EMF Exposure Evaluations For Future Networks Based on TDD and Massive MIMO: New International Regulations

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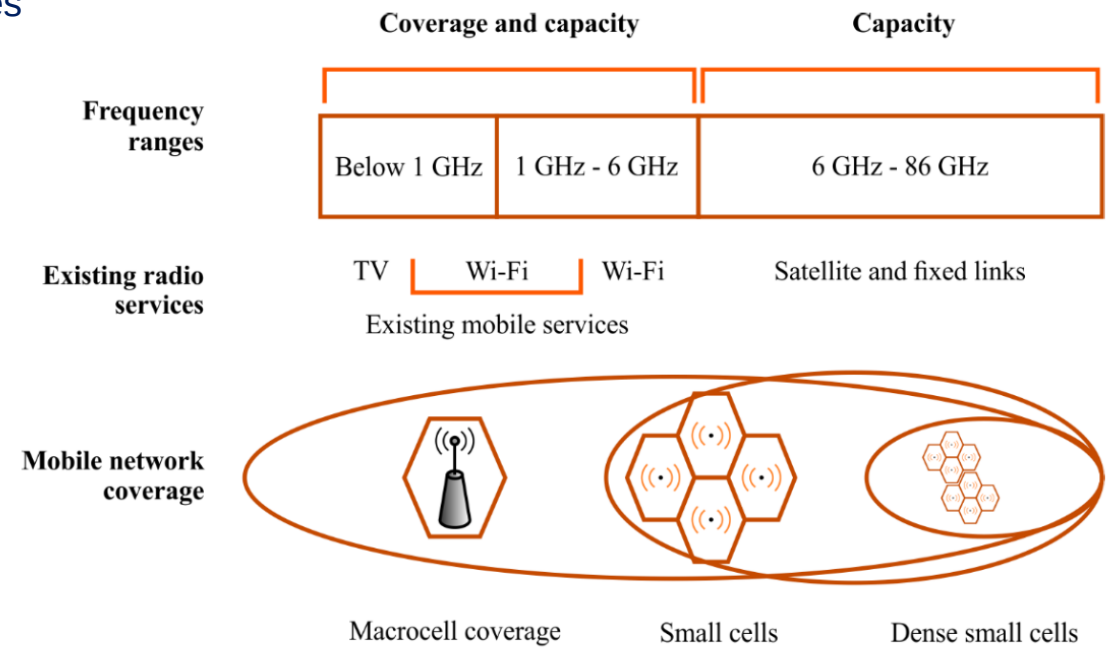
Future network 5G

- 5G future network will be a dense network with a large number of micro base stations, localized closer to the users and inside the buildings
- At the same time macro base stations and small cells will continue to be deployed, so the future network will be highly heterogeneous
- 5G spectrum needs will consider three key frequency ranges to deliver wide coverage and support all the planned services
  - sub-1 GHz
  - 1-6 GHz
  - above 6 GHz
- 5G paradigm suggests to ***revise EMF compliance assessment methodology*** for the regulatory requirements on human exposure by using ***new metrics measurements***



Source Rec. ITU-R K.Sup9 2017-F07

EMF Exposure Regulation – State of Art (1)

- **ICNIRP (**International Commission on Non-Ionizing Radiation Protection) **is an independent non-profit group of experts**, whose task is to assess the state of knowledge science-based about the effects of non-ionizing radiation on the health
- The **ICNIRP** is recognized as official collaborator of **WHO** (World Health Organization) for the issues related to the protection of public and workers from the effects of non-ionizing radiation exposure
- **ICNIRP's guidelines were published in 1998**, and have been incorporated into legislation or adopted as standards in many countries
- The **European Union adopts the ICNIRP Guidelines as EMF Exposure Regulation** implemented into:
    - Recommendation 1999/512/EC for general public exposure and into Directive 2013/35/UE for worker exposure.

EMF Exposure Regulation – State of Art (2)

- ICNIRP guidelines defined exposure limits in terms of
  - Specific absorption rate,
  - Electric field,
  - Magnetic field
  - Power density

Frequency	E (V/m)	H (A/m)	B(μT)	S (W/m)
0 - 1 Hz	/	3.2×10^4	4×10^4	/
1 - 8 Hz	10000	$3.2 \times 10^4/f^2$	$4 \times 10^4/f^2$	/
8 - 25 Hz	10000	4000/f	5000/f	/
0.025 – 0.8 kHz	250/f	4/f	5/f	/
0.8 - 3 kHz	250/f	5	6.25	/
3 - 150 kHz	87	5	6.25	/
0.15 – 1 MHz	87	0.73/f	0.92/f	/
1 – 10 MHz	$87/f^{1/2}$	0.73/f	0.92/f	/
10 – 400 MHz	28	0.073	0.092	2
400 – 2000 MHz	$1.375/f^{1/2}$	$0.0037/f^{1/2}$	$0.0046/f^{1/2}$	f/200
2 – 300 GHz	61	0.16	0.20	10

EMF Exposure Regulation – State of Art (3)

- Some countries, did not follow ICNIRP recommendations and defined national legislations for the protection of the health of the general public from EMF exposure
- The associated administrative procedures adopting more restrictive limitations with respect to the ICNIRP

Country	800 MHz	900 MHz	1800 MHz	2600 MHz
Belgium	20	21	29	31
Bulgaria, Lithuania	0.09 W/m^2			
Greece	23*/27	32*/35	45*/49	47*/51
Poland	0.1 W/m^2	0.1 W/m^2	0.1 W/m^2	0.1 W/m^2
Slovenia	12*/39	13*/41	18*/58	19*/61
Switzerland		4*/41	6*/58	64*/61
Italy	**20 / 6****	**20 / 6****	**20 / 6****	**20 / 6****
Malta, Romania, Sweden, Turkey, Hungary		41	58	61
Austria, Cyprus, Estonia, Finland, France Germany, UK, Luxembourg, Portugal, Czech Republic, Spain, Slovakia, Ireland	39	41	58	61

EMF Exposure and 5G Roll out

- Member States that adopted more restrictive limitations could impair the introduction of broadband wireless networks
- As a measure the European Commission indicated in the "***5G Action Plan***" the importance of **all European Countries to align their policies and legislations for EMF exposure** in order to promote an efficient 5G roll-out
- International Telecommunication Union (ITU) within the framework **ITU Regional Initiative for Europe on Development of Broadband Access and Adoption of Broadband**, promoted
  - ***European Country Case Studies*** to evaluate the impact of national legislation on the introduction of future 5G mobile network
  - **Italian Case Study** has been proposed by considering measurement campaigns of multi-technology (2G, 3G-4G) sites


EUROPEAN COMMISSION

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COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS

5G for Europe: An Action Plan

{SWD(2016) 306 final}

Italian EMF Regulations (1)

The Italian law is based on 3 different protection level

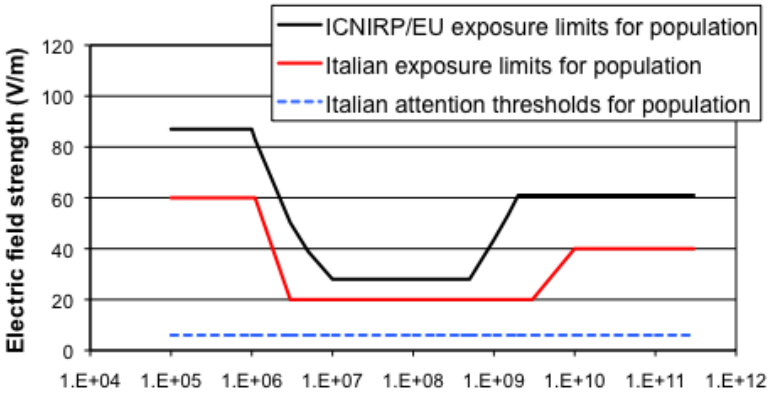


TABLE 3 COMPARISON BETWEEN ICNIRP REFERENCE LEVELS AND ITALIAN LEVELS FOR THE PUBLIC EXPOSURE TO RF FIELDS

FREQUENCY BAND [MHz]	ICNIRP LIMIT [V/m]	ITALIAN LIMIT [V/m]
800	39	
900	41	
1800	58	6
2100	61	
2600	61	

- The current Italian EMF Regulations has defined three set of EMF limits much lower than ICNIRP guidelines as recommended by the Eurepean Union
- An **exposure limit 20V/m** (average over any 6 minutes)
- **Two thresolds**
  - **Value of attention of 6 V/m** (average over 24 hours)
  - **Quality objective of 6 V/m** (average over 24 hours)

Italian EMF Regulations (2)

- The compliance with the value of attention and quality objective are obtained by considering for the EMF calculation as input:
  - the transmitted power averaged over 24 hours, evaluated on the basis of the reduction of the maximum power to the antenna connector with a specific factor that take into account the **temporal variability of the emission** of the plants within 24 hours
- The Italian Electro technical Committee established in the technical guide (CEI 211) a reduction factor of the maximum power, *α24*, as

$$P_{24h} = P_{MAX} * \alpha_{24}$$

Average transmitted power over 24 hours

Maximum transmitted power

Database per operators to collect values for each site and technology. The maximum value per year needs to be declarated for autorization process

Italian Case Study

- The activation of new RBS site is obtained by considering **preliminary simulations**, in order to verify the maximum electromagnetic level permitted for the authorization by assuming **the worst case situation**
  - free space propagation;
  - RBS operating at maximum transmitted power
- Moreover, evaluations can be also performed by considering, when available from the operators, the reduction factor *α24*
  - The introduction of the **reduction factor *α24* allows to account for the time variations of the RBS site transmitted power** and consequently can possibly ease the introduction of new technologies in the same location
  - This approach has been adopted to permit the migration from 3G towards 4G in the same RBS sites in the whole national territory **could be no more feasible for the 5G roll-out due to the site saturation effect**

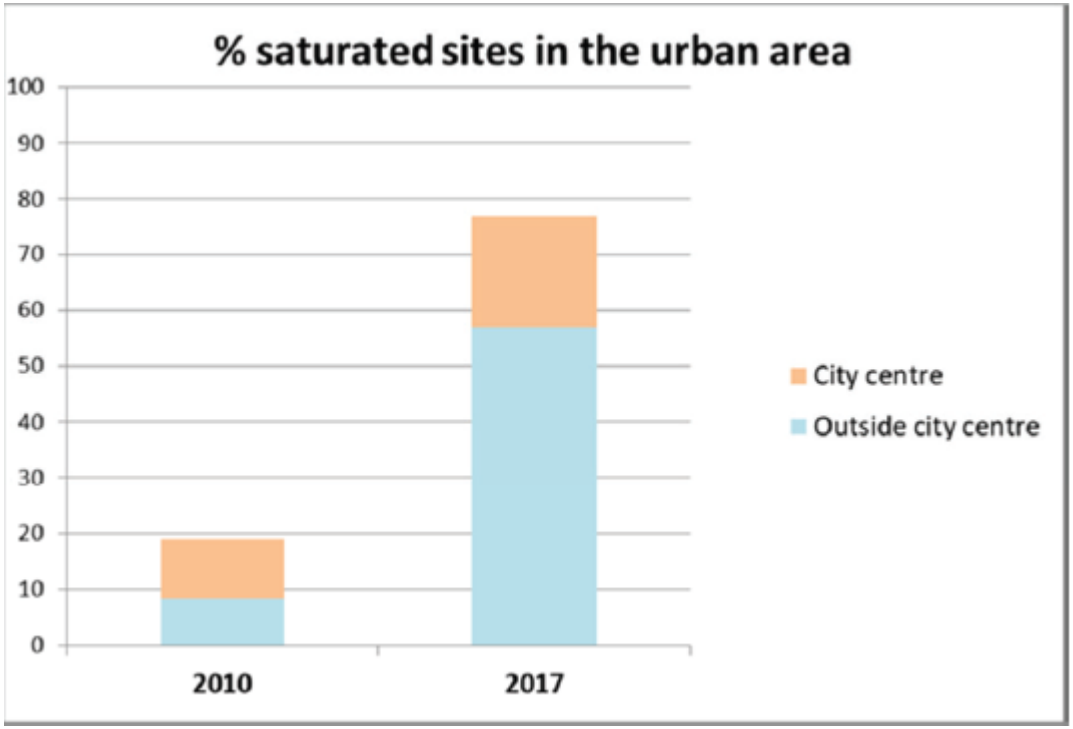
Source Rec. ITU-R M.2083-0

Italian Case Study: EMF Saturation effects

- ***System simulations***
  - Simulation results of the electromagnetic exposure have been carried out by considering real sites deployment in Bologna
  - **A comparative analysis** has been performed by evaluating the trend of the percentage of saturated sites taking into account the situation experimented in **2010** and in **2017**
- ***Saturation effects investigation***
  - **RBS site is assumed «saturated»** if the Electromagnetic field simulations experiment an **EMF value of 5 V/m** in selected zones under test for which it is needed to satisfy attention and quality limits (i.e. 6 V/m)
  - Evaluations have been performed starting from input data provided by the Local Region Agency to the Environmental Protection (Arpae) of Bologna

Italian Case Study: Results (1)

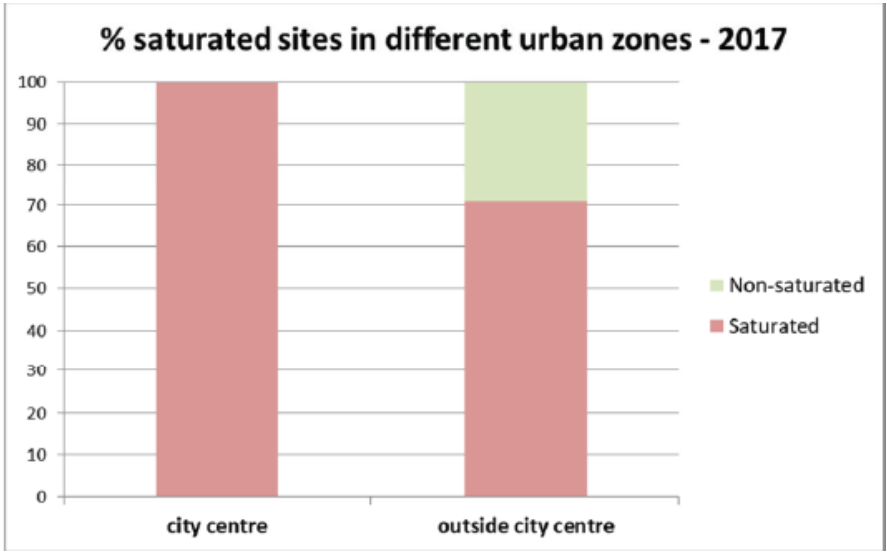
- The evolution of saturated sites from 2010 to 2017 shown that
  - the percentage of saturated sites has quadrupled from 2010 to 2017, ranging ***from 19% to 77%*** of the total number of sites in the city area
  - In 2010 the saturated sites for both city centre and outside the city (suburban areas) was around 10% for each type.
  - In 2017 22% of saturated sites in city centre and 55% in outside



Note that *the 22% of saturated sites in the city centre experimented in 2017, represent the whole number of sites located in dense urban area*

Italian Case Study: Results (2)

- Different urban areas in 2017 has been analysed
  - all sites in the City Centre Town are saturated (100%) and therefore cannot accommodate new technologies unless reconfigurations;
  - the percentage of saturated sites in peripheral areas of the city is 71%

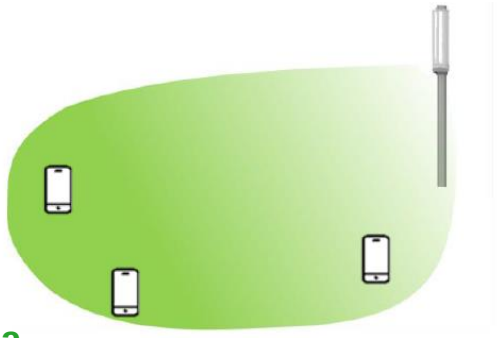


Note that** the considerable presence of saturated sites **increases complexity for the introduction of new technologies such as the 5G

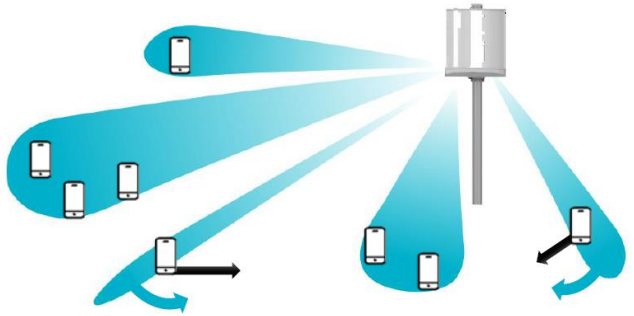
MIMO & 5G

5G New Radio (ITU, 3GPP) will be characterized by advanced antenna technologies such as Massive MIMO

- ***Energy transmitted in the directions where it is needed*** rather than in a wide sector constantly
- Traditional approach based on theoretical maximum power transmission could not more appropriate



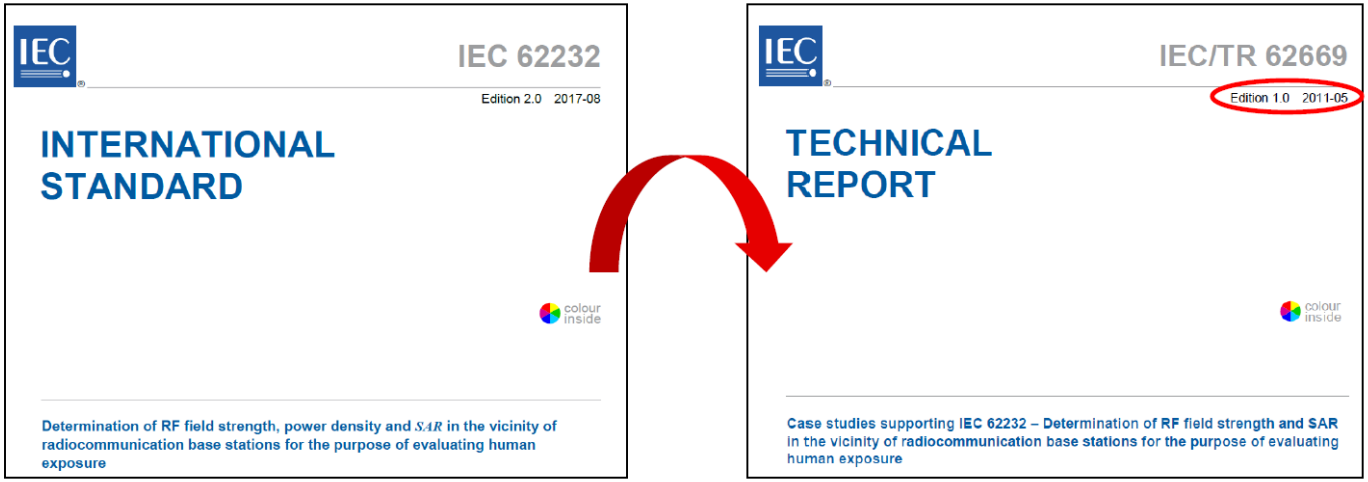
Traditional Antenna



MIMO Antenna

IEC & 5G

- The International Electrotechnical Commission (IEC) Committee has defined an improvement of exposure assessment methodologies including 5G frequencies
  - **Technical Committee TC106**: Methods for the assessment of electric, magnetic and eloctromagnetic fields associated with human exposure
  - **Maintenance Team 3**: Expert Committee responsible for the methods for the assessment of electric, magnetic, & electromagnetic fields associated with human exposure-base Stations



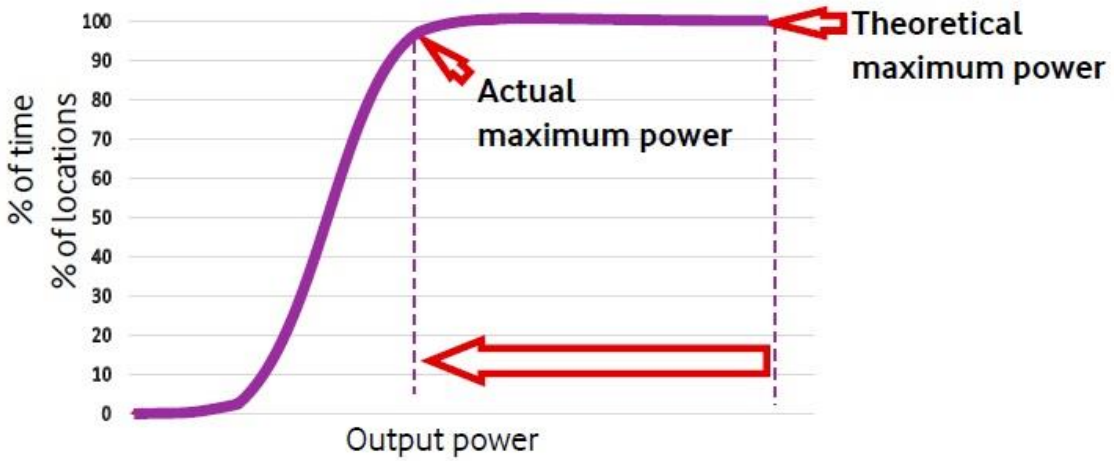
Publishided July 2018

Public Consultation up to December 2018

EMF & 5G (1)

- IEC defined guidelines (IEC62232 and TR62669) to consider realistic evaluations for 5G Access Network based on the **actual maximum power** instead of the nominal one, defined as the **95th percentile of all measured values that contribute to the EMF emission**

  - This approach takes into account the ***long-term behavior of spatial multiplexing capabilities of Massive MIMO antennas***, as well as radio resource utilization and TDD transmission intervals



EMF & 5G (2)

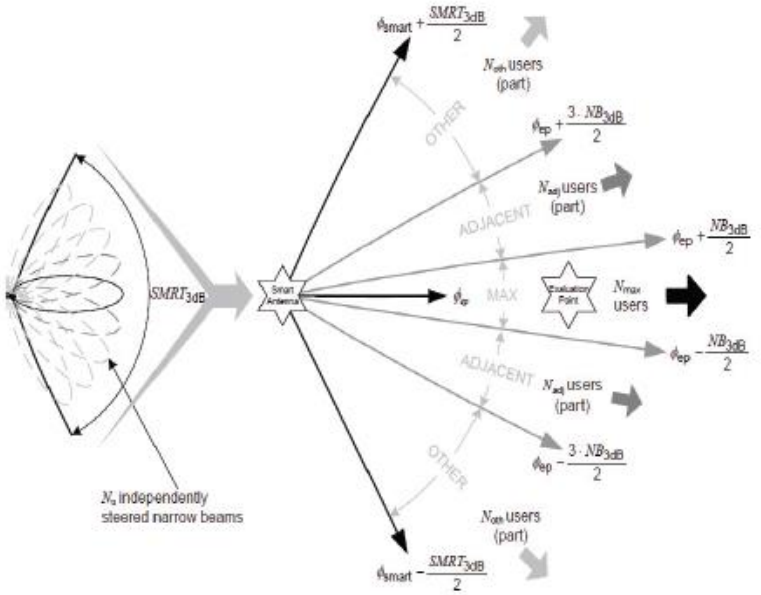
- IEC model is a ***statistical model*** to evaluate the effective power density by using advanced antenna technologies based on
  - a ***spatial probability*** by considering the Power density model for MIMO analysis
- Italian guidelines (CEI 211) consider
  - a ***temporal probability*** for power emission analysis according to the reduction factor *α24*
- ***Next step for Italy***

The statistical model IEC will be included in the CEI Italian guideline

IEC62232 Statistiacal model

Case study:

- all N_u are located in the same direction as the evaluation point and that all the transmitted power is directed towards the evaluation point ($N_{max} = N_u$)



Statistic number of users (N)

$$S_{sta} = S_u * (\delta_{max} * N_{max} + \delta_{adj} * N_{adj} + \delta_{oth} * N_{oth})$$

Narrow beams factor (δ)

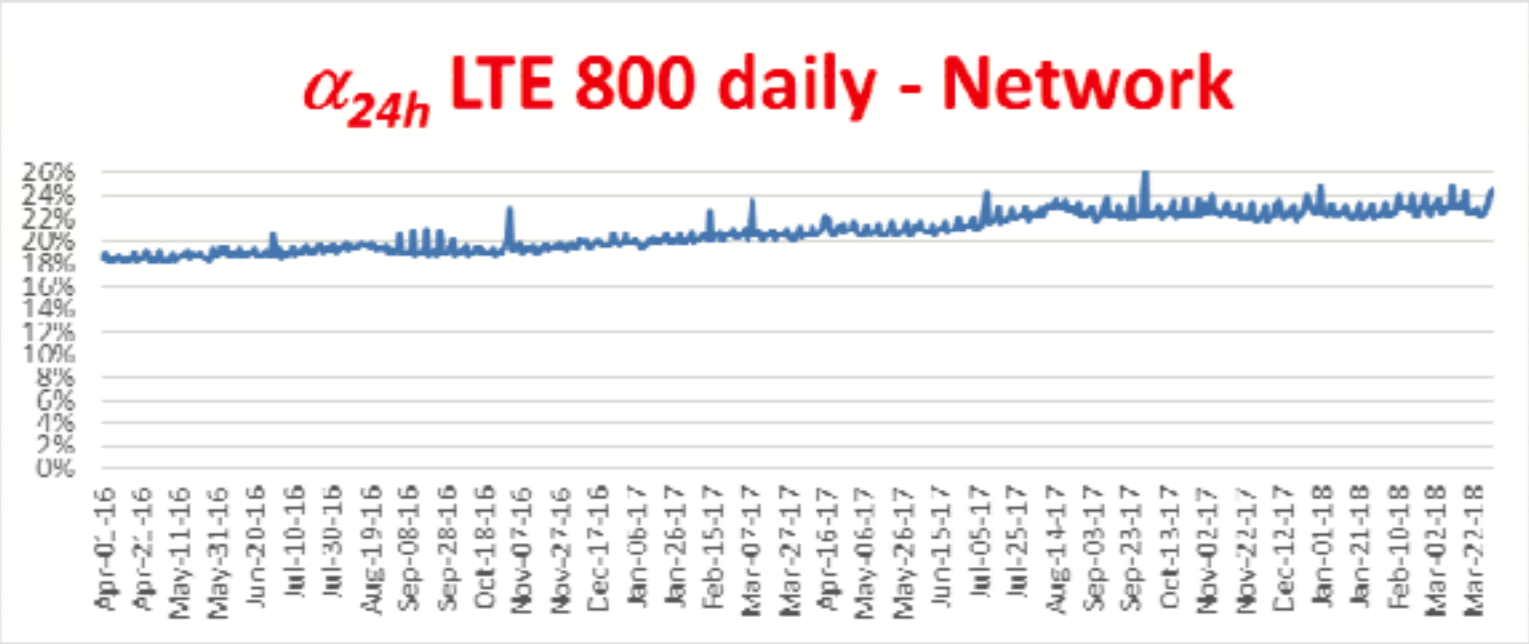
Deterministic conservative power density (S)

Our scope:

- to evaluate the effective EMF for a BS with MIMO technology and to verify that remains below the **ICNIRP guidelines** threshold
- To further evaluate, due to restrictive limits of some countries, emissions by including, as exemplary case, the **Italian temporal model**

Italian temporal distribution EMF evaluation for 4G Network

- The *α24* daily cofficient, for the exemplary case of 4G@800 MHz Vodafone network, is about ***23 %***
- ***Data collected for overall 4G Vodafone*** network confirmed that real emission are **much lower** than the theoretical maximum power used for EMF calculation for expousere limits compliance



Statistical EMF evaluation for MIMO

- Statistical EMF evaluation has been performed considering:
  - Statiscal model as indicated in the IEC guidelines to evaluate 95% power density @ distance *r =20 m* from the MIMO antenna (***spatial distribution***)
  - Statistical model as indicated in the IEC-62232 guidelines with the introduction of transmitted power reduction factor of *α24* daily cofficient as indicated in CEI-211 guidelines (***spatial distribution + temporal distribution***)

Statistical EMF evaluation for MIMO: Parameters

Antenna Paramters	
Antenna Type	Sectorial (4,4)
Frequency	800 MHz
$P_{Tx\ per\ sector}$	25-35 Watt
Gain	15-16 dBi
$SMRT_{3dB}$ (*)	120°
N_{3dB} (**)	15°
D_{ϑ}	1

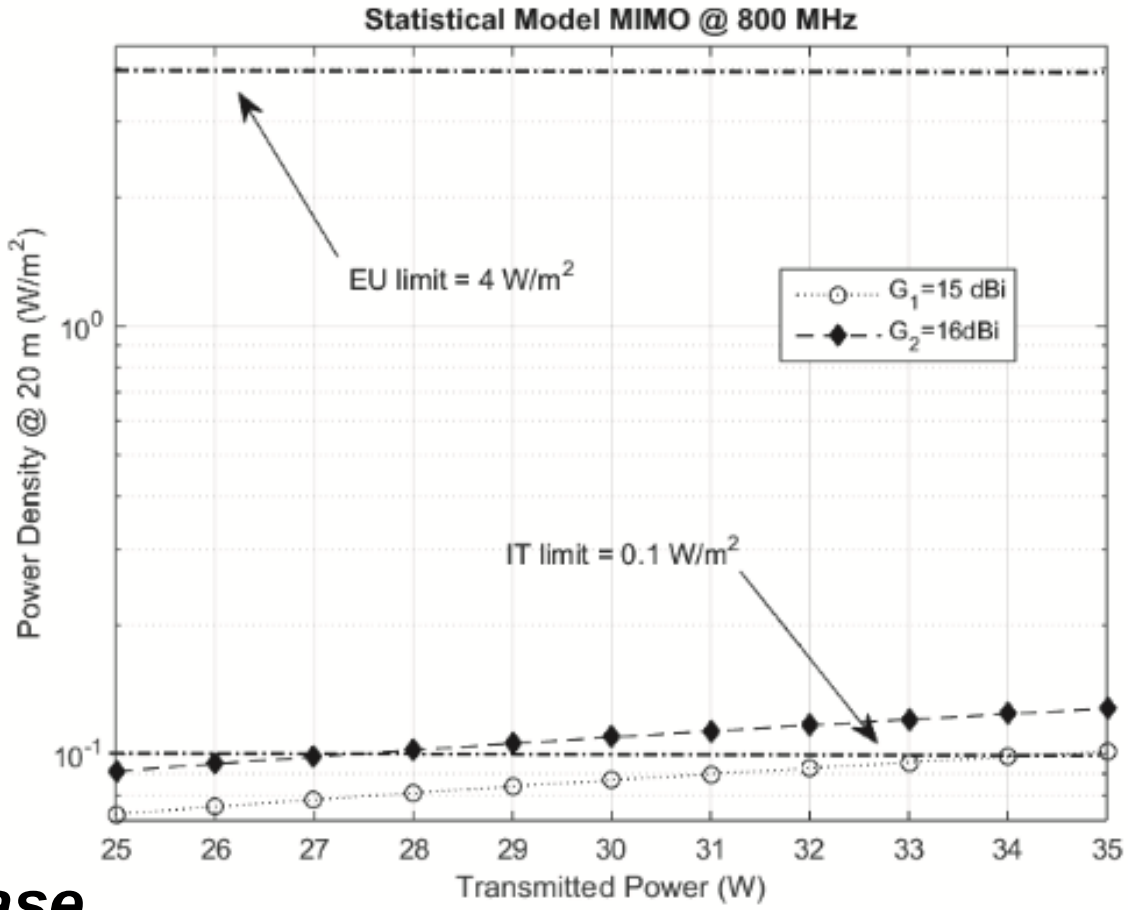
Statistical Model Paramters	
δ_{max}	1
δ_{adj}	0.5
δ_{oth}	0.0063
N_u	24
N_{max} (***)	6
N_{adj}(***)	9
N_{oth}(***)	9

(*) sector beamwidth
(**) beamwidth for user
(***) N values obatined by considering the cumulative probabiity function F(k,PR,N) that establishes the probability of less than k user out of N being within the target narrow beam for which 95% of power density is reached

Statistical EMF evaluation for MIMO: Results (1)

Statistical IEC model with MIMO@800 MHz verified that power density evaluations (@20 m):

- **extensively satisfy** the EU limit for all trasmitted power
- **are not able to satisfy** the permitted threshold of Italian limit for all transmitted antenna power and antenna gain

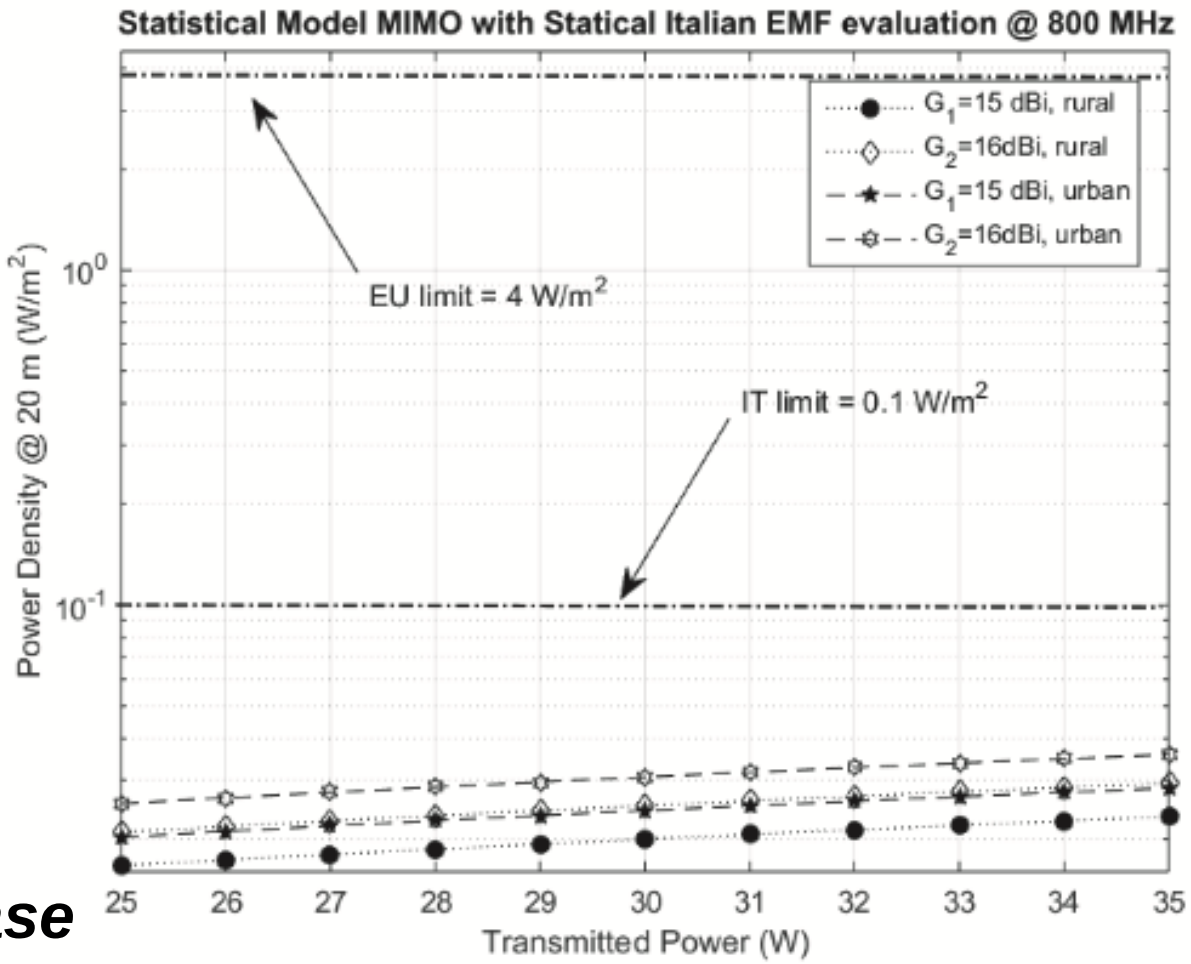


Urban Case

Statistical EMF evaluation for MIMO: Results (2)

Statistical IEC model with MIMO@800 MHz with the **Italian time-averaged model** verified that:

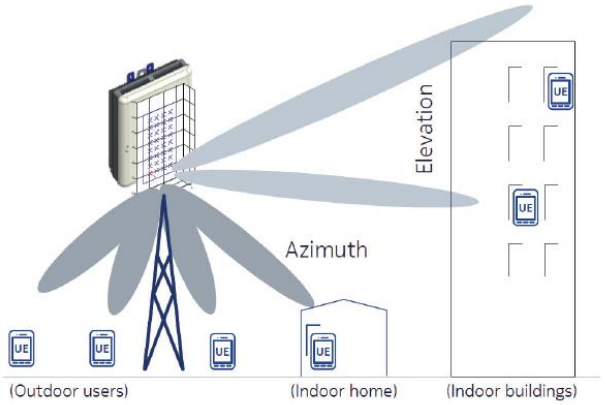
- power density evaluations **remain always below** the Italian limits regardless of the antenna gain and trasmitted power



Urban & Rural Case

Conclusion

- The 5G New Radio (NR) is characterized by **MIMO technology** for which the beam is steered in the directions where it is needed, rather than to constantly transmit energy in a wide sector
- A conservative approach where theoretical maximum power is transmitted in each possible direction for a long time **period in unrealistic**
- **The Italian case studies highliteghed that** the sites saturation conditions could be a challenge for the future 5G migration
- **IEC has defined in IEC62232 statistical model to investigate EMF emission for 5G**
  - The **statistical IEC model** has been investigated for MIMO@800 MHz network by considering *power density evaluations@20m* to verify the compliance with ICNIRP limits
  - The **statistical IEC MIMO** model can be applied in the Italian regulatory framework, on top of the average transmitted power evaluation, to calculate the EMF emissions from a Massive MIMO antenna, **avoiding the over-estimation introduced by the conservative deterministic model**



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Thank you!

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