FACULTY OF ENGINEERING
AND ARCHITECTURE

Evaluating the human exposure of a UAV-aided network

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Glossary

Isotropic Radiator A theoretical source of electromagnetic waves which radiates the same intesity in all directions.. 12

Acronyms

EIRP Equivalent Isotropical Radiation Power. 12

ICNIRP International Commission on Non-Ionizing Radiation Protection. 8

IEC International Electrotechnical Commission. 13

SAR Specific Absorption Rate. 13, 20

UABS Unmanned Arial Base Station. 9

UE User Equipment. 12–14, 20

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] and human exposure towards 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

The general goal is to temporarily take over the wireless communication in the event of a disaster causing the normal network infrastructure to malfunction.

One way of generating such an ad-hoc network that is easily distributed over a given area is with the aid of a drone. By attaching femtocell on these UAV's, a mobile base station is achieved. Such a device is called an Unmanned Arial Base Station (UABS)

The optimal placement for each UABS needs to be defined to make sure that as many users as possible are properly reconnected to the backbone network while satisfying certain restrictions. To make these calculations are as realistic as possible the architecture of the several buildings present in the area is described in a shapefile. A deployment tool calculates the optimal position of the UABS by taking the 3D models of the building into account along with some femtocell specifications and user distribution. This deployment tool is developed by the WAVES research group, a department within Ghent University.

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

TODO: waarin differentieert mijn MP zich????DS

1.3 Structure

The following chapter 2 exists of several succesive sections explaining how the electromagnetic exposure of a single human being is calculated. The first section 3.1.1 explains how the exposure is calculated between a user and a single femtocell. Section 3.1.2 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 Existing deployment tool

2.2 Capacity based deployment tool

research naar DL

2.3 whipp

research naar UL

3

Deployment tool

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

3.1 Calculating downlink exposure

3.1.1 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 3.1.

$$E_i = 10^{\frac{EIRP-43.15+20*\log(f)-PL}{20}} \tag{3.1}$$

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 3.1.1 and 3.1.1.

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 theorical 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 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 3.2.

$$EIRP = P_t + G_t - L_t \tag{3.2}$$

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

PL

At last, formula 3.2 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 [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 basestation exist or not. Both formulas expect a distance in kilometer.

input power hangt af van bs tot bs.

3.1.2 Combining exposure

manets -> exosure combineren

$$E_{tot} = \sqrt{\sum_{i=1}^{n} E_i^2} \tag{3.3}$$

3.2 Calculating uplink exposure

3.2.1 Specific absoption rate

todo: de 10g slaat al op localized, vandaar dat het maar 10g is, anders is het whole-body

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 electormagnic strenghts enters the body is defined as Specific Absorption Rate (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[8]. From now on, SAR_{10g} implicitly means local exposure.

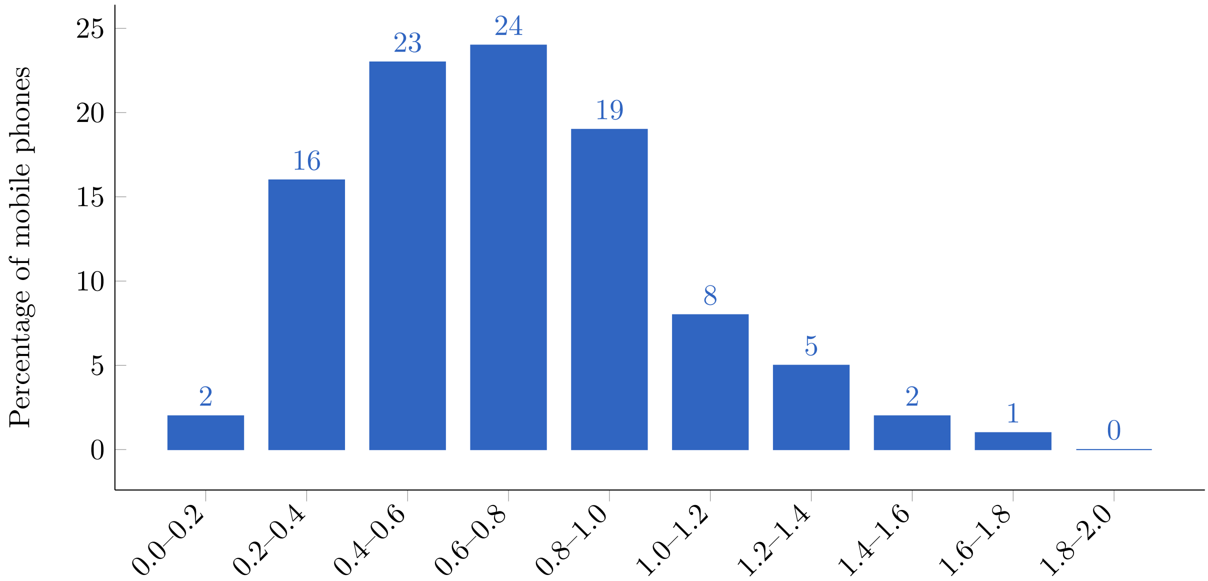
International Electrotechnical Commission (IEC) defines in IEC:62209-2 a maximum for a 10g tissue SAR_{10g}^{max} as 2 W/kg and a maximum for a 1g tissue SAR_{1g}^{max} as 1.6 W/kg. Most countries, including Belgium, enforce the 10g model and will, therefore, be the point of reference for this master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

$$SAR_{10g} = \frac{P_{tx}}{P_{tx}^{max}} * SAR_{10g}^{max} \tag{3.4}$$

Equation 3.5 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 folowing equation is used:

$$P_{Tx} = P_{sens} + PL \tag{3.5}$$

$$P_{sens} = P_{noise} + SNR - G + IL + NF + IF \tag{3.6}$$

4

Scenarios

5
Conclusions

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6
Deployment tool

6.1 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 3.1. 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 3.2. In the last place, equation 3.1 is used and the exposure is returned.

To combine all exposures for a specific user, equation 3.3 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

$PL \leftarrow$ 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 [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.

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

6.2 Implementation of uplink exposure

Analogously to the 6.1, 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 3.2.1 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_{watt}^{max} 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 $TX_{watt}^{max} \leftarrow dBm2W(23)$

3: $Tx_{watt} \leftarrow dBm2W(getActualTransmitPower(user))$
4: $SAR_{10g} \leftarrow \frac{Tx_{watt}}{TX_{watt}^{max}} * SAR^{max}$
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_{dBm}^{max} 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_{dBm}^{max} , 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 $Tx_{dBm}^{max} \leftarrow 23$

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