Exposure Assessment for 5G Massive MIMO Base Stations

The 5th International Conference:
„I have heard that the 5G network causes ... The development of mobile telecommunications networks in the era of disinformation - technology, health, regulations and education”

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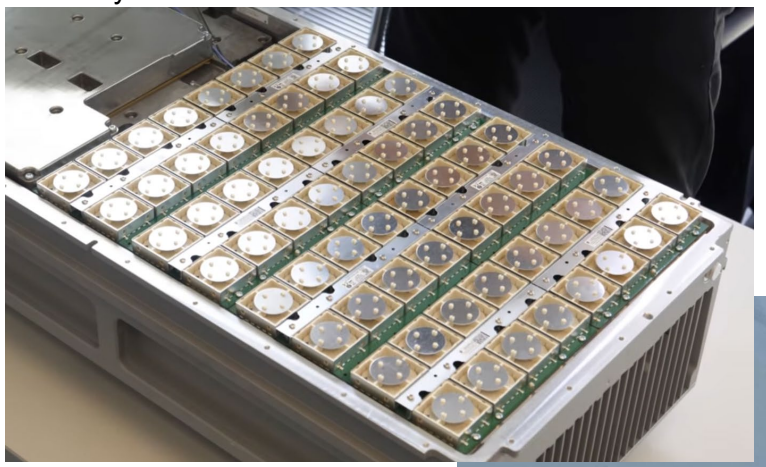
Exposure Assessment for 5G Massive MIMO Base Stations

Outline

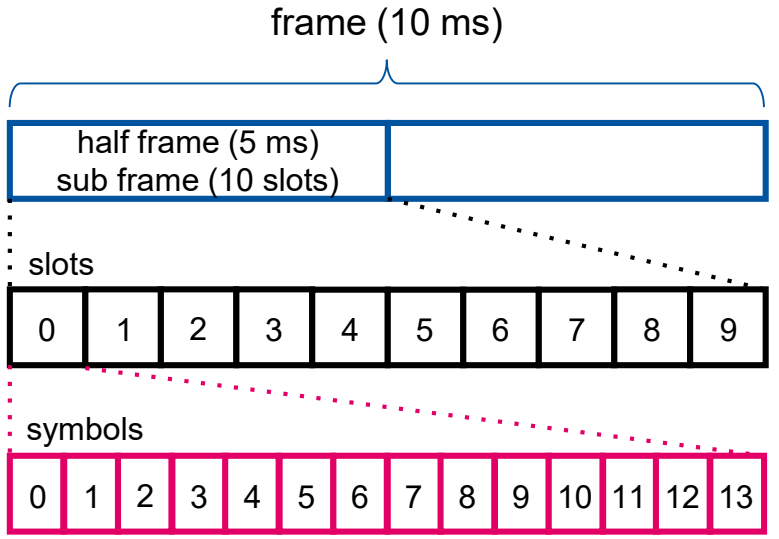
- Fundamentals about 5G
  - Differences to LTE
  - Massive MIMO antennas
  - Separation of broadcast and traffic beams
- Assessment of Theoretical Maximum Exposure
  - Current challenges
  - Measurement procedures
  - Approach for extrapolation to theoretical maximum exposure

source: youtube/Telekom Netz

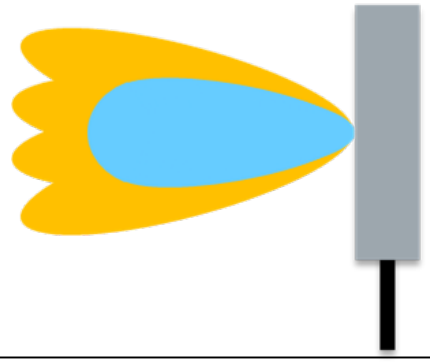


Differences to LTE

- Similar waveform, but flexible frame structure
  - So far, mostly an SCS of 30 kHz is used (LTE: 15 kHz)
  - Symbol duration of 35.7 µs is only half compared to LTE (71.4 µs)
- Higher channel bandwidths possible
- In band n78 (3.3-3.8 GHz), a usage of TDD is specified
  - Shares of uplink and downlink can be flexibly chosen on a slot-base
  - In practice: TDD is based on a slot periodicity of e.g. 5 with dedicated slots for downlink and uplink as well as mixed slots
- Usage of beamforming antennas
  - The radiation of signalization and traffic is split into different beams (broadcast and traffic beams)
  - No cell-specific reference signal (as the RS in LTE)
  - Traffic beams can be directed to areas in the cell, where service is needed



Frame structure for 30 kHz SCS

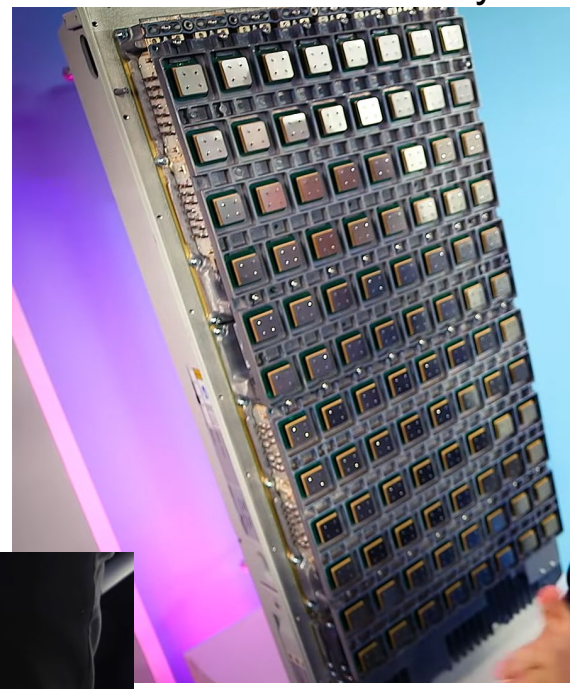


Massive MIMO Antennas

Beamforming

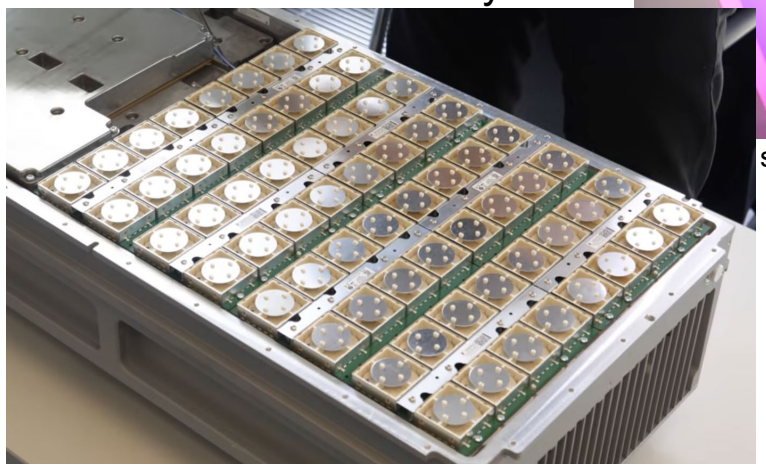
- Massive MIMO antennas are uniform rectangular antenna arrays
- Huge number of antenna elements leads to a high gain of the entire antenna array
- Beams can be switched/formed to adapt to varying traffic demand and channel conditions in horizontal and vertical domain
  - Codebook based beamforming: discrete beam directions
  - Reciprocity based beamforming: optimal radiation pattern to fully exploit the transmission channel
- It is possible to radiate multiple beams simultaneously

12x8x2 element array



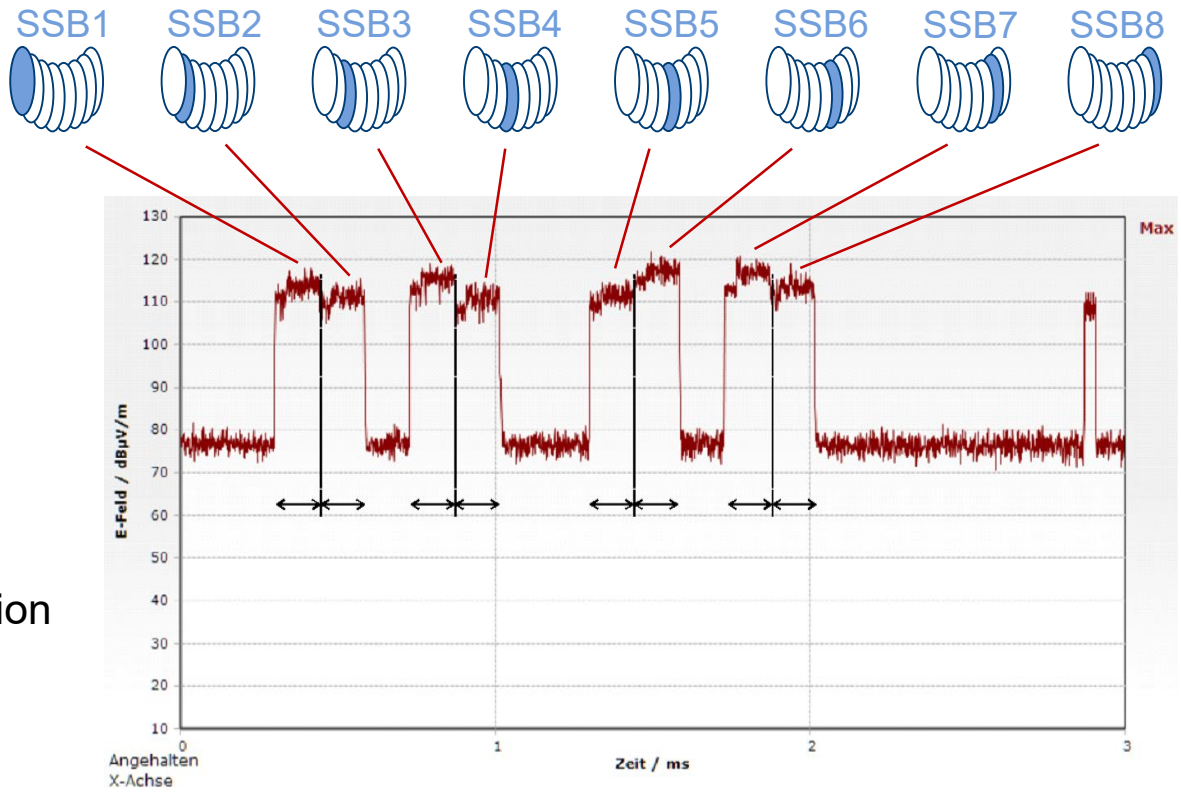
source: youtube/Netzgeschichten

8x8x2 element array



source: youtube/Telekom Netz

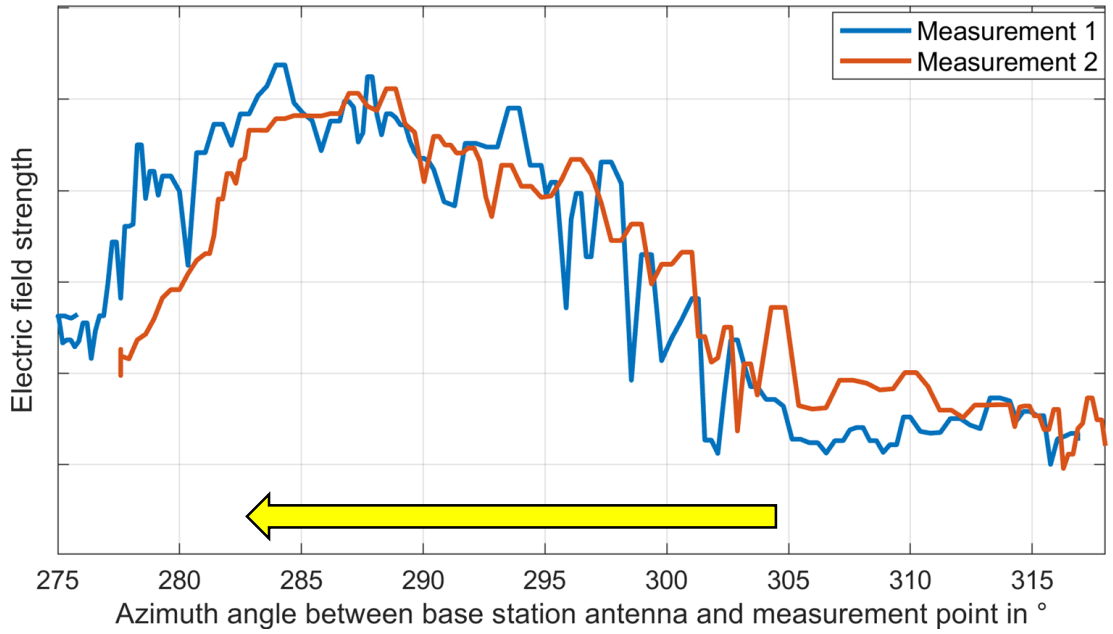
Broadcast and traffic beams



- When massive MIMO antennas are used, signalization and traffic can be radiated with different antenna patterns
  - Signalization: broadcast/SSB beams
  - Traffic: traffic beams
- Broadcast beams:
  - Radiated signal: SS/PBCH block (SSB)
  - Each SSB within a burst set corresponds to one beam direction
  - Maximum no. of beams: 8 in FR1
- Traffic beams:
  - Radiated signal: PDSCH (among others)
  - Beam directions may be based on a grid of beams with very fine angular spacing (codebook-based beamforming) or individual determination of an optimal radiation pattern (reciprocity-based beamforming)

Crossing a traffic beam

- Measurement of the electric field strength when crossing the beam
- Traffic beam was directed to UE carrying out a download
- Measurement results could be reproduced



There were no vehicles on the parking deck during the measurement

“Worst case” exposure

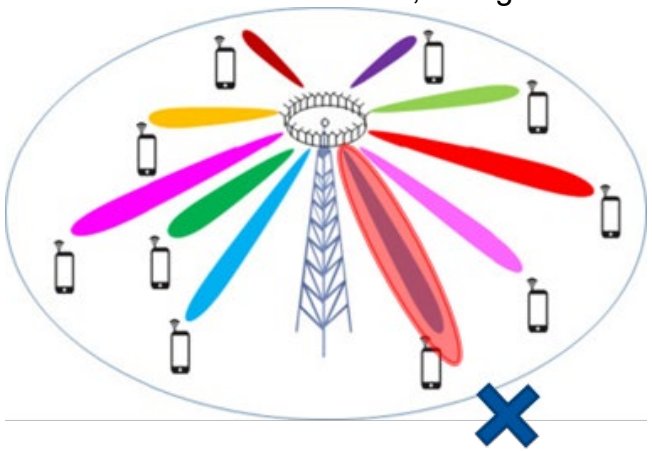
- Sites may be certified by measurement or calculation
- In many countries, the „worst case” or “highest possible” exposure in areas accessible to the public is relevant
- Normally, a base station cannot be artificially switched to the maximum operation condition for measurements
  - suitable measurement and extrapolation techniques were developed for other mobile network technologies
- Basic idea for extrapolation to highest possible exposure:
  - Measurement of exposure to traffic independent signal E_{signal}
  - Extrapolation to maximum possible exposure E_{max} using the factor $\sqrt{\frac{P_{max}}{P_{signal}}}$

Worst case beam configuration

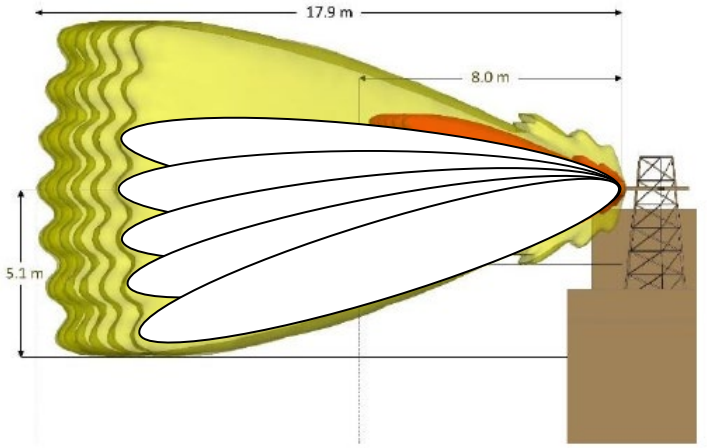
- The worst case beam configuration is
  - a single beam
  - with maximum antenna gain
  - which is radiated with maximum possible/applied transmit power
  - and reaches the measurement point via one LOS path

- Impact on site certificate applications: The envelope over all possible beam configurations has to be considered

Source: Khandaker, Wong



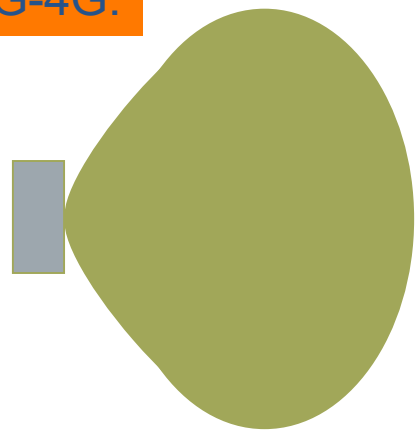
measurement point



Source: Ericsson

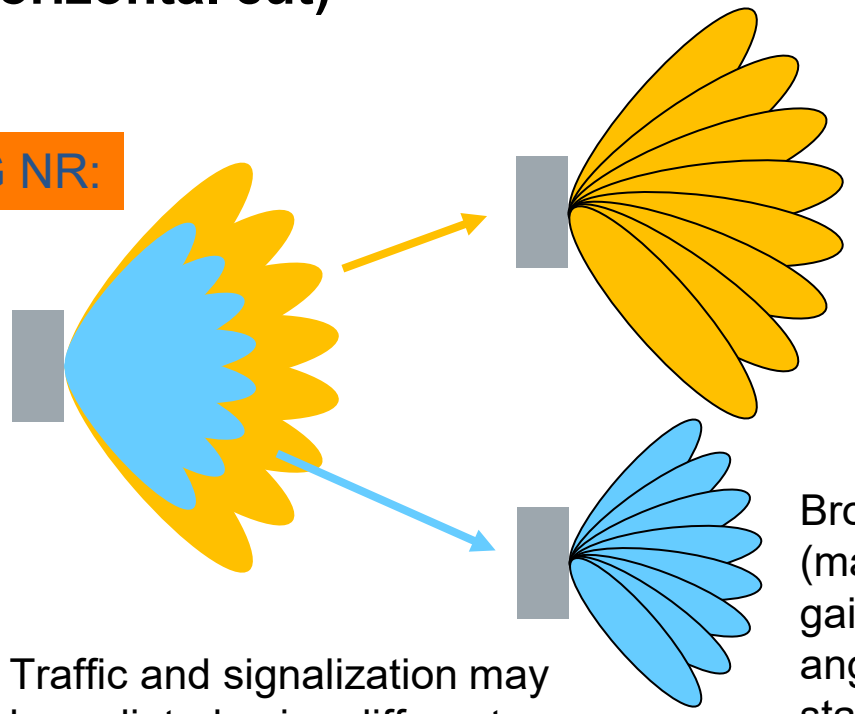
Separation of broadcast and traffic beam (horizontal cut)

2G-4G:



Traffic and signalization are radiated using the same antenna pattern

5G NR:



Traffic beams (high gains, switched)

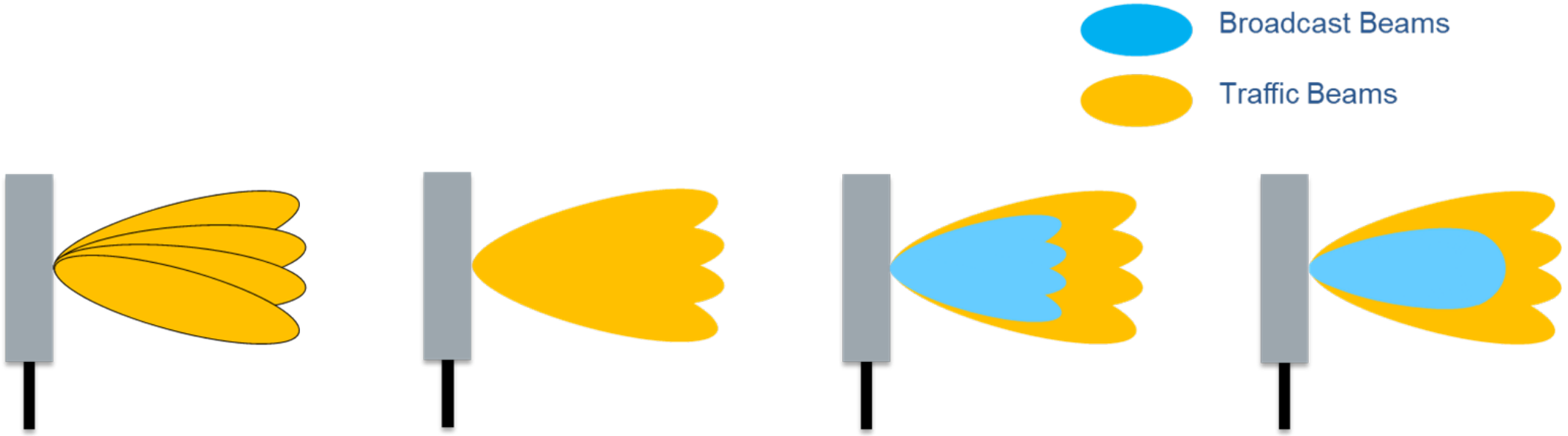
Broadcast beams (may have less gain or lower angular range, static or scanned)

Traffic and signalization may be radiated using different antenna patterns

- Idea: Measure exposure to load-independent signal radiated by broadcast beams and extrapolate to traffic beams

from: C. Bornkessel, T. Kopacz, S. Schießl, D. Heberling and M. Hein, “Challenges to Assess Human Exposure to 5G Massive MIMO Base Stations”, BioEM 2019.

Same shape of the envelopes of broadcast and traffic beams?



4 different states of traffic beams in elevation

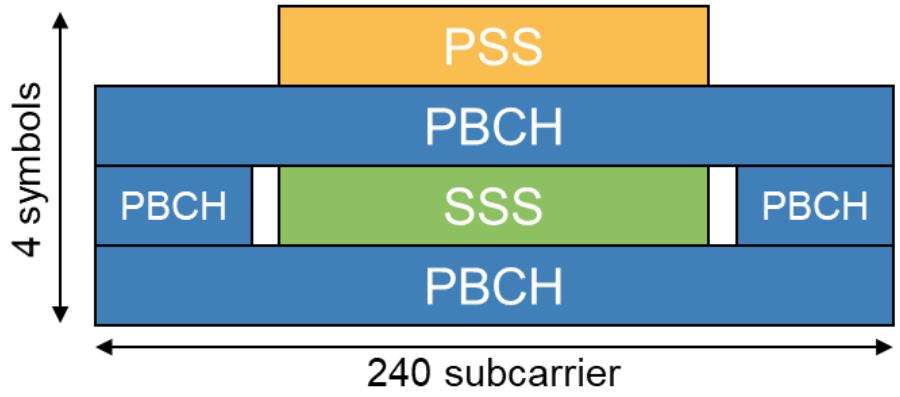
envelope over all traffic beams

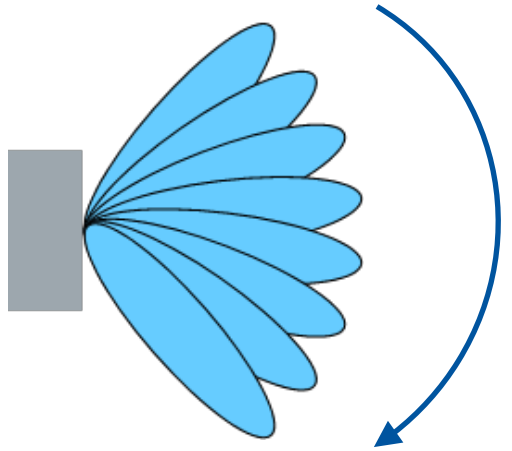
envelope of broadcast and traffic beams are identical in shape

envelope of broadcast and traffic beams are **not** identical in shape

from: C. Bornkessel, T. Kopacz, S. Schießl, D. Heberling and M. Hein, “Challenges to Assess Human Exposure to 5G Massive MIMO Base Stations”, BioEM 2019.

Traffic load independent signals radiated by broadcast beams



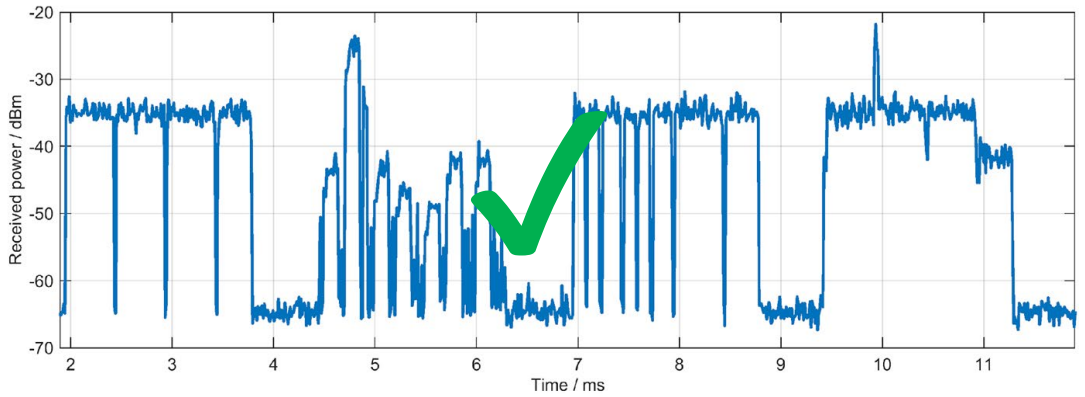


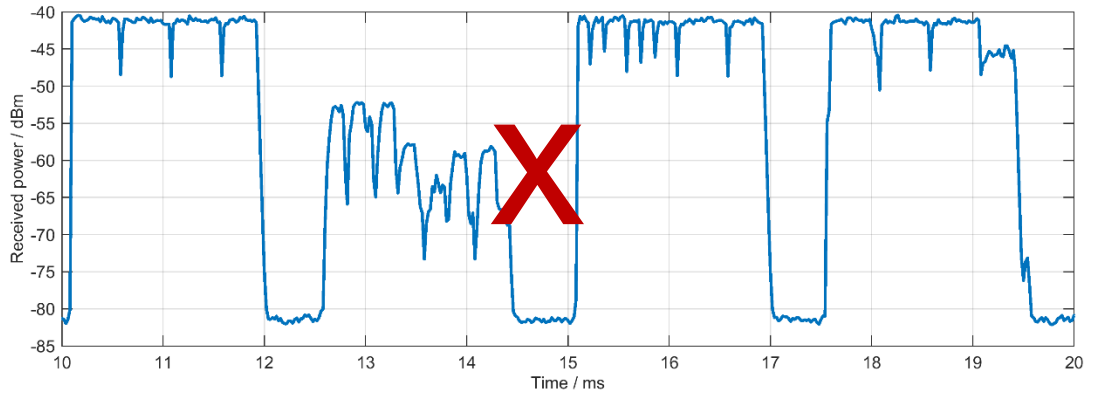
broadcast beam sweeping

- In 5G, the SS/PBCH block (SSB) may be used as a base for an extrapolation to theoretical maximum exposure
  - radiated by the broadcast beams
  - transmitted with a fixed periodicity (usually 20 ms)
  - exposure to the SSB can be measured by frequency-selective or code-selective measurements

Time-domain measurement of SSB in presence of traffic

- With frequency-selective measurements, the exposure to the strongest SSB can be determined and used for extrapolation
  - Caution: Measurement settings are crucial for obtaining a reliable RMS value
- But: SSB spectrum is just partially occupied by SSBs
- In case the SSBs
  - dominate the exposure, this approach works
  - are masked by traffic, this approach leads to an overestimation of exposure
  - are masked by SSBs from neighbor cells, this approach may lead to an underestimation of exposure
- Code-selective SSB measurements are possible solution to overcome this problem



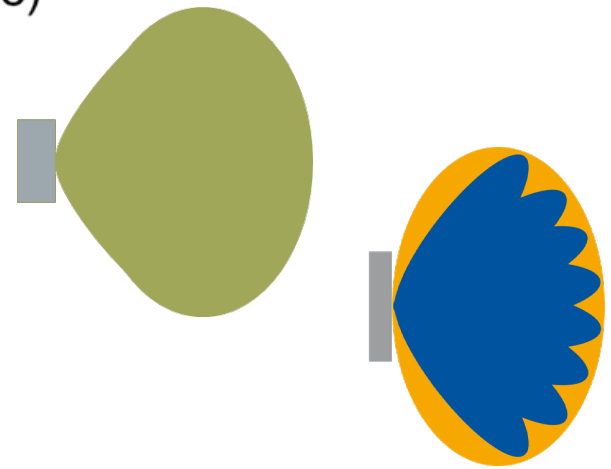


Code-selective measurement

- Using code-selective measurement equipment, the exposure to the SSB can be
  - separated by beam indices
  - separated by physical cell IDs
  - is independent of cell load
- For exposure measurements, the power level of the synchronization signal is determined
  - according to LTE, given as RSRP of the secondary synchronization signal SSS
  - referred to the bandwidth of a subcarrier

Exposure extrapolation procedure for 5G

- Measure the exposure to a load-independent signal/channel, which is radiated with constant power: SSB (referred to the bandwidth of a subcarrier)
- Spectral extrapolation to maximum exposure taking into account the max. signal bandwidth $BW_{signal,max}$ and the subcarrier spacing SCS: $E_{max} = E_{SSB,SC} \cdot \sqrt{\frac{BW_{signal,max}}{SCS}}$
- TDD factor can be additionally considered (e.g. -1,3 dB for 74 % downlink duty cycle)
- For 5G systems without massive MIMO antennas, this gives already the theoretical maximum exposure
- For 5G systems using massive MIMO antennas, additionally the beamforming has to be taken into account:
  - Logarithmic difference between the radiation patterns of traffic and broadcast beams
  - Individually for each measurement point



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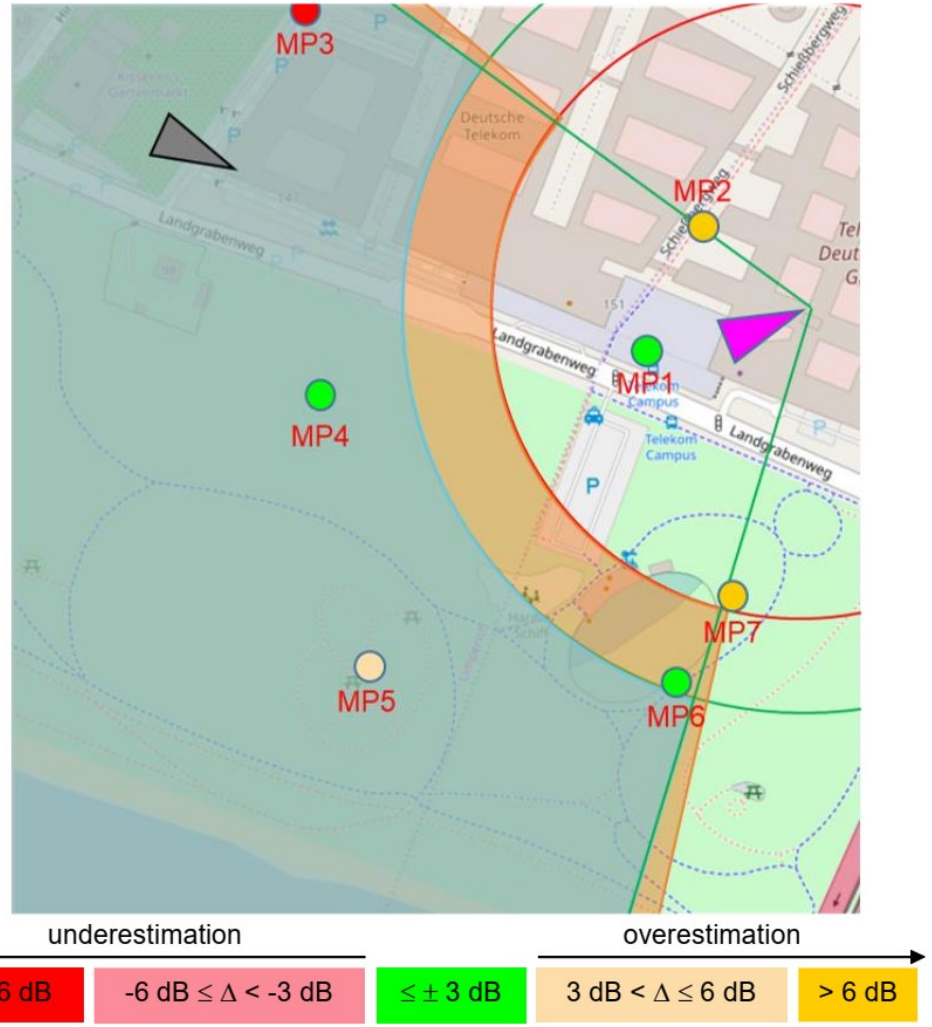
Exposure Assessment for 5G Massive MIMO Base Stations | Theoretical Maximum Exposure

Performance of exposure extrapolation (massive MIMO)

- Spectral measurement of exposure to SSB and extrapolation
- Validation of extrapolated value: exposure measurement during the exposure worst case (generated by user equipment)
- Findings:
  - Good agreement for measurement points
    - with LOS to the antenna
    - being located in the middle of the cell
  - Overestimation for measurement points
    - with NLOS to the antenna
    - being located at the cell edge
  - Underestimation for a measurement point being located in adjacent cell □ this underlines the necessity of code-selective measurements



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Conclusion

- 5G is based on ODFMA, but provides following differences to 4G:
  - Higher channel bandwidths and TDD
  - Beamforming antennas: separation of broadcast and traffic radiation + no cell-specific reference/synchronization signals
- Challenges regarding the assessment of worst case exposure in 5G
  - The worst case exposure is a radiation of a traffic beam with 100 % cell load, which is directed towards the measurement point
  - A suitable base for the extrapolation to theoretical maximum exposure is the SS/PBCH block (SSB)
    - radiated by broadcast beams, may be beam-specific
    - preferably measured using code-selective measurement equipment (SSB can be covered by traffic or SSBs from neighbor cells)
  - The separation of broadcast and traffic radiation might be taken into account by an additional extrapolation factor considering the difference between traffic and broadcast beams individually for each measurement point

Measurement campaign for exposure in networks with 5G massive MIMO

- Research project by the German Federal Office for Radiation Protection: “Consideration of current mobile network antenna technology for the assessment of RF-EMF exposure”
  - Determination of typical and theoretical maximum exposures
  - Base station types: 5G massive MIMO in the 3.6 GHz band
  - Base station environments: urban, sub-urban, rural
  - Usage scenarios: idle, typical usage, maximum usage
- Project is carried out by us in collaboration with TU Ilmenau and EM-Institut
- Publication of final report: approx. summer 2021

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Thank you
for your attention

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