International Agency for Research on Cancer
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SCIENTIFIC MEETING

Radiofrequencies and health:

research in a fast-moving environment

23rd November 2022
Espace Diderot - Paris

#RadiofrequencesRS

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Challenges and changes in RF-EMF exposure measurements

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Ghent University UGent-WAVES

HUMAN EXPOSURE BY ELECTROMAGNETIC RADIATION

- People worried about health effects electromagnetic radiation
  - Correct information important
  - Regional procedures and norms Flanders, Brussels, ….
  - 5G
- Wireless IoT and 5G emerging technologies: more devices radiating, more discussions
  - WHO, IARC
  - ICNIRP 2020 norms, IEEE 2019
  - Horizon Europe, ANSES
  - ....

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CONTENT

- Context & Objective
- Exposure: 2010 4G → now 5G
- 3 measurement methods for in-situ exposure
- In-situ measurements: new applications
  - 5G-NR macro cells
  - 5G-NR small cells
- Discussion & Conclusions

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CONTEXT & OBJECTIVE

Challenges: Fifth generation (5G) of wireless communications technologies

→ Massive multiple-input-multiple-output (MaMIMO)

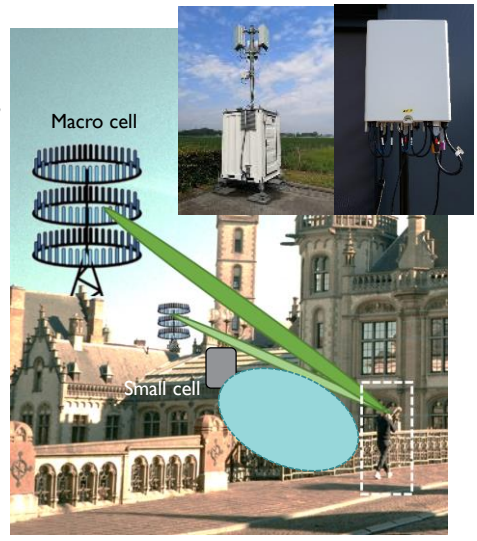
→ Dynamic beamforming and Adaptive Antenna Systems AAS

→ 5G small cells

→ Uncertain impact on our everyday exposure to radiofrequency (RF) electromagnetic fields (EMF)

Objective:

- 4G versus 5G exposure
- Experimental methods for 5G NR base station exposure
- EMF exposure levels 5G macro and 5G small cells
  - Exposures of *users* and *non-users*



Source: dr. ir. S. Aerts

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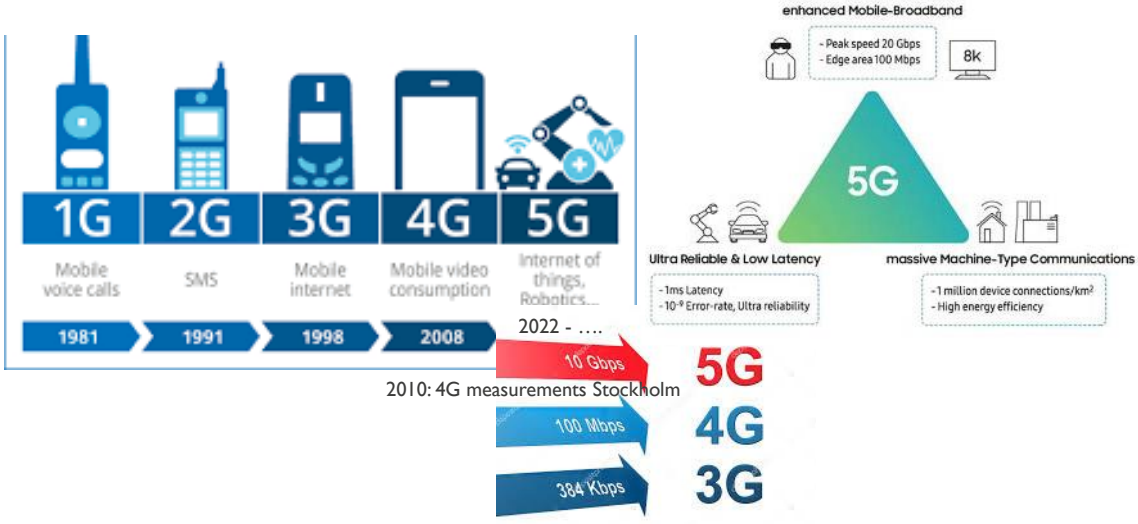
CELLULAR NETWORK EVOLUTION



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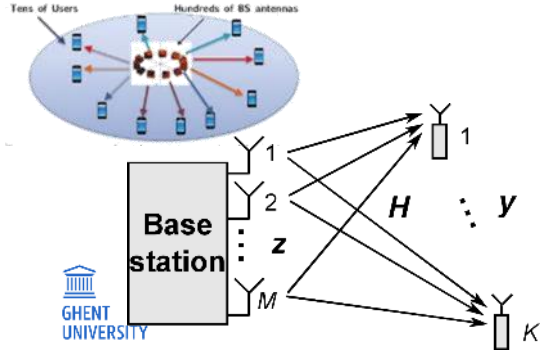
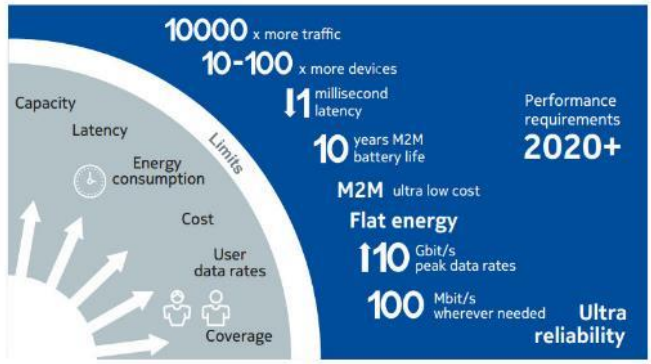
5G IS PRESENT

- 5G-NR (New Radio)
  - Massive amount antennas in base stations **MaMIMO**
  - **Small cells**
  - **mm-wave** technology
- Exposure assesment of 5G





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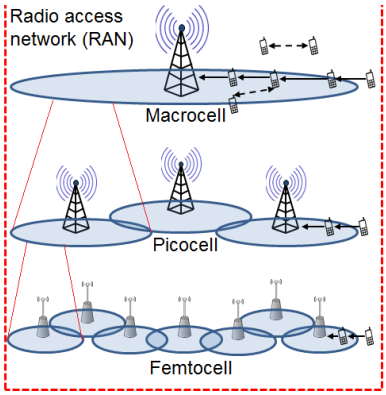
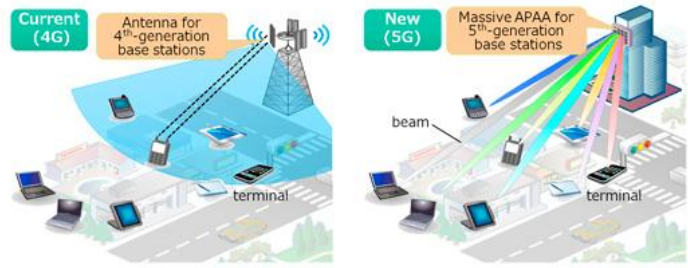
SMALL CELLS



MAMIMO: 4G VERSUS 5G



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EXPOSURE ASSESMENT DIFFERENCES 4G AND 5G

- 4G
  - Any user or non-user in a cell around a base station is exposed all the time
  - **Exposure is dependent on**
    - Gain of the antenna pattern towards the user
    - Distance from the antenna
    - Global network traffic of all users
- 5G
  - Only **user** is exposed and also non-users exposed *near* users in first 5G networks
  - Exposure is present only during the use by the user
  - Multiple users can be served at the same time (power will be divided over the users)
  - **So exposure in the cell will be dependent on**
    - The number of active users
    - The traffic of a user at a specific location

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METHOD 1: SPOT SPECTRAL MEASUREMENTS

MEASUREMENT SETUP

Rohde & Schwarz FSV-30 spectrum analyzer

Narda SRM-3006 field strength analyzer

TOWARDS 5G → 5G user equipment (**UE**) needed

- Using iperf app: beam carrying **maximum downlink traffic** forced toward the **UE (and probe)**
- Positioned on the line probe – beam steering base station

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METHOD 1: 5G-NR BASE STATION MEASUREMENT PROCEDURE

MAXIMUM THEORETICAL EXPOSURE LEVEL

- E_{MAX} = **maximum** theoretical electric-field strength = case where all subcarriers (N_{sub}) are transmitted at the same time with the same, maximum possible power per RE)
  - Based on the measurement of received power $P_{RE,SSB}$ per RE of the (dominant) SSB
    - $P_{RE,SSB}$ => $E_{RE,SSB}$ (conversion depends on measurement equipment)

INSTANTANEOUS TIME-AVERAGED EXPOSURE LEVEL

- E_{AVG} = instantaneous time-averaged field strength = case as is
- Can be measured directly with spectrum analyser SA setup

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METHOD 1: 5G-NR BASE STATION MEASUREMENT PROCEDURE

5-STEP PROCEDURE FOR NR FIELD TESTS ***PART IEC STANDARD 62322***

Step 1 Spectrum overview to identify NR channel

Step 2 In-band measurement of the NR channel to locate NR broadcast signal

Step 3 Measurement of the electric-field level per resource element of the NR broadcast signal and/or the downlink traffic signals

➢ **Step 5** Extrapolation to **maximum electric-field level**

Step 4 Measurement of the **average, instantaneous** electric-field level of the NR channel

S. Aerts *et al.*, "In-situ measurement methodology for the assessment of 5G NR massive MIMO base station exposure at sub-6 GHz frequencies," *IEEE Access*, vol. 7, pp. 184658–184667, 2019, doi: 10.1109/ACCESS.2019.2961225.

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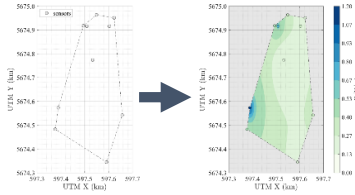
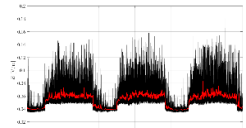
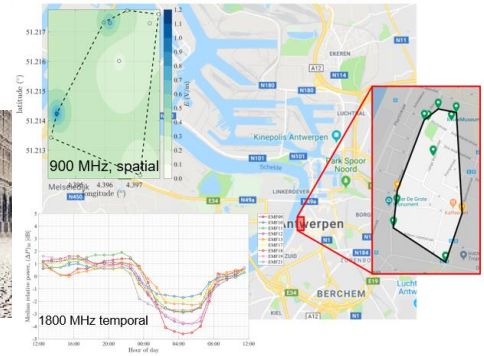
METHOD 2: MONITORING NETWORK - TEMPORAL VARIATIONS

- **Design** of fixed and mobile **low-cost RF EMF sensors**
- Deployment of an RF EMF exposure sensing network







Fixed EMF sensors

Mobile EMF sensors

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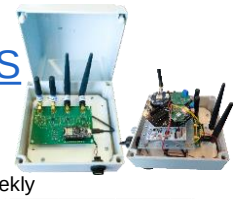
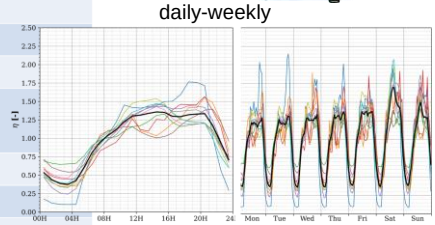
METHOD 2: EMF MULTI-BAND RF-EMF SENSORS

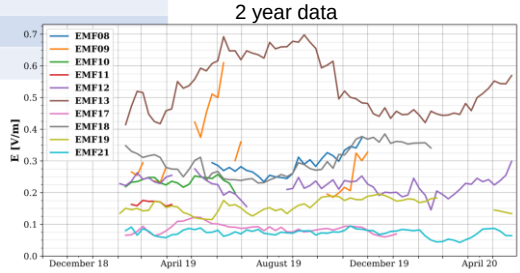


Frequency range	**791–3700 MHz**
• Frequency band 1	'800 MHz': 791–821 MHz
• Frequency band 2	'900 MHz': 925–960 MHz
• Frequency band 3	'1800 MHz': 1805–1880 MHz
• Frequency band 4	'3600 MHz': 3550–3700 MHz
Outer Dimensions (L x W x H)	18 x 18 x 15 cm^3
Dynamic range	60 - 70 dB
Sensitivity	5 mV/m
Supply voltage	5 VDC USB power
Output sampling time	1000 ms
Internal sampling time	11 ms

daily-weekly



2 year data



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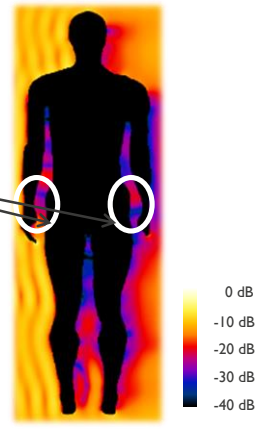
METHOD 3: PERSONAL EXPOSURE MEASUREMENTS

MEASUREMENT SETUP

- Everyday life: exposure measured using personal exposimeters
  - Microenvironmental measurements and survey studies
- Depends on location on body: large measurement uncertainty



influence body

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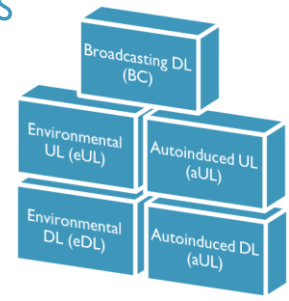
METHOD 3: PERSONAL EXPOSURE MEASUREMENTS

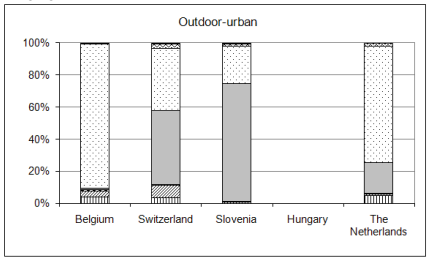
RESULTS

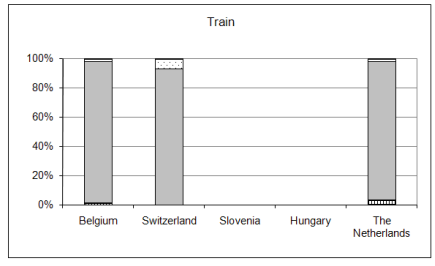
- Everyday life 2010: outdoor urban; public transport
- To now: 5G exposimeters

2022: new protocol Velghe 2021



2010





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M. Velghe, S. Aerts, L. Martens, W. Joseph, A. Thielens,
"Protocol for Personal RF-EMF Exposure Measurement Studies in 5th Generation Telecommunication Networks", Environmental Health, 2021

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Method 1
Exposure of 5G-NR macro cells

IN-SITU MEASUREMENTS: **MACRO CELLS**

COMMERCIAL NR NETWORK

- Swisscom network
  - Four NR MaMIMO base station sites (8-port CSI-RS)
  - Antenna input powers P_{in} 1.6 to 8.1 W (32.1–39.1 dBm)
    - ! Much lower than BS radio product's maximum input power of 200 W
    - Due to restrictive EMF limits in Switzerland
  - Beamsteering, so user device needed to "attract" traffic beam

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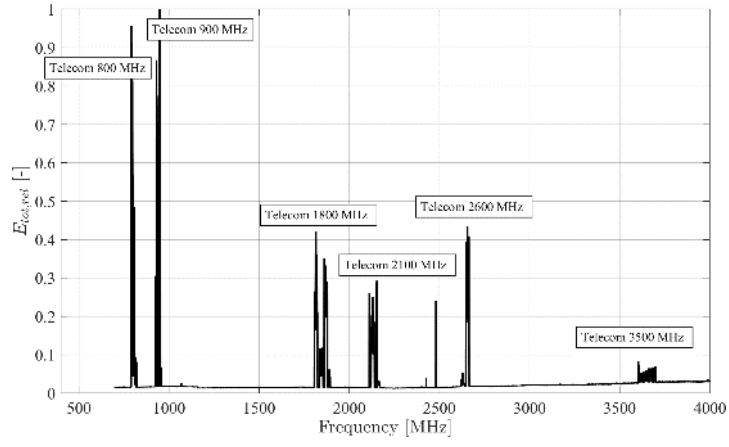
IN-SITU MEASUREMENTS

IMPACT OF COMMERCIAL NR NETWORK ON RF-EMF EXPOSURE

- From Step-1 overview measurement, **wireless telecommunication signals** at:
  - 800 MHz
  - 900 MHz
  - 1800 MHz
  - 2100 MHz
  - 2600 MHz
  - **3500 MHz**
- Additional measurements with SRM to put in perspective impact of 5G NR commercial Network on the environmental RF-EMF exposure



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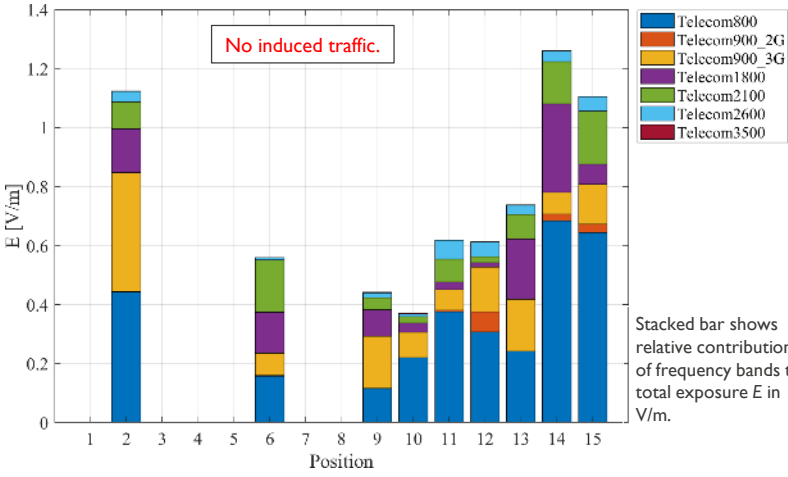
IN-SITU MEASUREMENTS

IMPACT OF COMMERCIAL NR NETWORK ON RF-EMF EXPOSURE



Stacked bar shows relative contribution of frequency bands to total exposure *E* in V/m.

Telecom frequency band	$E_{avg,\ max}$ [V/m]
800 MHz	0.93
900 MHz (2G)	0.20
900 MHz (3G)	0.67
1800 MHz	0.62
2100 MHz	0.45
2600 MHz	0.23
3500 MHz [no UE]	0.04
Cumulative	**1.26**

➔ Telecom 800 MHz, 900 MHz and 1800 MHz dominant contributions to environmental RF-EMF exposure

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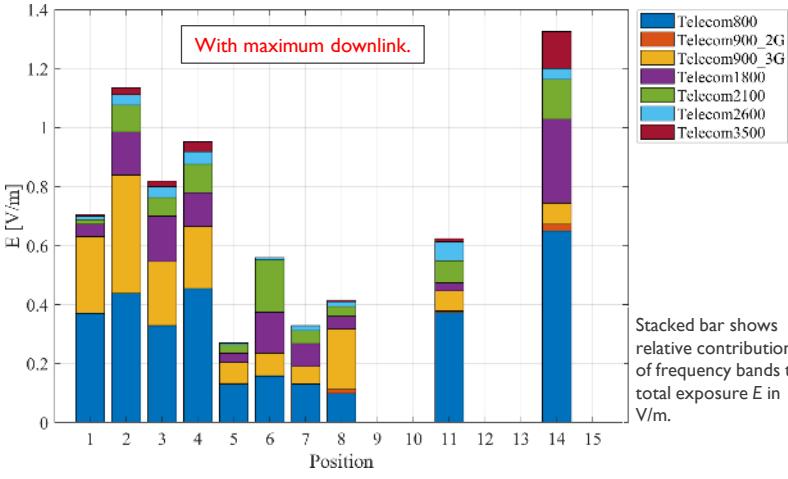
IN-SITU MEASUREMENTS

IMPACT OF COMMERCIAL NR NETWORK ON RF-EMF EXPOSURE



Stacked bar shows relative contribution of frequency bands to total exposure *E* in V/m.

Telecom frequency band	$E_{avg,\ max}$ [V/m]
800 MHz	0.93
900 MHz (2G)	0.17
900 MHz (3G)	0.67
1800 MHz	0.62
2100 MHz	0.42
2600 MHz	0.22
3500 MHz [with UE]	0.41
Cumulative	**1.33**

Other bands than NR: measured as is, without additional, self-induced traffic

➔ **Very limited impact of the commercial NR network on environmental RF-EMF exposure**

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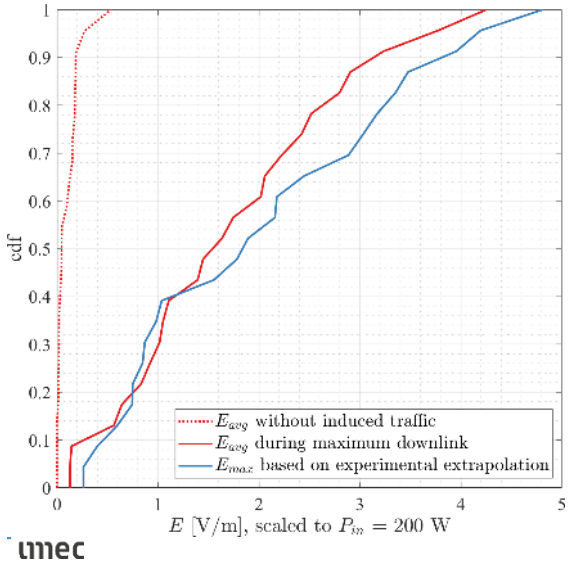
IN-SITU MEASUREMENTS

RESULTS SCALED TO P_{IN} = 200 W



- E_{avg} and E_{max} scaled to BS radio product's maximum input power of 200 W
- ➢ Maximum exposure level: 4.81 V/m *(0.62% of ICNIRP reference level)*

	min	max	p_{50}	p_{95}
E_{avg} without traffic [V/m]	n/a	0.53	0.05	0.37
E_{avg} with 100% downlink [V/m]	0.13	4.25	1.63	3.94
E_{max} [V/m]	0.26	4.81	1.89	4.41

- ➢ Possibly larger impact on environmental exposure, though E_{avg} of ~0.5 V/m (without traffic) would still result in limited contribution to environmental exposure (see previous slide)

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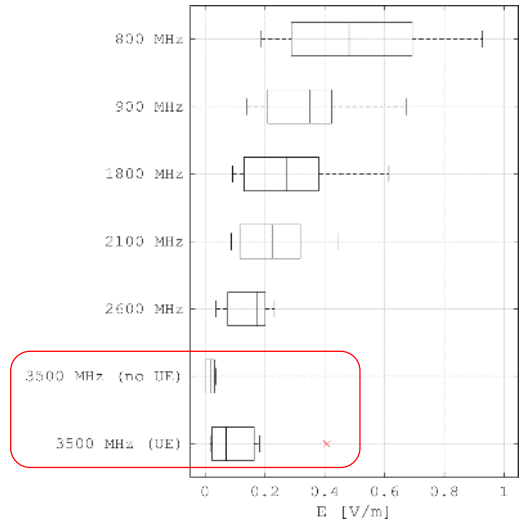
RESULTS

IMPACT OF COMMERCIAL NR NETWORK ON RF-EMF EXPOSURE

- Additional measurements with SRM of all telecommunications signals present
- Limited contribution of 5G NR network, especially for non-users, compared to any of the other telecommunications networks



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Method 1
Exposure of 5G-NR small cells

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IN-SITU MEASUREMENTS: **SMALL CELLS**

5G NR SMALL CELLS

- 5G "small cells" Belgium
  - Site 1 : Base station radio:
    - Frequency band: 3.75-3.80 GHz (➔ channel bandwidth of 50 MHz)
    - MaMIMO with 64T64R (beamforming); Height: ~5.5 m
  - Site 2 Base station radio:
    - Frequency band: 3.41-3.45 GHz (➔ channel bandwidth of 40 MHz)
    - 4T2R antenna (no beamforming); Height: ~4.5 m

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DISCUSSION

RESULTS SCALED

- To **EIRP 50 dBm** (= 100 W) ('E100' classification in EU legislation)
  - Cut-off distance between general public and occupational exposures: 1 m distance [1]
  - For **Advanced Antenna Systems (AAS)**: **maximum transmit power** of **30 dBm** (= 1 W) [1]
- To **realistic use case**
  - Video call
- **For non-users**
  - Without other users: based on $E_{avg,min}$ without active UE
  - With other users: based on $E_{avg,max}$ with active UE maximizing downlink traffic load, multiplied by **spatiotemporal duty cycle** to take into account distribution of users and usage in time and space [2]

[1] S. Forge *et al.*, "Light Deployment Regime for Small-Area Wireless Access Points (SAWAPs)", A study prepared for the European Commission, 2018.
[2] S. Shikhantsov *et al.*, "Ray-Tracing-Based Numerical Assessment of the Spatiotemporal Duty Cycle of 5G Massive MIMO in an Outdoor Urban Environment," *Appl. Sci.* vol. 10, p. 763, 2019.

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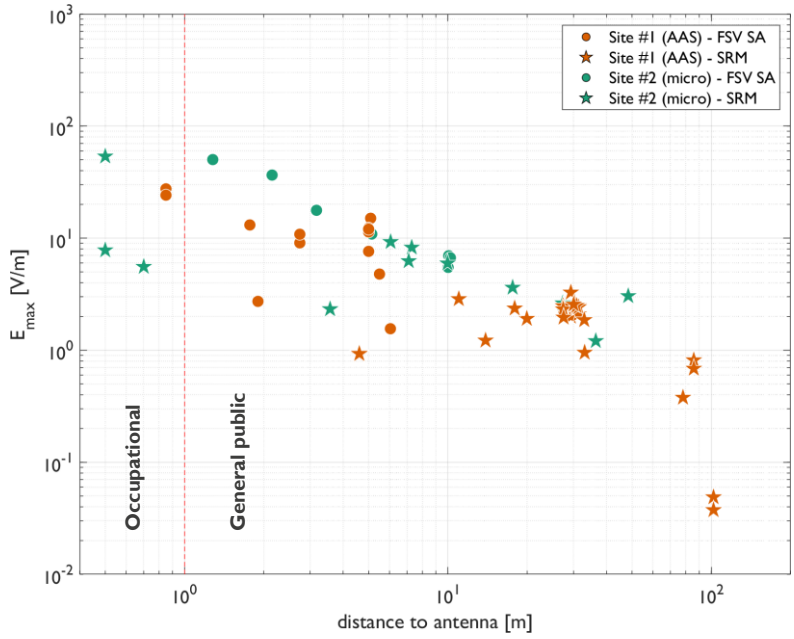
RESULTS
→ SMALL CELL

Theoretical maximum exposure (E_{max}) at all outdoor positions

d = [0.5, 102] m
E_{max} = [0.04, 54] V/m
log(*E*) ~ log(*d*)

Similar exposure levels, even though EIRP of Site #1 is 55 dBm and Site #2 50 dBm



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RESULTS: USERS VS. NON-USERS

Category	General public	
	AAS	Micro cell
Theoretical maximum	13.1 (4.6%)	50.8 (68%)
Realistic maximum ***Single user with base station at maximized downlink traffic capacity.***	12.8 (4.4%)	36.6 (36%)
Typical user ***Single user performing video call.***	4.2 (0.47%)	15.5 (6.4%)
Non-user without other users	2.4 (0.15%)	5.0 (0.66%)
Non-user with (many) other users ***Based on realistic maximum exposure and spatiotemporal duty cycle.***	5.7 (0.86%)	35.9 (34%)

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DISCUSSION & CONCLUSIONS

- Assessment of RF-EMF exposure to 5G NR base stations: 5G device needed!
  - Macro cells in commercial network in Switzerland; small cells in Belgium
  - User device in same beam or other beam than measurement device
- Macro cells
  - USER and USER DEVICE!! Assessment of E_{max} through extrapolation
  - Feasible to extrapolate to E_{max} without knowledge of the antenna radiation patterns
  - When scaled to max input powers of 200 W
    - All field levels still well below ICNIRP reference level (maximum ratio: 0.62%)
    - Impact remains limited when traffic is limited
- Small cells
  - Typical exposures: user (average and max), typical user, non-user w and w/o other users
    - 5G AAS is more efficient: lower for non-user is possible than microcell
  - Results scaled to small-cell powers
    - + Results interpolated to real use case (video call); values below ICNIRP/FCC reference levels
- Future Work: 4 EU projects!!
  - Mm-waves ($f > 24$ GHz), FR2 bands
  - Advanced MaMIMO techniques for Adaptive Antenna Systems AAS
  - IEC and CENELEC standardization

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ACKNOWLEDGMENTS

- Sam Aerts, Kenneth Deprez, Leen Verloock
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- Pung Tran, PhD and Robert G. Olsen, PhD, Prof.

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