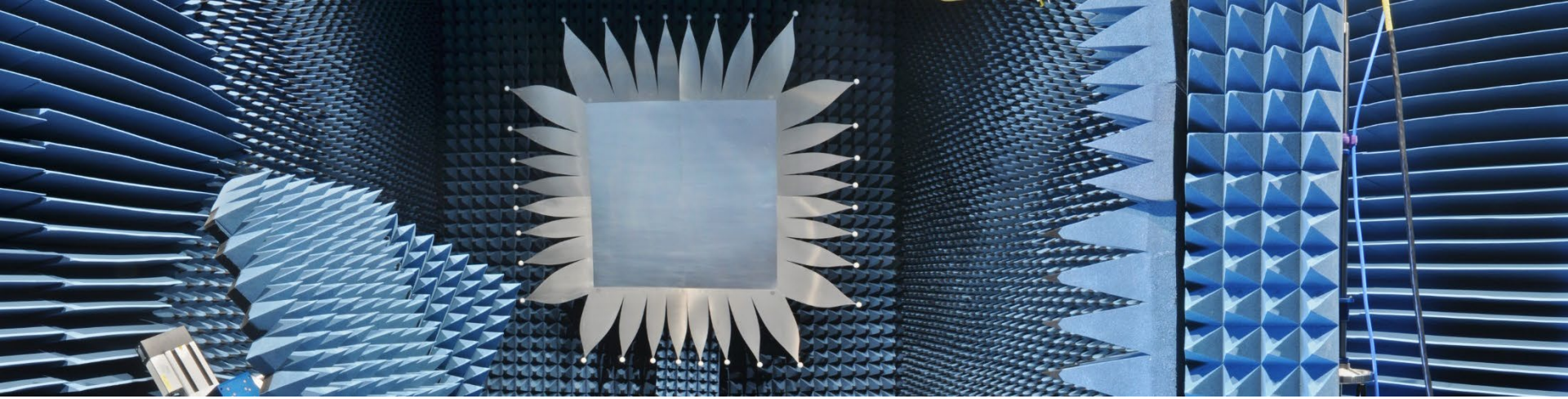

Massive MIMO Antennas – Impact on Compliance Distances and Challenges for Human Exposure Assessment

Fourth International Conference
“Electromagnetic field and the future of telecommunications. Research. Monitoring. Domestic and foreign experience.”

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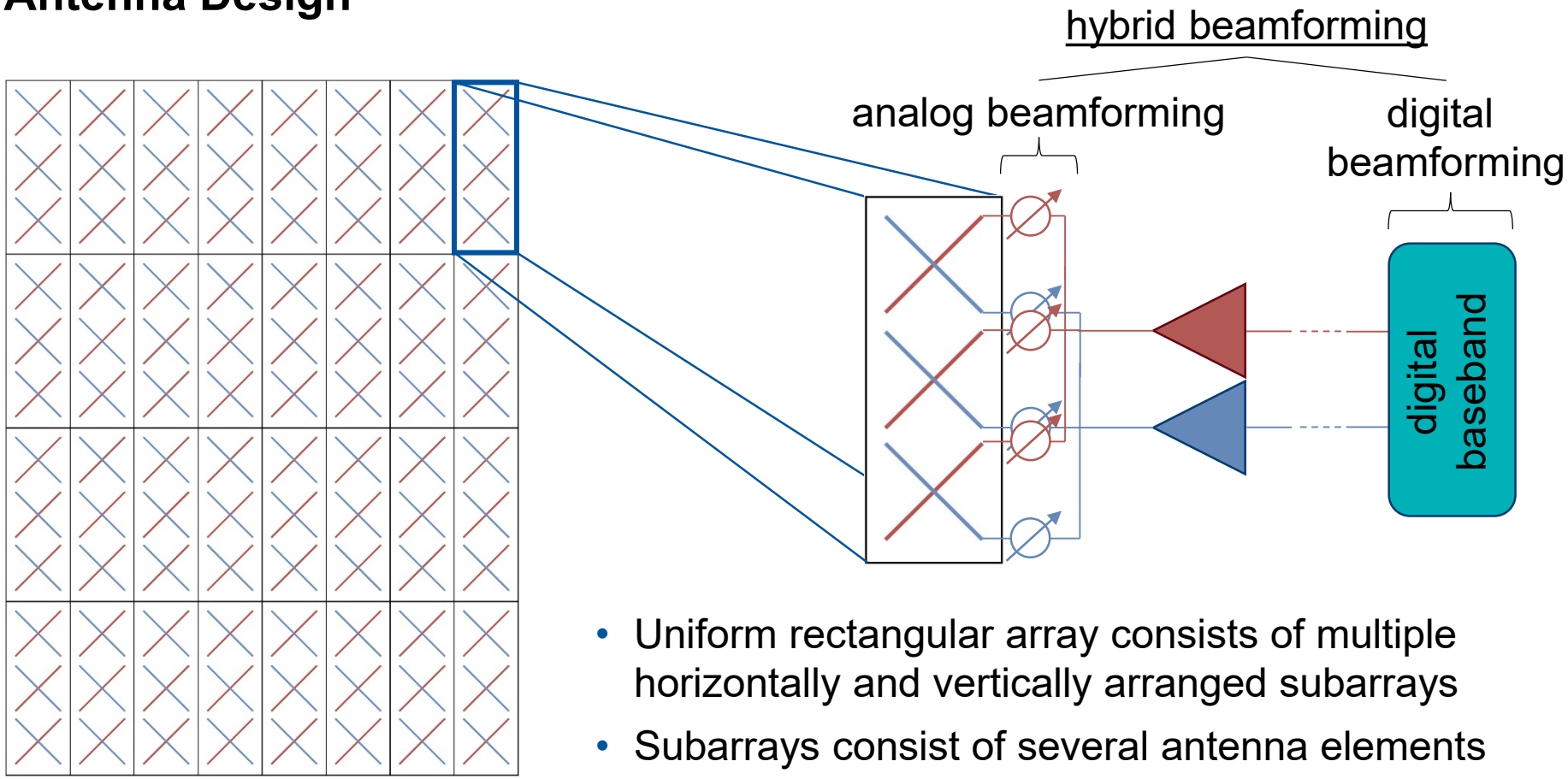
Outline

- Massive MIMO Antennas
  - Design and operation principle
  - Impact on compliance distances
- Challenges for Human Exposure Assessment
  - Motivation
  - Worst case beam configuration?
  - How to deal with broadcast and traffic beam sweeping?
  - Traffic load independent signals in 5G?
- First Measurement Results
- Conclusion and Outlook

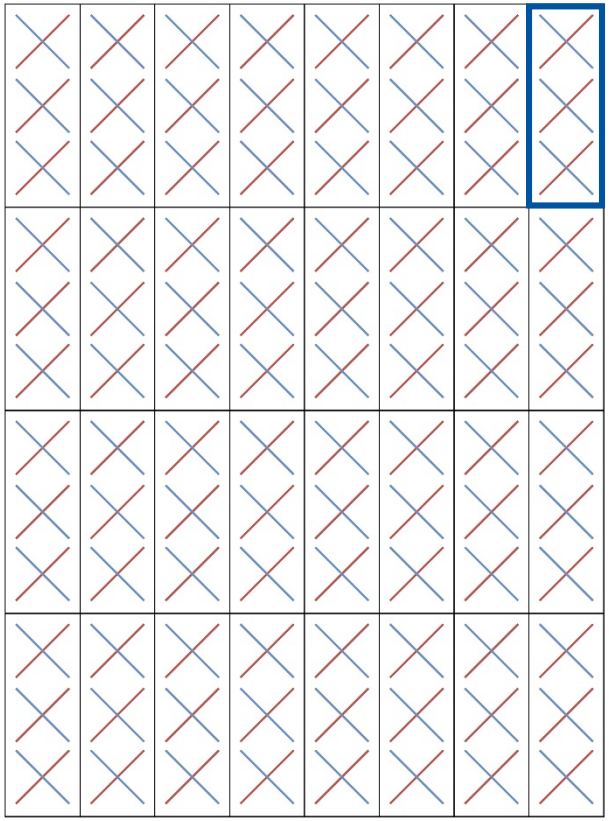
Antenna Design



Example of a 64 TRx (4x8x2) antenna

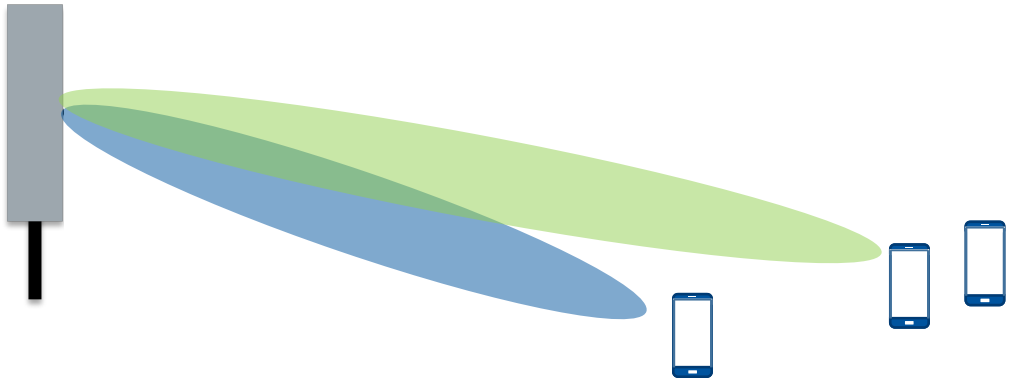
- Uniform rectangular array consists of multiple horizontally and vertically arranged subarrays
- Subarrays consist of several antenna elements
- Hybrid beamforming to achieve desired radiation

Beamforming



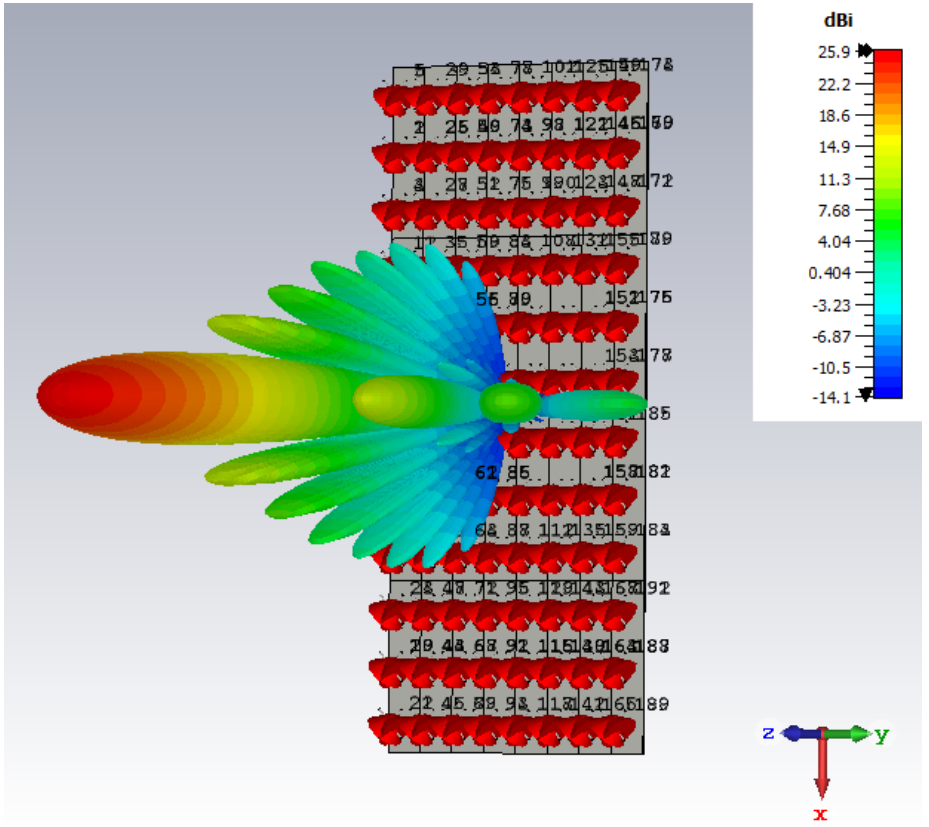
Example of a 64 TRx (4x8x2) antenna

- Huge number of antenna elements leads to a high gain of the whole antenna array
- Beams can be swept dynamically in horizontal and vertical domain
- Possible to radiate multiple beams simultaneously
- Grating lobes occur in the vertical cut due to a vertical subarray spacing larger than $\lambda/2$

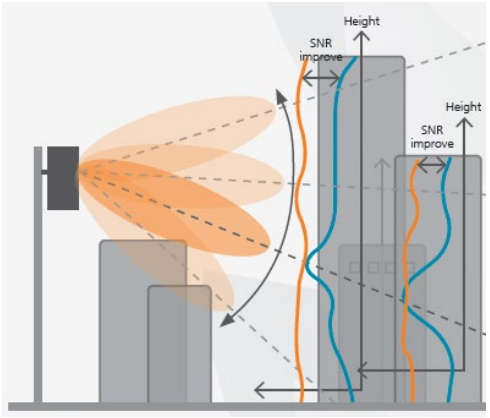


Directivity of a 64 TRx Massive MIMO Antenna

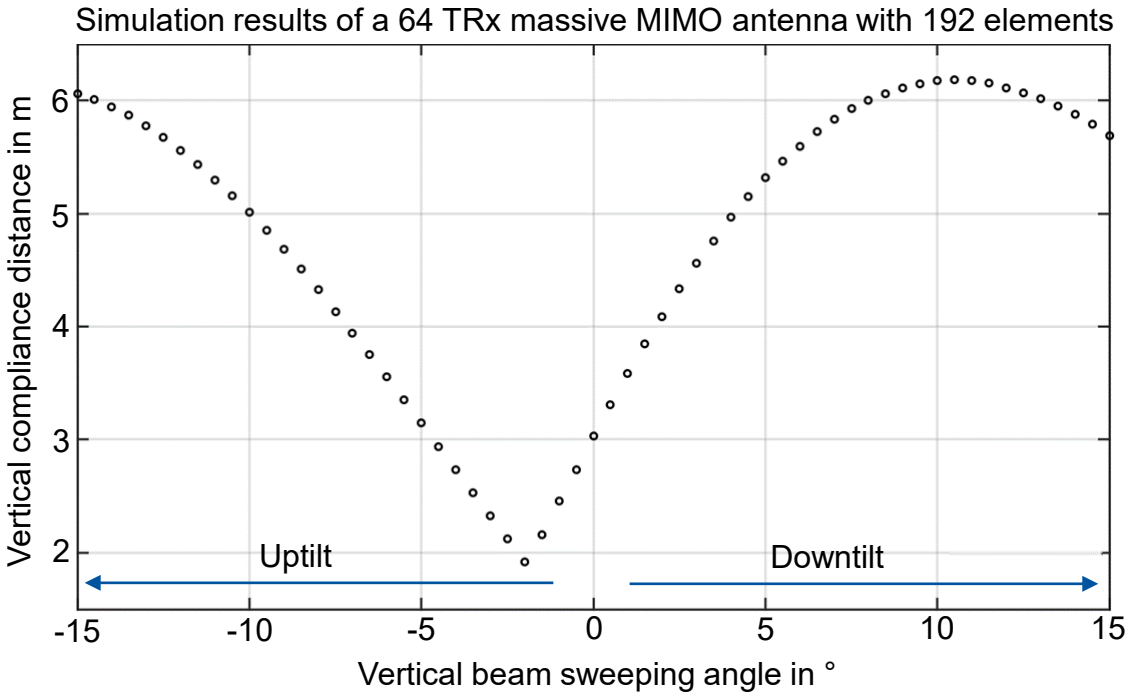
- Directivity of a 192 element antenna array
- Uniform excitation
- No beam sweeping



Impact of vertical beam sweeping on the vertical compliance distance



source: Huawei

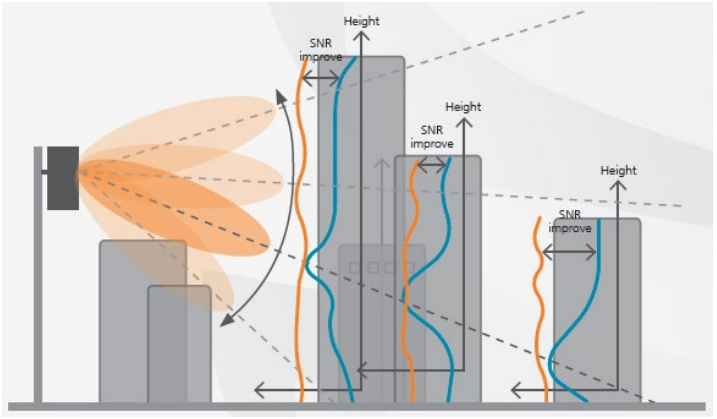


Vertical beam sweeping leads to increased vertical compliance distances compared to base station antennas without vertical beam sweeping used so far

Challenges for Human Exposure Assessment | Motivation

Enhanced complexity of 5G exposure assessment to get a site certificate

- Installation on existing base station sites
- Higher channel power due to higher signal bandwidth
  → increases compliance distances
- Higher antenna gain
  → increases compliance distances in boresight
- Higher vertical beam sweeping angle
  → increases vertical safety distances
- Beam sweeping complicates numerical and measurement based exposure assessment and site certification



Source: Huawei

Source: Khandaker, Wong

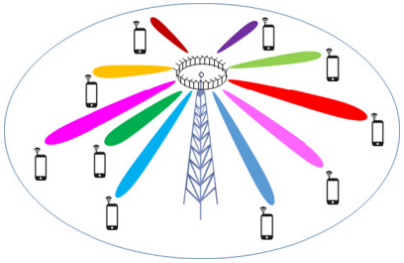
Worst case exposure

- In many countries, the „worst case” or “highest possible” exposure in areas accessible to the public is relevant
- Site may be certified by measurement or calculation
- Normally, a base station cannot be artificially switched to the maximal operation condition for measurements → suitable measurement and extrapolation techniques were developed for other mobile radio networks (GSM, UMTS, LTE, WiMAX)
- 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 $[P_{max}/P_{signal}]^{1/2}$

Challenges for Human Exposure Assessment | Assessment of Worst Case Exposure

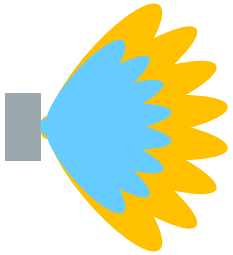
Basic questions regarding worst case exposure for 5G/Massive MIMO

- Which beam configuration generates the highest exposure at a given measurement point?

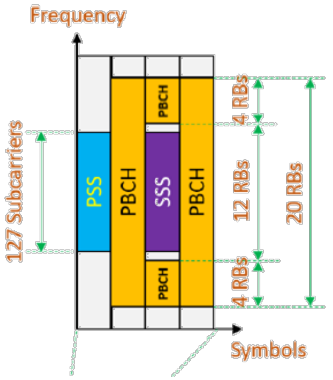


Source: see Khandaker, Wong

- How to deal with non-stationary beams and the separation of broadcast and traffic beam?



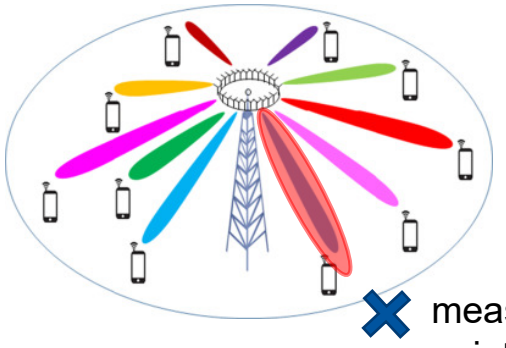
- Which traffic load independent signals are available for the extrapolation of the base station exposure to its theoretical maximum?



Source: Lin et al.

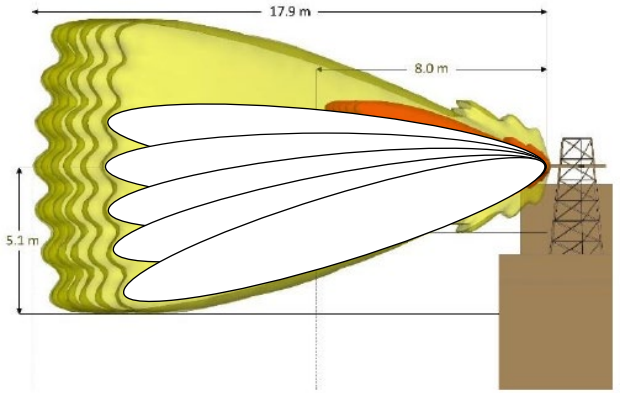
Worst Case Beam Configuration

- 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



source: Khandaker, Wong

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

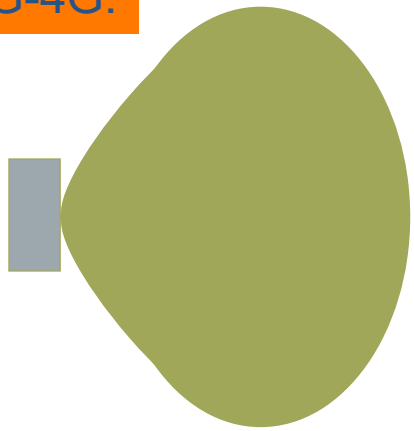


source: Ericsson

Challenges for Human Exposure Assessment | Assessment of Worst Case Exposure

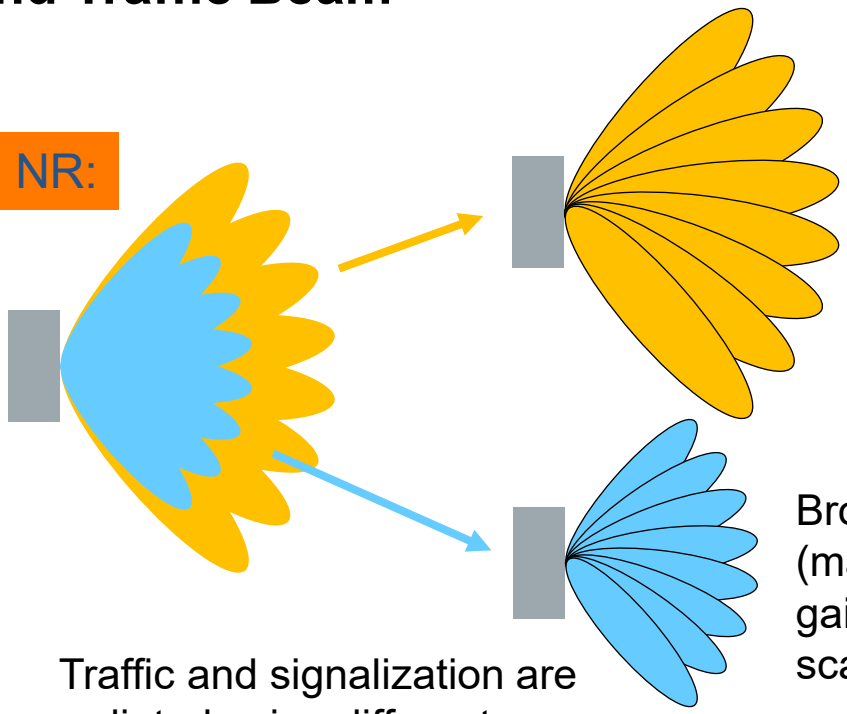
Separation of Broadcast and Traffic Beam (Horizontal Cut)

2G-4G:



Traffic and signalization are radiated using the same antenna pattern

5G NR:

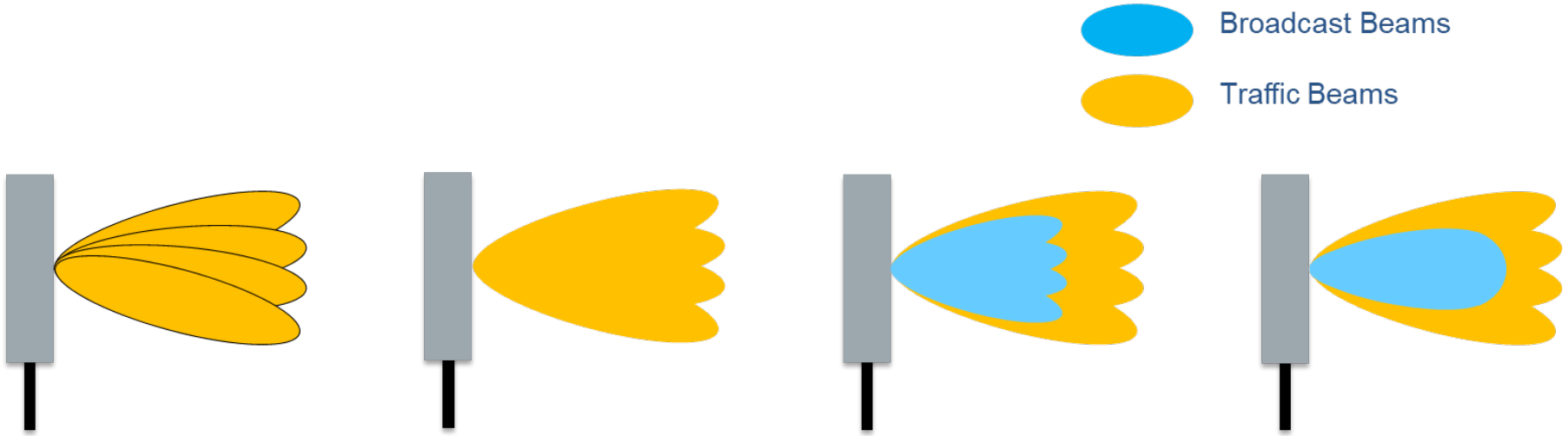


Traffic and signalization are radiated using different antenna patterns

- Idea: Exposure measurement of traffic independent signal radiated by broadcast beams and extrapolation to traffic beams

Challenges for Human Exposure Assessment | Assessment of Worst Case Exposure

Same shape of the envelopes of broadcast and traffic beams?



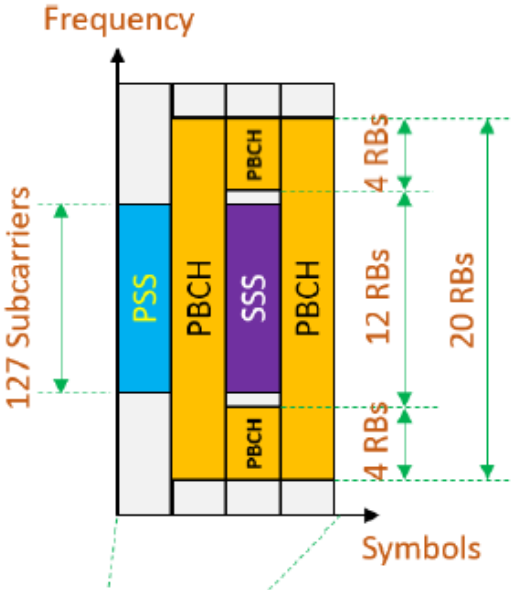
4 different states of traffic beams in elevation

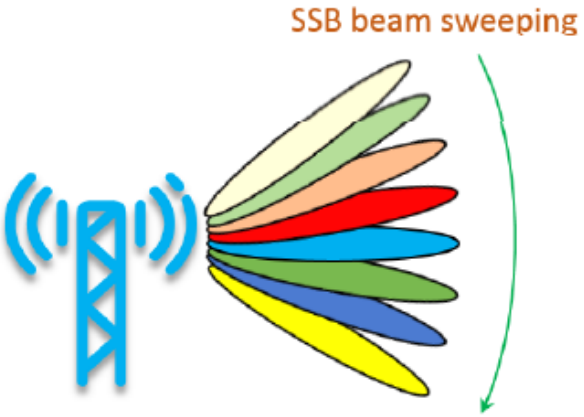
envelope over all traffic beams

envelope of broadcast and traffic beams are identical in shape

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

Traffic Load Independent Signals Radiated by Broadcast Beams



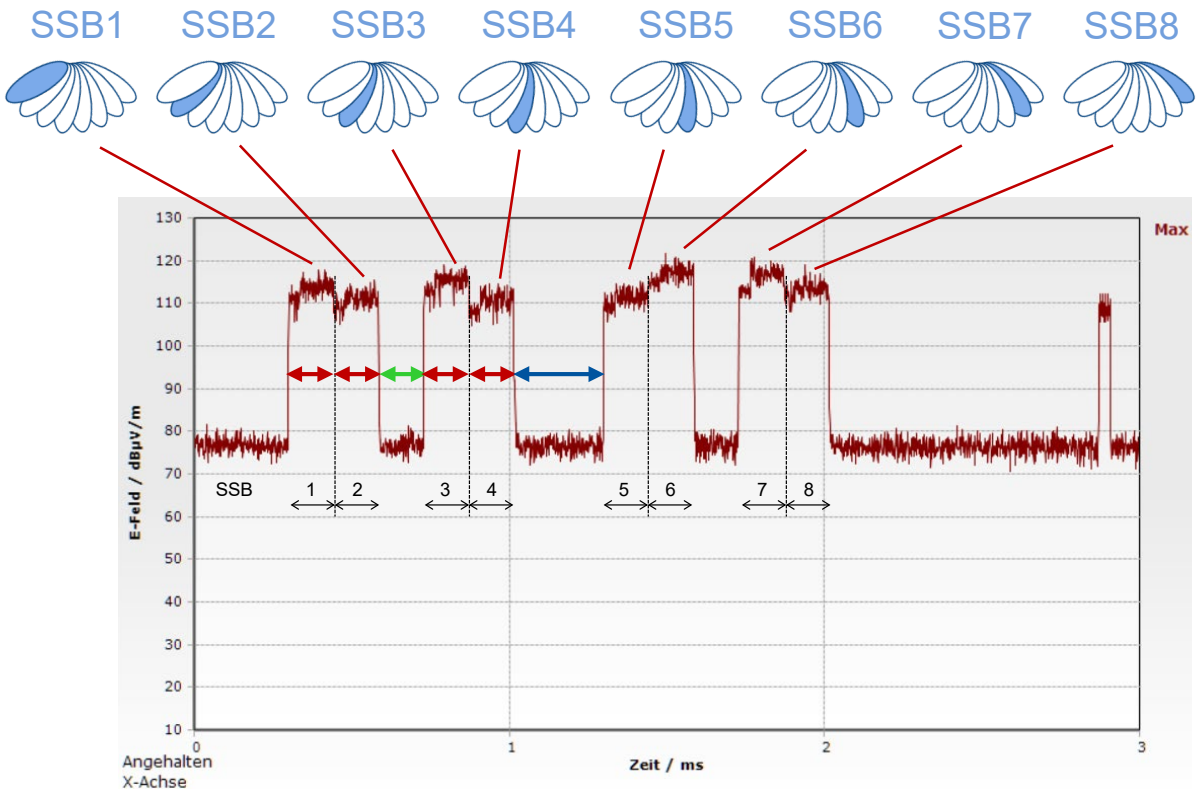


source: Lin et al.

- In 5G, a cell-specific reference signal (CRS) radiated by the broadcast beams does not exist anymore
- Alternatively, the SS/PBCH block (SSB) may be used
  - frequency vs. code-selective measurement

Broadcast Beam in Time Domain

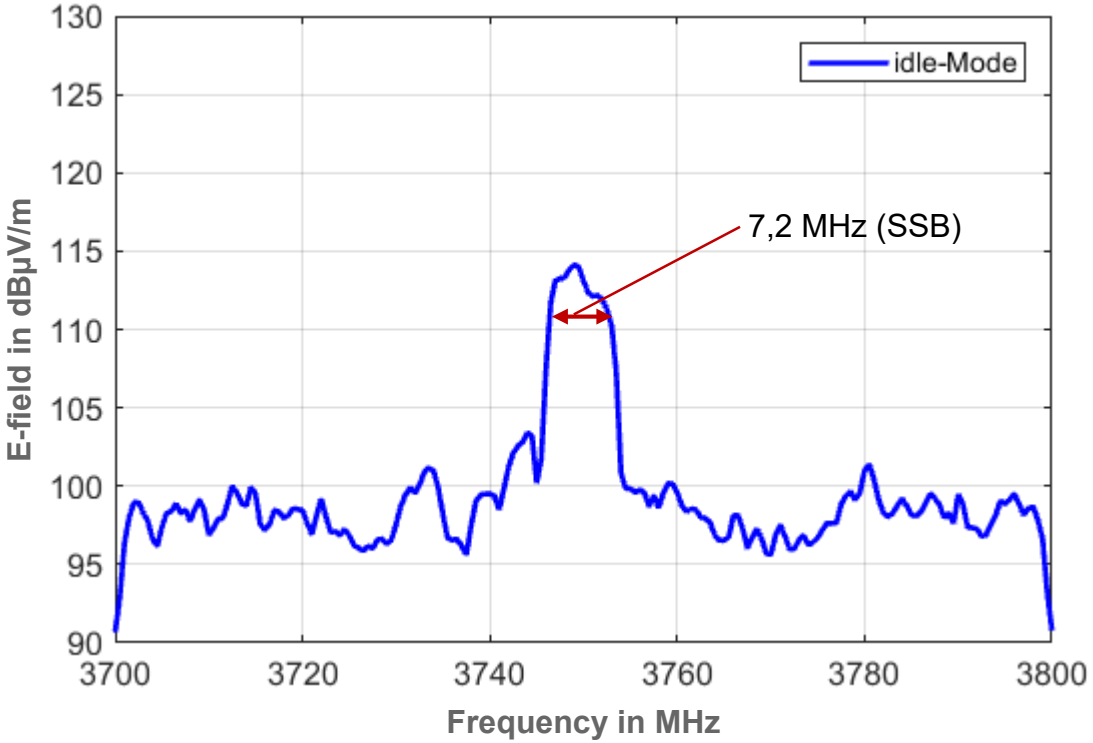
- 5G base station in Berlin with 8 broadcast beams
- SBB periodicity: 20 ms
- Each SSB is radiated by an individual broadcast beam

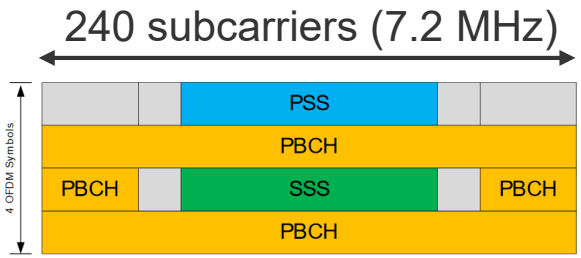


source: Keysight

Broadcast Beam in Frequency Domain

- Without traffic: PBCH/SS block (SSB) with a bandwidth of 7.2 MHz can be clearly identified in the spectrum
- With traffic (1 active UE): SSB is masked by 13 dB with traffic signal

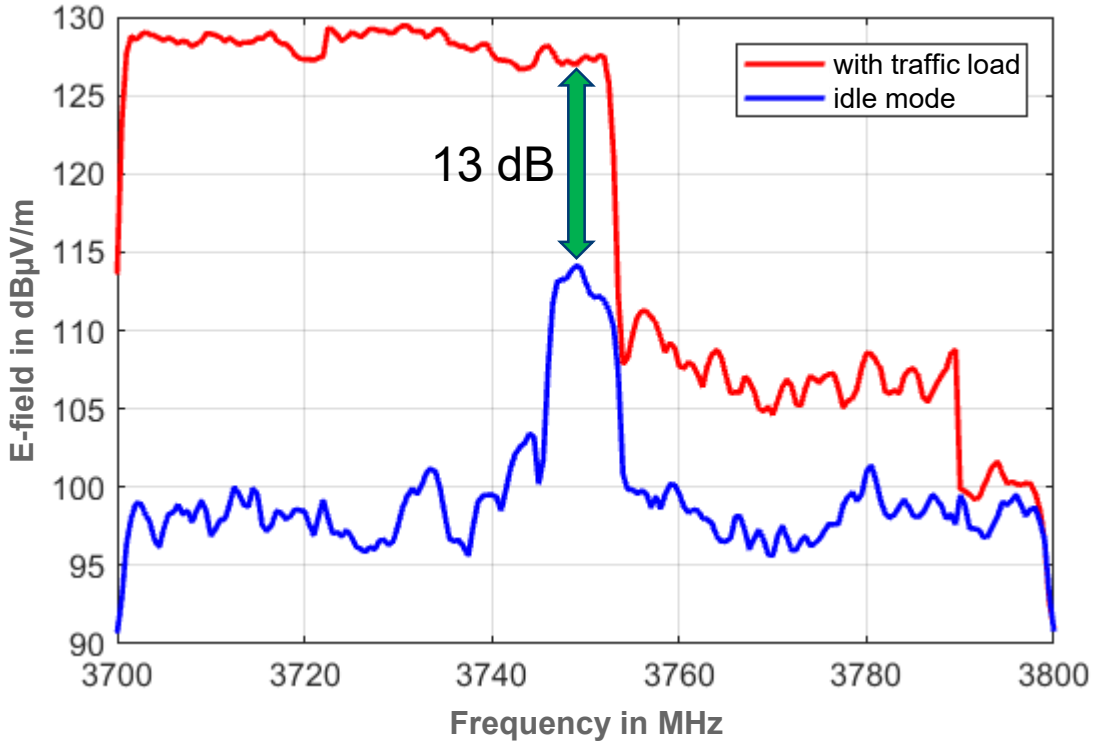


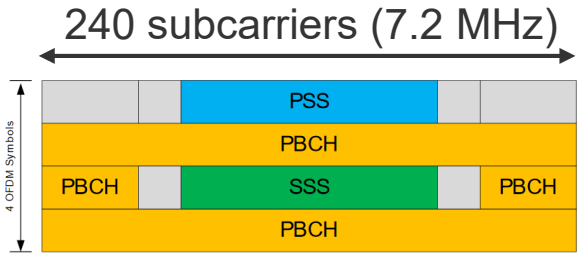


source: Keysight

Broadcast Beam and Traffic Load in Frequency Domain

- Without traffic: PBCH/SS block (SSB) with a bandwidth of 7.2 MHz can be clearly identified in the spectrum
- With traffic (1 active UE): SSB is masked by 13 dB with traffic signal

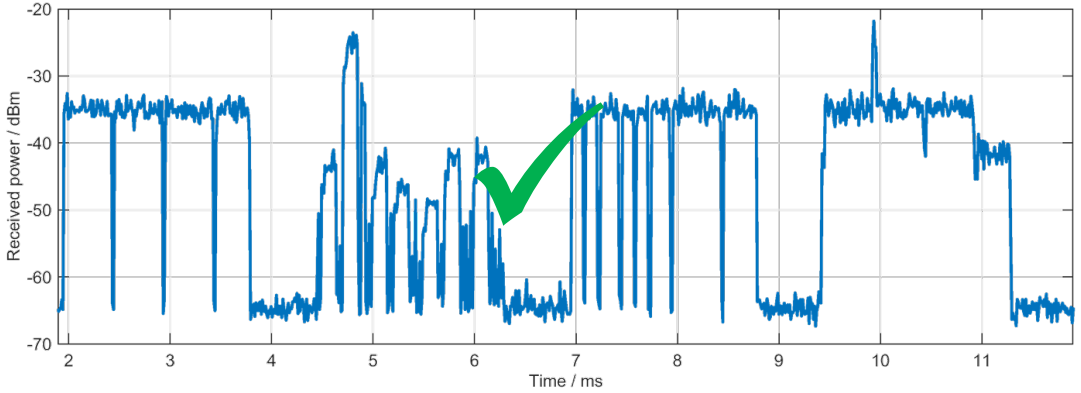


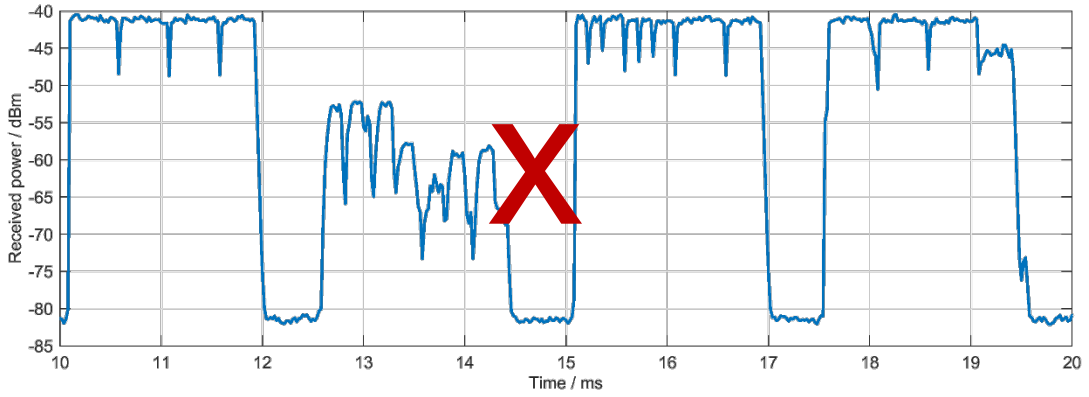


source: Keysight

SSB and Traffic Load in Time Domain

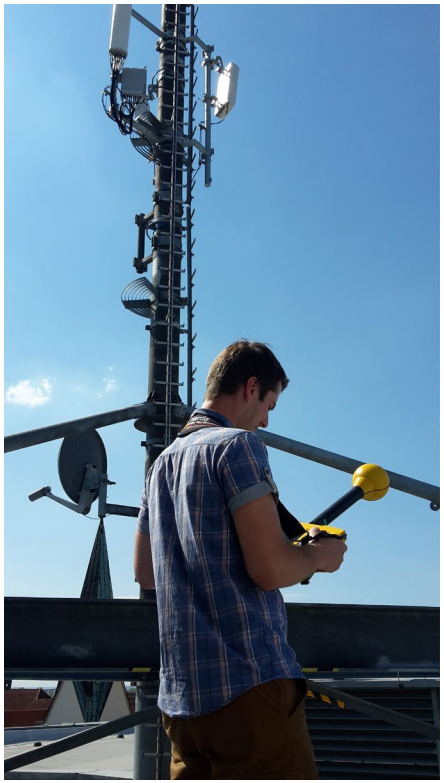
- With frequency-selective measurements, the exposure in SSB spectrum is determined and extrapolated
- But: This spectrum is just partially occupied by the SSB
- In case the SSB
  - dominates the exposure, this approach works
  - is masked by traffic, this approach leads to an overestimation
- Code-selective SSB measurements may be an option to solve this problem



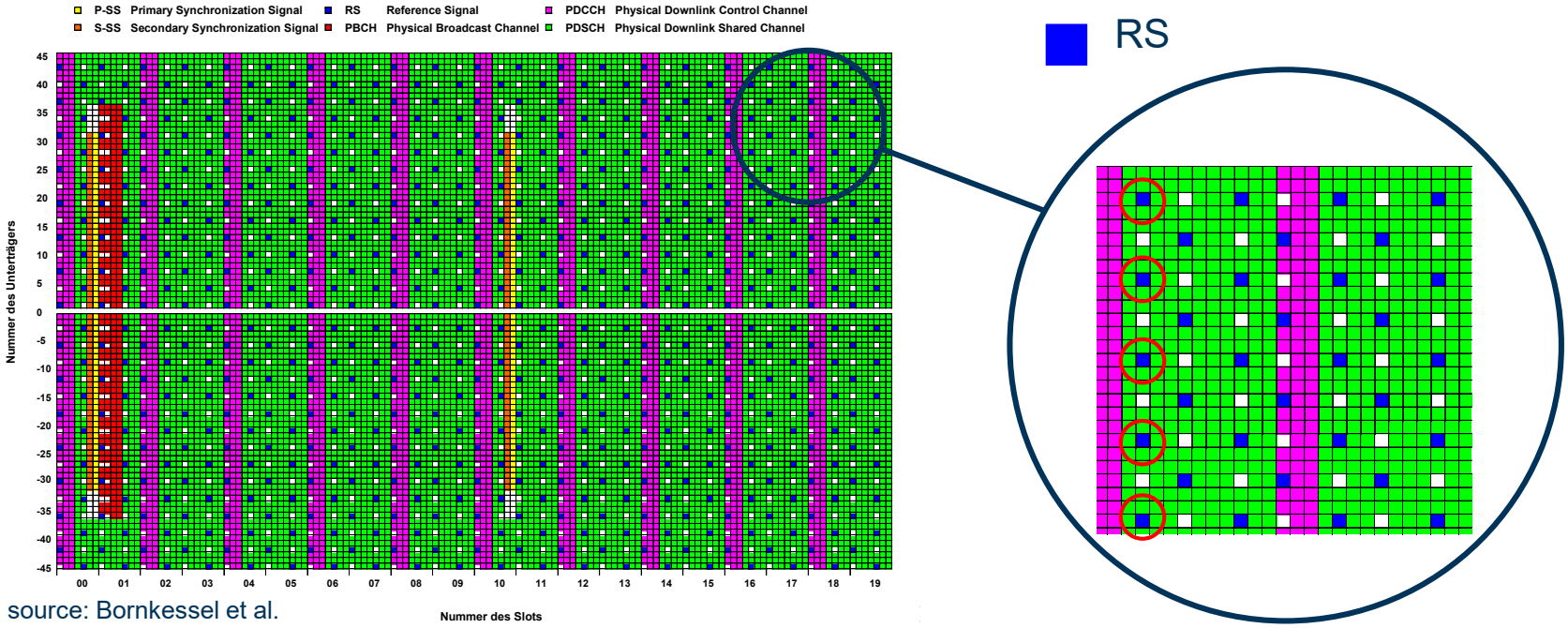


4G Massive MIMO Base Station in Merseburg

- Background: Limitation of challenges regarding exposure assessment to beamforming (established measurement and extrapolation procedure for LTE exists)
- Measurement around a 4G massive MIMO base station
- Broadcast beam (stationary):
  - Antenna gain comparable to passive 4G antennas used so far
- Traffic Beams:
  - Orientation of traffic beams could be triggered by software-modified UE carrying out downloads
  - Worst case beam configuration: max. antenna gain (> 8 dB higher than broadcast beam) and max. transmit power
- Approach:
  - Code-selective exposure measurement of the cell-specific RS (broadcast beam) and extrapolation to full utilization
  - Validation by measurement of exposure during actual full utilization



Code-Selective Extrapolation for Conventional LTE



source: Bornkessel et al.

- Code-selective measurement of the average exposure of one RS symbol
- Taking into account both antenna polarizations (RS_0 and RS_1 or RS_{sum})
- Extrapolation factor: $10 \cdot \log_{10}(1200)$ (20 MHz channel bandwidth, no RS boosting)

Extrapolation Factor for LTE Massive MIMO

Constant antenna gain difference between traffic and broadcast beams

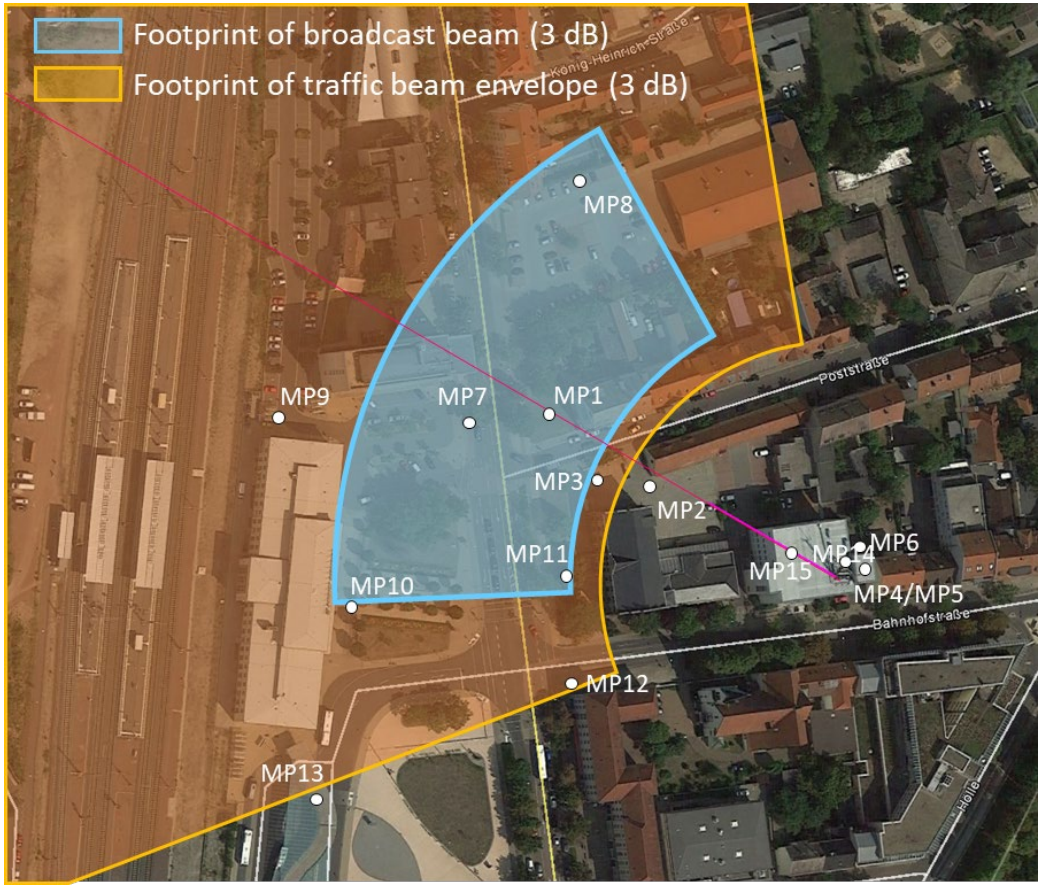
$$(10 \log 1200) + \Delta G - 1{,}3\ \text{dB}$$

Extrapolation from one resource element (RE) to whole signal bandwidth (1200 REs)

Downlink duty cycle

Measurement Points and Footprints of the Beams (Horizontal Cut)

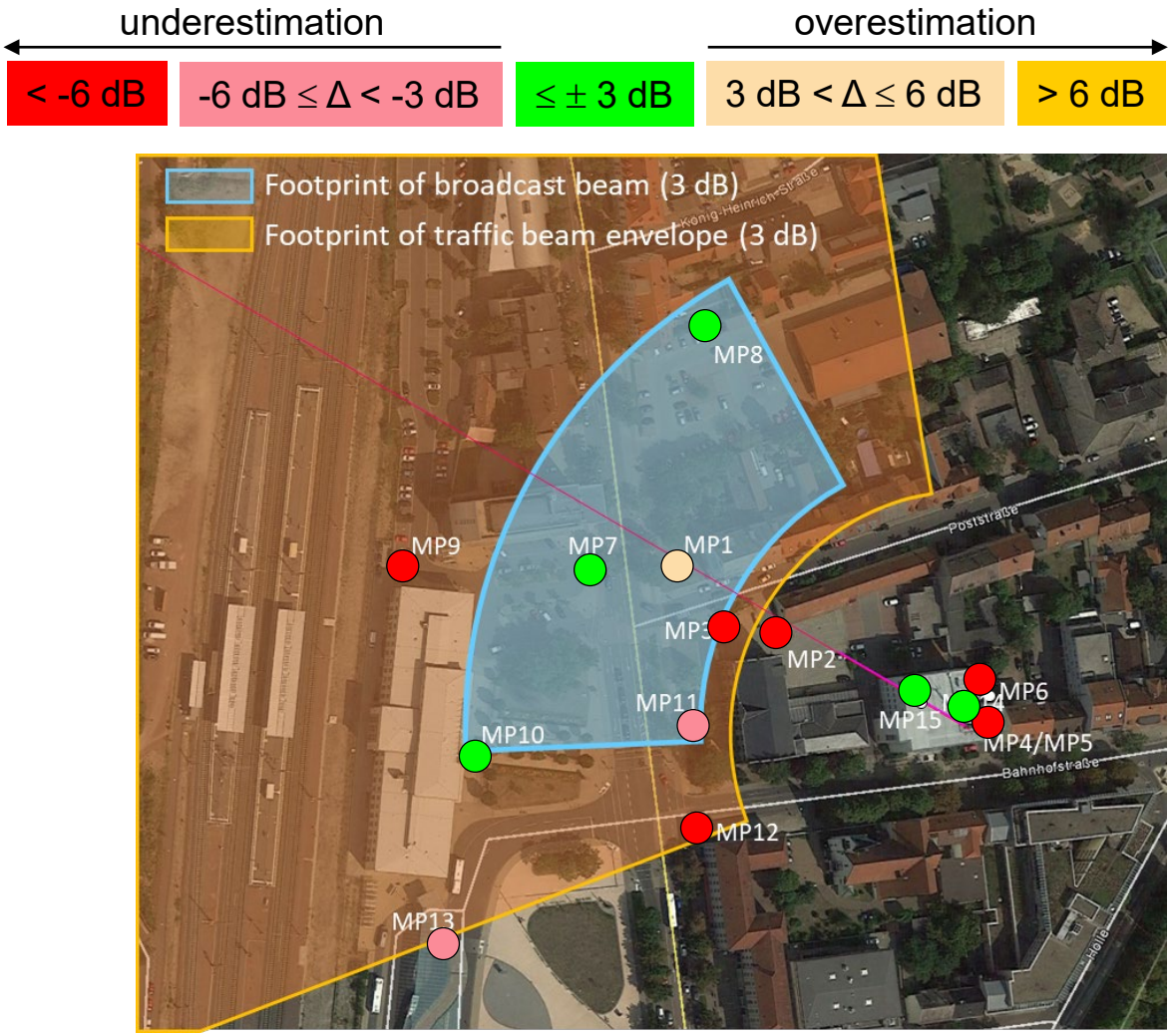
- Footprint of traffic beams is larger than that of the broadcast beams
  - in transition zone: higher/undefined extrapolation factor
  - possible underestimation of the exposure with generalized extrapolation factor
- Measurement points:
  - LOS/NLOS to antenna
  - indoor/outdoor
  - inside/outside the footprints of broadcast and/or traffic beams



First Measurement Results | Exposure Extrapolation

Results

- Generalized extrapolation factor leads to massive underestimation at some measurement points
- Measurement method with constant antenna gain difference only suitable for points
  - with LOS to antenna
  - located outdoors
  - inside broadcast and traffic beams



Summary and Outlook

- Vertical beam sweeping has a massive impact on vertical compliance distances
  → limitation of the vertical beam sweeping range decreases compliance distances
- Previous approaches to exposure assessment in 2G-4G networks will no longer be applicable to 5G, but urgently needed
- Accuracy of a generalized extrapolation factor strongly depends on the location of the measurement point w.r.t. both beams
- The SSB radiated by the broadcast beam(s) may be used as a base for an extrapolation, but will require code-selective SSB measurement techniques as soon as 5G cells will provide realistic traffic conditions
- First measurement results are promising, some questions are still to be solved before a reproducible procedure can be defined
- When developing new radio technologies, it is necessary to standardize possibilities to evaluate their (max. possible) exposure e.g. by test modes

Thank you
for your attention

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