5G to 6G basestation beamforming trends

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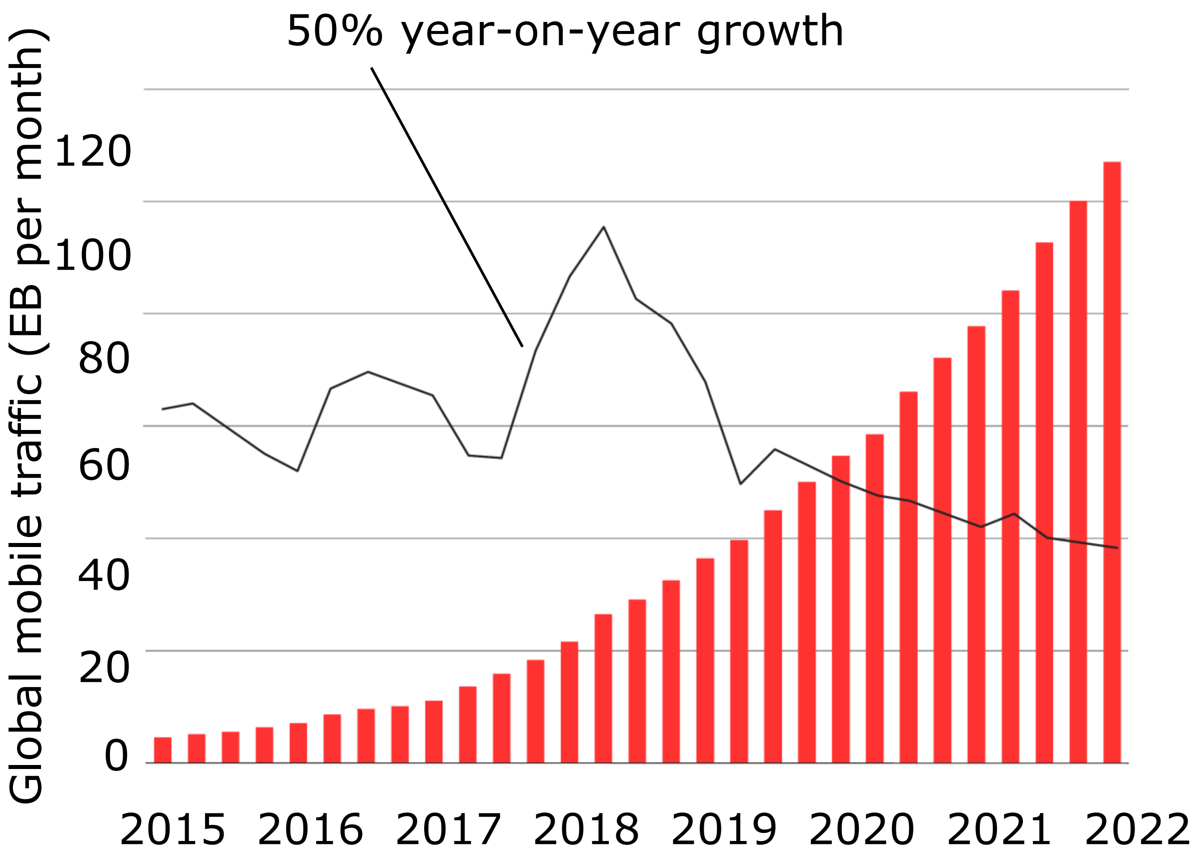
Outline

- Introduction
- What is 6G?
- Beamforming benefits and evolution
- High frequency technology limitations
- 100Gbps demo at 100GHz
- Full duplex
- Summary

Mobile Communication Trend



Area throughput [bit/s/km²]

$$C = B \times \sum_{\text{layers}} \log_2\left(1 + \frac{S}{N}\right) \times D$$

Bandwidth [Hz]

Spectral efficiency [bit/s/Hz/cell]

Cell density [cells/km²]

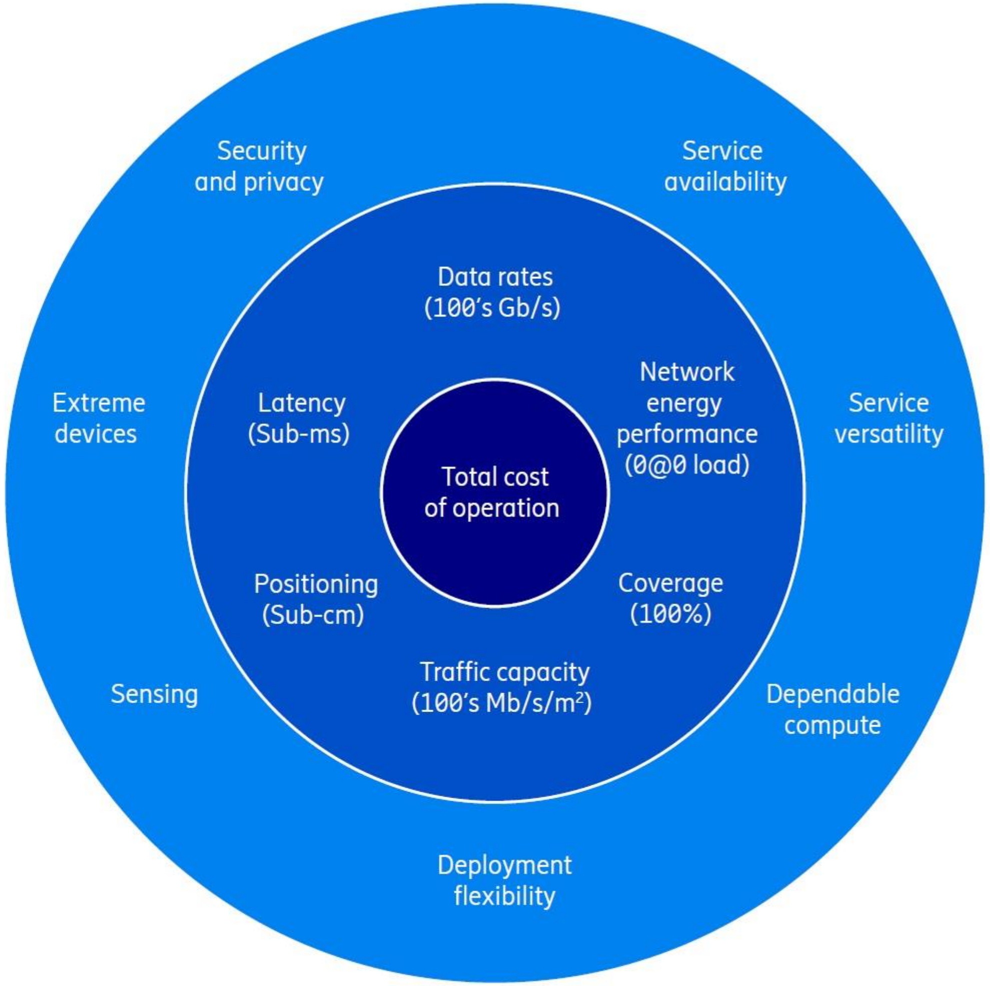
5G introduced beamforming and mmW

- mmW giving ~10x BW vs. sub-6GHz=>
  - extreme throughput in ~LOS,
  - beamforming to extend coverage
- Beamforming and MU-MIMO at sub-6GHz
  - “cheating” Shannon
  - more capacity without densification

$$C = B \times \sum_{\text{layers}} \log_2\left(1 + \frac{S}{N}\right) \times D$$

Many more layers, due to SDM

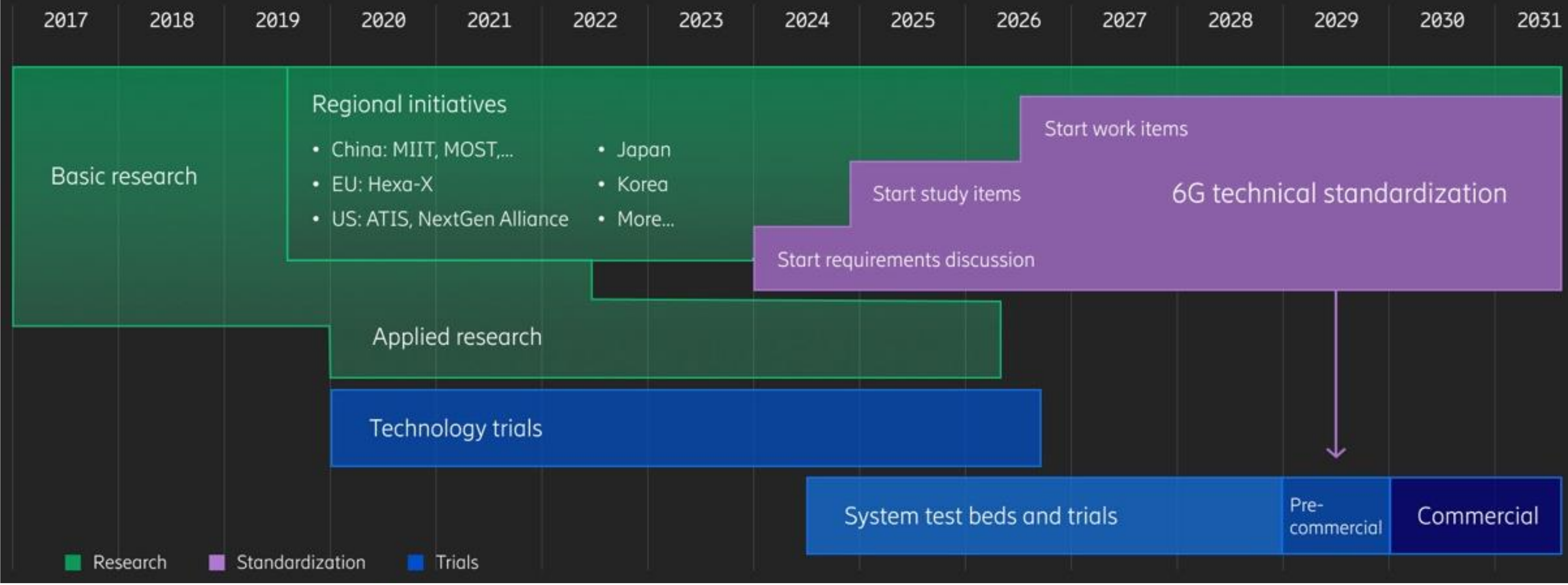
What is 6G?



- Communication
  - Data rate 100 Gb/s
  - Latency 1 ms
  - Coverage 100% (NTN)
  - Capacity 100 $Mb/s/m^2$
- Data generation
  - Positioning → Sensing
- Energy efficiency

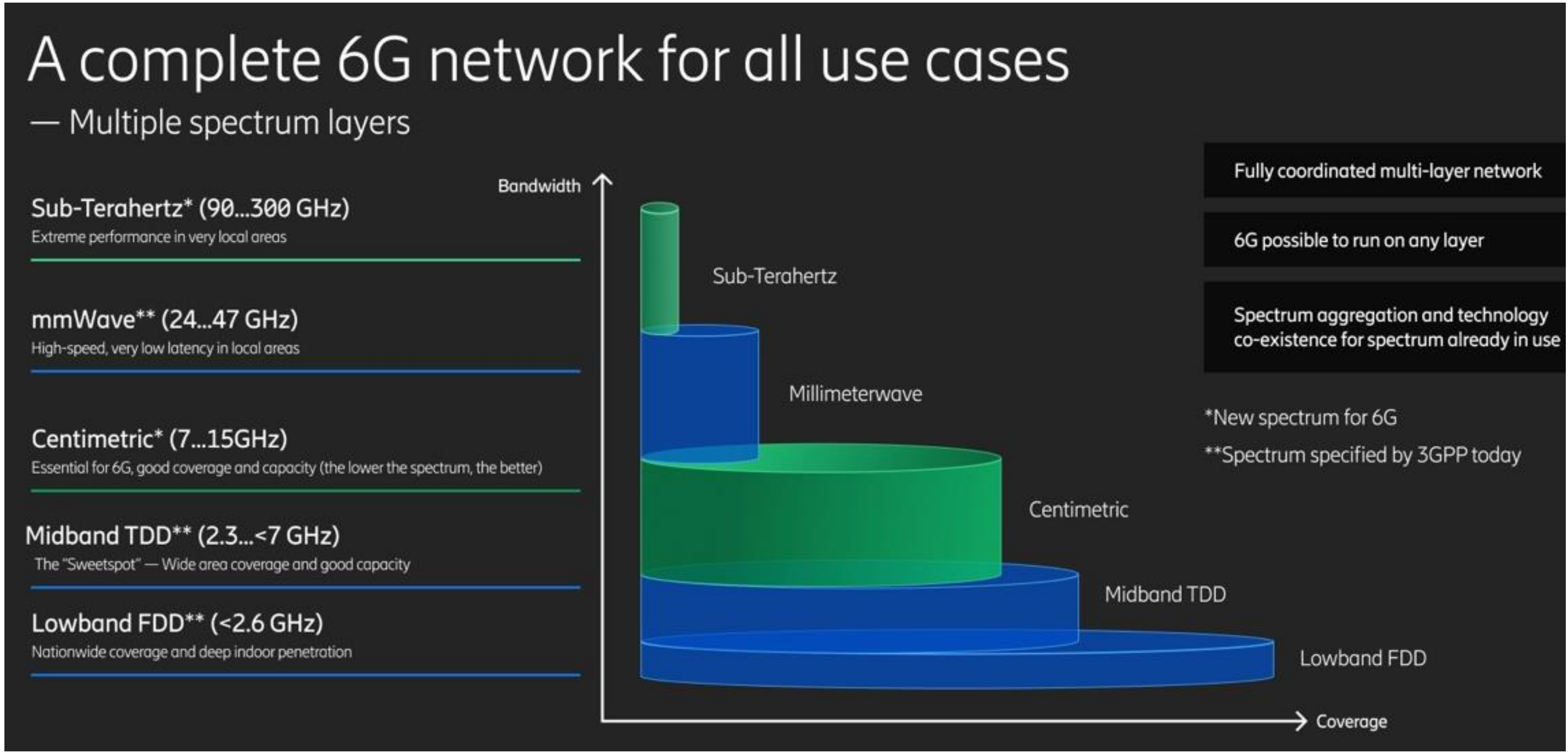
- Adaptive network
  - Integrated access backhaul
  - Dynamic deployment
  - Multi-hop connectivity
  - Low cost, high flexibility
- Reliable network
  - D-MIMO (CoMP, mTRP)
  - Dense deployment
  - Multi-path connectivity
  - Relay and mesh network
- Computation
  - Centralized → Distributed (edge computing)

Timeline perspective



Increasing capacity by adding more spectrum

- **High frequency**
  - High propagation loss
  - High peak rates
  - Low latency
  - High angular resolution
  - Sensing/Imaging
- **Low frequency**
  - Low propagation loss
  - Interference limited
  - Mobility
  - Massive MTC

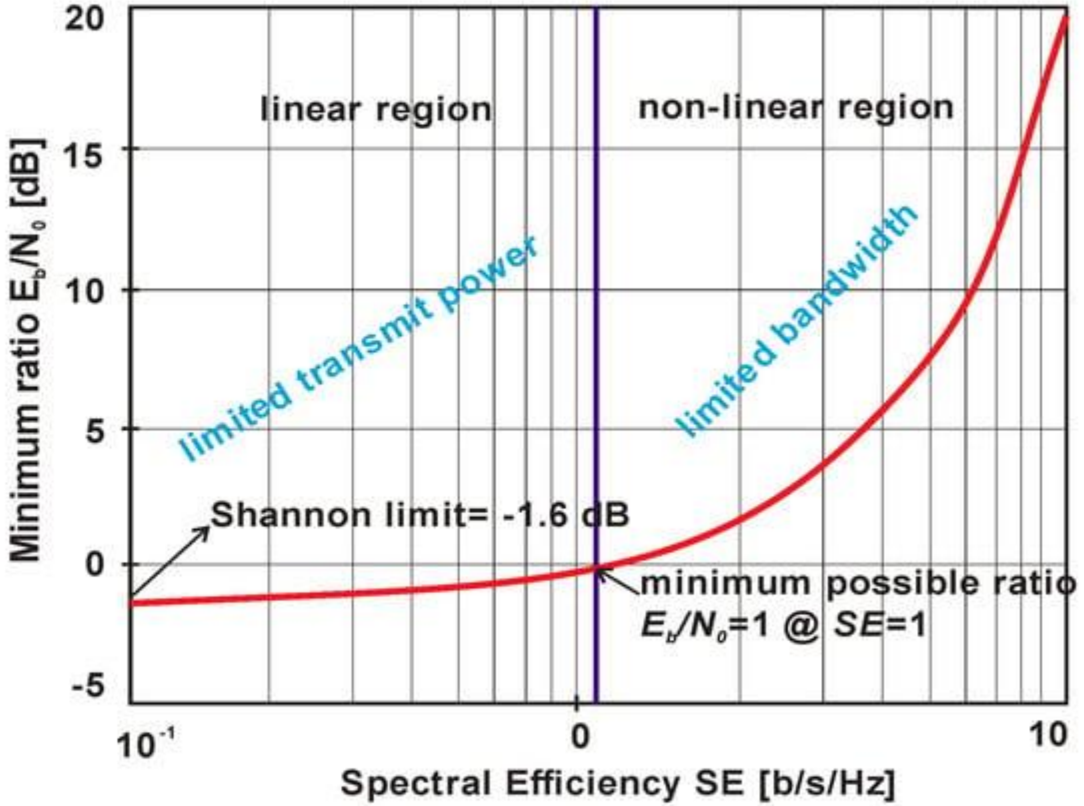


Shannon considerations

- High SNR for extreme throughput, not power efficient
- Low SNR => low #bps/Hz– consumes a lot of capacity (BW)
- Sweet-spot in the middle

- Move users to correct frequency band for optimum capacity
- Beamforming and MU-MIMO also avoids being in the bandwidth limited region, increasing capacity

- Complex problem since UE traffic varies a lot



DL vs. UL power balance

- 1000x power difference between DL and UL
- In addition, TDD with 4:1 DL:UL ratio
- Mobile broadband>= unbalanced traffic need
  - Future use cases need more UL (e.g. holographic communication)
- Beamforming and MU-MIMO splits BS power between multiple UEs

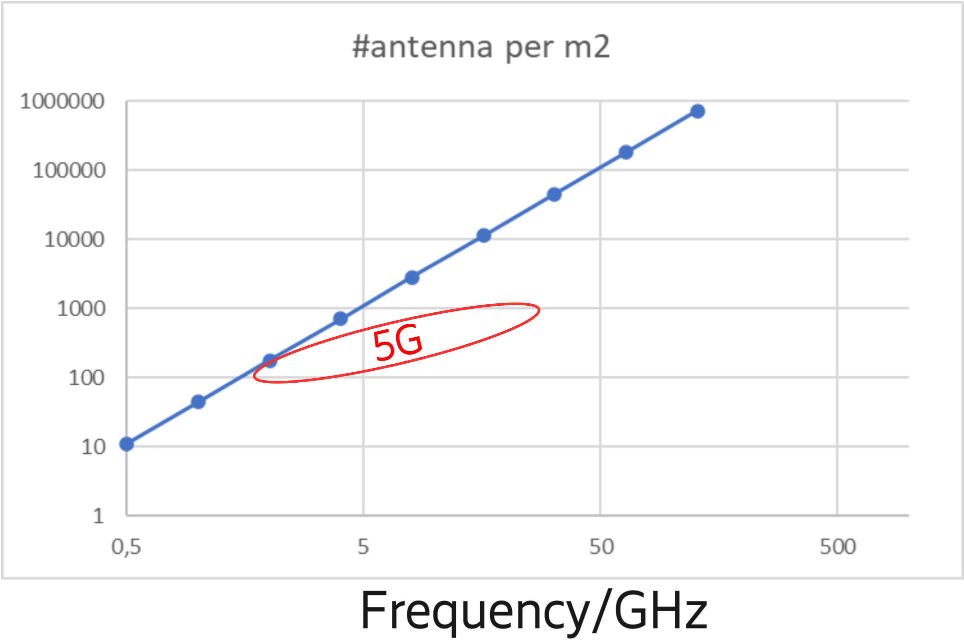
200W

200mW

- More antenna elements (electrically larger arrays) is beneficial:
  - Lowered BS power while maintaining EIRP (power efficiency)
  - More simultaneous UE:s, MU-MIMO
  - Better UL linkbudget

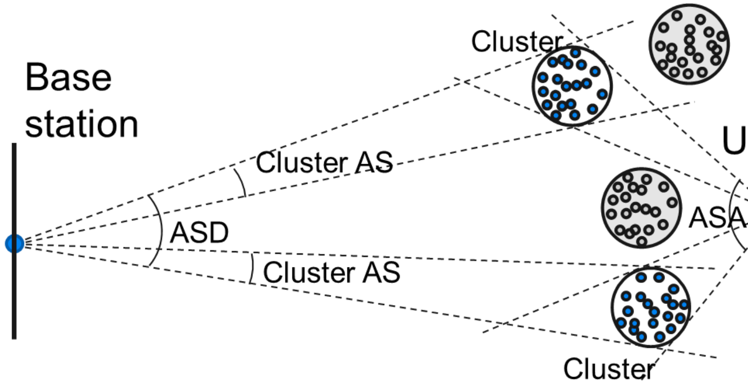
High frequency operation=> Need large arrays to overcome path loss

- Constant antenna area required to maintain UL linkbudget, (assuming fix UE EIRP)
- Maximum basestation antenna area ~1 m^2, limited by wind-load
- Extreme # antenna elements feasible at high frequencies - from antenna area point of view

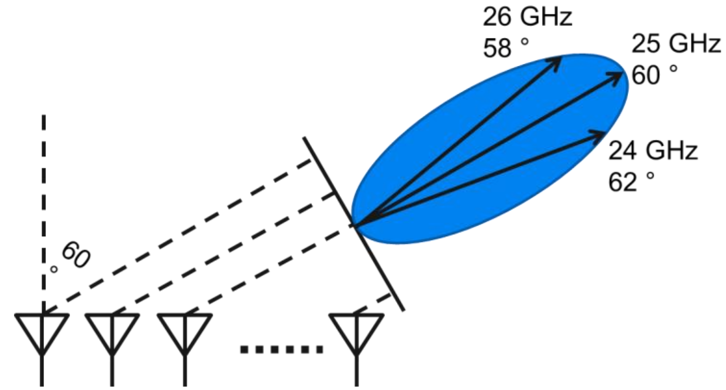


How many antenna elements makes sense?

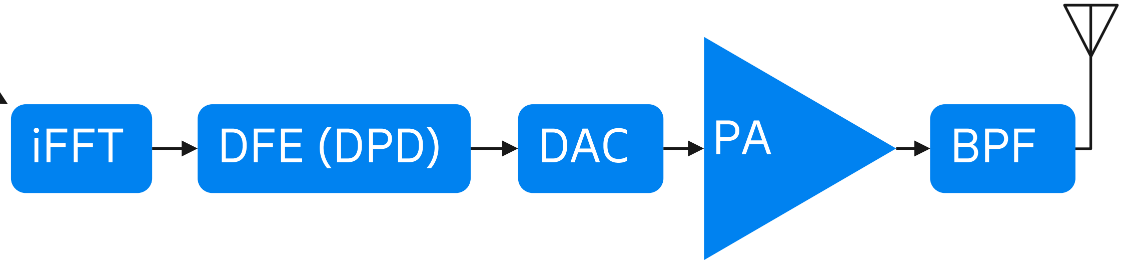
- Angular spread – deployment dependent, non-line of sight
  - Normally more angular spread in azimuth



- Wide relative BW => Beam squint
  - Mainly a problem with analog BF using phaseshifters



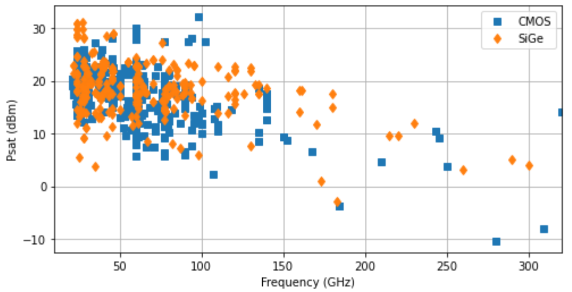
- Digital BF – cost/power/complexity
  - Hybrid beamforming a good compromise
  - Adds spatial limitations in co-scheduling



- Beam management with narrow beams is complex
  - Initial access & beam maintenance

High frequency technology limitations

https://ideas.ethz.ch/research/surveys/pa-survey.html



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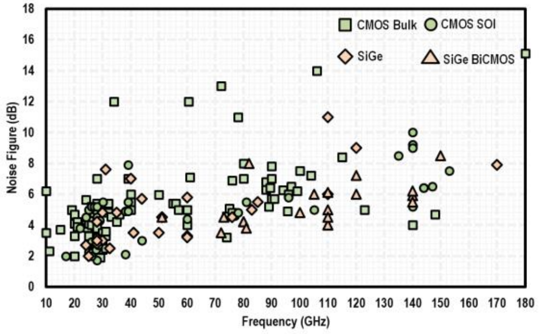
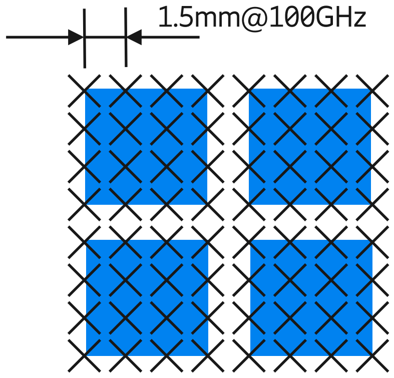


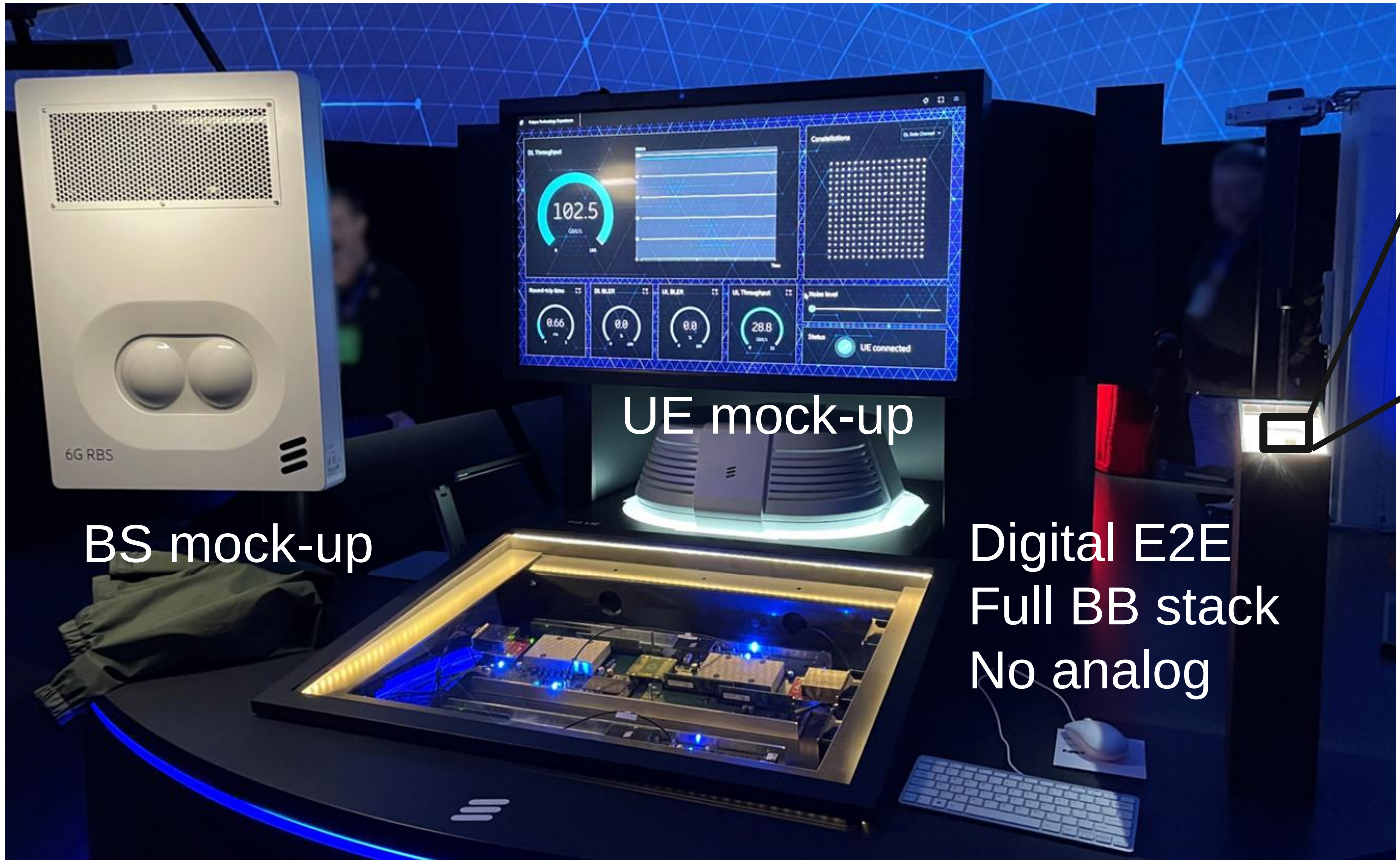
- SubTHz => approaching f_T/f_{max} of present RFIC technology
  - Costly to even generate gain
- PA power and efficiency drops, LNA NF increases, Switch and routing loss increases
- Wide bandwidth=> Converter power increases

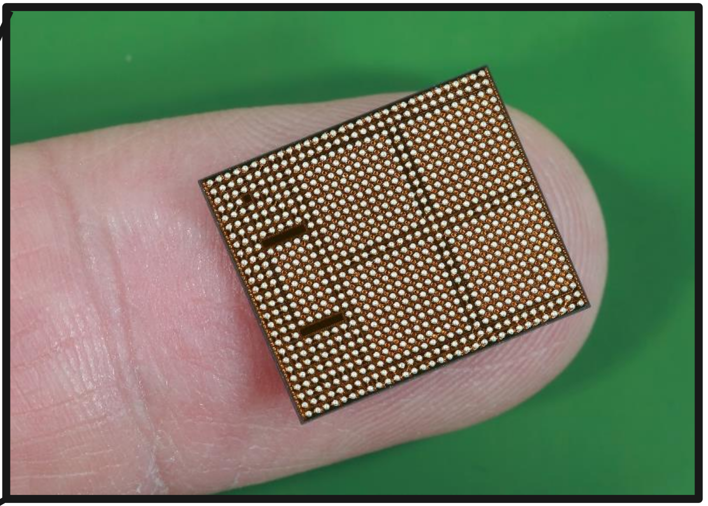
- Available area per antenna drops ~1/f^2
  - Subarrays; separate RX/TX panels; single-polarized panels
- Routing loss very high
  - Antenna-In-Package ; Antenna-On-Chip



100 GHz Demo at MWC2023

100 Gbps peak downlink throughput
4 layers, 6.22 GHz BW at 100 GHz
0.7ms ping time





AiP module (16.5x14 mm)

- 8x8 array
- 64 TX/64 RX in 4 RFIC
- 1 up/down conversion IC

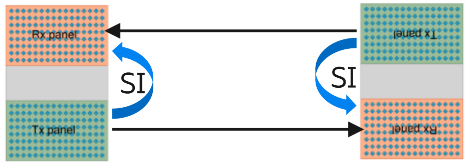
https://www.youtube.com/watch?v=VReHh_ohXJg

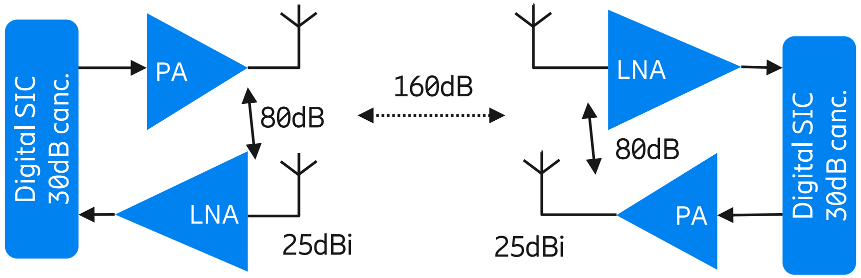
Full duplex operation

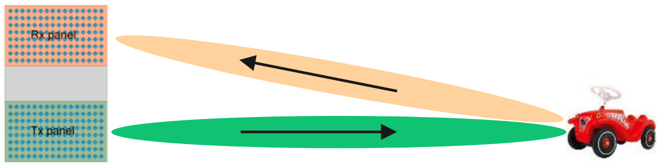
- Full duplex – doubling channel capacity, reducing latency
- High frequencies (mmW)=>can fit two arrays with several 100 elements
- ~10 wavelengths separation=>antenna port isolation in the order of 80 dB
- All together 80+25+25+30=160dB isolation
- Full duplex have other issues – CLI (cross link interference), BS<->BS, UE<->UE, BS<->UE

- Two antenna panels also enables monostatic radar

Full duplex







Summary

- 6G RF is mainly an evolution of 5G, no revolution
- New frequency bands needed to keep up with traffic growth
  (Centimetric band to avoid densification)
- SubTHz has lots of opportunities for performance enhancements
- SubTHz operation enables extreme throughput and new use cases
- Beamforming is here to stay and increasingly important at higher frequencies