FACULTY OF ENGINEERING
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Evaluating the human exposure of a UAV-aided network

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Dankwoord

todo

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Glossary

Isotropic Radiator A theoretical source of electromagnetic waves which radiates the same intesity in all directions.. 18

spurious radiation according to the thefreedictionary.com: Any emission from a radio transmitter at frequencies outside its frequency band. Also known as spurious emission.. 16, 17

Acronyms

1

Introduction

1.1 Outline of the issue

Society is constantly getting more and more dependent on electronic communication. On any given moment in any given location, an electronic device can request to connect to a bigger wireless medium. Devices need more then ever to be connected starting from small IOT sensors up to self-driving cars.

Once again it becomes clear why we're on the eve of a new generation of cellular communication named 5G. This new technology is capable of handling millions of connections every square meter while satisfying only a few microseconds of a delay and providing connections up to 10Gbps [1].

Also in exceptional and possibly life-threatening situations, we rely on the cellular network. For example during the terrorist attacks in Zaventem, a Belgian city. Mobile network operators saw all telecommunications drastically increasing causing moments of contention. Some operators decided to temporarily exceed the limited exposure in order to handle all connections. [2]

Electromagnetic exposure can however not be neglected. Research shows how exesive electromagnetic radiation can cause diverse biological side effects [3]. Because of public concern, the World Health Organization had launched a large, multidisciplinary research effort which eventually concluded that there was no sufficient evidence that confirmed that exposure to low level electromagnetic fields harmfull is [4].

1.2 Objective

In this master dissertation the electromagnetic exposure of a user is investigated taking all prominent sources into account which include the user's own mobile device, basestations and other users their User Equipment (UE).

In order to determine the magnitude of exposure to which users in a certain area are exposed, various values need to be known. Not only the used technology but also the position of users and basestations need to be known. To make this research possible, an existing planning tool is used which gives insight in users and basestation distributions. Bitrates of idividual users, power useage of the different electronical devices and which basestations handels which users. The tool describes in other words a fully configured network. In this way, all needed parameters will be known.

The electromagnetic exposure will then be analysed by applieing the tool in different scenarios. During the simulations it is investigated how various input variables influence the network.

The calculation of electromagnic exposure originating from base stations is discussed in variously discussed in litterture. Papers who convert electromagnetic exposure into a single value is rather limited. Not only how electromagnetic exposure behaves but also related values like power consumption or even coverage.

research question 1: How can a Unmanned Arial Base Station (UABS) network be optimized to minimize global exposure and overal power consumption? What are the effects on the network?

research question 2: What are the advantages and disadvantages of a model as described in research question 1 compared the the already existing pahtloss oriented model.

research question 3: How does the UABS fly height influence uplink and downlink exposure?

1.3 Structure

TODO: update this section

The following chapter 2 exists of several succesive sections explaining how the electromagnetic exposure of a single human being is calculated. The first section 4.2.2 explains how the exposure is calculated between a user and a single femtocell. Section 4.2.2 defines how to combine all exposures from the different femtocells towards a single users. Finaly, section **??** explains how directional antenna's are taken into account.

2

State of the art

2.1 Deployment tool for an UAV network

The tool is also able to calculate a more precisly pathloss since

The calculation of electromagnetic radiation require several input values which need to be known. To fullfill this, a deployment tool developped by The WAVES research group at UGent has therefore developed a deployment tool which distributes UAVs equiped with femtocell base stations. These kind of UAVs will be called a UABS.

A deployment tool for an UAV-aided emergency network is described in [5]. The idea is that in case of a disaster, the existing network might be damaged and won't be able to handle all users who are trying to reconnect to the backbone network. A fast deployable network is suggested in [5] by using UABSs. These are UAVs equiped with femtocell base stations and will be distributed over the disaster area, orchestrated by the deployment tool.

The deployment tool will try to calculate the optimal placement for each UABS and requires therefore a description of the area where the UAV-aided network needs to be deployed. This is done with the use of so-called shape files. Theses files contains tree dimensional descriptions of the buildings present in the area and are key values in approaching results as realistic as possible. Furthermore, the tool also requires a time period and a configuration file containing technical specifications of the type of UABS that is being used. The tool will thereafter randomly distribute users over the area and assigns a certain bitrate to them.

In a second phase, the optimal possition for each UABS is calculated. This is done by trying to locate a UABS above each active user. Two options are possible. If a flighheigt is defined, a basestations is placed above each user at the given height, unless a building is abstructing it's location. Then, no basestation will be located above that user. If no flighheigt is given to the tool, the basestation is located 4 meters above the outdoor user or 4 meters above the building where the indoor user resides. The later is only allowed if the suggested heigt remains below the given maximum allowed height.

Finally, all UABS are sorted on wether they were active or not, followed by the increasing pathloss from each UABS to that user. So the algirtm starts by checking for each active UABS if it can cover the user. If this is the case, the user will be connected to this UABS. If not, the second active basestation with a (slightly) worse pathloss is considered. If no active basestation is suitable, inactive UABS are considered. The user remains uncovered if no UABS is found. The reasoning behind first only considering basestations that are already active is the hight cost that comes allong with each drone.

Up till now, the tool has only calculated some suggestions. The effective provisioning is done in the fourth phase where drones are sorted by the ammount of users it covers. As long as UABS are available in the facility where they reside, UABS are provisioned and its users are marked as covered.

2.2 Electromagnetic exposure

2.2.1 Electromagnetic field radiation

People in a telecommunication network are exposed to far field electromagnetic radiation originating from basestations and other UE. Network planners need to make sure that the the electromangteic fields (expressed in V/m) does not exceed limitations enforced by the government. These limits are location dependend. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) suggests a limitation of 61 V/m. In Brussels, for example, is a far more restrictive limitation enforced of 6 V/m for all sources [6, 7].

todo: gedetailleerde uitleg in J23.

Specific absorption rate

Specific Absorption Rate (SAR) represents the rate that electromagnteic energy is absorption by human tissue with the thermal effect as it's most important consequence. The ICNIRP has concluded that the threshold effect is at 4 W/kg meaning that any higher absorption rate would overwhelm thermoregulatory capacity of the human body. Whole body values between 1 and 4 W/kg increases the temparture of human body less then 1°C which is proven not to be harmfull for a healthy human being[8]. Thereafter, a safety margin is introduced to tackle unknown variables like experimental errors, increased sensitivity for certain population groups and so on. This results in a whole body SAR_{10g} of $0.8W/kg$ and $2W/kg$ for localized SAR_{10g} values for the head and torso aera [9].

todo: de 10g slaat al op localized, vandaar dat het maar 10g is, anders is het whole-body todo: we kunnen niet sar10gmax gebruiken want This means that the SAR calculations will be worst-case and possibly an overestimation of the real localised SAR. (herwoorden voor plagiaat) Human exposure caused by downlink traffic is a not negligible asset. However, telecommunications is not a one-way street. When connecting to a UMTS network, also uplink data caused by the UE should be considered. UE generates, just like femtocells, electromagnetic waves to which a user is exposed. A part of this radiation goes to the femtocell, another part enters the body of its user. How much electormagnic strenghts enters the body is defined as SAR and is measured with 10g biological tissue which represents the human skin. This value will from now on be expressed as SAR_{10g}. A mobile device induces two types of exposure: local and whole-body.

2.2.2 Related work

The goals of this master dissertation is the investigation of electromagnetic exposure considering all sources. Three types of sources are considered: electromagnetic radiation caused by basestations, near field radiation from the users own device and far field radiation originating from other users their equipment. This electromagnetic radiation is thereafter absorbed by the human body which will be expressed in SAR values. Different type of SAR-values exist like whole body SAR which is the average absobed radiation over the entire body. Also more precise SAR-values exist which go under the name of localized SAR-values and only cover a part of the human body like the head.

Several papers exist calculating exposure originating from certain sources but very limited research has been done covering the whole picture. In [10] is described how electromagnetic radiation of several WiFi access points is being calculated. The authors of [6] used this knowledge to investigate electrmangetic exposure originating from basestations in a more outdoor environment. [7, 11] addresses the fact that also uplink (UL) traffic from the user's device should be considered. They therefore investigated indoor exposure. They did not only consider the electromagnetic radiation but also how much is absorbed by the body wich will be expressed as specific absorption rate. Since the authors only covered voice calls, uplink SAR was expressed in localized SAR values while the downlink traffic is expressed in whole body SAR. With the advent of 5G, a paper [12] has been published describing how localized SAR values are achieved from all sources. More precisly: all mobile phones and all basestations in the network after which they converted the electromagnetic exposure to localized SAR values. Finally, [13] describes how both UL and downlink (DL) traffic can be converted in whole body SAR values making it possible to achieve an overall picture. They applied this formula howevery only for the user's own device.

In a realistic network like the used deployment tool, some users are calling while annother part is using other type of telecommunication services like browsing the web. Therefore, all absorbed electromagnetic exposure should be expressend in whole body SAR while still covering all sources.

2.3 Technologies

2.3.1 LTE

The tool make usage of Long-Term Evolution (LTE) which is by the general public better known as 4G which allowes better UL and DL dataspeeds compared to its predecessors and is based on an all IP architecture. LTE can cover macrocells supporting cell sizes ranging from 5 km up to 100 km. These type of antennas are usally attached to transmission towers along highways or on top of buildings. LTE supports however also smaller cells like femtocells covering only a few hunderd meters. They are therefore more portable, require less energy and won't require a telecommunication operator because of it's simplicity. Femtocell basestations are therefore used by the deployment tool. Futher, LTE also support both frequency division duplex (FDD) and time division duplex (TDD).

FDD makes simultanious UL and DL traffic possible by assiging different frequencies within the frequency range to both data streams. A small guardband is used between UL and DL directions in other to prevent interference.

TDD allowes UL and DL by splitting the time domain. Meaning that both traffic directions use the same frequency and therefore alternatly (in time) use the frequency spectrum. Again, a small time intervall is used to prevent interference in case of a slightly bad timed syncronization.

This master dissertation will make usage of FDD.

2.3.2 Type of antenna

An important part of this master dissertation is the type of antennas that will be used by the basestations. Since the deployment tool make usage of drones in other to possition the femtocell basestations in the right posistion, conventional sector antennas as used by terestrial transmission towers won't be a good idea. The characteristics of microstrip antennas will therefore be investigaged.

Microtstrip anntenas provide several advantages compared to traditional antennas [14, 15]. Microstrip antennas are lightweight, low in cost and thin causing them to be more aerodynamic which is a usefull feature since the atennas will be attached to flying drones.

A basic microstrip antenna like figure 2.1 consisting a ground plane and a radiating patch which are seperated with a dielectric substrate. Several constructions exist like microstrip patch antenna, microstrip slot antenna and printed dipole antenna which has all similar characteristics. They are all thin, support dual frequency operation and they all have the dissadvatage of spurious radiation.The microstrip patch and slot antenna support both linear and circular polarization while the printed dipole only support linear polarization. Further is the fabrication of a microstrip patch antenna considered to be the easiest of its competitors.

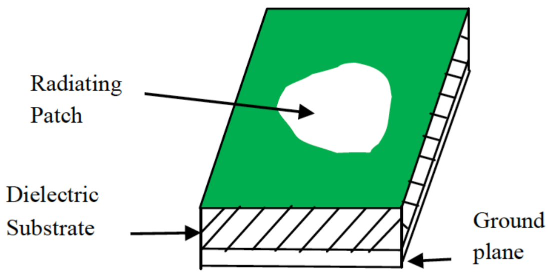


Figure 2.1: General design of a microstrip antenna

The microstrip antenna requires besides the groundplane, dielectric substrate and the radiation pach also a feed line. Several feeding techiques exists of which the most popular are: coaxial probe feeding, microstrip line and apeture coupling. (todo: more refs? gebruik nummer twee van J13 (p2))

A first feeding method is with the usage of a coaxial cable where the outer conductor is attached to the ground plane and the inner conductor to the radiationg patch. Modelling is however difficult, escpecially for thic substrates as will be used in this master dissertation. A second option is the usage of a microstrip line. This type of feeding is much easier to model since the microstrip line can be seen as en extenstion of the radiating patch. A dissadvatage is that the antenna will transmit at frequencies outside the aimed band which is also known as spurious radiation which therefore limits bandwith. A thirt is proximity coupling which has the largest bandwidth and low spurious radiation. It consist however of two dielectric substrates causing the overall thickness of the antenna to increase as well as it's fabrication difficulty. (todo: tekst te weinig, bespreek ook apperture coupled attenna (zelfde paper als de rest)) The increasing usage of the microstrip patch antennas can be explained by it's easy fabrication and lightweightness and therefore knows a widespread application in the millitary, global possitioning systems, telemedicine and WiMax applications and so on. The authors also state that some of the dissadvatages like lower gain and power handling can be solved with the usage of an array configuration.

At last, also the materials of the antenna need to be considered. The radiationg patch mainly rectengular. In fact is any given shape possible but other configurations then a cirle or a rectangle will require large nummerical computation [15]. The radiating patch is usualy made of a thin layer of either gold or copper [15, 16]. Further is also the dielectric constant of the substrate important which typially varies between 2.2 and 12. Finding a good dielectric depends how the antenna will be deployed and it's usage. According to [16] will a lower dielectric constant with a thic substrate result in better performance, better efficiency and larger bandwiths. On the other hand will according to [15] a larger dielectric constant reduce de dimensions of the antenna which is also usefull when attaching the antenna to a limited surface. Therefore is opted for a glass as dielectric substrate with a constant of 4.4.

3

Scenarios

3.1 A single user

A first scenario will investigate how SAR_{10g} is influenced in an isolated environment meaning there is nor influence from other base stations nor other UE. The tool will provision one single drone and position it directly above the user. These results will however depend on the position of the user. If the randomly generated location of the user is indoor, the expected height of the user is half of the height of the building. Investigating the electromagnetic exposure and the drone power consumption depends however on the distance between both user and UABS. For a more consistent result, the user will therefore be positioned outside when systematically increasing the fly height. Another considered variable is the transmitting power of the UABS.

This scenario deducted with two type of antennas. First, an Isotropic Radiator will be used and thereafter a realistic antenna. It is expected that after the introduction of an realistic antenna, the user coverage will decrease.

The tool will therefore run different simmulations. The first group is with an Isotropic Radiator. A first set of simmulations is with a fixed flyheight of 100m which is the proposed flyheight by [5] but with a variable transmit power of the base station. The set investigates the influence of a variable flyheight with a constant maximum transmit power of 33dBm as defined in [5].

Both series will also be investigated with a realistic radiation pattern. The user coverage will be compared.

3.2 Increasing traffic with only one drone available

The previous scenario will be extended for an increasing amount of users.

3.3 Increasing traffic with an undifend amount of drones

When more drones are available, an optimization strategy can be applied. The tool checks the capacity of the basestations and decides thereafter wich basestation the user should be connected to. The original algorithm checks all pahts between the user that need to be connected with all drones. Thereafter, the drones which path experience the least pathloss and still has the capacity to cover an addition user will be selected. The authors from [6] proposed however annother optimization strategy which tries to minimize electromagnetic exposure and power consumption.

The input variables flyheight, transmit power and number of users will be used to see how electromagnetic exposure, power consumption en number of drones are influenced for different optimization strategies and type of antennas.

Since there is no fixed budget limitation, the number of drones are unlimited. The tool will therefore try to connect each user and coverage will be expressed in number of drones required to cover as much users as possible instead of having a limited number of drones as in scenario and therefore has only a limited coverage expressed in percentage.

4

Methodology

4.1 Tool

The goals

4.2 Electromagnetic exposure

4.2.1 Calculation of total whole body SAR10g

The overall SAR_{10g}^{head} can be calculated by a simple sum of individual SAR values [12]. The position of the phone is however unknown. This is because the tool assigns a bitrate to a user depending on the service he is using meaning that users in the network are not only calling but are able of browsing the web aswell. Since calculating the SAR_{10g}^{head} would imply the phone is being hold next to the head, this would result in incorrect conclusions. The induced electromagnetic radiation will therefore be expressed in function of the entire body.

$$SAR_{10g}^{wb,total} = SAR_{10g}^{wb,ul} + SAR_{10g}^{wb,dl} + SAR_{10g}^{wb,neighbours}$$

The first parameter, $SAR_{10g}^{wb,ul}$, will indicate the absorbed electromagnetic radiation in the whole body originating from the users own phone whereas the second parameter $SAR_{10g}^{wb,dl}$ will represent the absorbed electromagnetic radiation by all the basestations in the considered area. As last, $SAR_{10g}^{wb,neighbours}$ specifies the same as the previous but with electromagnetic radiation originating from other users their UE.

4.2.2 Calculating downlink expsure

Calculating exposure towards a single femtocell

To determine the total exposure of a single human being or even of the entire network, the electric-field $\vec{E}$ of a single femtocell i should be calculated. The formula to determine this electromagnetic value E (expressed in V/m) for a specific location is given in equation 4.1.

$$E_i = 10^{\frac{EIRP-43.15+20*\log(f)-PL}{20}} \tag{4.1}$$

TODO: write EIRP - Attenuation (A t)
This formula requires several values to be known. The frequency f on which the tranmitting antenna is operating is expressed in MHz. The other values are explained in 4.2.2 and 4.2.2.

Equivalent Isotropical Radiation Power A directional antenna can achieve gain by focussing it's input power into certain directions. By doing this, some areas experience a decreased radiation power in order to gain radiation power in the other privileged areas. If a theorical isotropic radiator todo: uileggen wat isotropic radiator isexisted, the Equivalent Isotropical Radiation Power (EIRP) is the power it would require to achieve the same power level as the actual antenna's main lob. The main lob is the area of the directional antenna experiencing the most gain. This EIRP value can be calulated as described in eq 4.2.

$$EIRP = P_t + G_t - L_t \tag{4.2}$$

Pathloss At last, formula 4.2 requires the path loss (dB). In order calculate the path loss, an appropiate propagation model is required. Several propagation models exists and the tool already uses the Walfish-Ikegami model [5]. This is because the Walfish-Ikegami model performs well for femtocell networks in urban areas. The chosen propagation model consists of two formulas depending on whether a free line of sight between the user and the basestation exist or not. Both formulas expect a distance in kilometer.

input power hangt af van bs tot bs.

Attenuation todo

Combining exposure

Since the user location in the UAV-aided network is known, the exposure is not calculated for gridpoints but for active users. compared to gridpoints in ref state of art manets -> exosure combineren

$$E_{tot} = \sqrt{\sum_{i=1}^{n} E_i^2} \tag{4.3}$$

Converting downlink electromagnetic exposure to SAR_{10g}^{wb}

Only values for wifi are known but the frequency of LTE is very similar. [13]

4.2.3 Uplink exposure

specific absorption rate into the head

todo: de 10g slaat al op localized, vandaar dat het maar 10g is, anders is het whole-body todo: we kunnen niet sar10gmax gebruiken want This means that the SAR calculations will be worst-case and possibly an overestimation of the real localised SAR. (herwoorden voor plagiaat)

Human exposure caused by downlink traffic is a not negligible asset. However, telecommunications is not a one-way street. When connecting to a UMTS network, also uplink data caused by the UE should be considered.

UE generates, just like femtocells, electromagnetic waves to which a user is exposed. A part of this radiation goes to the femtocell, another part enters the body of its user. How much electormagnic strenghts enters the body is defined as SAR and is measured with 10g biological tissue which represents the human skin. This value will from now on be expressed as SAR_{10g}.

A mobile device induces two types of exposure: local and whole-body. Whole-body exposure can be neglected compared to the much higher local exposure[**?**]. From now on, SAR_{10g} implicitly means local exposure.

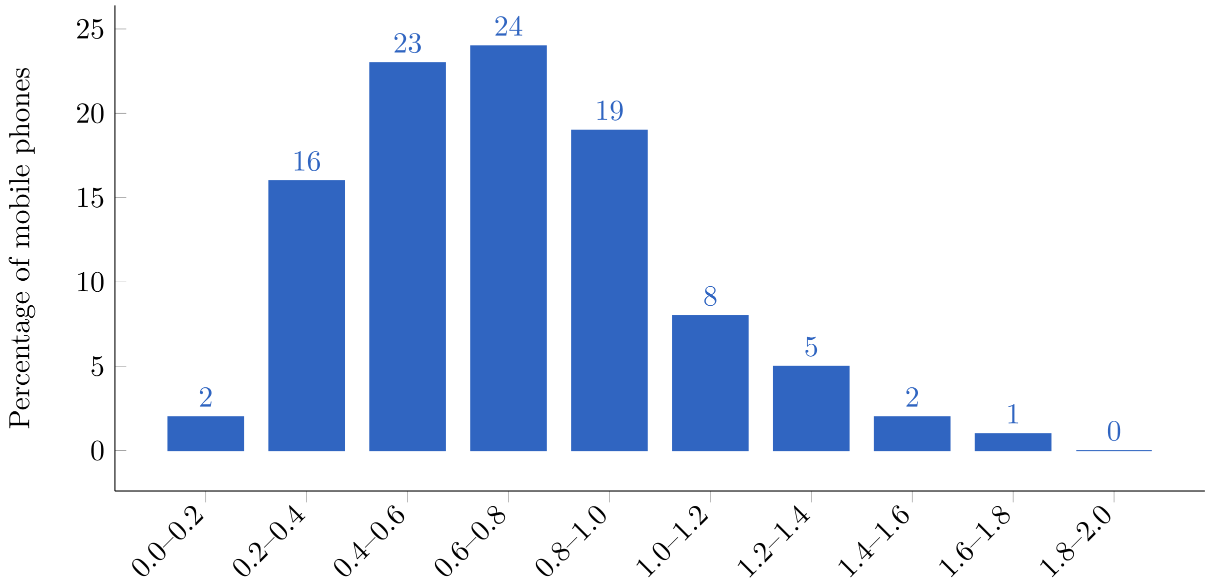
International Electrotechnical Commission (IEC) defines in IEC:62209-2 a maximum for a 10g tissue SAR_{10g}^{max} as 2 W/kg and a maximum for a 1g tissue SAR_{1g}^{max} as 1.6 W/kg. Most countries, including Belgium, enforce the 10g model and will, therefore, be the point of reference for this master dissertation.

The SAR_{10g} values are phone dependent. The reported values by companies of mobile devices are worst-case scenarios meaning that the values are measured when the phone is transmitting at maximum power. This is an understandable decision but won't result in a realistic scenario since modern cellular networks use power control mechanisms to prevent over radiation of a nearby device. UE will therefore never use more energy than necessary to maintain a connection.

To compensate for this overestimation, the actual SAR_{10g} of each user will be predicted. These will, however, remain an estimation since the position of the phone related too the head differs from user to user. For example, by holding the phone differently, a hand can absorb more or less electromagnetic radiation. TODO: bron.

$$SAR_{10g} = \frac{P_{tx}}{P_{tx}^{max}} * SAR_{10g}^{max} \tag{4.4}$$

Equation 4.4 is used to predict the actual SAR_{10g} of a certain user. The SAR value is different for each mobile device. An average is calculated based on 3516 different phones from various brands using an up-to-date German database [17]. When the phone is positioned at the ear, an average of 0.7 W/kg is found with a standard deviation of 0.25 W/kg which are very similar results as in Ref. [**?**]. The median of 0.67 is used.



todo: xlabel, zeggen dat bovengrens niet inbegrepen is en titel geven.

The P_{Tx}^{max} is for LTE and UMTS 23 Dbm [18, 7].

To predict the effective transmitted power by the UE, the folowing equation is used:

$$P_{Tx} = P_{sens} + PL \tag{4.5}$$

Specific absorption rate for the whole body

4.2.4 Defining an antenna

A microstrip patch antenna is chosen because it allowes easy production but more important it has a low weight and has a thin profile causing it to be very aerodynamic which is usefull when attaching it to an UABS [19].

The dimensions of the antenna depend on the frequency it is operating and the characteristics of the used substrate. The antennas will be radiationg at a center frequency f_0 of 2.6Ghz. A substrate with a higher dielectric constant and low height reduces the dimentions of the antenna and a lower dielectric constant with a high height improves antenna performance. The used substrate will therefore be glass with a dielectric constant of 4.4. The height of the antenna is also limited to 2.87 mm in order to keep the antenna light and compact [15]. The formulas from [15] are [16] applied.

description	symbol	value
center frequency	f_0	2600 Hz
dielectric constant	ϵ_r	4.4
heigt of the substrate	h	0.00287m

Table 4.1: Overview of configuration parameters

$$W = \frac{c}{2 * f * \sqrt{\frac{\epsilon_r + 1}{2}}}$$

Which C the speed of light, f being the center frequency of 2600 Hz and a dielectric contanst of $\epsilon_r = 4.4$ a width of 3.51 mm is achieved.

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} * \left(1 + 12 * \frac{h}{W}\right)^{-\frac{1}{2}}$$

The height of the dielectric is choses to be 2.87mm in order to keep the antenna smal and light**??**. ϵ_r is the permitivity constant of the substrate and depends of the used matieral. In this paper, a substrate like glass is chosen because of the high dielectric constant of $\epsilon_r = 4.4$ compared to other matierals like teflon with only a dielectric constant of $\epsilon_r = 2.2$ This is because larger dielectric decreases the dimentions of the antenna patch **??** and therefore indirectly also decreases the dimentions of the entire antenna surface which comes in handy for the limited space on drones. When substituting these values, a ϵ_{reff} of 3.91 is determined.

$$L_{eff} = \frac{c}{2 * f * \sqrt{\epsilon_{reff}}}$$

Applying this formula with the known values of above the L_{eff} results in 29.16 mm.

$$\Delta L = 0.412 * h * \frac{(\epsilon_{reff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\epsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.8\right)}$$

By substituting the values from above, the length extension determines that ΔL equals 1.3071 mm.

Finally can the lenght of the patch be calculated using the expression: $L = L_{eff} - 2 * \Delta L$ which result in 26.55 mm which result in an antenna like 4.1.

The transmission line model is in fact only applicable for an infinite ground plane but it has been proven that similar results can be achieved if the groundplane's dimentions are bigger then the patch of approximatly 6 times the height of the dielectric substrate [15, 16].

$$L_g = 6 * h + L$$
$$W_g = 6 * h + W$$

Therefore should the lengt of the groundplane L_g be at least 0.0438m and a width of W_g 0.0524m.

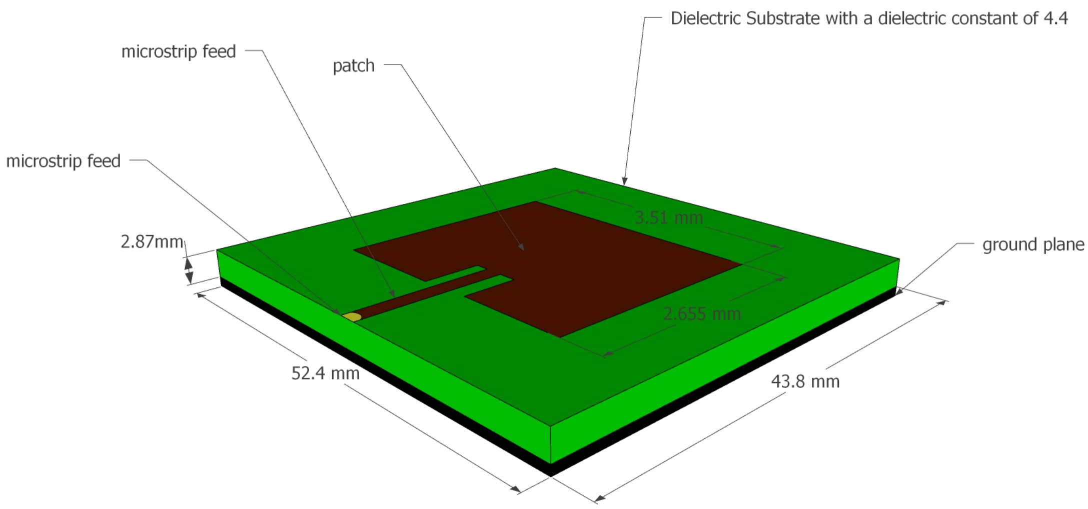


Figure 4.1: Design of the microstrip patch antenna.

4.2.5 Radiation pattern

Mathlab is able to generate the radiation pattern for the this microstrip patch antenna. The code in 1 starts with defining the dielectric substrate which will be glass with a dielectric constant of 4.4 and a height of 0.00287m. Thereofter is de microstrip patch antenna generated with the width and lenght being the dimensions of the radiation patch and the GroundPlaneLength and GroundPlaneLength the dimensions of the groundplane and dielectric substrate. The FeedOffset is the releative offset from the center where the radio frequency power is fed to the radiating patch which here wil be at the edge which is in figure 4.1 is indicated with the yellow dot. At last is the dielectric object given to the patchMicrostripInsetfed object.

Generating the pattern is done with the 'pattern' command. The first value is the patchMicrostripInsetfed object followed by the frequency in wich the antenna will be operating. Optionaly can a azimuth value be parsed like in line 7 and 8 where 90 and 0 stand for relatively the H-plane and E-plane.

```
1 d = dielectric("Name",'glass',"Thickness",0.00287,"EpsilonR",4.4)
2 p = patchMicrostripInsetfed("Width",0.0351,"Length",0.02655,
3     "GroundPlaneLength",0.0438,"GroundPlaneLength",0.0524,
4     "FeedOffset",[-0.021885 0],"Substrate", d)
5
6 pattern(p,2.6e9, "CoordinateSystem", 'polar', "Normalize",true)
7 pattern(p,2.6e9, 90, "CoordinateSystem", 'polar', "Normalize",true)
8 pattern(p,2.6e9, 0, "CoordinateSystem", 'polar', "Normalize",true)
```

Listing 1: Mathlab code to generate radiation pattern for a microstrip patch antenna

Running the configuration from 1 will generate the radiation pattern from figure 4.2. When running the same configuration for a slitly bigger square antenna with an edge of 0.060m, the radiation pattern from 4.3 is achieved. It becomes clear that the radiation pattern from figure 4.2 has a higher attenuation in de direction it is not facing compared to the radiation pattern of figure figure 4.3. If it is assumed that drones fly lower then users are possitioned in some buildings, the pattern of 4.2 would be a better approach. However, for the continuation in this master dissertation, the radiation pattern from figure 4.2 is assumed since the antenna is the smallest and therefore more suitable to attach to the limited space available under the drone. A datasheet of the exact values from both radiation patterns can be found in appendix A.

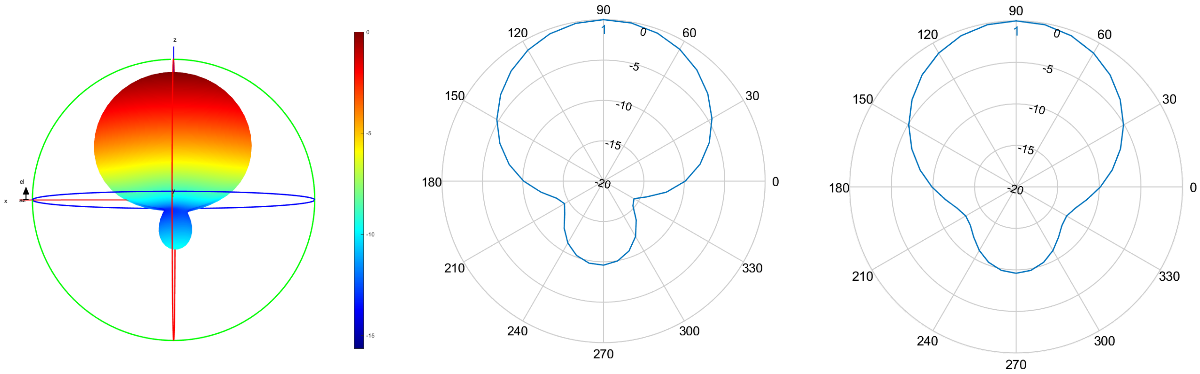


Figure 4.2: Radiation pattern 1: 3D model of the entire pattern on the left with the configuration as discribed above. In the middel a 2D radiation pattern of the E-plane and at the right a 2D model of the H-plane.

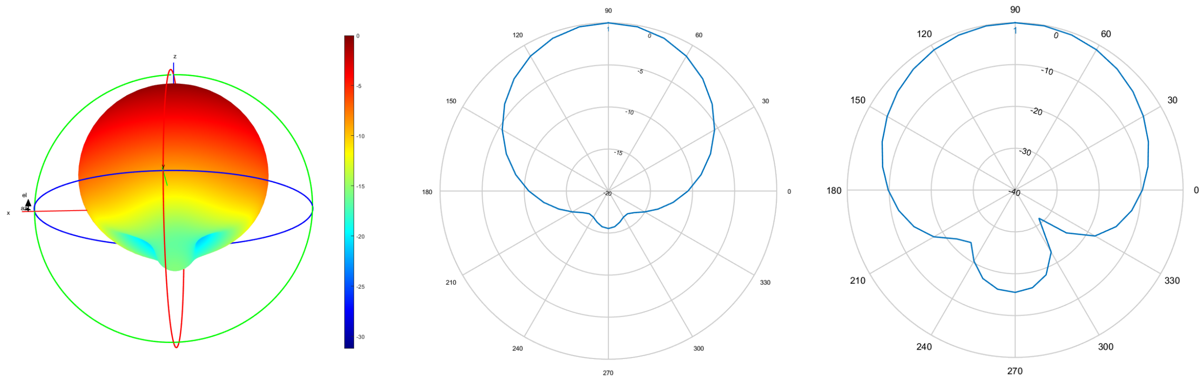


Figure 4.3: Radiation pattern 2: Generated with a groundplane of 0.06m by 0.06m. On the left is the 3D model of the entire pattern plotted. In the middel a 2D radiation pattern of the E-plane and at the right a 2D model of the H-plane.

5

Implementation

5.1 Implementation of downlink exposure

Schrijf over hoe die exposure nu toegevoegd is aan de tool. -Wat deed de tool al? Users en femtocell's uniform verdelen op publiek transport, uabs etc - dat de exposure pas op het einde wordt berekend nadat het netwerk gemodeleerd is.

Algorithm 1 describes the implementation on how to calculate the exposure of a user towards a single base station as described in formula 4.1. Several values need to be known for this to work. In the first place, the path loss is calculated. However, the different path loss values are already calculated during the network initialization phase and can, therefore, be reused on the condition they were saved. By only calculating the path loss once, the time complexity of the tool decreases drastically. Afther this, the gain is calculated by adding the antenna gain to the current input power of the antenna and by substracting the feeder loss as already stated in equation 4.2. In the last place, equation 4.1 is used and the exposure is returned.

To combine all exposures for a specific user, equation 4.3 is translated into algortim 2. Finaly, this needs to be repeaded for every users. Algorithm 3 is used to iterate over each user and each simulation and saves the computed value into the appropriate attribute.

To provide a summary of how the network is performing on electromagnetic exposure, a weighted

Algorithm 1 getExposure

Input user, basestation

Output exposure of a user towards a single basestation

```
PL ← path loss between user and basestation
gain ← getBSantennagain + basestation.getInputPower - getBSFeederLoss
exposure ← 10^((EIRP−43.15+20*log(f)−PL)/20)
return exposure
```

$PL \leftarrow$ path loss between user and basestation

$gain \leftarrow$ getBSantennagain + basestation.getInputPower - getBSFeederLoss

$exposure \leftarrow 10^{\frac{EIRP-43.15+20*\log(f)-PL}{20}}$

return $exposure$

Algorithm 2 getTotalExposure

Input user, basestations[]

Output combined exposures from each basestation for a given user

$E_{tot} \leftarrow 0.0$

for all basestation in basestations **do**

  $E \leftarrow$ getExposure(user, basestation)

  $E_{tot} \leftarrow E_{tot} + E^2$

$E_{tot} \leftarrow sqrt(E_{tot})$

return E_{tot}

Algorithm 3 Calculate and save the total exposure for each user in each simulation

Input users[][], basestations[][]

Output /

for $simulation = 1, 2, \ldots basestations$ **do**

  for all user in users[simulation] **do**

    $user.exposure \leftarrow getTotalExposure(user, basestations[simulation])$

average is calculated. This is implemented in algorithm 4 which takes all users for a specified simulation and two weighting factors w_1 and w_2. They respectively correspond to the 50th percentile and 95th of the ordered users' exposure. The two weights get equal importance of 0.5. This is because also higher values should be taken into account and not compensated with very low values. The formula will only use electric field strengths where users are active as opposed to [6] where the area is divided into grids and the exposure is calculated for every gridpoint. The reasoning behind this is that the goal of this master dissertation is to calculate the average exposure of the user and not of the entire area.

The formula first calculates the index where the mean value and the 95th percentile should be located. Afterwards, the exposure is calculated using interpolation if necessary.

Algorithm 4 globalUserExpsoure

Input users[], w_1, w_2

Output Weighted average of the median and the $95th$ percentile electric field strenght

Sort users by E_{tot}

▷ E50

$meanIndex \leftarrow \frac{users.length}{2}$

if users.length % 2 == 0 **then**

  $E_{50} \leftarrow users[meanIndex].exposure$

else

  $E_{50} \leftarrow \frac{(users[\lceil meanIndex \rceil].exposure)+(users[\lfloor meanIndex \rfloor].exposure)}{2}$

▷ E95 with interpolation

$X \leftarrow users.length * 0.95$

$X_1 \leftarrow \lfloor x \rfloor$

$X_2 \leftarrow \lceil x \rceil$

$Y_1 \leftarrow users[X_1].exposure$

$Y_2 \leftarrow users[X_2].exposure$

$E_{95} \leftarrow Y_1 + \left(\frac{(X-X_1)}{(X_2-X_1)} * (Y_2 - Y_1) \right)$

return $\frac{(w_1 * E_{50})+(w_2 * E_{95})}{w_1+w_2}$

5.2 Implementation of uplink exposure

Analogously to the 5.1, the uplink calculator will determine the uplink exposure and save in the appropriate user object. The calculator starts with iterating over each user in each simulation and calls the getSar() function.

?? is implemented in **??**. The function requires a user as input for which the uplink exposure should be calculated and two constant values which should be declared once. The maximal allowed SAR_{10g} as discussed in **??** and maximal permitted transmission power of 23 dbm.

Also, the actual transmitting power of the UE needs to be calculated using the getActualTransmitPower function.

Both Tx_{watt} and TX^{max}_{watt} are converted to watt. This is because the decibel variant can range from -57 dBm to 23 dBm [**?**]. Converting to Watt results in a solely positive fraction.

After having multiplied with the maximum allowable SAR, the actual uplink exposure is returned.

Algorithm 5 getSar

Input user
Output SAR_{10g}

1: const $SAR^{max} \leftarrow 0.67$
2: const $TX^{max}_{watt} \leftarrow dBm2W(23)$

3: $Tx_{watt} \leftarrow dBm2W(getActualTransmitPower(user))$
4: $SAR_{10g} \leftarrow \frac{Tx_{watt}}{TX^{max}_{watt}} * SAR^{max}$
5: **return** SAR_{10g}

The implementation for getActualTransmitPower is described in **??**. This function requires a user as a parameter and will calculate the real used power for transmission in dBm. Once again, a global constant value is defined describing the maximum allowable transmitting power Tx^{max}_{dBm} expressed in dBm. The predicted transmitting power is achieved by subtracting the path loss between the user and the affective femtocell with the receiver sensitivity of the femtocell. However, this value can't be higher then Tx^{max}_{dBm} , if this is the case the maximum allowable transmitting power is returned instead.

Algorithm 6 getActualTransmitPower

Input user
Output The actual used power for transmition in dBm.

1: const $Tx^{max}_{dBm} \leftarrow 23$

2: $Tx_{dBm} \leftarrow user.getPathLoss() - technology.getFemtocellReceiverSensitivity(user.getRxSNR)$
3: **return** $min(Tx_{dBm}, Tx^{max}_{dBm})$

Algorithm 7 getAttenuation

Input azimuthOffset, elevationOffset

Output attenuation in dBm

const $SAR^{max} \leftarrow 0.67$

const $TX_{watt}^{max} \leftarrow dBm2W(23)$

$Tx_{watt} \leftarrow dBm2W(getActualTransmitPower(user))$

$SAR_{10g} \leftarrow \frac{Tx_{watt}}{TX_{watt}^{max}} * SAR^{max}$

return SAR_{10g}

6
Conclusions

todo

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Appendices

A
Datasheet: radiation patterns

Table A.1 gives an overview of the attenuation in the E and H plane. The first radiation pattern is with a square groundplane with an edge of 0.060 meter while the second pattern is more of a rectangular shape with a width of 0.0524m and a lenght of 0.0438m. All other settings are equal as defined in 4.2.4

Table A.1: Overview of attenuation in dBm

	pattern 1		pattern 2	
angle	E	H	E	H
0	0,00	0,00	0	0
10	-0,17	-0,14	-0.1561	-0.158
20	-0,67	-0,57	-0.5797	-0.6257
30	-1,48	-1,27	-1.263	-1.386
40	-2,57	-2,22	-2.193	-2.412
50	-3,90	-3,39	-3.357	-3.665
60	-5,40	-4,73	-4.741	-5.099
70	-7,09	-6,23	-6.337	-6.658
80	-8,82	-7,87	-8.136	-8.278
90	-10,54	-9,70	-10.11	-9.88
100	-12,20	-11,84	-12.14	-11.34
110	-13,73	-14,37	-13.81	-12.47
120	-15,04	-17,65	-14.42	-13.00
130	-16,01	-21,83	-13.72	-12.82
140	-16,47	-23,63	-12.41	-12.08
150	-16,42	-20,37	-11.15	-11.15
160	-16,05	-17,49	-10.21	-10.33
170	-15,69	-15,93	-9.683	-9.786
180	-15,54	-15,54	-9.596	-9.596
190	-15,69	-16,30	-9.963	-9.784
200	-16,05	-18,44	-10.79	-10.33
210	-16,42	-22,85	-12.07	-11.15
220	-16,47	-31,23	-13.71	-12.07
230	-16,00	-24,07	-15.25	-12.80
240	-15,03	-18,05	-15.65	-12.99
250	-13,72	-14,42	-14.3	-12.45
260	-12,20	-11,81	-12.11	-11.33
270	-10,54	-9,70	-9.882	-9.866
280	-8,82	-7,87	-7.859	-8.267
290	-7,09	-6,23	-6.069	-6.649
300	-5,40	-4,73	-4.502	-5.093
310	-3,90	-3,39	-3.154	-3.661
320	-2,57	-2,22	-2.029	-2.409
330	-1,48	-1,27	-1.138	-1.384
340	-0,67	-0,57	-0.4963	-0.6246
350	-0,17	-0,14	-1143	-0.1575