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Impact of EMF limits on 5G network roll-out

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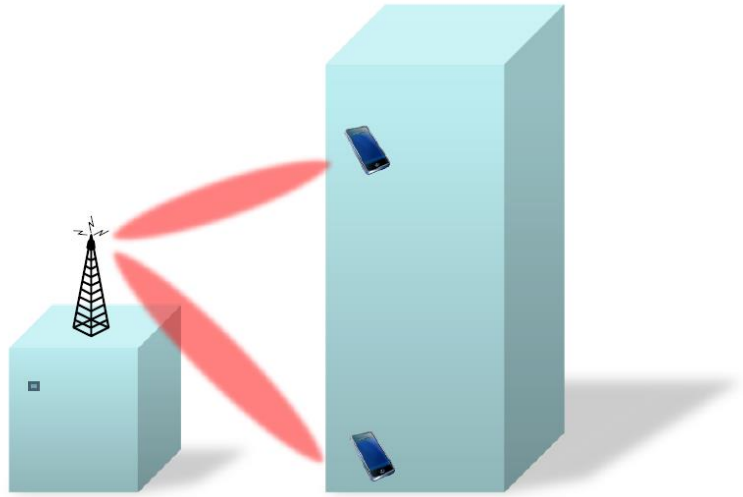
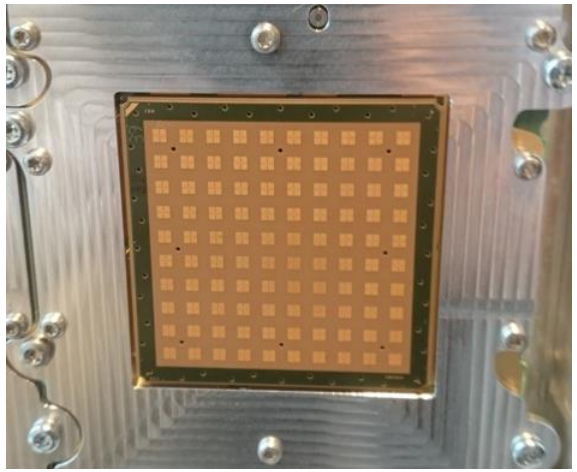
EMF challenges for 5G

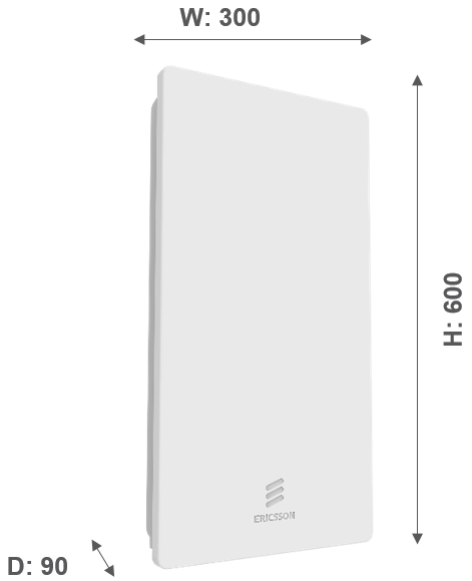
- Massive MIMO and beamforming
  - More complex EMF compliance assessments
  - Potentially higher EIRP and larger EMF compliance boundaries (exclusion zones) than for conventional antennas if theoretical maximum power is used for all beams
  - Site design of increasing importance – especially in countries using limits lower that ICNIRP guidelines
- Frequency bands above 10 GHz
  - EMF assessment methodology and standards available but need to be further refined
  - International EMF limits more conservative in the nearfield which may lead to larger compliance distances for small cell base stations

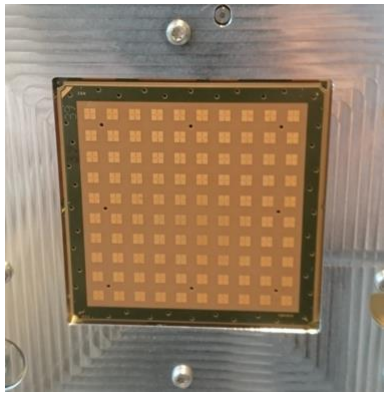




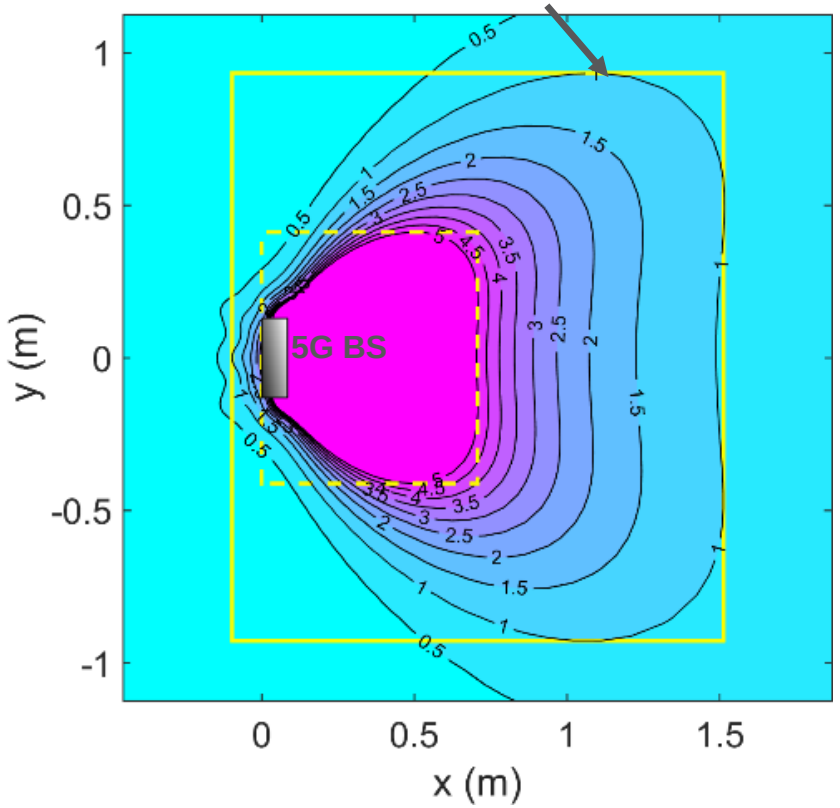
28 GHz 5G massive MIMO small cell

Ericsson AIR 5121
28 GHz
512 antenna elements
8 beams
< 1 W total output power
24 dBi antenna gain
Beam steering: ± 60° (h), ± 15° (v)





Exclusion zone,10 W/m^2
(ICNIRP power density limit for the general public)

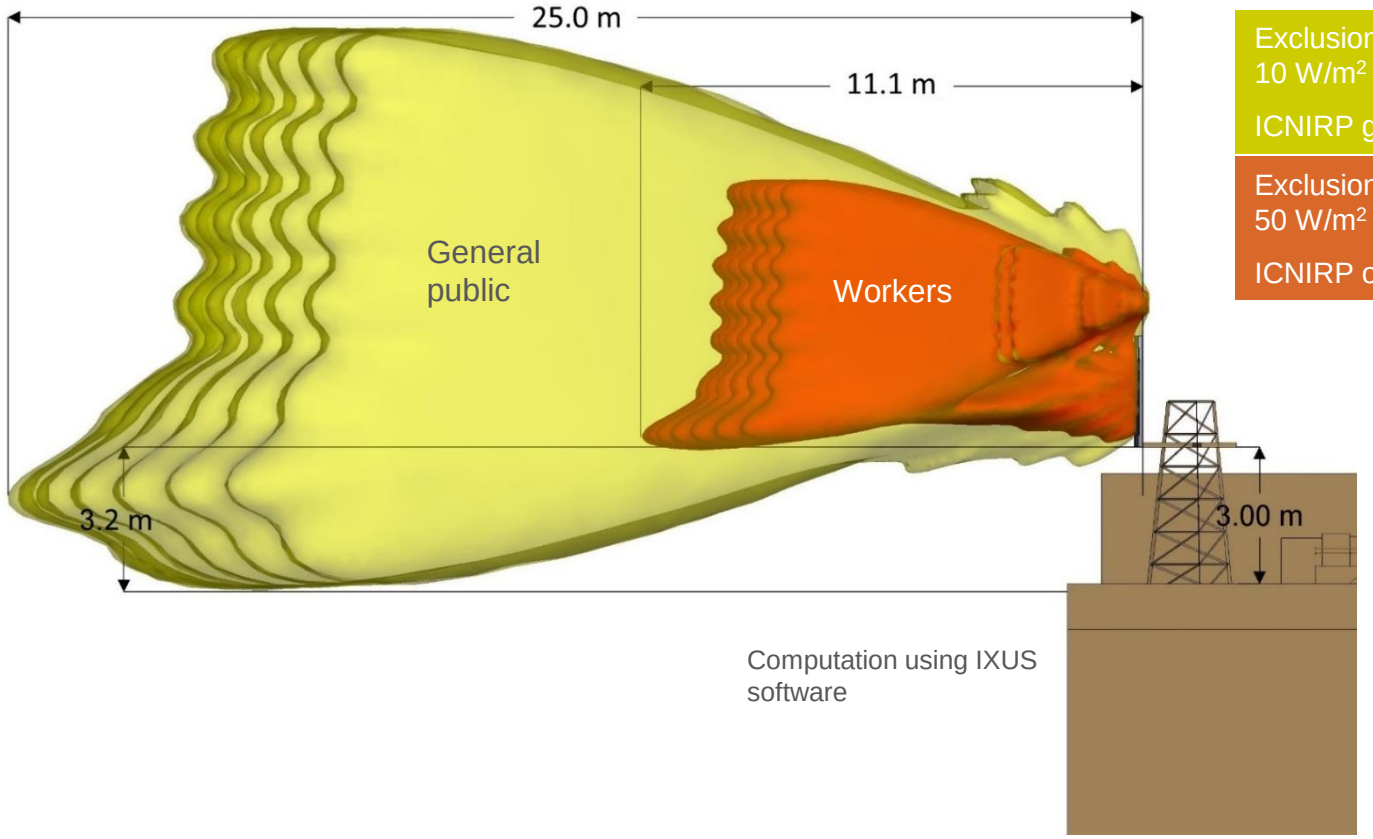


Computation assuming maximum power in all beam directions, TDD taken into account

ICNIRP limit compliance not an issue for normal installations – although larger exclusion zone than for 3G/4G
10x larger exclusion zone with 1/100 of ICNIRP – installations may be challenging

3.5 GHz 5G site with massive MIMO

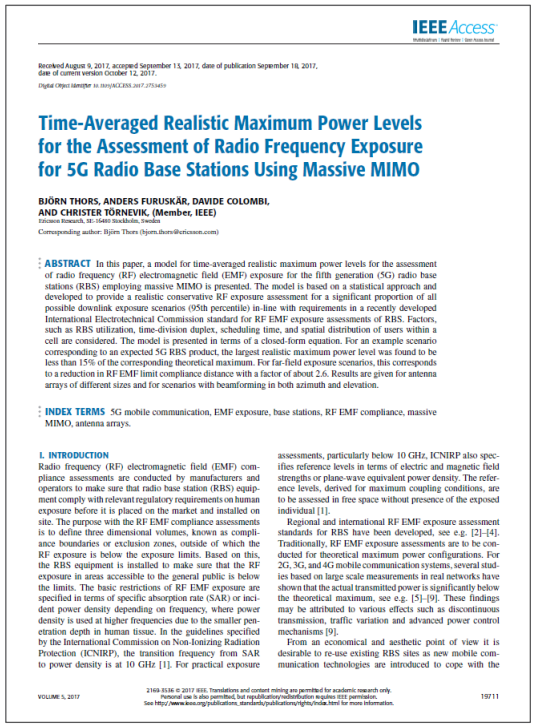
- 3.5 GHz, 200 W
- Massive MIMO (64 elements)
- EIRP of 72 dBm
- Installation on existing site with 2G, 3G and 4G antennas
- Theoretical maximum power (100% simultaneous utilization) assumed for all antennas



Very large exclusion zone due to unrealistic power - may lead to substantial 5G deployment challenges
IEC 62232 (2017) and ITU-T K.100 standards open up for use of actual maximum output power (95th percentile)

Actual maximum power of 5G massive MIMO antennas

Statistical model developed that takes into account base station utilization, scheduling time, distribution of user equipment, and time-division duplexing to determine actual power



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Time-Averaged Realistic Maximum Power Levels for the Assessment of Radio Frequency Exposure for 5G Radio Base Stations Using Massive MIMO

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ABSTRACT In this paper, a model for time-averaged realistic maximum power levels for the assessment of radio frequency (RF) electromagnetic field (EMF) exposure for the fifth generation (5G) radio base stations (RBS) employing massive MIMO is presented. The model is based on a statistical approach and developed to provide a realistic conservative RF exposure assessment for a significant proportion of all possible downlink exposure scenarios (95th percentile) in-line with requirements in a recently developed International Electrotechnical Commission standard for RF EMF exposure assessments of RBS. Factors, such as RBS utilization, time-division duplex, scheduling time, and spatial distribution of users within a cell are considered. The model is presented in terms of a closed-form equation. For an example scenario corresponding to an expected 5G RBS product, the largest realistic maximum power level was found to be less than 15% of the corresponding theoretical maximum. For far-field exposure scenarios, this corresponds to a reduction in RF EMF limit compliance distance with a factor of about 2.6. Results are given for antenna arrays of different sizes and for scenarios with beamforming in both azimuth and elevation.

INDEX TERMS 5G mobile communication, EMF exposure, base stations, RF EMF compliance, massive MIMO, antenna arrays.

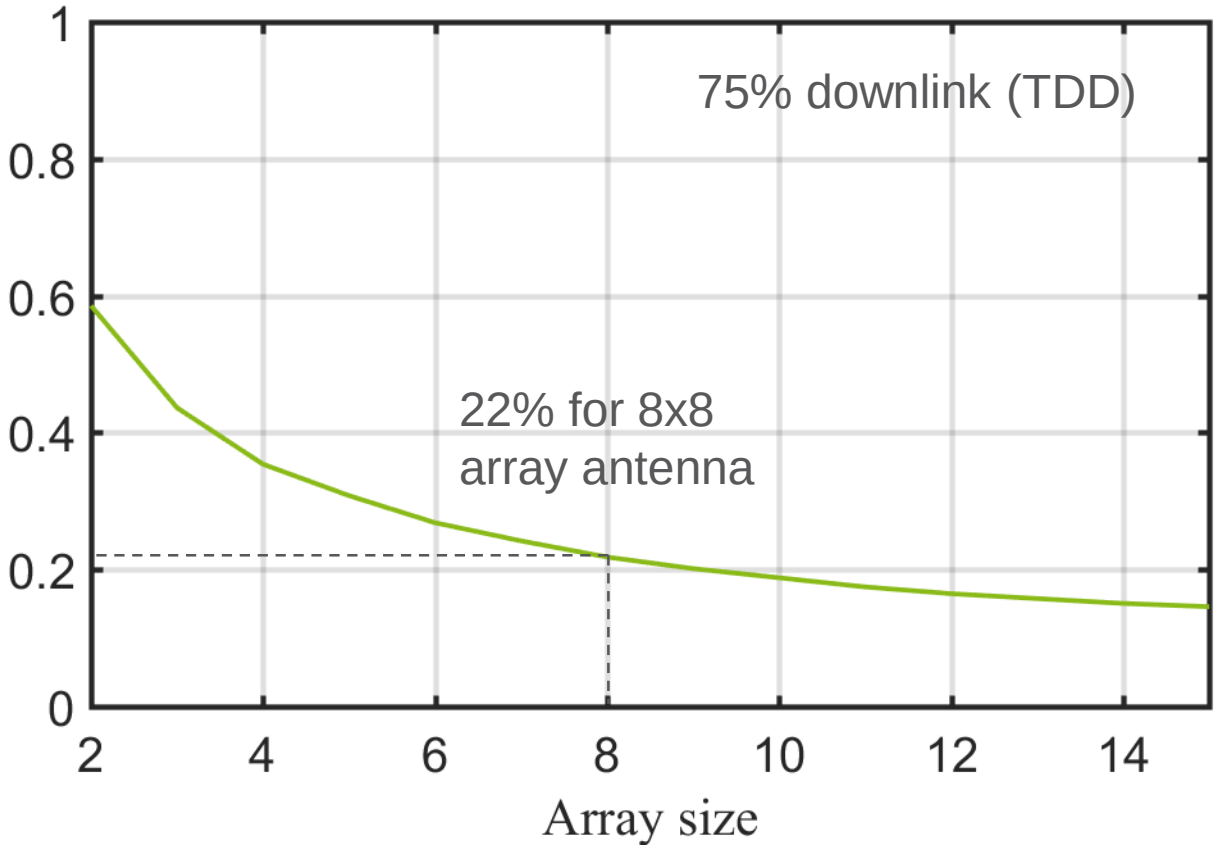
I. INTRODUCTION

Radio frequency (RF) electromagnetic field (EMF) compliance assessments are conducted by manufacturers and operators to make sure that radio base station (RBS) equipment comply with relevant regulatory requirements on human exposure before it is placed on the market and installed on site. The purpose with the RF EMF compliance assessments is to define three dimensional volumes, known as compliance boundaries or exclusion zones, outside of which the RF exposure is below the exposure limits. Based on this, the RBS equipment is installed to make sure that the RF exposure in areas accessible to the general public is below the limits. The basic restrictions of RF EMF exposure are specified in terms of specific absorption rate (SAR) or incident power density depending on frequency, where power density is used at higher frequencies due to the smaller penetration depth in human tissue. In the guidelines specified by the International Commission on Non-Ionizing Radiation Protection (ICNIRP), the transition frequency from SAR to power density is at 10 GHz [1]. For practical exposure assessments, particularly below 10 GHz, ICNIRP also specifies reference levels in terms of electric and magnetic field strengths or plane-wave equivalent power density. The reference levels, derived for maximum coupling conditions, are to be assessed in free space without presence of the exposed individual [1].

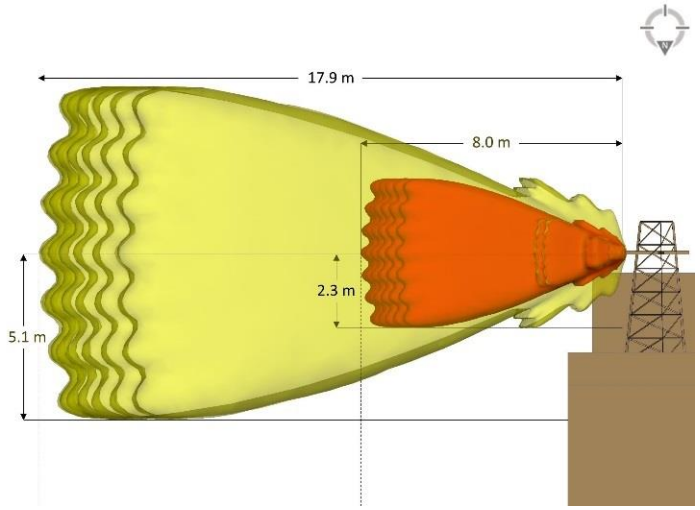
Regional and international RF EMF exposure assessment standards for RBS have been developed, see e.g. [2]–[4]. Traditionally, RF EMF exposure assessments are to be conducted for theoretical maximum power configurations. For 2G, 3G, and 4G mobile communication systems, several studies based on large scale measurements in real networks have shown that the actual transmitted power is significantly below the theoretical maximum, see e.g. [5]–[9]. These findings may be attributed to various effects such as discontinuous transmission, traffic variation and advanced power control mechanisms [9].

From an economical and aesthetic point of view it is desirable to re-use existing RBS sites as new mobile communication technologies are introduced to cope with the

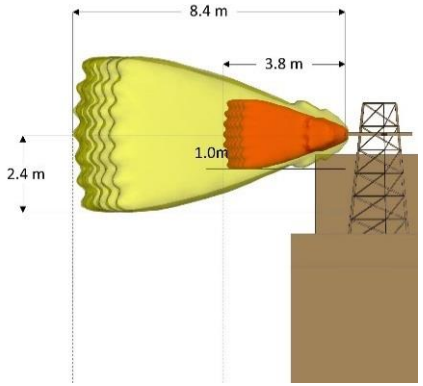
Fraction of total power contributing to the EMF exposure as function of antenna array size (95th percentile)



Rationale for actual maximum power use



- Not all power will be focused in the same direction for several minutes
- 100% utilization is very unlikely
- TDD will limit transmit time

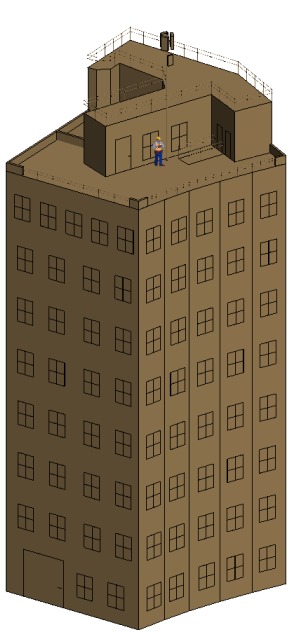


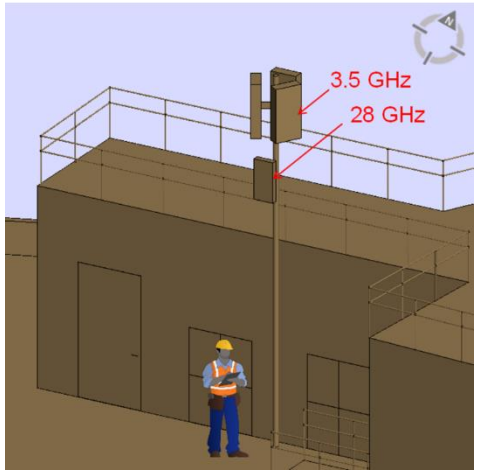
3.5 GHz 5G base station compliance boundary determined using **theoretical maximum** transmitted power (200 W)

3.5 GHz 5G base station compliance boundary determined using **actual maximum** transmitted power (44 W)

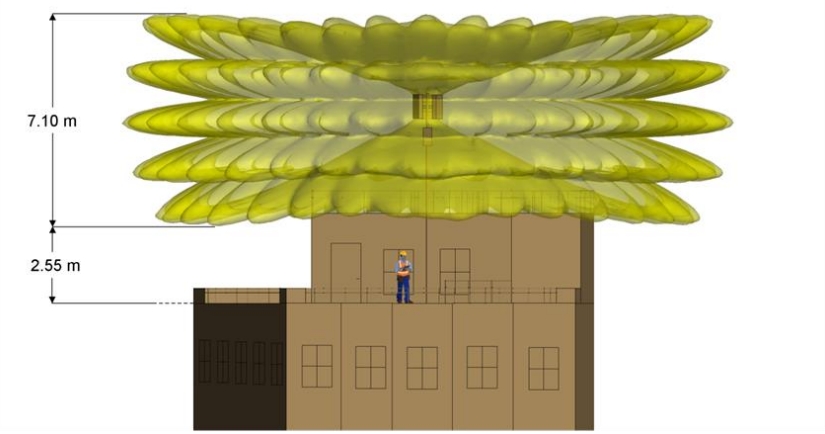
Example: 5G site with massive MIMO

3.5 GHz and 28 GHz, actual maximum power



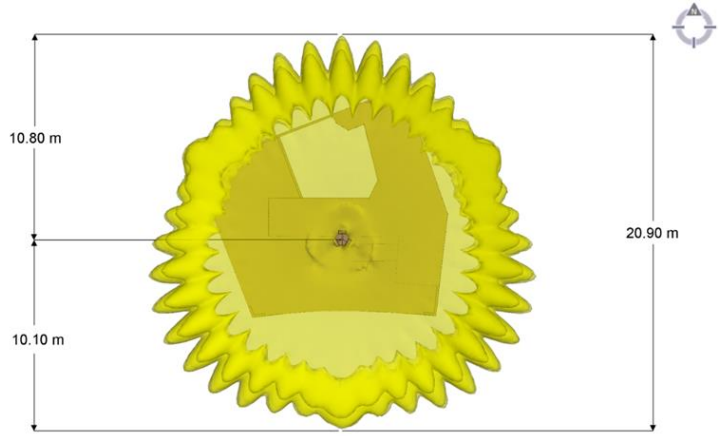


5G urban roof-top installation



Exclusion zone
10 W/m^2

ICNIRP general public limit



Actual maximum power = 25% of theoretical maximum

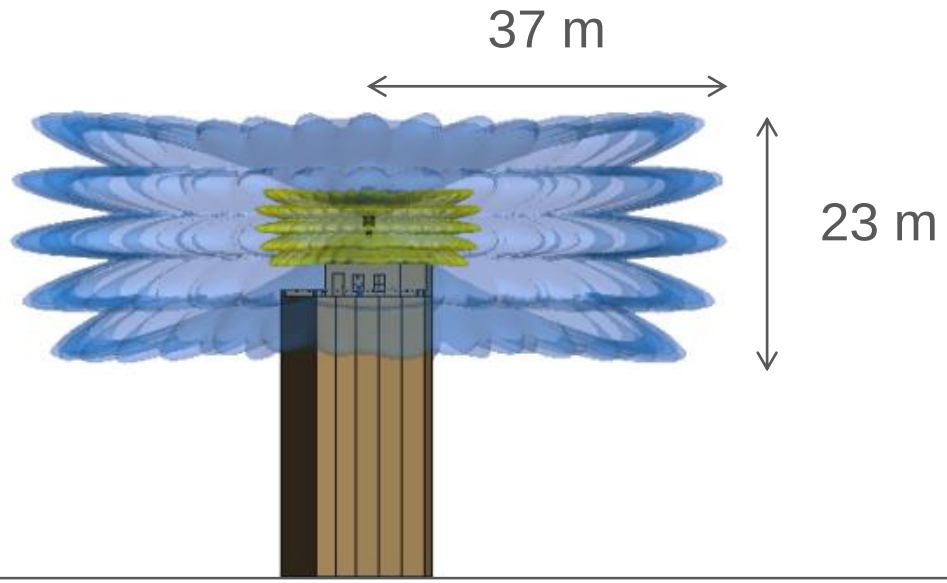
RF EMF exposure below ICNIRP limits in public areas

Case study to be included in IEC TR 62669 (2018) and ITU-T Supplement on 5G EMF compliance

Impact of lower national EMF limits
1/10 of ICNIRP limit

5G site

3.5 GHz, three sectors
28 GHz, one sector
Actual maximum power



Exclusion zone
10 W/m^2

ICNIRP limit

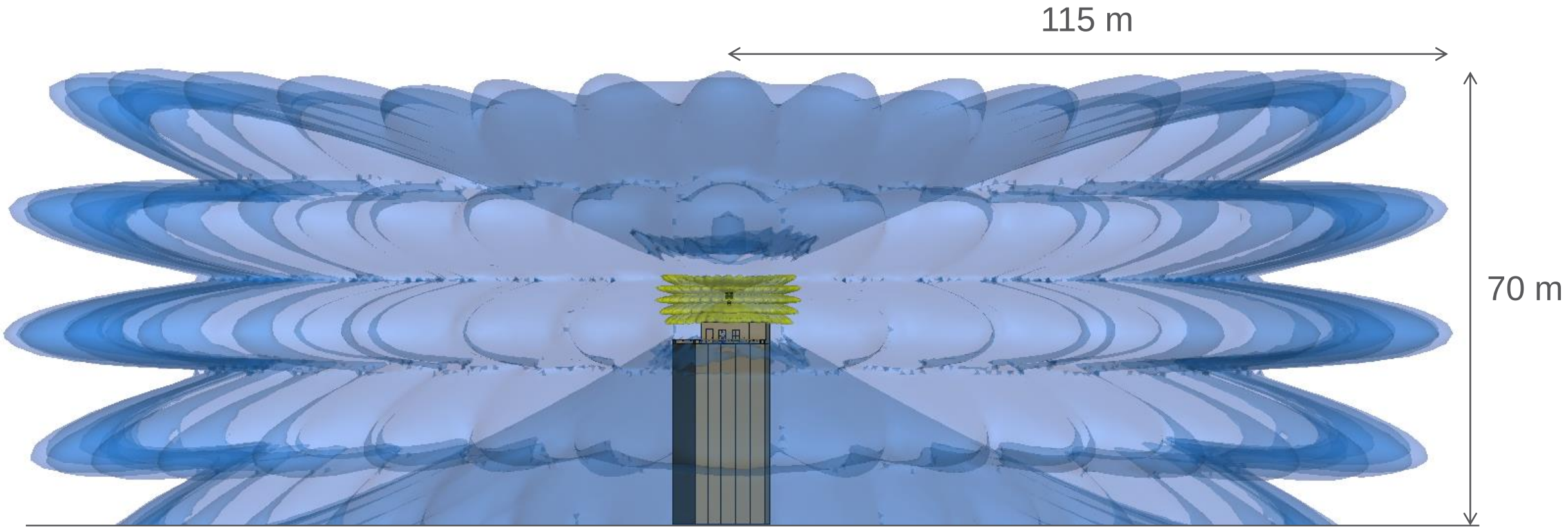
Exclusion zone
1 W/m^2

1/10 of ICNIRP limit

Size of exclusion zone makes 5G network roll-out very challenging

Impact of lower national EMF limits

1/100 of ICNIRP limit



Size of exclusion zone
makes 5G network roll-out
a major problem or impossible

Exclusion zone
10 W/m^2
ICNIRP limit

Exclusion zone
0.1 W/m^2
1/100 of ICNIRP limit

Conclusions

- EMF compliance may be a challenge for 5G massive MIMO sites if assuming theoretical maximum power for all beams
- International standards IEC 62232 and ITU-T K.100 open up for use of actual maximum power to perform realistic EMF compliance assessments
- Statistical model to determine actual maximum power of 5G massive MIMO antennas has been developed: found to be around 25% of theoretical maximum power for 8x8 array antennas
- In countries with EMF limits significantly below the international science-based ICNIRP limits the roll-out of 5G networks will be a major problem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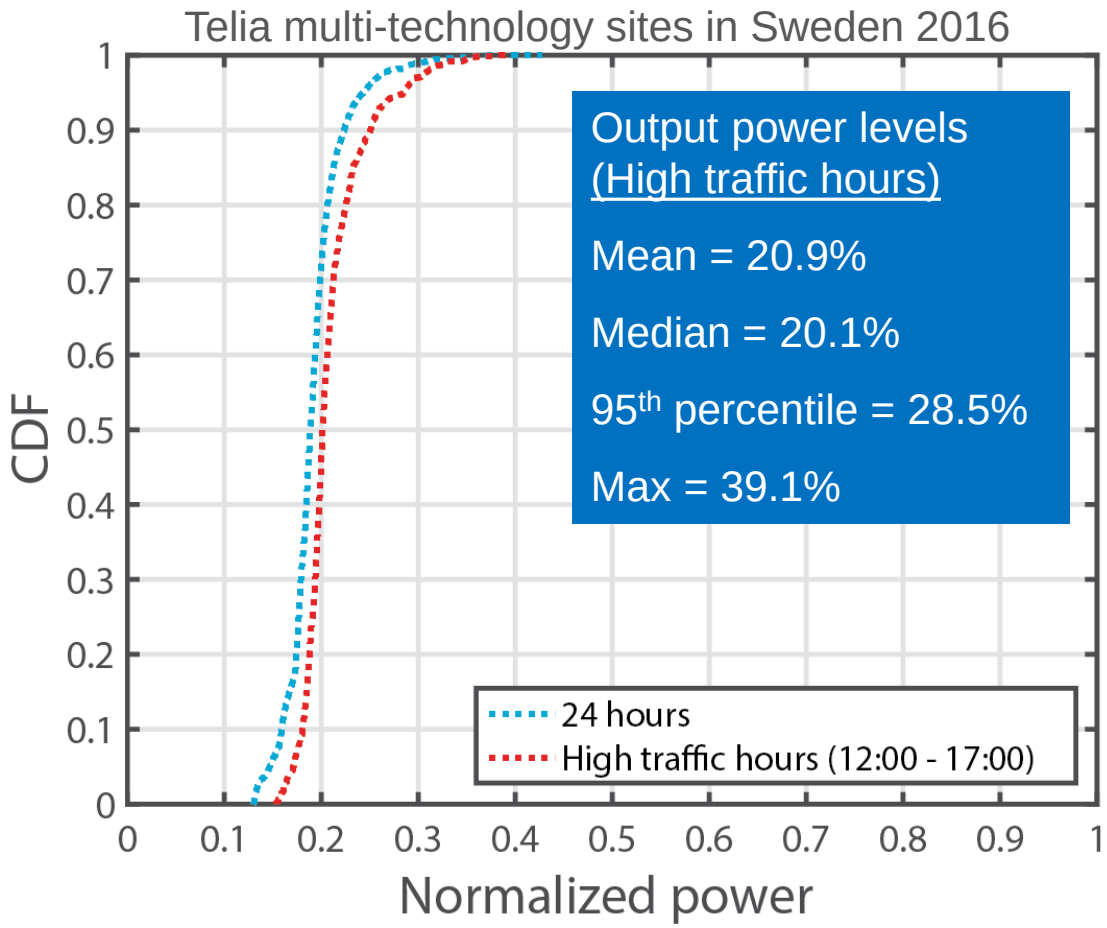
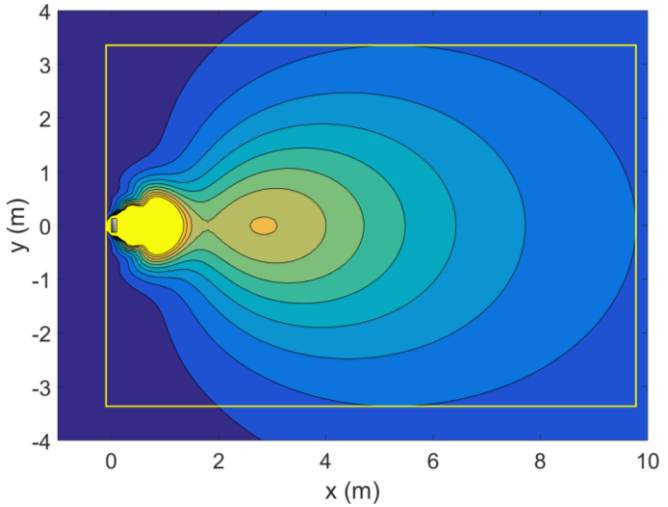
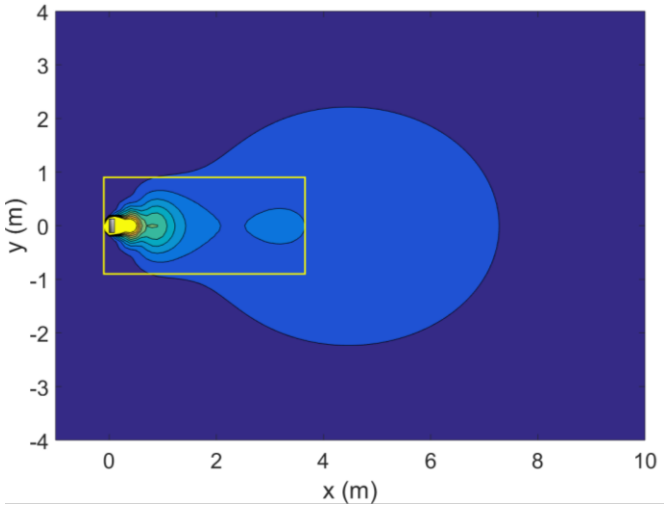
Actual maximum power use example

Impact on exclusion zone – 2G/3G/4G multi-technology site





Theoretical maximum total output power applied



95th percentile of the combined output power values applied