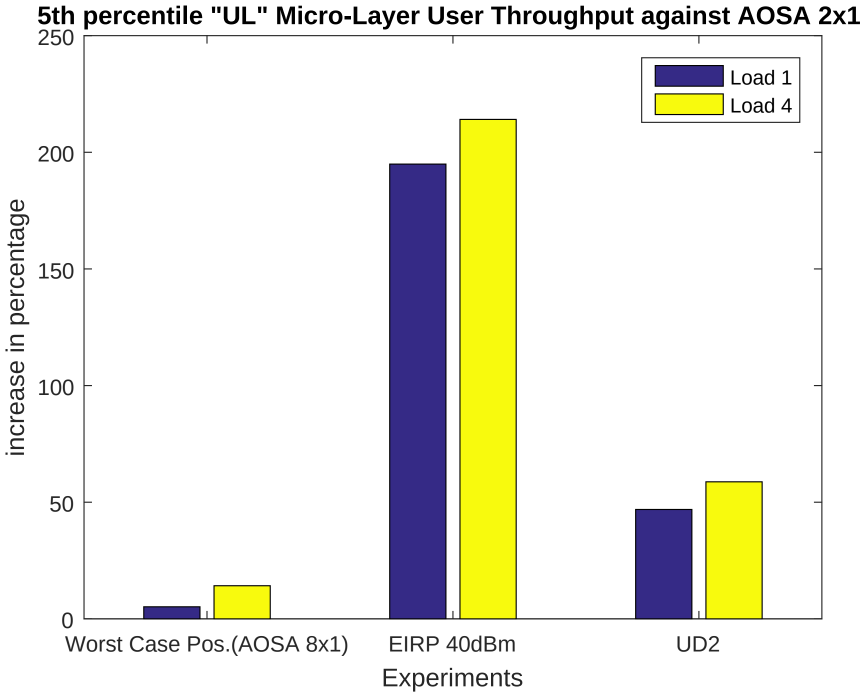

Figure 6.3: Percentage increase in 5th percentile user throughput for uplink

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