UNIVERSITY OF CASSINO AND SOUTHERN LAZIO
Department of Electrical and Information Engineering "Maurizio Scarano"

Electromagnetic Compatibility: Modelling and Measurements

Online Workshop
24/05/2021

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MASTER OF SCIENCE IN
TELECOMMUNICATIONS ENGINEERING

4G and 5G control signals: Stability analysis

Auditorium “Luigi Papa” – Cassino (FR) Italy – 29/04/2021

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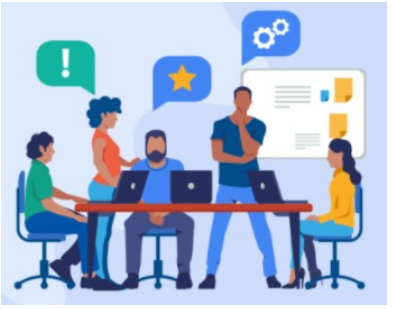
Co-Supervisor
Prof. Domenico Capriglione
Prof. Marco Donald Migliore

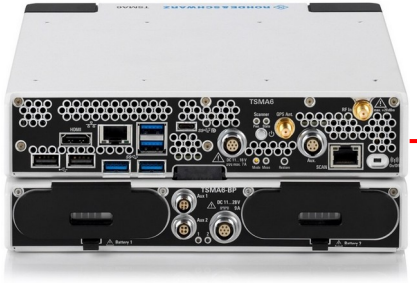
Thesis Workflow

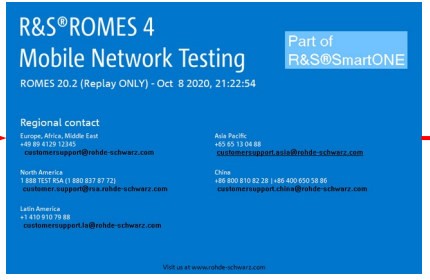
Standards, Technical Reports, Scientific Papers, …

RESEARCH

Review Meetings





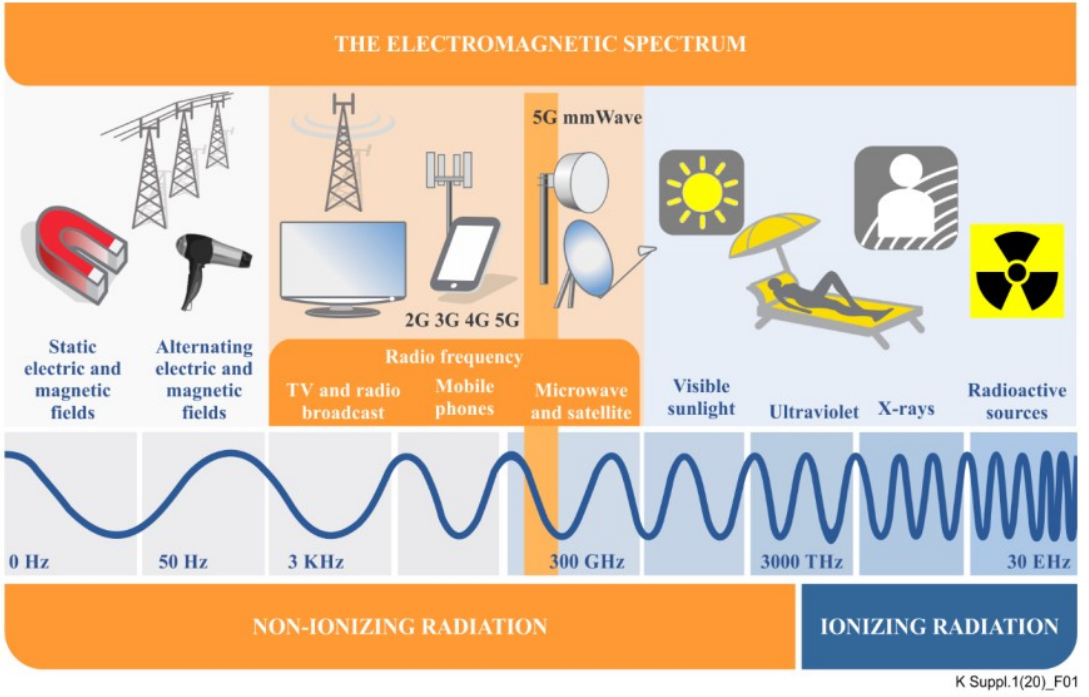


Acquisition | Selection and Export | Manage | Elaboration | Presentation

EXPERIMENTAL

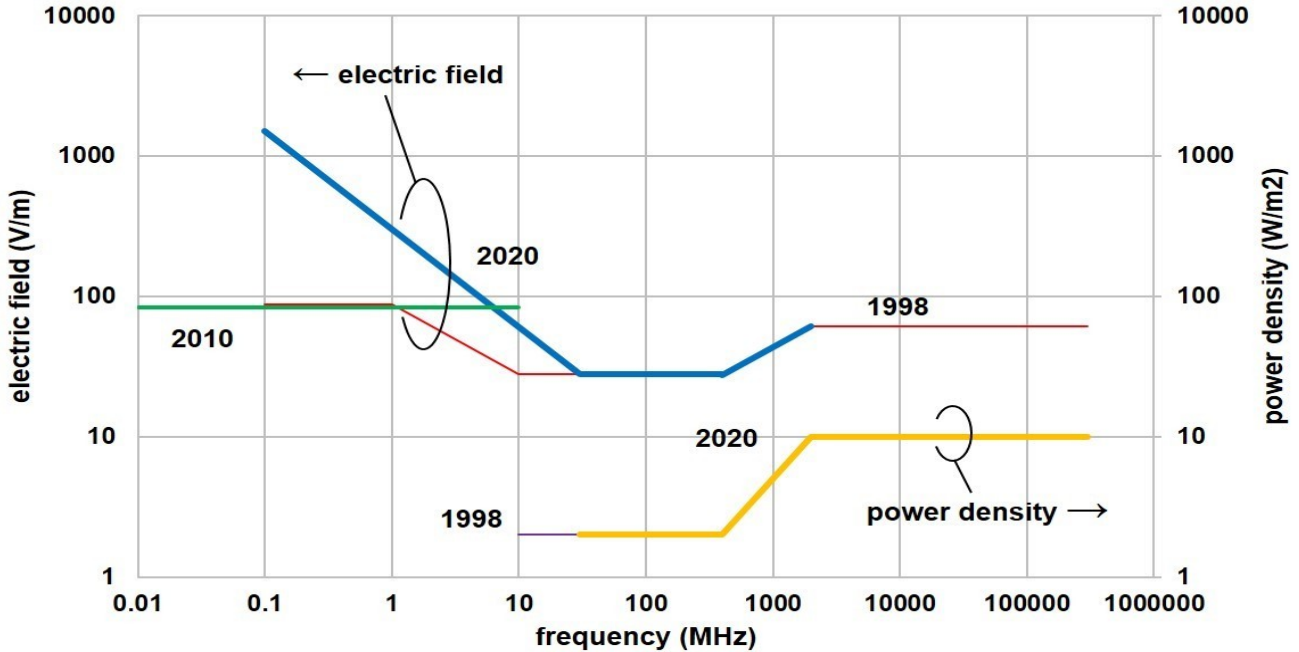
RF EMF Human exposure

- Main RF EMF sources
  - Radio and TV Broadcast
  - Mobile cellular networks
  - Microwave and Satellite
- Limits
  - WHO / ICNIRP Guidelines
- Measurement Methods
  - IEC (CEI) 62232:2017



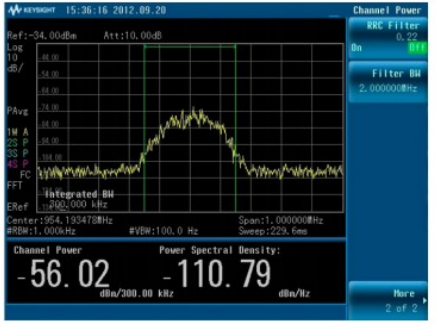
WHO / ICNIRP Guidelines

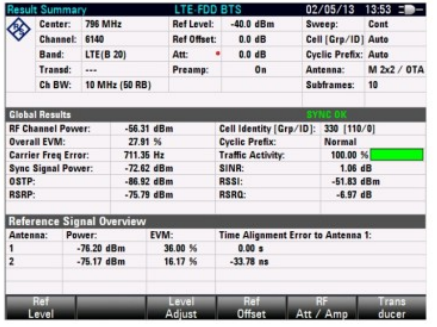
- ICNIRP 2020: GUIDELINES FOR LIMITING EXPOSURE TO ELECTROMAGNETIC FIELDS (100 kHz to 300 GHz)
  - The averaging time for whole-body exposure restriction has been changed from 6 minutes (ICNIRP 1998) to 30 minutes (ICNIRP 2020), to better match the time taken for body core temperature to rise.



IEC 62232:2017

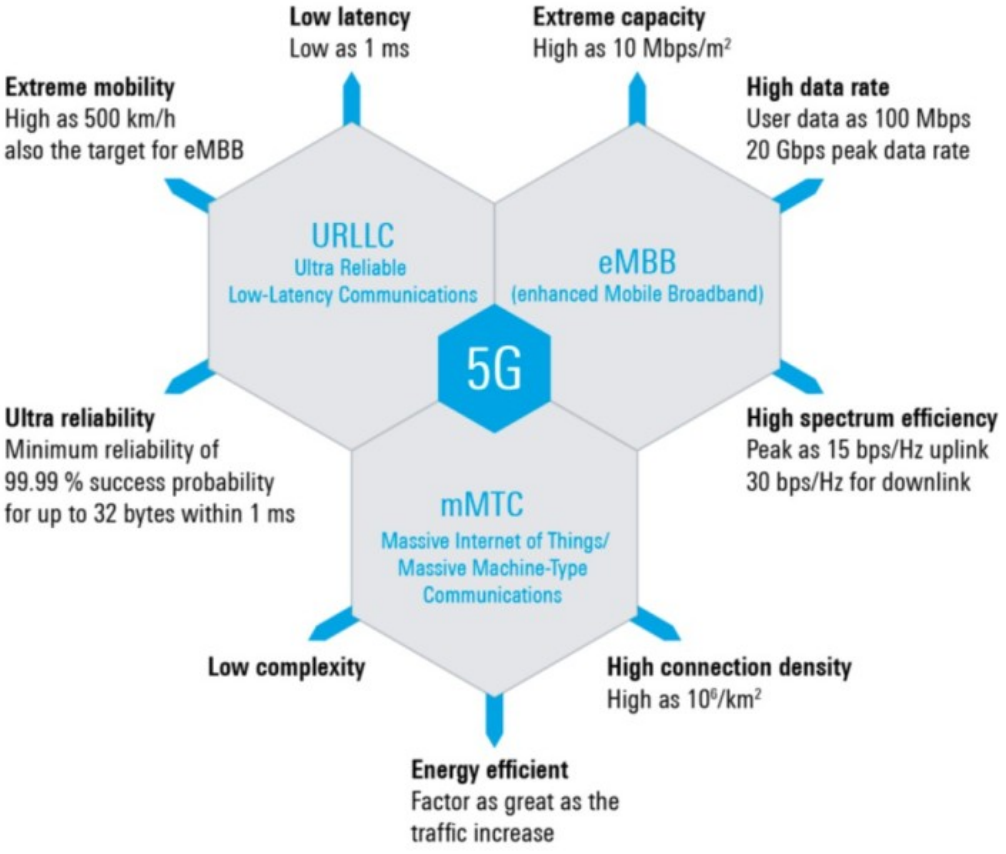
- Type of measurement
  - Broadband
  - Frequency-selective
    - Basic spectrum analyzers
    - Spectrum analyzers with technology specific decoding
    - Vector spectrum analyzers
  - Extrapolation to maximum RF field strength
    - Control signal (always on, stable)





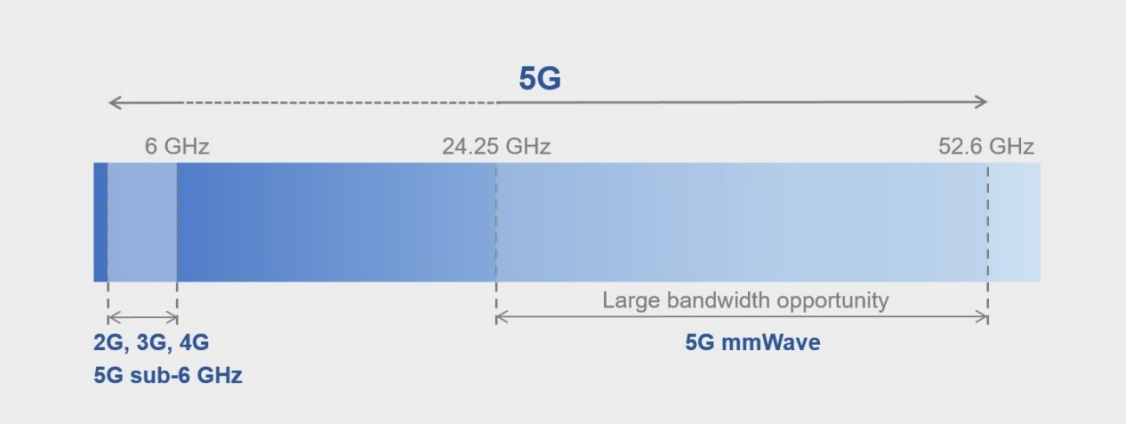
5G essentials

- Services
  - Enhanced Mobile BroadBand
  - Massive Machine-Type Communications
  - Ultra-Reliable Low-Latency Communications
- New Radio (NR)
  - new spectrum
  - high flexibility on the physical layer
  - massive MIMO (beamforming)



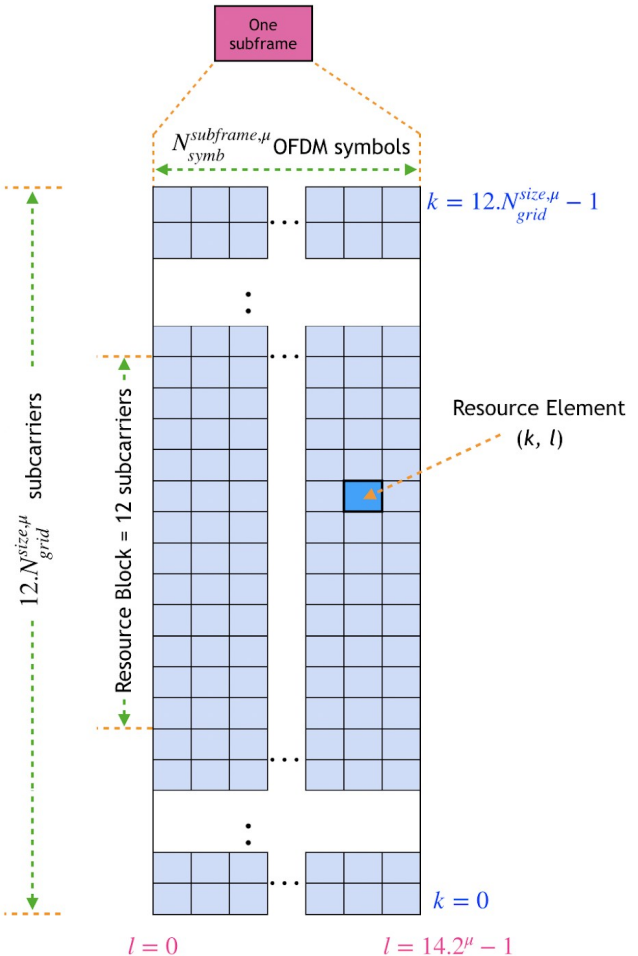
New spectrum

- Standard
  - FR1 410MHz-7125 MHz (sub 6GHz)
  - FR2 24250 MHz-52600 MHz (mm wave)
- Europe
  - 700 MHz
  - 3.4-3.8 GHz
  - 24.25-27.5 GHz



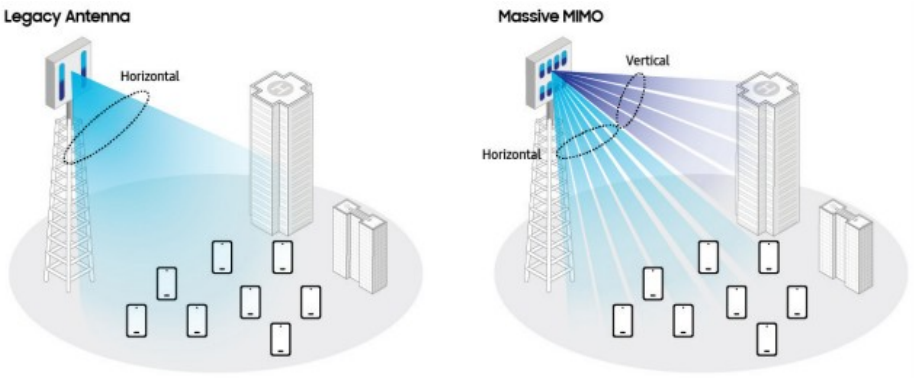
High flexibility PHY layer

- Flexible numerology
  - SCS 15/30/60/120/240 kHz
- Bandwidth parts
  - Different QoS
- Frame structure
  - Radio frame 10 ms
  - 10/20/40/80/160 slots per frame



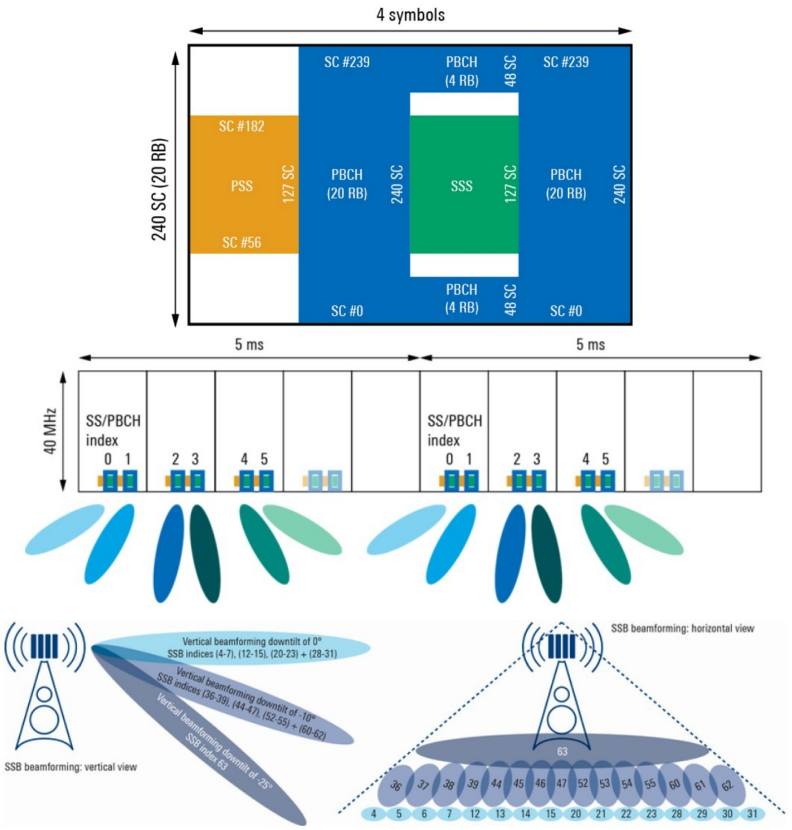
Massive MIMO

- At least 64 cross-polarized antennas to be Massive
- Beamforming
- Beamsteering



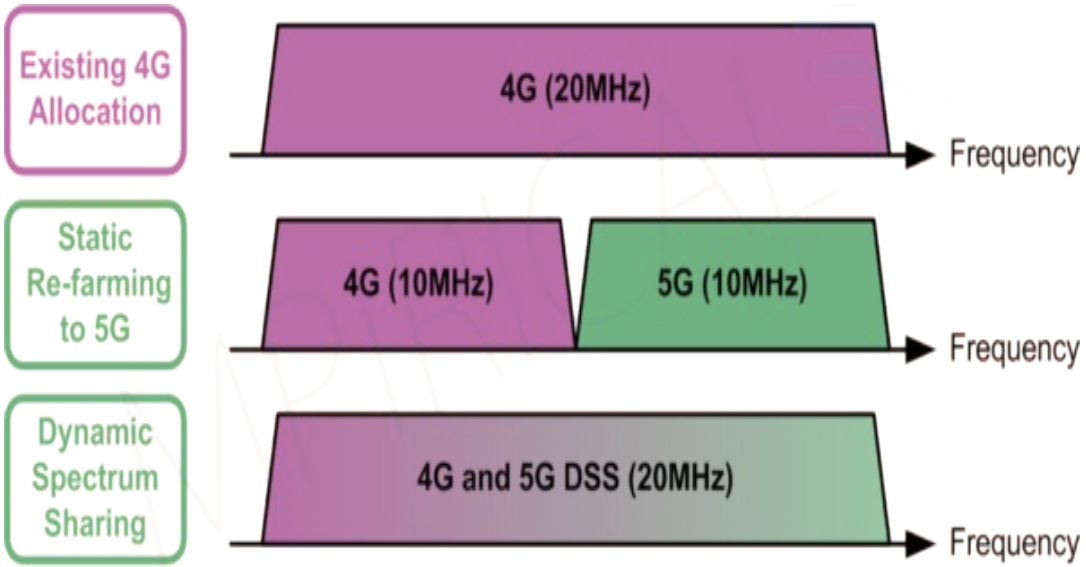
SS/PBCH block (SSB)

- Physical channel: PBCH
- Physical signals: DMRS for PBCH, PSS, SSS
- Presence: “Always on air”
- Position: Anywhere
- Periodicity: 5/10/20/40/80/160 ms
- L_{max} max number of SSBs per burst
  - $f_c < 3GHz \rightarrow L_{max} = 4$
  - $f_c > 3GHz \rightarrow L_{max} = 8$
  - $f_c > 24{,}25\ GHz \rightarrow L_{max} = 64$



4G and 5G coexistence

- Dynamic spectrum sharing
  - Allow coexistence bewteen 4G LTE and 5G
  - Enables 5G inside 4G LTE frequency Band
  - Based on the flexible design of NR physical layer
  - Pros
    - Quick 5G coverage
    - Only 5G users are made aware of it
    - LTE devices remain unaffected
  - Cons
    - Overall performance degradation of 4G and 5G



5G Extrapolation proposals (1)

- **Proposal 1**
  - ARPA Lazio, ARPA Piemonte, Vodafone Italia S.p.A., DIEI and ELEDIA@UniCAS Research Laboratory from University of Cassino and Southern Lazio and ICEmB from Genoa
- **Proposal 2**
  - Swiss Federal Institute of Metrology METAS
- **Proposal 3**
  - Narda Safety Test Solutions GmbH
- **Proposal 4**
  - Department of Information Technology of Ghent University and Ericsson

$$E^{5G,max}_{proposal\,1} = E^{max}_{5G} = AF\sqrt{\frac{N_{SC} F_{TDC} F_{beam} Z_{in} < P^{PBCH-DMRS}_{RE,max} >}{\alpha R}}$$

$$E^{5G,max}_{proposal\,2-csm} = E_h = \sqrt{\sum_{i=1}^{n} E^2_{i,h}} \qquad E_{i,h} = E^{SSS(RE)}_{i,max} \cdot K_i(\phi_i, \theta_i)$$

$$E^{5G,max}_{proposal\,2-fsm} = E_h = \left(E^{measured}_{i,max} \cdot \sqrt{\frac{1}{127}} \cdot K^{FSM}_i \right) \cdot \max_{i=1\ldots n} K_i(\phi_i, \theta_i)$$

$$K_i(\phi_i, \theta_i) = K^{SSS(RE)}_i \cdot K^{antenna}_i(\phi_i, \theta_i) \cdot K^{duplex} \cdot K^{stat}_i$$

$$E^{5G,max}_{proposal\,3-ssdm} = EI_{max} = \frac{E^2_{SSS}}{E^2_{ref}} \times \frac{N_{SC}}{127} \times k_{TDD} \times k_{system}$$

$$E^{5G,max}_{proposal\,3-fsm} = EI_{max} = \frac{E^2_{SSblock}}{E^2_{ref}} \times \frac{N_{SC}}{127} \times k_{TDD} \times k_{system}$$

$$E^{5G,max}_{proposal\,4} = E_{max} = \sqrt{\alpha}\sqrt{12 N_{RB}} E_{RE\_SSB}$$

5G Extrapolation proposals (2)

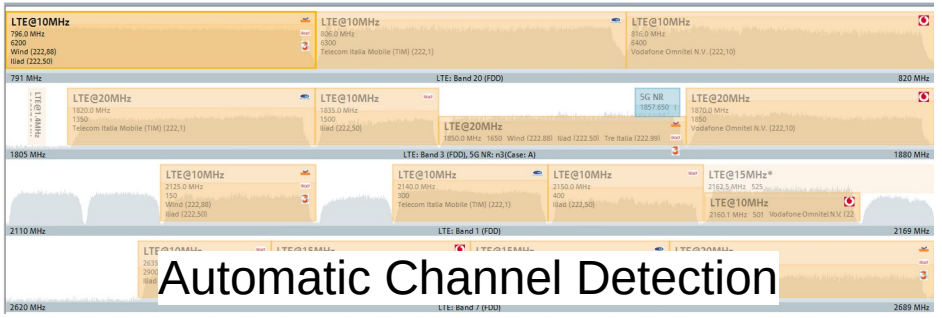
- Common approach
  1) Measure signal from SS/PBCH block on resource element basis
  2) Total number of subcarriers
  3) TDD duplexing scheme
  4) Boost of the traffic
- Additional statistical factor
  - Users position

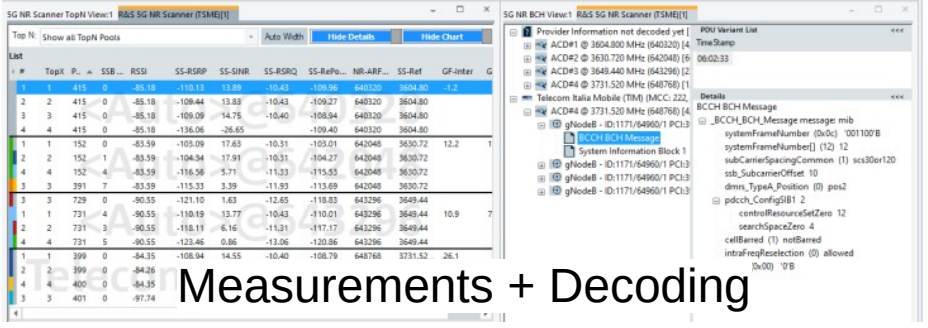
	Proposal 1	*Proposal 2*	*Proposal 3*	*Proposal 4*
Measurement Type	Decoder	Decoder	Decoder	Basic SA
		Basic SA	Basic SA	
Measured value per RE	PBCH-DMRS	SSS	SSS	SS/PBCH
		SSS	SS/PBCH	
Total number of RE	N_{SC}	$K_i^{SSS(RE)}$	N_{SC}	$12 \cdot N_{RB}$
Downlink duty cycle	F_{TDC}	K^{duplex}	k_{TDD}	F_{TDD}
Differences between control signal and data signal beam	F_{beam}	$K_i^{antenna}$	k_{system}	α

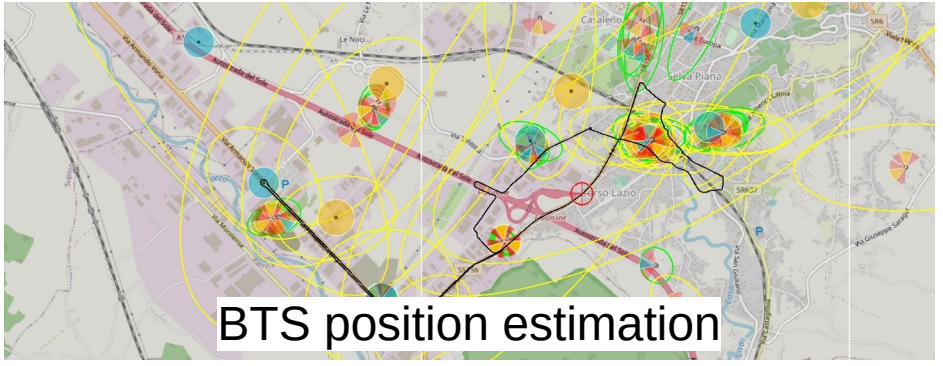
	Proposal 1	*Proposal 2*	*Proposal 3*	*Proposal 4*
Statistical factor (under development)	F_{PR}	K_i^{stat}	k_{system}	*Spatial duty cycle*

R&S TSMA6 + ROMES

- Network Scanner
  - It performs same measurements done in the end-user device
  - Passive measurement device
- Measured value
  - SS-RSRP (Secondary Synchronization-Reference Signal Reveived Power)
    - the linear average over the power contributions of the resource elements that carry the Secondary Synchronization Signal (SSS)

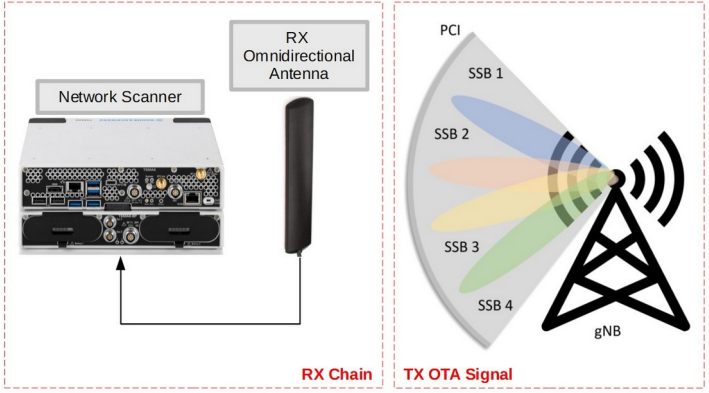






Site n.1 - Setup

- Cassino (FR)
- Indoor Antenna
- Data measured from 19/03/21 00:00:00 to 21/03/21 23:59:59

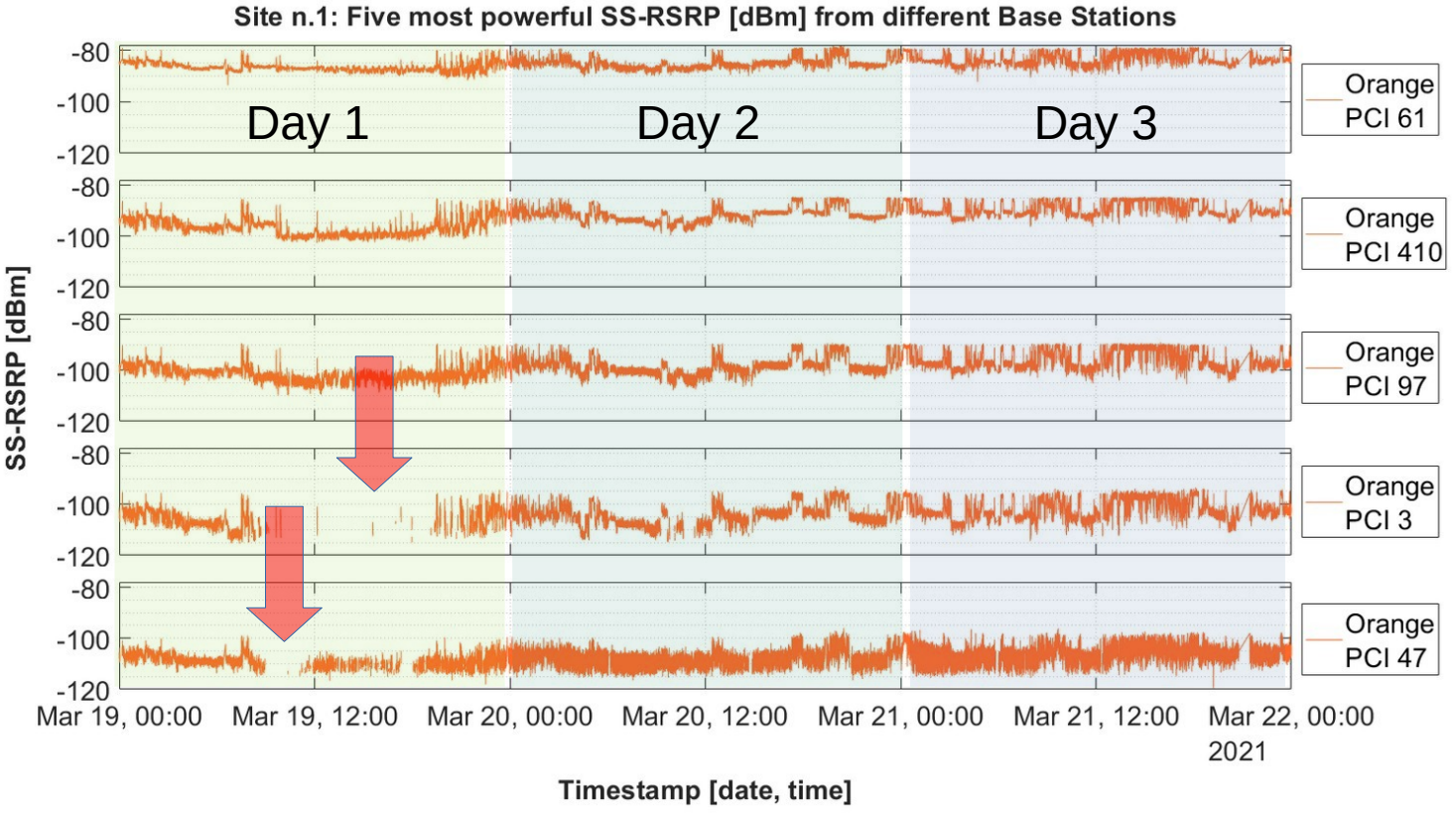


Site n.1 - Measured signals

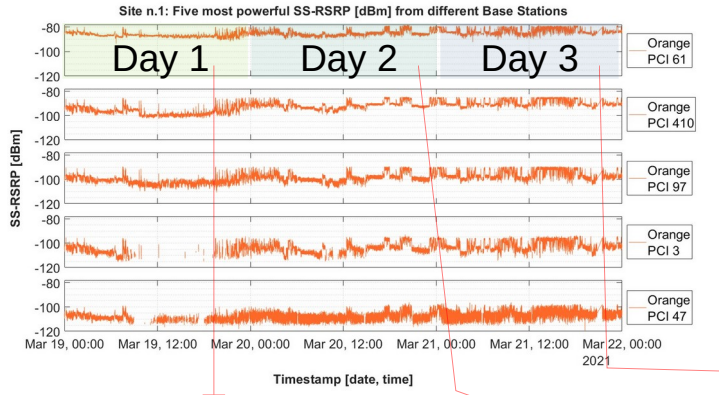
- 5G DSS signals from Orange Provider
- 3gpp n3 band (1800MHz)
- Five most powerful SS-RSRP received from different base stations

PCI	*SSB index number*	*Total Number SSB blocks*	*Signal*	*Provider*	*5G NR 3gpp band*	*SCS [kHz]*
61	2	1	5G DSS	Orange	n3	15
410	2	1	5G DSS	Orange	n3	15
97	2	1	5G DSS	Orange	n3	15
3	2	1	5G DSS	Orange	n3	15
47	2	1	5G DSS	Orange	n3	15

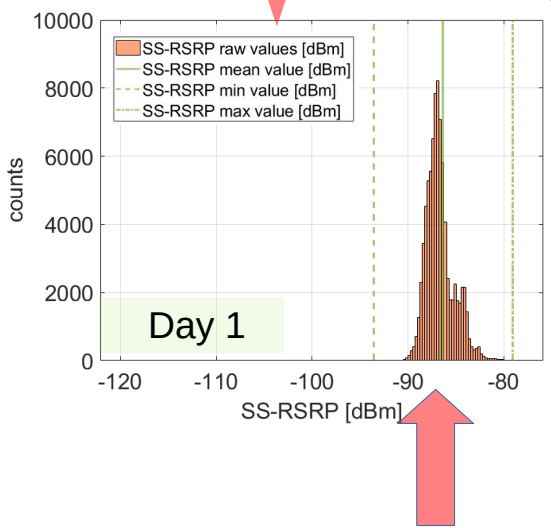
Site n.1 - Measured data

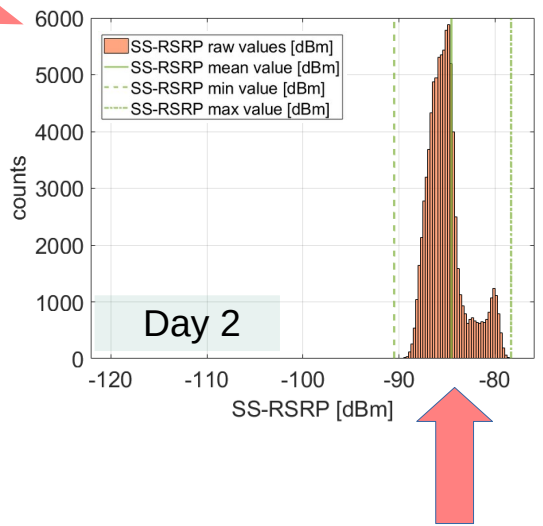


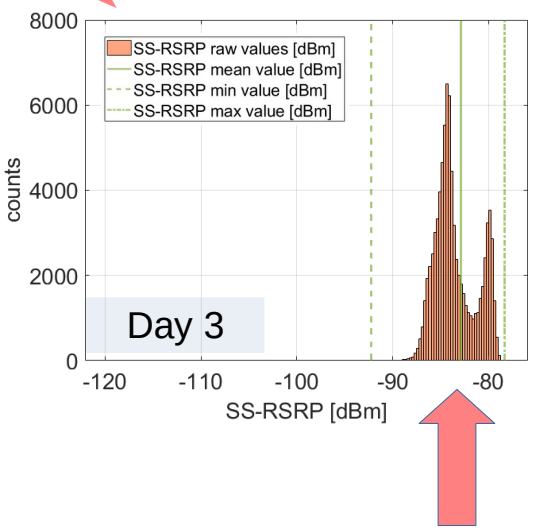
Site n.1 - PCI 61 - daily analysis



PCI 61 – Orange Provider				
Day	Mean [dBm]	SD [dB]	Min [dBm]	Max [dBm]
1	-84,6	1,5	-93,6	-79,0
2	-84,5	2,1	-90,5	-78,4
3	-82,9	1,9	-92,3	-78,4



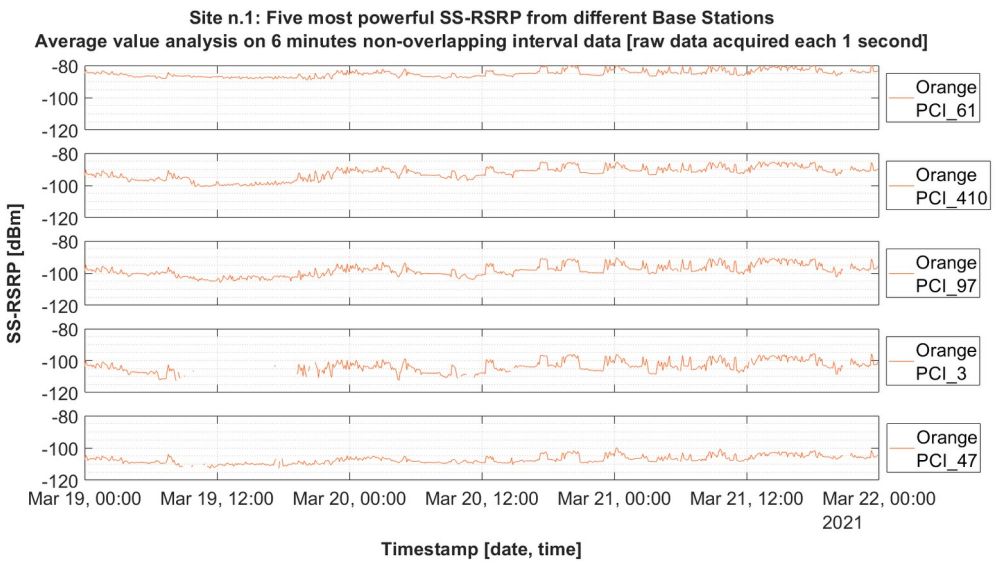




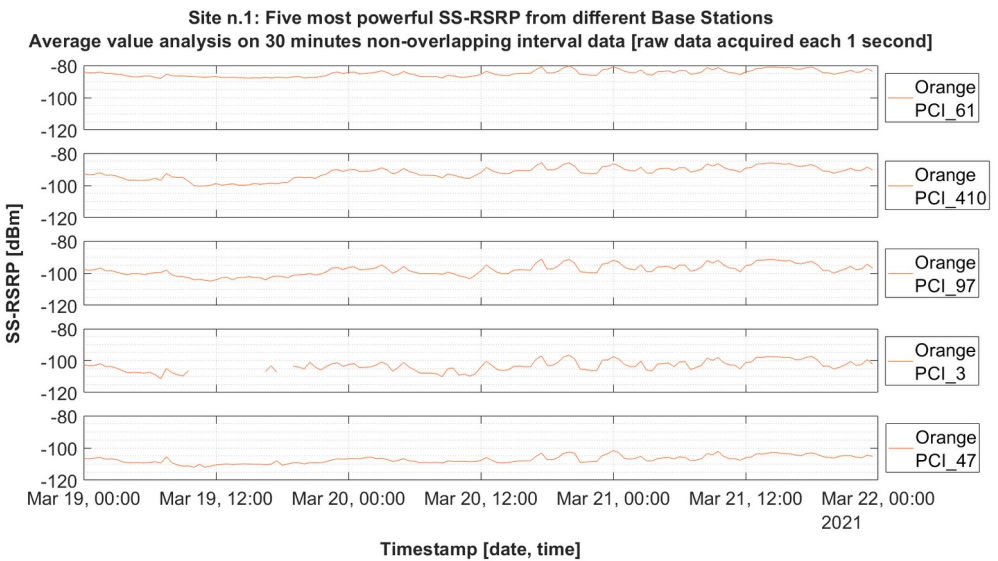
Site n.1 - 6 and 30 minutes analysis

whole-body exposure restrictions
6 minutes ICNIRP 1998
30 minutes ICNIRP 2020

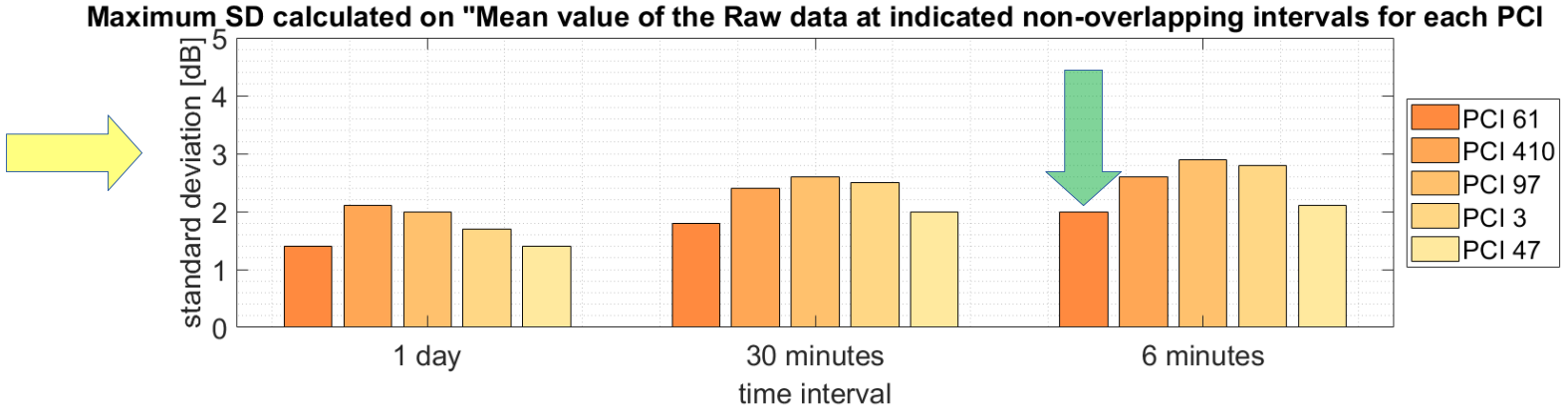
6 minutes Mean applied on raw data

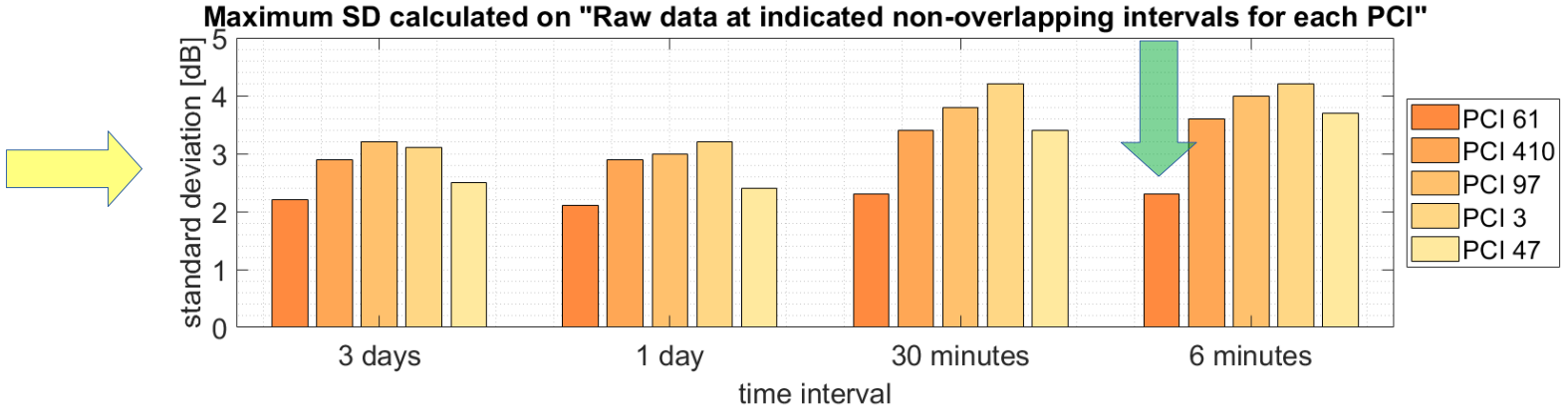


30 minutes Mean applied on raw data



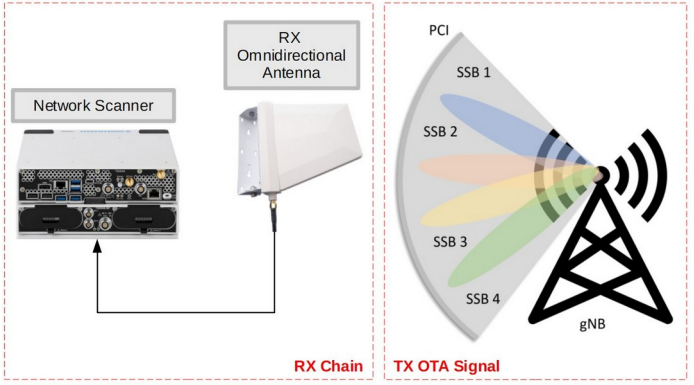
Site n.1 - SD worst case analysis





Site n.2 - Setup

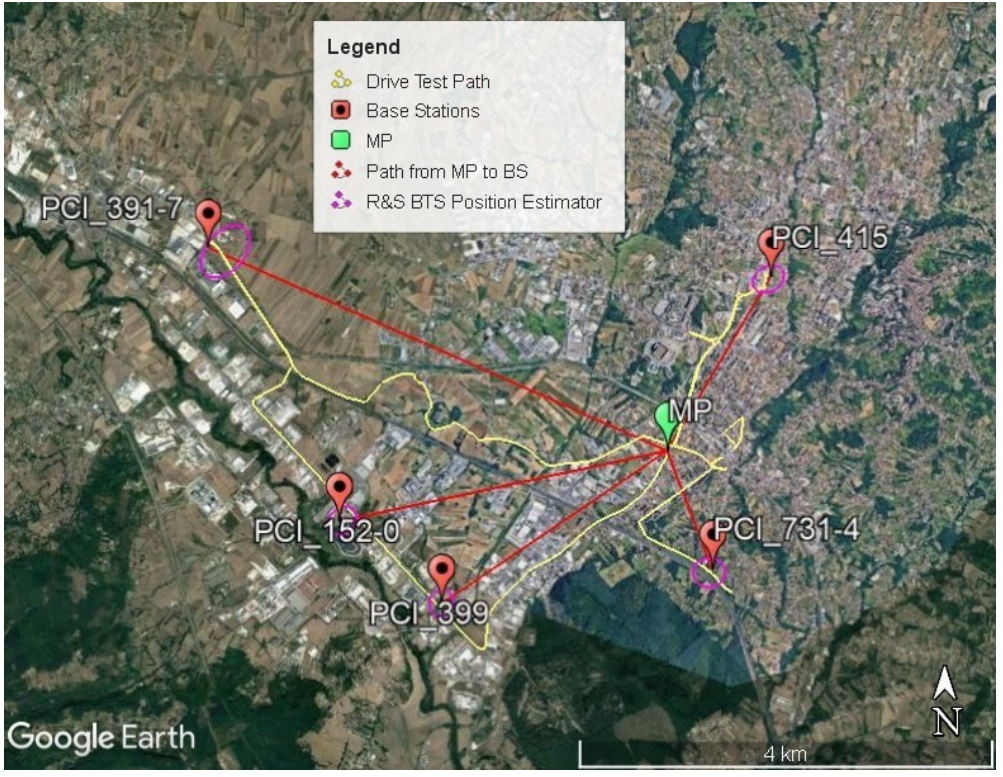
- Frosinone (FR)
- Outdoor Antenna
- Data measured from 29/03/21 00:00:00 to 31/03/21 23:59:59



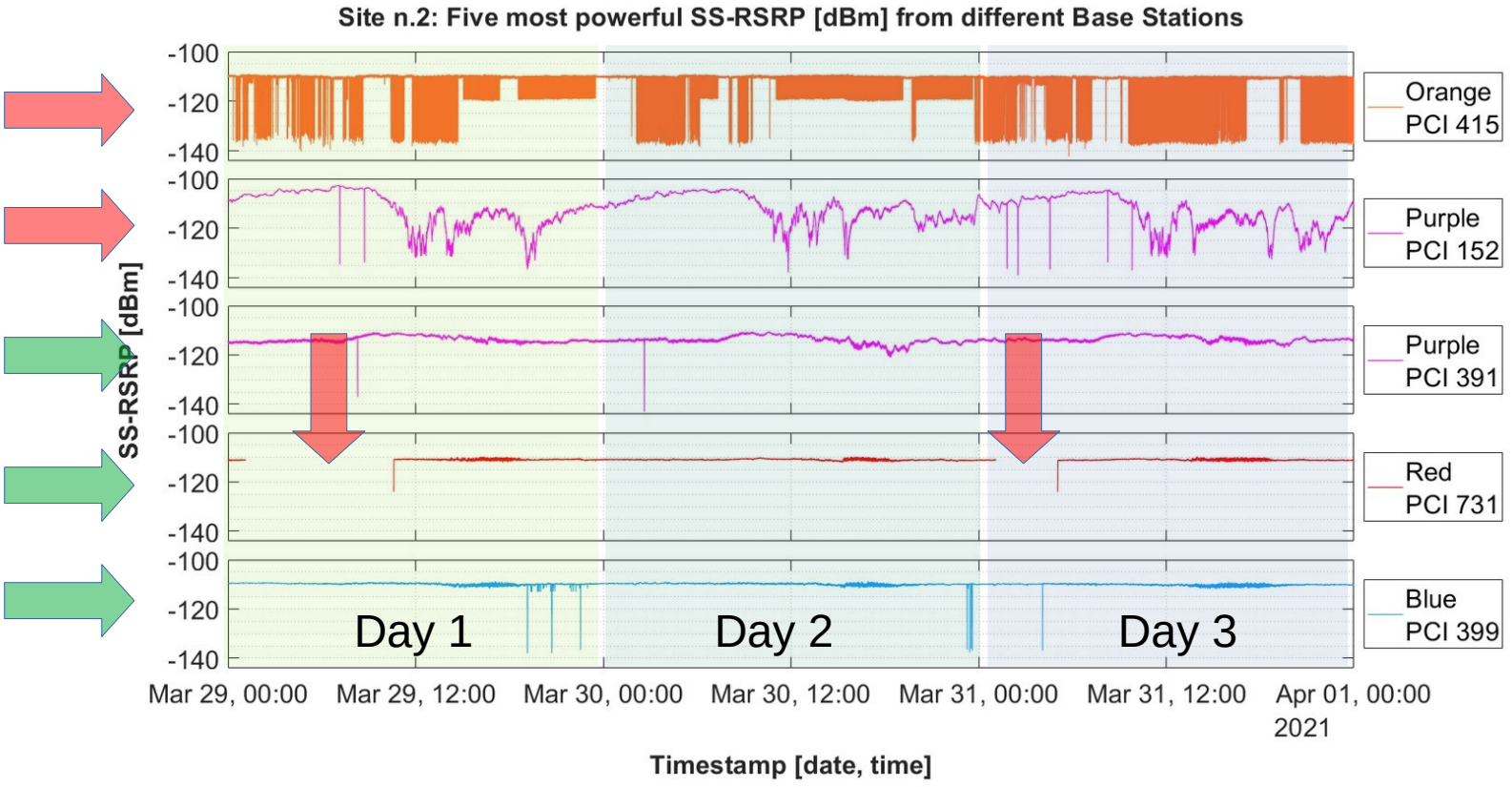
Site n.2 - Measured signals

- 5G signals from different Providers
- 3gpp n78 band (3600-3800MHz)
- Five most powerful SS-RSRP received from different base stations

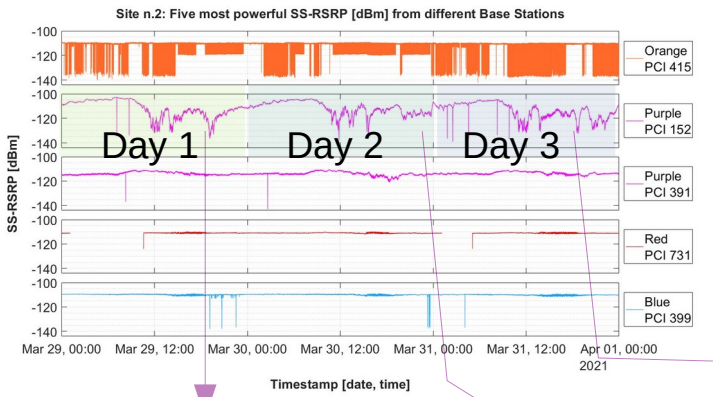
PCI	*SSB index number*	*Total Number SSB blocks*	*Signal*	*Operator*	*5G NR 3gpp band*	*BW [MHz]*	*SCS [kHz]*
415	0	1	5G	Orange	n78	20	30
152	0	8	5G	Purple	n78	20	30
391	7	8	5G	Purple	n78	20	30
731	4	8	5G	Red	n78	20	30
399	0	1	5G	Blue	n78	80	30



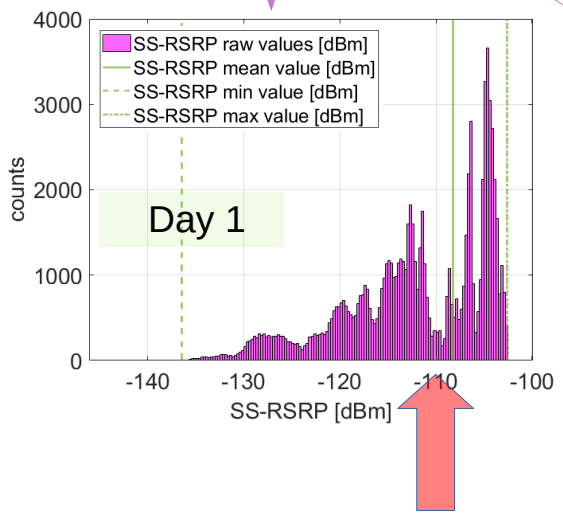
Site n.2 - Measured data

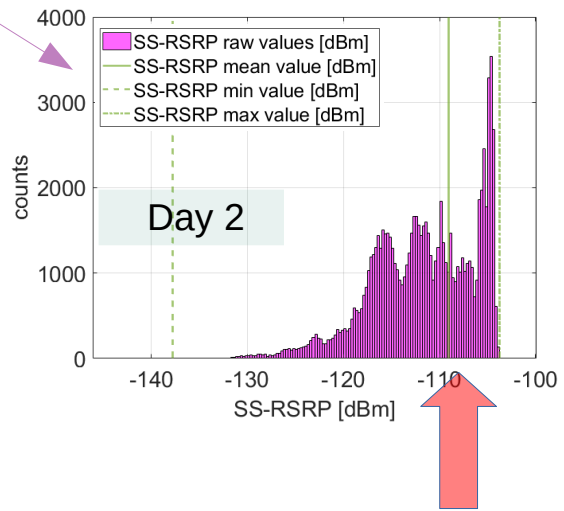


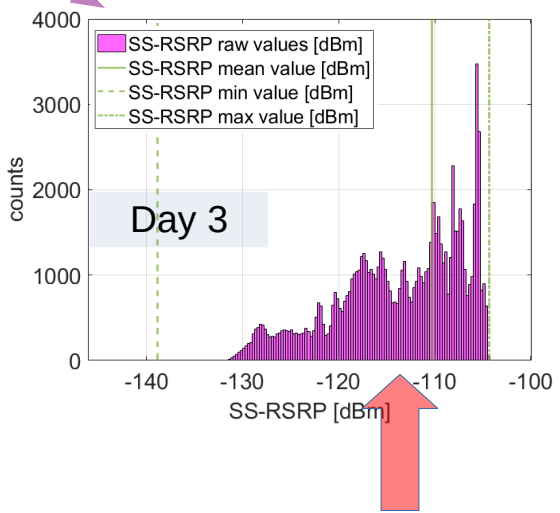
Site n.2 - PCI 152 - daily analysis



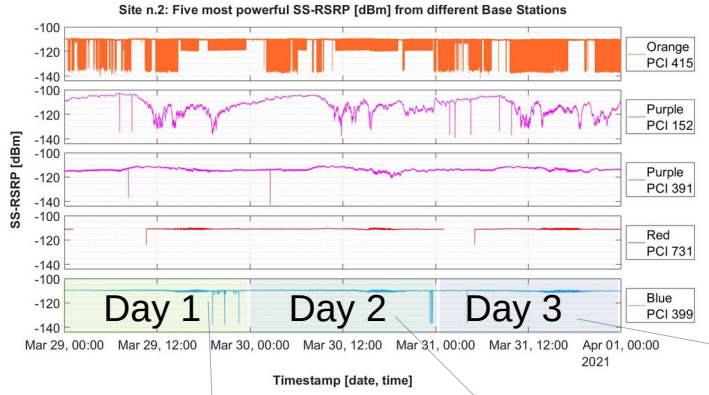
PCI 152 – Purple Provider				
Day	Mean [dBm]	SD [dB]	Min [dBm]	Max [dBm]
1	-108,2	3,0	-136,4	-102,6
2	-109,1	2,9	-137,8	-103,7
3	-110,3	3,0	-138,9	-104,3



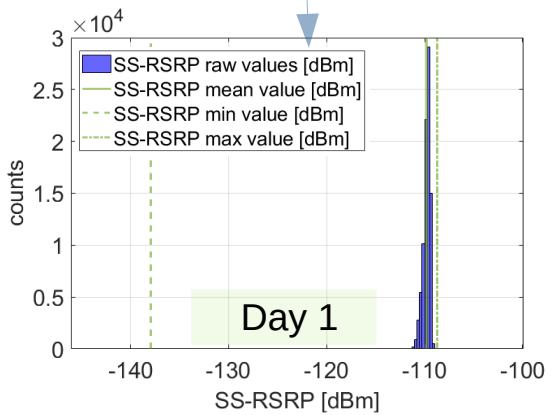


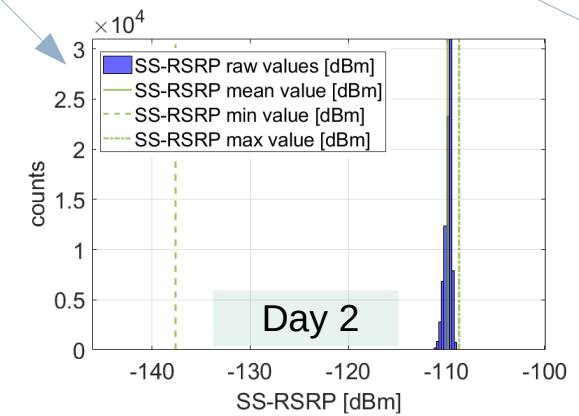


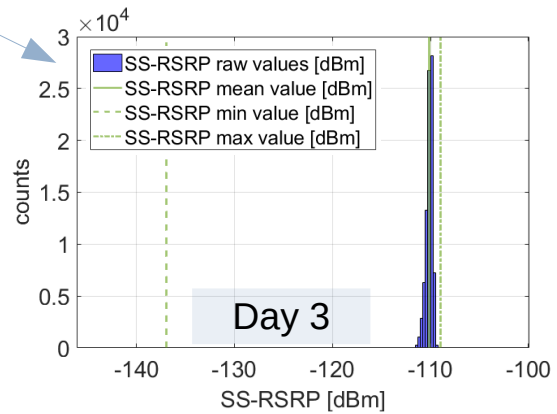
Site n.2 - PCI 399 - daily analysis



PCI 399 – Blue Provider				
Day	Mean [dBm]	SD [dB]	Min [dBm]	Max [dBm]
1	-109,8	0,3	-137,9	-108,7
2	-109,8	0,3	-137,6	-108,7
3	-110,1	0,3	-136,9	-108,9



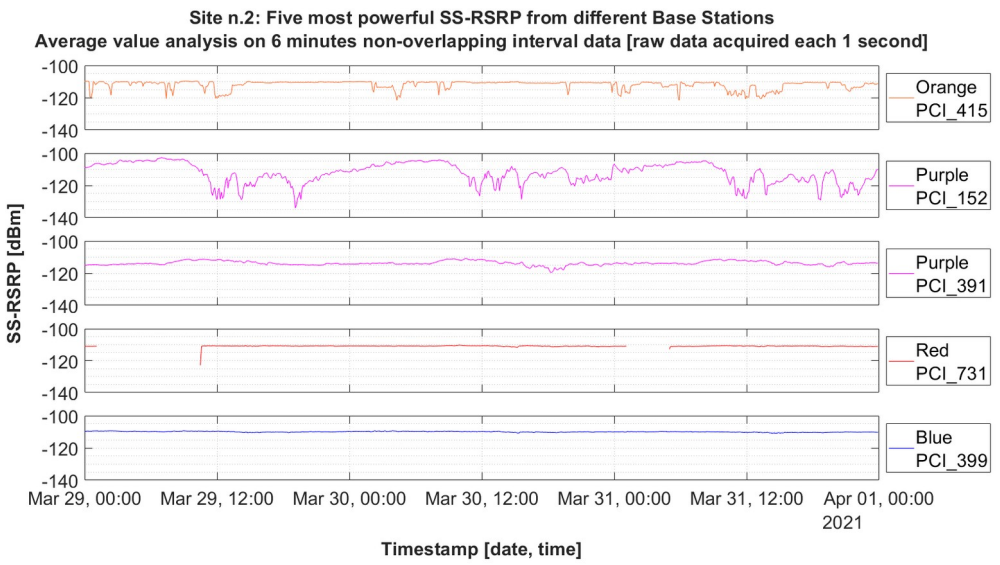




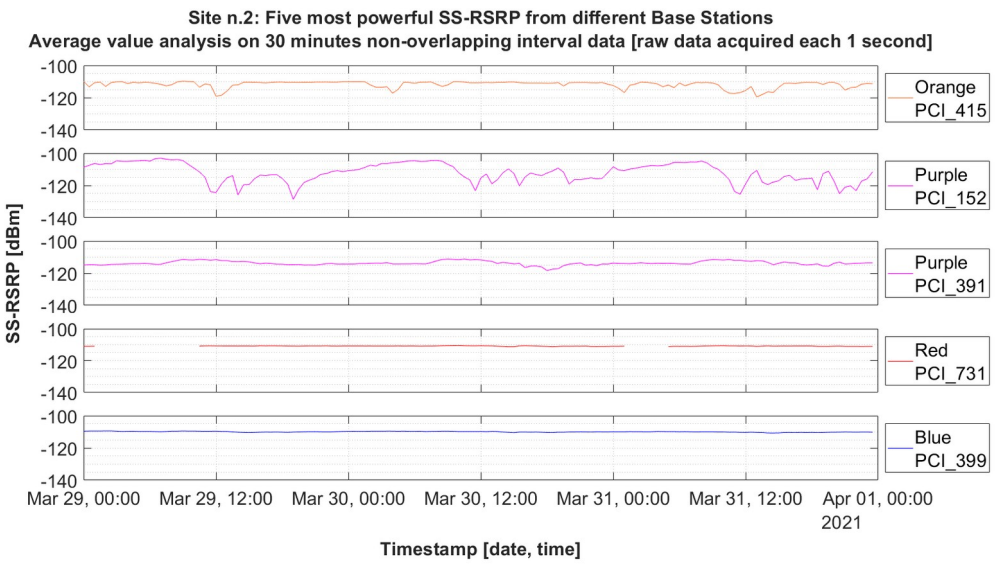
Site n.2 - 6 and 30 minutes analysis

whole-body exposure restrictions
6 minutes ICNIRP 1998
30 minutes ICNIRP 2020

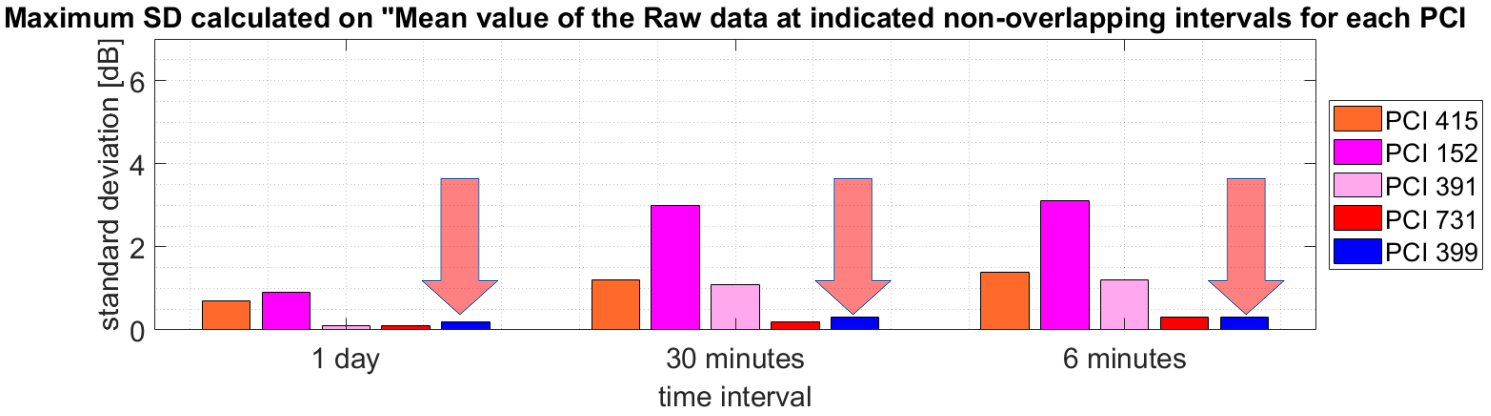
6 minutes Mean applied on raw data

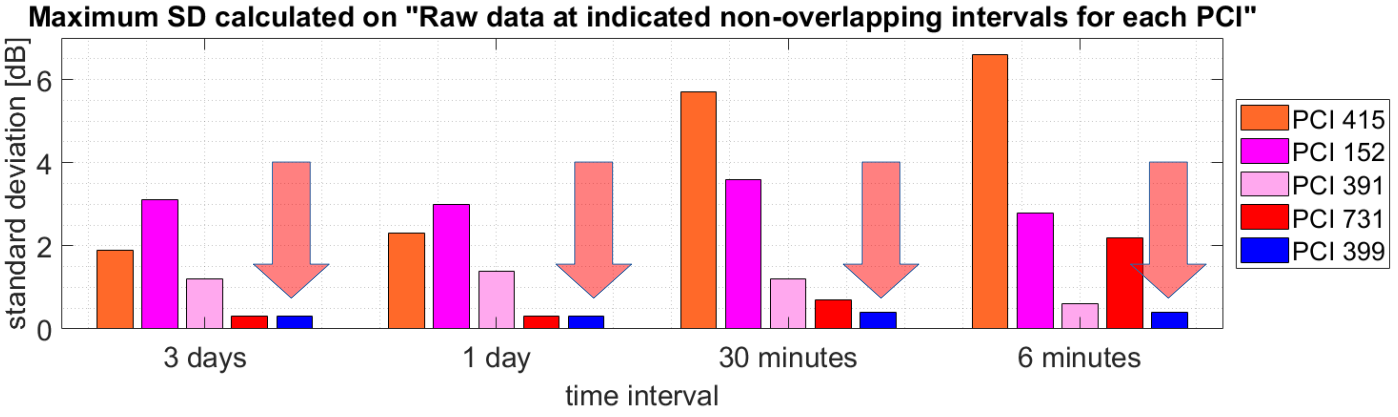


30 minutes Mean applied on raw data



Site n.2 - SD worst case analysis





Conclusions

- From Site n.1 analysis the observed signals show a variability greater than expected. This variability also results from the daily comparison.
- From Site n.2 analysis, conflicting results are observed. Three of them are stable and have shown limited variability even over short measurement intervals. The other two show variability greater than expected.
- In this context it is difficult to give a definitive conclusion. Especially considering the operating conditions in which the measurements were made. In particular, there was no information on the actual operative conditions of the base stations observed.
- However, looking only at the results of last three observed signal, they seems to have the required requirements, but without looking for the causes of the variability of first two signals, nothing definitive can be said.

Further developments

- In this work only the power (SS-RSRP) of the observed signals was evaluated. The network scanner is also able to measure the values of the Signal to Interference & Noise Ratio (SINR) and a quality index (SS-RSRQ) of the reference signal. These values could be correlated to the measured power signal in order to find conditions in which it is possible to discard the unsuitable power values.
- It might be interesting to make a measurement setup using other type of instrumentation to highlight the differences. Furthermore, given that the network scanner performs the same measurements as a mobile phone, it would be interesting to develop a measurement sensor using a 5G mobile phone or a developing board if it exists.

Thank you for your attention

Mobile Cellular Frequencies