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## Glossary

**Isotropic Radiator** A theoretical source of electromagnetic waves which radiates the same intensity in all directions.. 8

# Acronyms

**EIRP** Equivalent Isotropical Radiation Power. 8

**ICNIRP** International Commission on Non-Ionizing Radiation Protection. 5

**IEC** International Electrotechnical Commission. 9

**UABS** Unmanned Arial Base Station. 6

**UE** User Equipment. 8–10

# 1

## Introduction

### 1.1 Outline of the issue

Society is constantly getting 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. More and more devices need to be connected like IOT devices starting from small 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 electromagnetic radiation can cause diverse biological side effects [3] and human exposure to these electromagnetic waves should be limited. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) suggests a limitation of 61 V/m. Also on national levels restrictions have been

enforced but differ from location to location. In Brussels for example is a far more restrictive limitation enforced of 6 V/m for all sources [4, 5].

## 1.2 Objective

In order to provide a network, even if the existing network is damaged, a deployment tool has been developed by the UGent. The idea is to attach base stations to unmanned aircraft. Such a device is called an Unmanned Arial Base Station (UABS). The tool calculates where drones need to be positioned to connect an active user to the backbone network.

todo: several files, namelijk 4. This tool requires two input files. Firstly, a so-called shapefile of the disaster area describing the location of different buildings and their design. Secondly, the time period of the disaster is provided. The tool generates random users in different locations requiring certain bitrates.

Hereafter, the optimal locations for the different UABS are calculated. It is assumed that the entire existing network infrastructure down is and all active users, therefore, need to be reconnected.

The deployment tool does not calculate the electromagnetic exposure of the different active users in the area.

TODO: waarin differentieert mijn MP zich????

## 1.3 Structure

The following chapter 2 exists of several successive sections explaining how the electromagnetic exposure of a single human being is calculated. The first section 2.1.1 explains how the exposure is calculated between a user and a single femtocell. Section 2.1.2 defines how to combine all exposures from the different femtocells towards a single users. Finally, section ?? explains how directional antenna's are taken into account.

# 2

## State of the art

todo: Downlink traffic is created by modulation of frequencies caused by a base station. However,

### 2.1 Calculating downlink exposure

#### 2.1.1 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 2.1.

$$E_i = 10^{\frac{EIRP - 43.15 + 20 \cdot \log(f) - PL}{20}} \quad (2.1)$$

This formula requires several values to be known. The frequency  $f$  on which the transmitting antenna is operating is expressed in MHz. The other values are explained in 2.1.1 and 2.1.1.

#### **EIRP**

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 theoretical Isotropic Radiator existed, the Equivalent Isotropical Radiation Power (EIRP) is the power it would require to achieve the same power level as the actual antenna's main lobe. The main lobe is the area of the directional antenna experiencing the most gain. This EIRP value can be calculated as described in eq 2.2.

$$EIRP = P_t + G_t - L_t \quad (2.2)$$

This value is expressed in dBm and requires three values.  $P_t$  is the transmit power (dBm),  $G_t$  is the gain (dBi) of the transmitting antenna and  $L_t$  stands for its cable loss (dB) [6].

## PL

At last, formula 2.2 requires the path loss (dB). In order to calculate the path loss, an appropriate propagation model is required. Several propagation models exist and the tool already uses the Walfish-Ikegami model [7]. 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 base station exist or not. Both formulas expect a distance in kilometer.

input power hangt af van bs tot bs.

### 2.1.2 Combining exposure

manets -> exposure combineren

$$E_{tot} = \sqrt{\sum_{i=1}^n E_i^2} \quad (2.3)$$

## 2.2 Calculating uplink exposure

### 2.2.1 Specific absorption rate

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 User Equipment (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

electromagnetic strength enters the body is measured with 10g biological tissue which represents the human skin and will 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[8]. From now on,  $SAR_{10g}$  implicitly means local exposure.

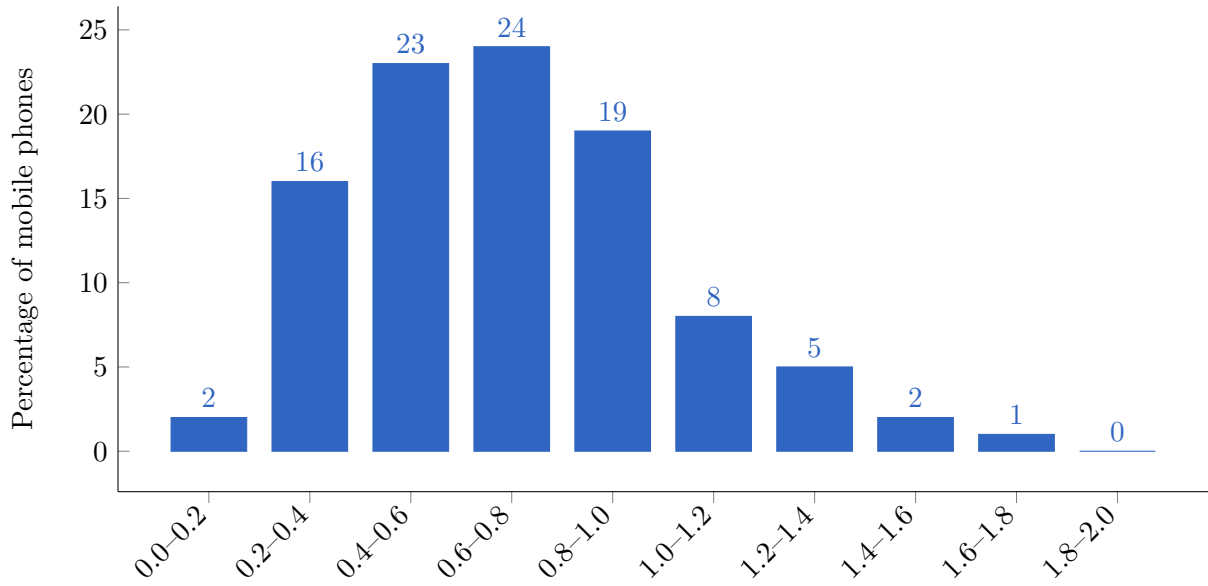
International Electrotechnical Commission (IEC) defines in IEC:62209-2 a maximum for a 10g tissue  $SAR_{10g}^{max}$  as 2 W/kg and a maximum for a 1g tissue  $SAR_{1g}^{max}$  as 1.6 W/kg. Most countries, including Belgium, enforce the 10g model and will, therefore, be the point of reference for this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

$$SAR_{10g} = \frac{P_{tx}}{P_{tx}^{max}} * SAR_{10g}^{max} \quad (2.4)$$

Equation 2.5 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 [9]. 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. [8]. 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 [10, 11].

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

$$P_{Tx} = P_{sens} + PL \quad (2.5)$$

$$P_{sens} = P_{noise} + SNR - G + IL + NF + IF \quad (2.6)$$

# 3

## Deployment tool

### 3.1 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 2.1. 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. After this, the gain is calculated by adding the antenna gain to the current input power of the antenna and by subtracting the feeder loss as already stated in equation 2.2. In the last place, equation 2.1 is used and the exposure is returned.

To combine all exposures for a specific user, equation 2.3 is translated into algorithm 2. Finally, this needs to be repeated 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

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**Algorithm 1** getExposure

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**Input** user, basestation

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**Output** exposure of a user towards a single basestation

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- 1:  $PL \leftarrow$  path loss between user and basestation
  - 2:  $gain \leftarrow$  getBSAntennagain + basestation.getInputPower - getBSFeederLoss
  - 3:  $exposure \leftarrow 10^{\frac{EIRP - 43.15 + 20 \cdot \log(f) - PL}{20}}$
  - 4: **return**  $exposure$
- 

---

**Algorithm 2** getTotalExposure

---

**Input** user, basestations[]

---

**Output** combined exposures from each basestation for a given user

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- 1:  $E_{tot} \leftarrow 0.0$
  - 2: **for all** basestation in basestations **do**
  - 3:      $E \leftarrow$  getExposure(user, basestation)
  - 4:      $E_{tot} \leftarrow E_{tot} + E^2$
  - 5:  $E_{tot} \leftarrow \text{sqrt}(E_{tot})$
  - 6: **return**  $E_{tot}$
- 

---

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

---

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

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**Output** /

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- 1: **for**  $simulation = 1, 2, \dots, basestations$  **do**
  - 2:     **for all** user in users[simulation] **do**
  - 3:          $user.exposure \leftarrow$  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 [4] 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.

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**Algorithm 4** globalUserExpsoure

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**Input**  $users[]$ ,  $w_1$ ,  $w_2$

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

1: Sort users by  $E_{tot}$

▷ E50

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

3: **if**  $users.length \% 2 == 0$  **then**

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

5: **else**

6:    $E_{50} \leftarrow \frac{(users[meanIndex].exposure) + (users[meanIndex].exposure)}{2}$

▷ E95 with interpolation

7:  $X \leftarrow users.length * 0.95$

8:  $X_1 \leftarrow \lfloor x \rfloor$

9:  $X_2 \leftarrow \lceil x \rceil$

10:  $Y_1 \leftarrow users[X_1].exposure$

11:  $Y_2 \leftarrow users[X_2].exposure$

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

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

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### 3.2 Implementation of uplink exposure

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**Algorithm 5** getSar

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**Input** user**Output**  $SAR_{10g}$ 

- 1: const  $SAR^{max} \leftarrow 0.67$
  - 2: const  $TX_{watt}^{max} \leftarrow dBm2W(23)$
  - 3:  $Tx_{watt} \leftarrow dBm2W(getActualTransmitPower(user))$
  - 4:  $SAR_{10g} \leftarrow \frac{Tx_{watt}}{TX_{watt}^{max}} * SAR^{max}$  **return**  $SAR_{10g}$
- 

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**Algorithm 6** getActualTransmitPower

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**Input** user**Output** The actual used power for transmittion in dBm.

- 1: const  $Tx_{dBm}^{max} \leftarrow 23$
  - 2:  $Tx_{dBm} \leftarrow getFemtocellReceiverSensitivity(user) + user.getPathLoss()$
  - 3: **return**  $\min(Tx_{dBm}, Tx_{dBm}^{max})$
- 

---

**Algorithm 7** getFemtocellReceiverSensitivity

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**Input** user**Output** The receiver sensitivity of the femtocell in dBm

- 1:  $SNR \leftarrow user.getRxSNR$
  - 2:  $gain \leftarrow technology.getMSantennagain$
  - 3:  $implementationLoss \leftarrow technology.getImplementationLoss$
  - 4:  $interferenceMargin \leftarrow technology.getCellInterferenceMargin$
  - 5:  $noiseFigure \leftarrow technology.getNoiseFigure$
  - 6:  $thermalNoise \leftarrow technology. - 108.1$
  - 7: **return**  $thermalNoise + SNR - gain + implementationLoss + noiseFigure + interferenceMargin$
-

# 4

## Scenarios



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