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Glossary

Isotropic Radiator A theoretical source of electromagnetic waves which radiates the same intesity in all directions.. 7

Acronyms

EIRP Equivalent Isotropical Radiation Power. 7, 8

ICNIRP International Commission on Non-Ionizing Radiation Protection. 5

UABS Unmanned Arial Base Station. 6

UE User Equipment. 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 succesive 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. Finaly, section **??** explains how directional antenna's are taken into account.

2

State of the art

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.

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

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 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 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 2.2.

$$EIRP = P_t + G_t - L_t \tag{2.2}$$

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 2.2 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.

2.1.2 Combining exposure

manets -> exosure combineren

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

2.2 Calculating uplink exposure

2.2.1 Specific absoption rate

todo: schrijf dat dit afhankelijk is van de possitie https://ieeexplore.ieee.org/abstract/document/1634754 Downlink traffic is created by modulation of frequencies caused by a base station. However, telecommunications is not a one-way street. A user's mobile phone also creates uplink traffic and therefore also creating electromagnetic fields. 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 which will be indicated as SAR_{10g} from now on [8].

The SAR_{10g} values in datasheets of mobile devices are worst cases meaning that the value is 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 preventing over radiation of a nearby device.

todo: as your mobile does not use more energy than is necessary to establish a connection with the network

To compensate for the overestimation of SAR_{10g}^{max}, a realistic SAR_{10g} is calculated based on the transmitting power of device. Equation 2.5 is used to calculate this value with P_{tx} the actual used power to communicate to the connected base station and P_{tx}^{max} the power used by the mobile device to achieve SAR_{10g}^{max}.

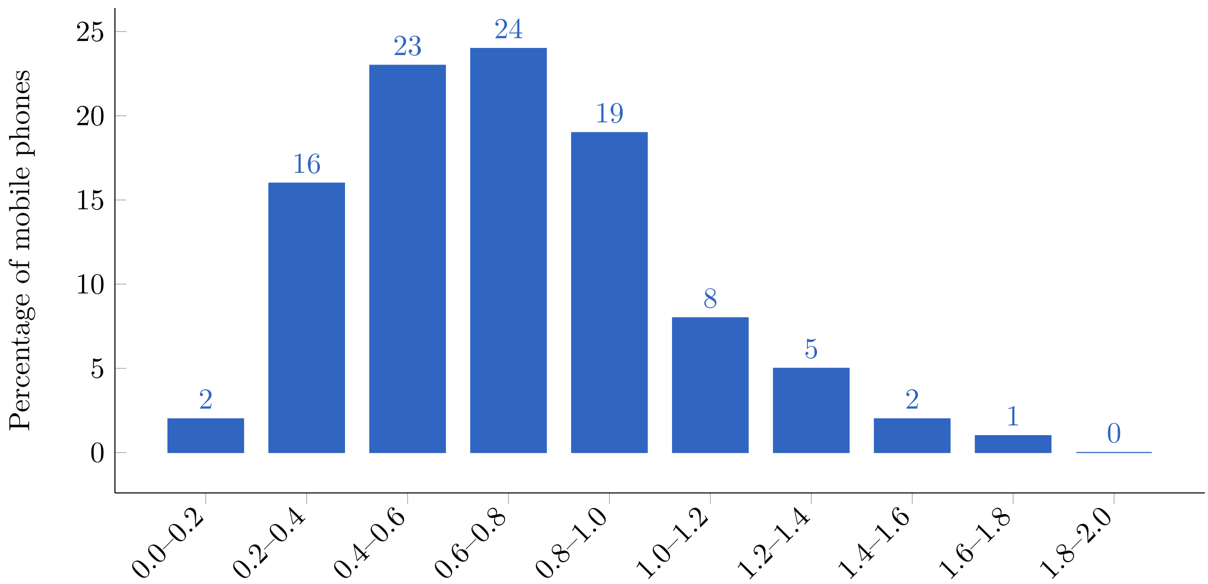
todo: possitionering van de gsm beinvloed sar daar is ook ugent paper over maar daar gaan we hier niet op in. todo: schrijf dat max 2 W/kg is.

$$SAR_{10g} = \frac{P_{tx}}{P_{tx}^{max}} * SAR_{10g}^{max} \tag{2.4}$$

The SAR value is dependent from mobile device to mobile device. An average is calculated based on 3516 different phones from various brands using an up-to-date German database [9].

TODO: paper J10.1.1 schrijft over dat ze de mediaan gebruiken als data MAAR ze raporteren wel de avg. Wat is het verschil?

When the phone is possitionned 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].



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 User Equipment (UE), the folowing equation is used:

$$P_{Tx} = P_{sens} + PL \tag{2.5}$$

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

3
Deployment tool

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. 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 2.2. In the last place, equation 2.1 is used and the exposure is returned.

Algorithm 1 getExposure

Input user, basestation

Output exposure of a user towards a single basestation

1: $PL \leftarrow$ path loss between user and basestation

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

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

4: **return** $exposure$

To combine all exposures for a specific user, equation 2.3 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.

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

To provide a summary of how the network is performing on electromagnetic exposure, a weighted 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 $\frac{(w_1 * E_{50})+(w_2 * E_{95})}{w_1+w_2}$

4
Scenarios

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