Session #2: Emerging Technology Trends

16 July 2024

Technology Enablers for 6G

by

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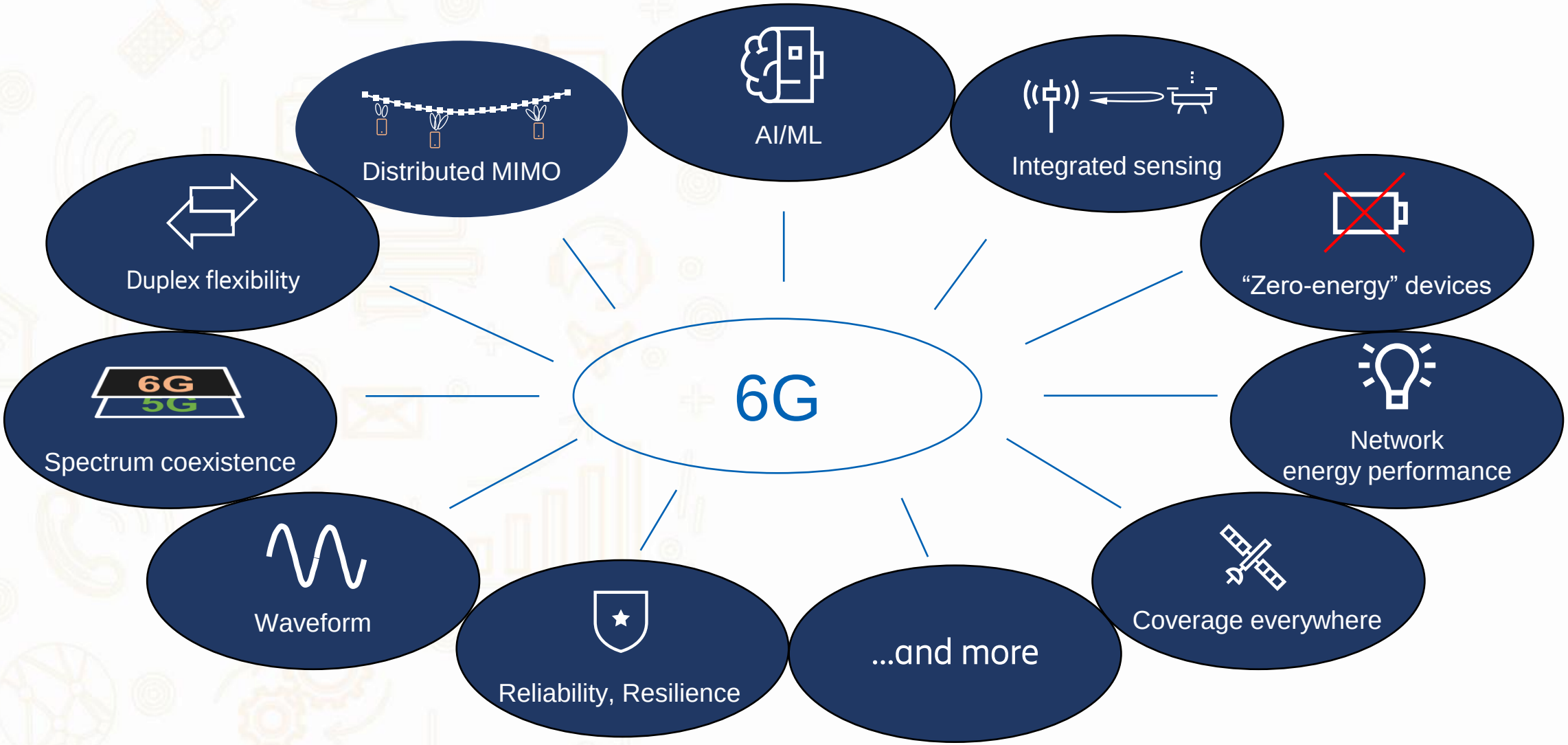
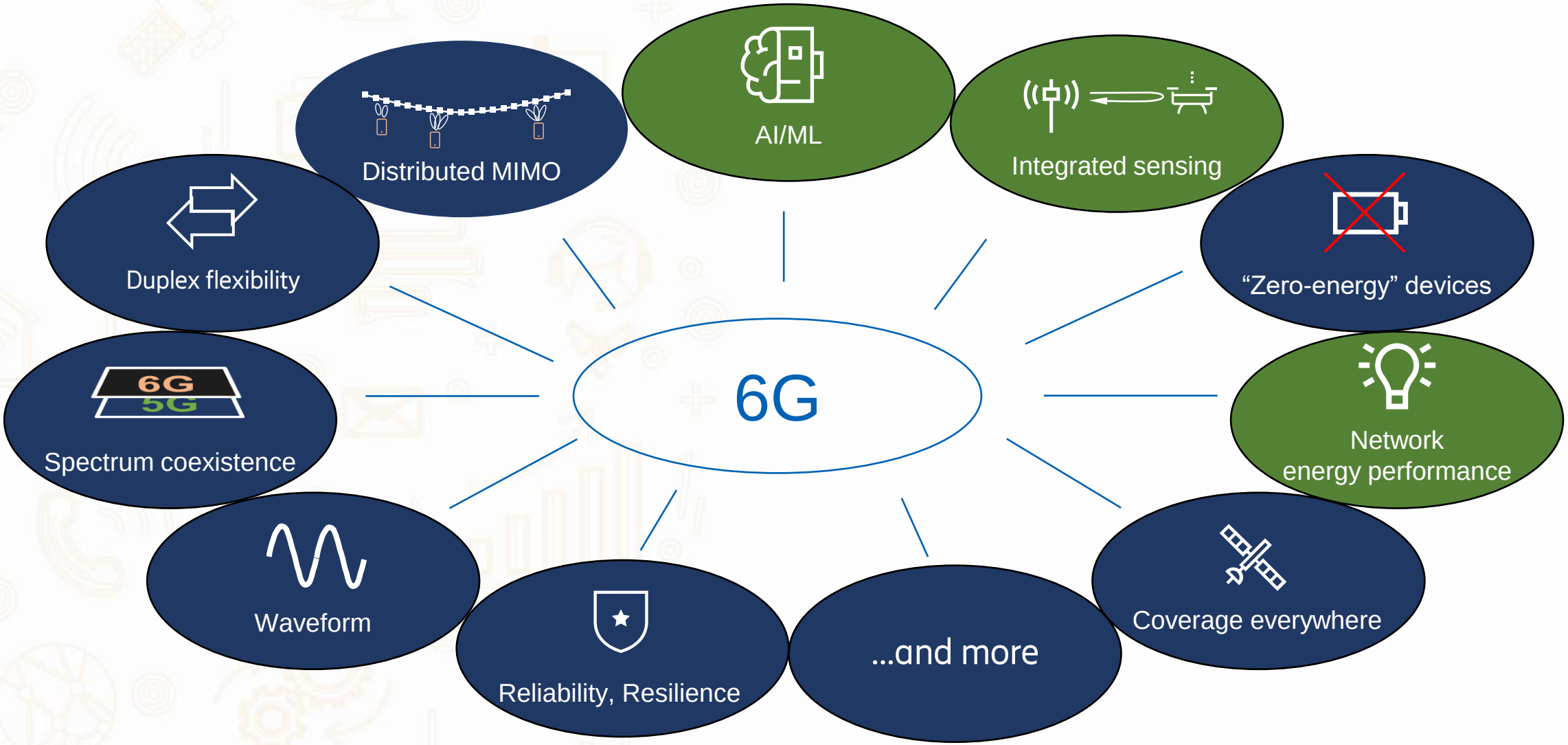
6G Technology Components/Areas



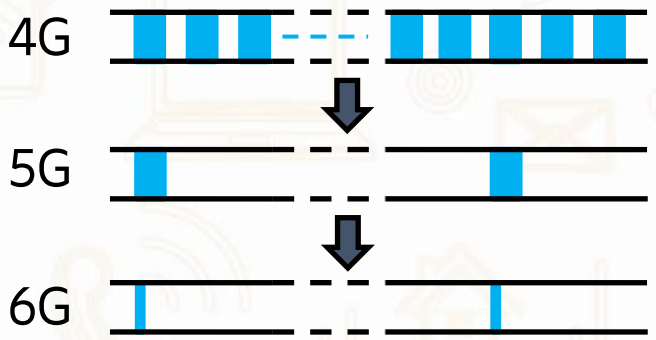
6G Technology Components/Areas



Energy Efficiency

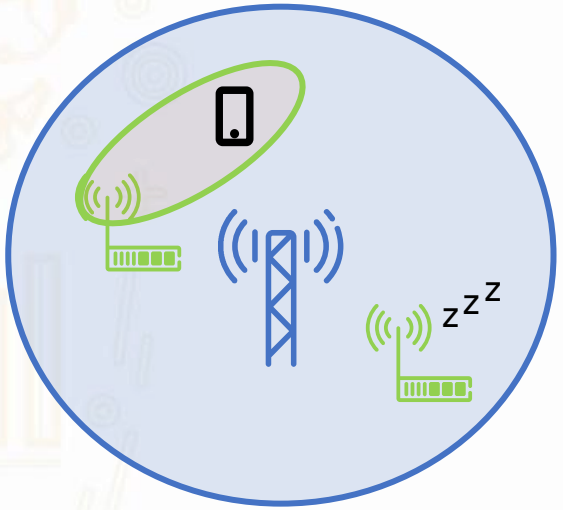
Lean Design Continues to be Important

Enhance lean design in Time domain



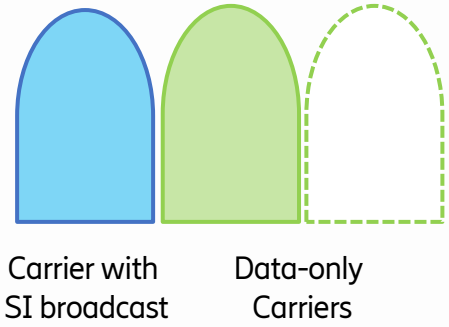
Further reduced duty cycle for "always-on" signals

Extend lean design to spatial/node domain



Nodes only transmitting when connected devices

Extend lean design to Frequency domain



Carriers only transmitting when connected devices

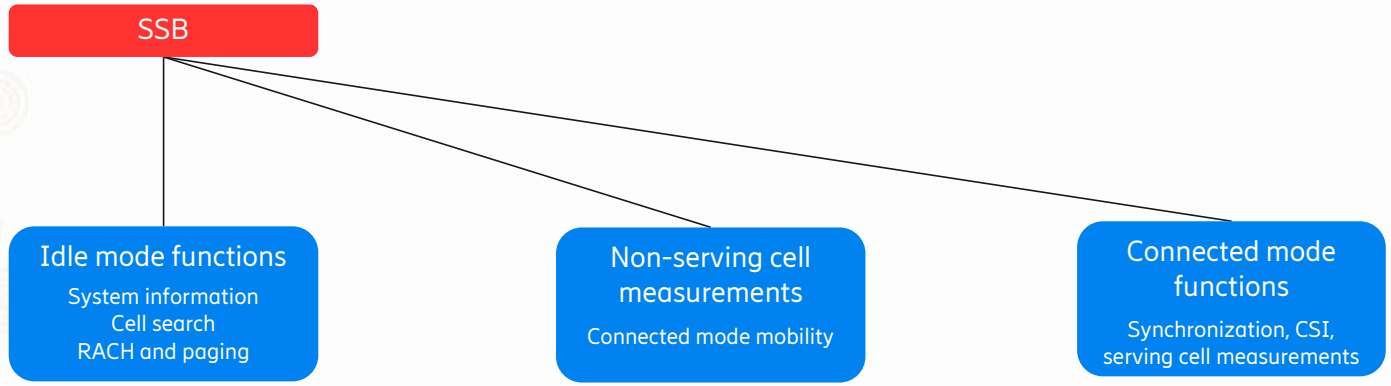
Energy Efficiency

Decoupling Idle and Active States

5G

SSB used for both idle and connected mode procedures

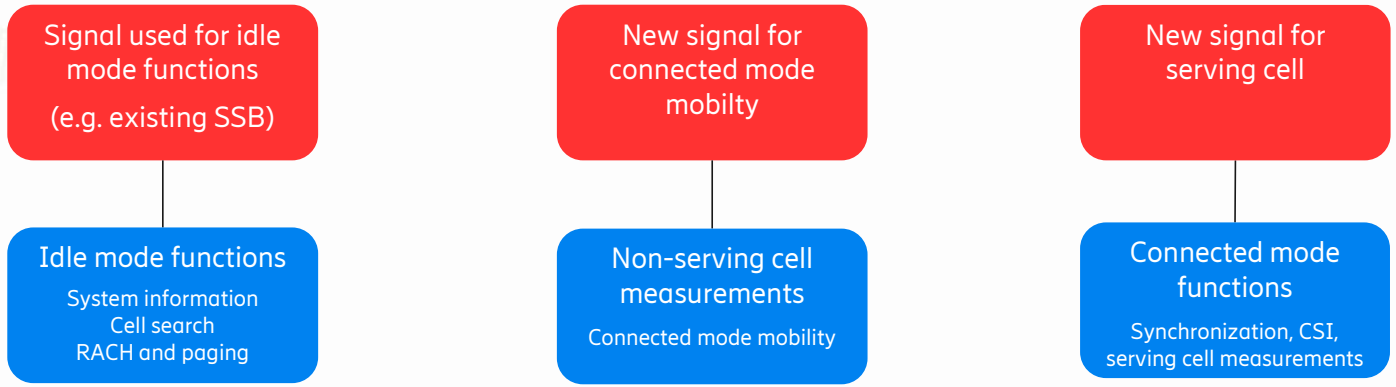
The spec allows mobility measurements on CSI-RS but it is not used in the field



6G

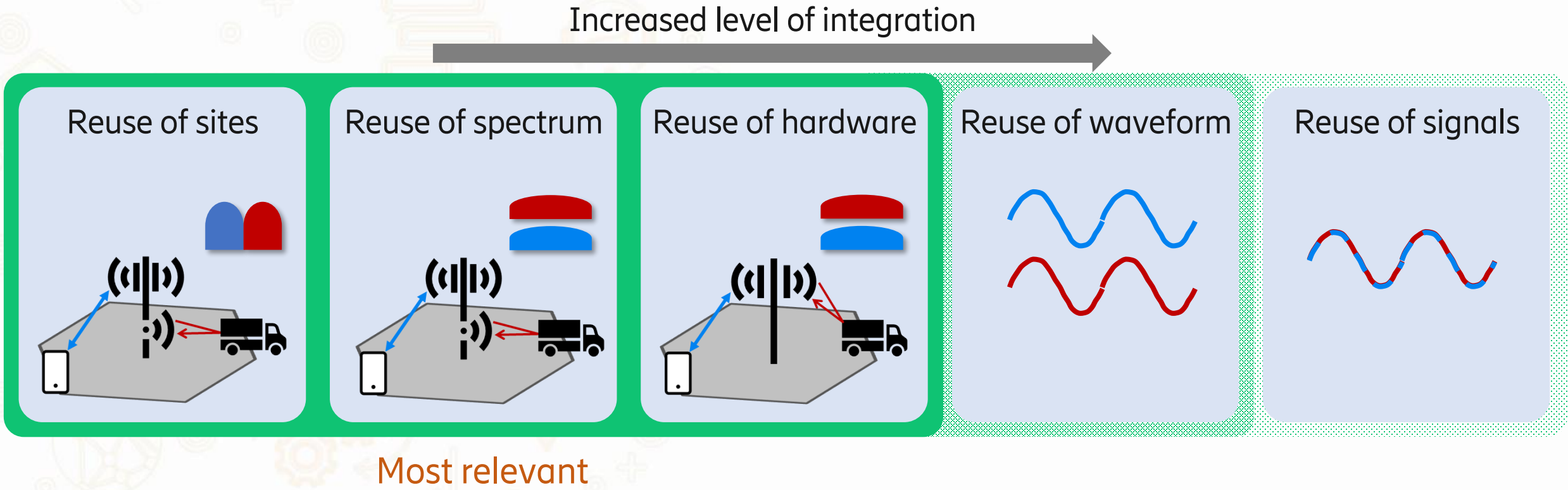
Separate signals for idle and connected mode procedures

Enables separate optimization for different states



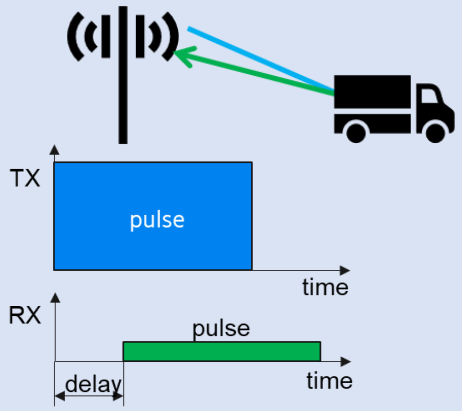
What is Integrated Sensing?

Sensing functionality as an *integrated* part of the communication network



How to Sense?

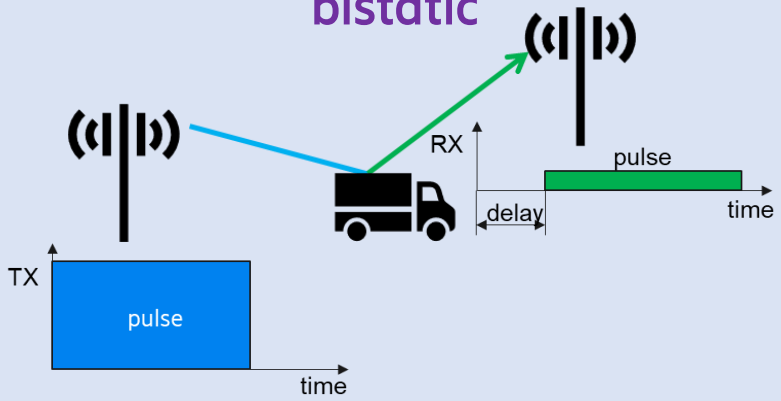
monostatic



Full-duplex operation needed

Or “blind zone” around TX node

bistatic

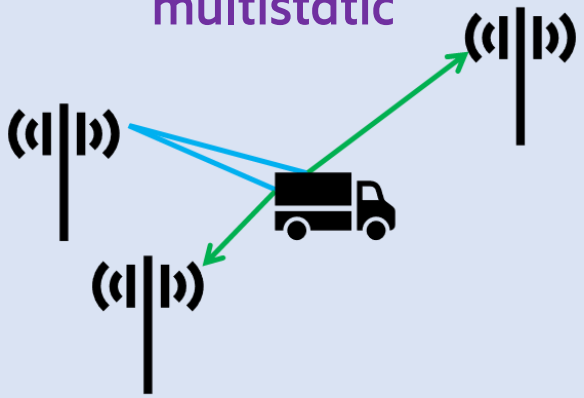


Tight synchronization needed

Line-of-sight to multiple nodes

“Blind-zone” around TX/RX line

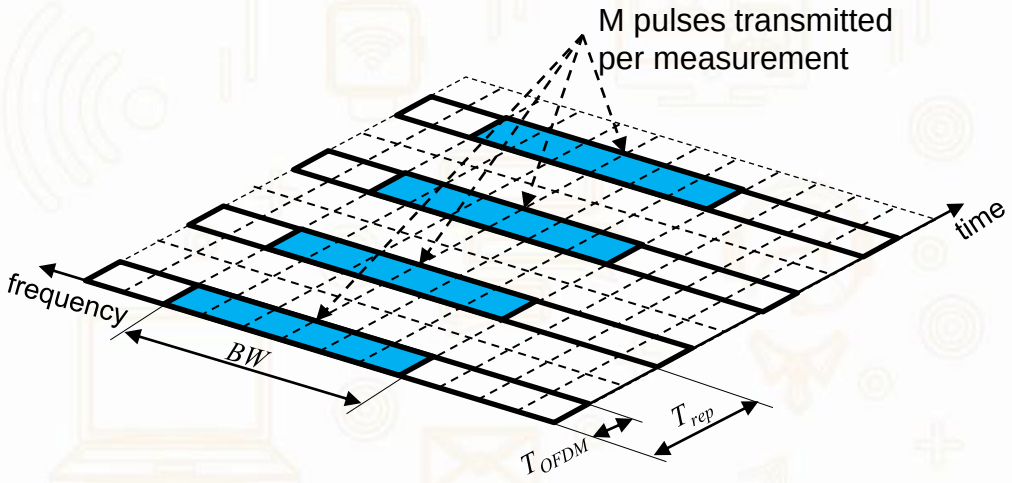
multistatic



Extension of bistatic sensing

Sensing Parameters

Assuming OFDM-based waveform and monostatic sensing



Range resolution

- $R_r = \frac{c}{2BW}$

Unambiguous velocity

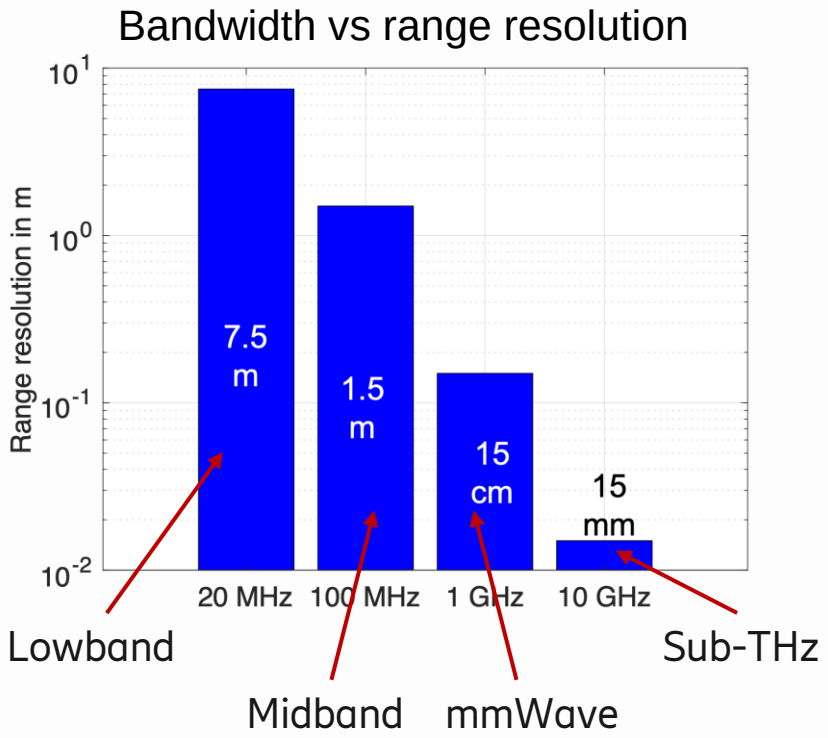
- $v_u = \frac{c}{4f_c T_{rep}}$

Velocity resolution

- $v_r = \frac{c}{2f_c M T_{rep}}$

Example

- Carrier frequency $f_c = 3.5$ GHz
- Required range resolution: 1 m
- Required unambiguous velocity: ±50 km/h
- Required velocity resolution: 1 km/h
- $BW = 150$ MHz
- $T_{rep} = 1.5$ ms (or less)
- $M = 100$



Integrated Sensing and Communication

Interference

Monostatic sensing (with long pulses) suffers from self-interference

Sensing signal both transmitted and received by network nodes

—Sensing signal transmitted from one network node (“downlink”) and received by another network node (“uplink”)

➡ Inherently “cross-link”

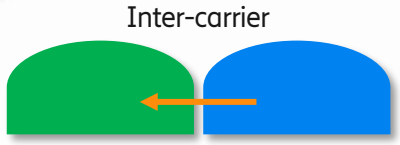
Sensing signals preferably transmitted in downlink resources

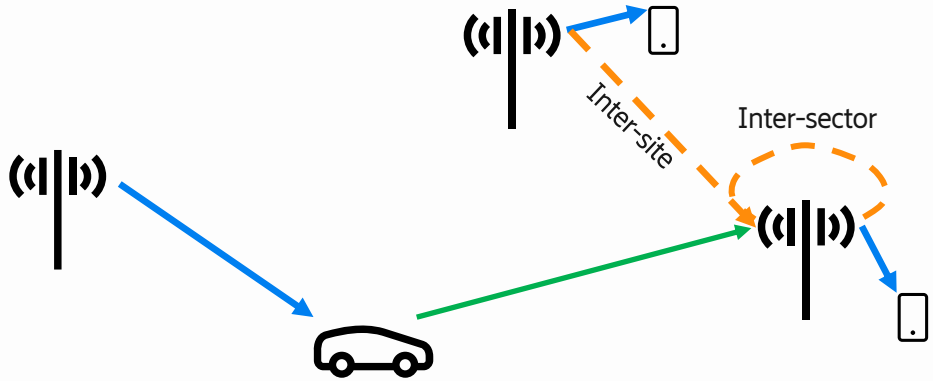
—Avoids cross-link interference from sensing-signal transmissions to uplink communication

➡ Cross-link interference from downlink communication to sensing-signal reception

—Inter-site / inter-sector / inter-carrier

—Impacts reception of sensing signals

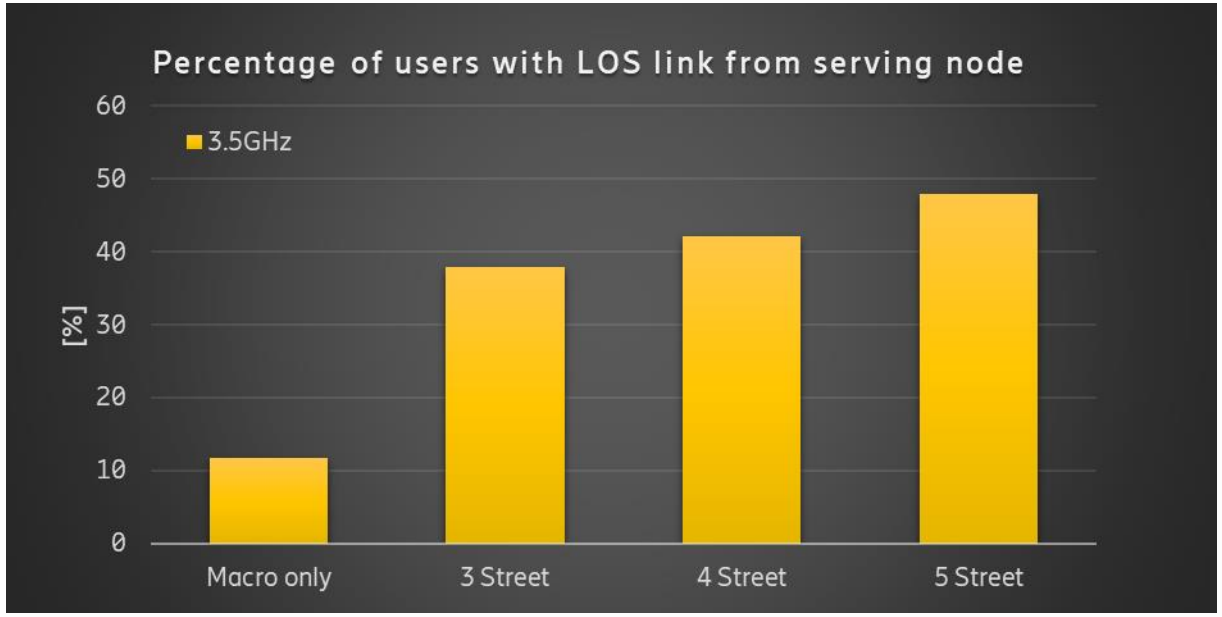




Integrated Sensing and Communication

Los Probability to Base Station

- In addition to interference, also LoS to multiple base stations a challenge
- Plot shows probability of LoS to at least one base station, probability of LoS to multiple base stations (needed for multistatic sensing to multiple base stations) lower
- Probability of LoS links between UE and base station
  - ISD: 450 m



Baseline is "Macro only", densification done via adding street sites

Integrated Sensing and Communication

Including UEs and other nodes

Depending on scenario a base station may not be able to receive sensing signals due to interference

In a multistatic setup objects must have LoS link to multiple TX/RX sensing nodes but in a cellular network cell overlap is typically minimized

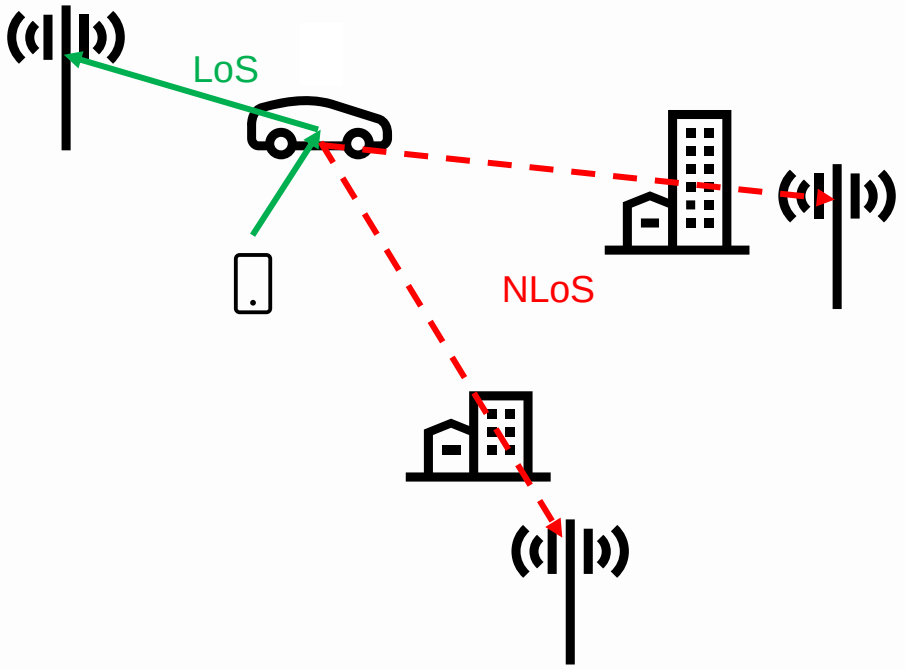
The communication infrastructure is complemented by RX sensors (location and orientation are known)

- Note: RX sensors could be external 3rd party sensing receivers

UEs are added as TX and/or RX sensing nodes (UE sync, location and orientation accuracy must be determined)

- Note: UEs could also be operator-deployed and stationary, mitigating some UE challenges

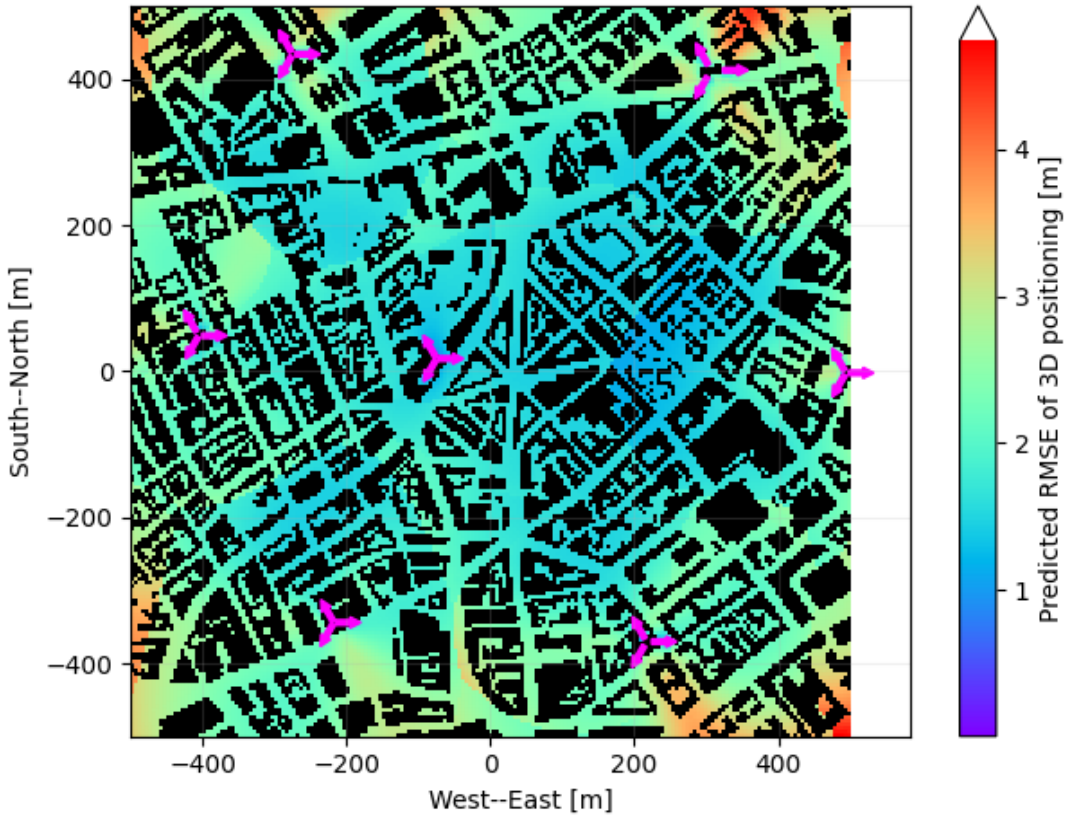
Sensors and UEs experience same interference as communication UEs



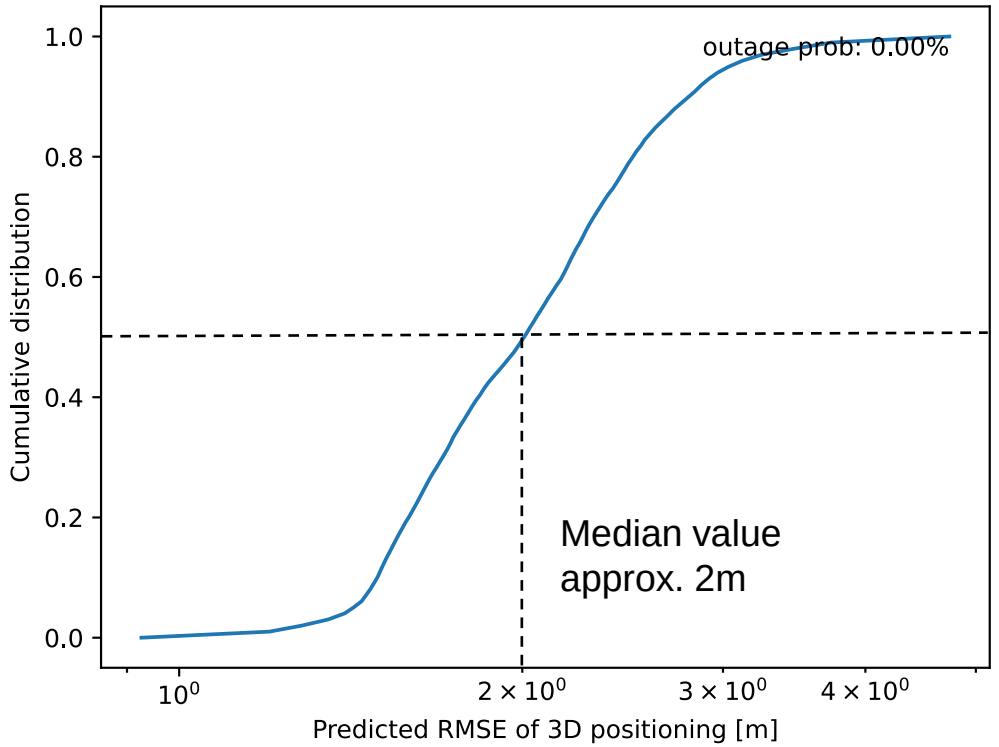
Example: UE acts as additional transmitter

Sensing of UAVs

Performance map for drone flying over London



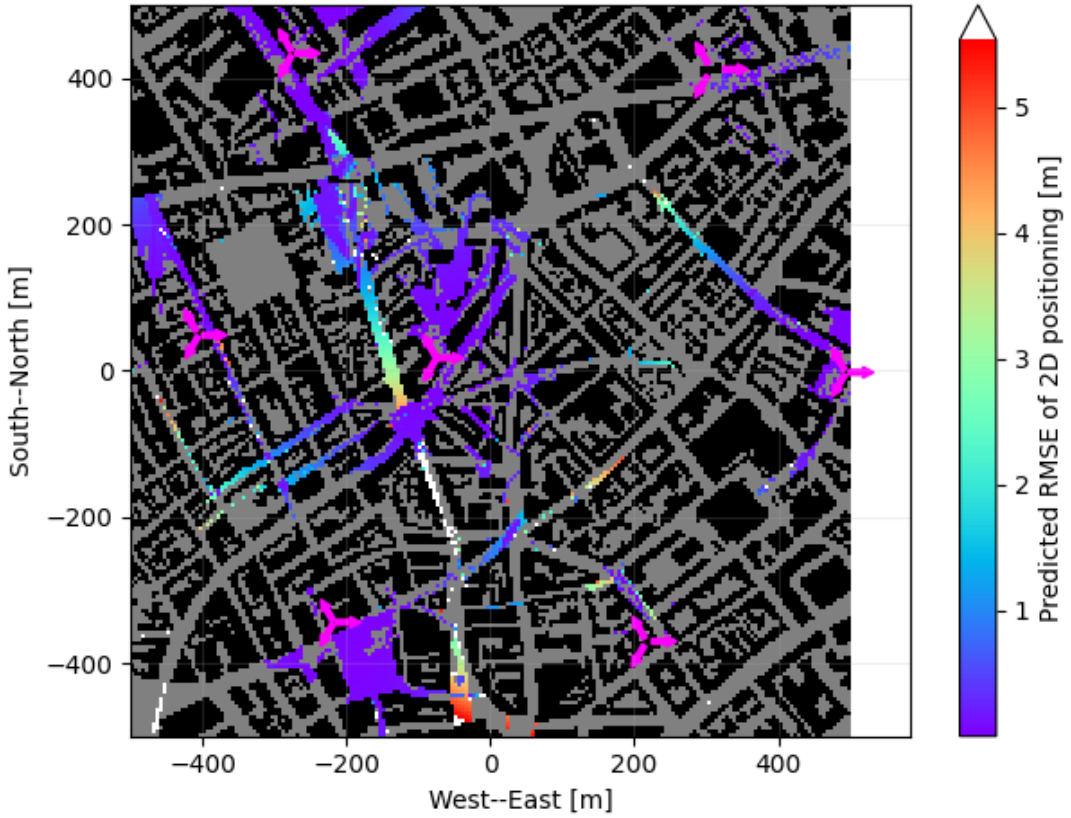
CDF for drone flying over London



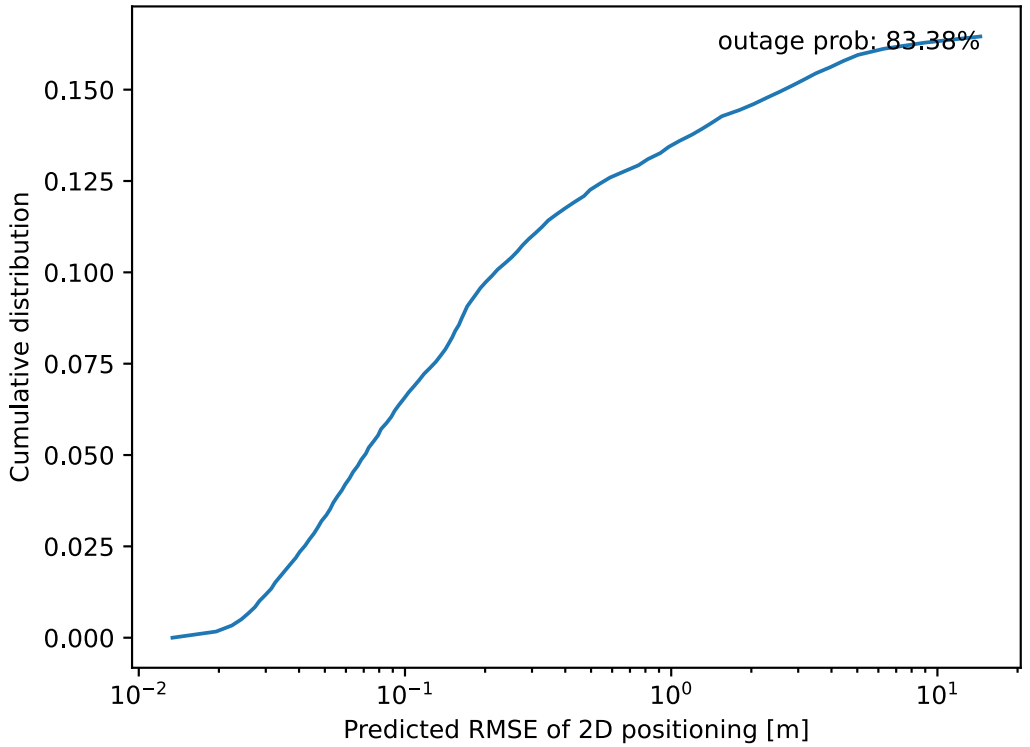
Note: Black areas have not been evaluated due to lack of data

Sensing in a City

Performance map for ground target in London



CDF for ground target in London



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MIMO in 6G

6G MIMO will build on the 5G MIMO framework

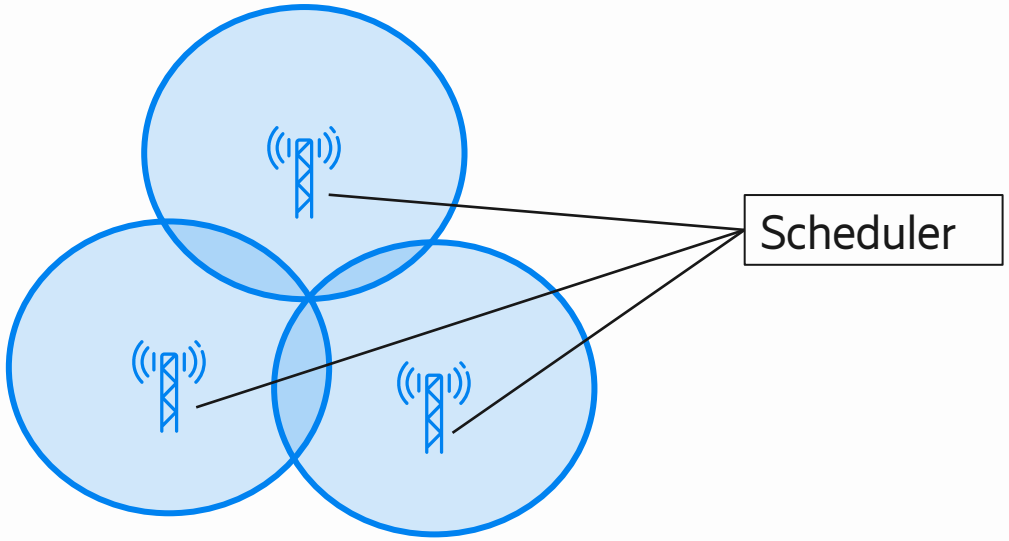
- Massive MIMO will remain important – reuse of current site grid
- Distributed MIMO will increase in importance – useful for dense deployments

"Scalable" design

- Dynamically adapt number of RF chains to reduce energy consumption

Trend towards scheduling across multiple TRPs and carriers

- Largely an implementation aspect but refined signaling structures can simplify coordination
- Improved spectral efficiency, improved energy efficiency, cloud-friendly implementation



Beamforming for Centimetric Band

5G NR supports sub-6 GHz (“FR1”) and millimeter-wave (“FR2”)

- FR1 designed primarily with digital beamforming in mind
- FR2 designed primarily with analog beamforming in mind

Current assumption: Expand digital beam-forming into centimeter range

AI for PHY

Overview

MIMO

Multi-antenna operation can potentially be improved in many aspects using AI/ML, e.g. optimizing precoders in non-ideal conditions, improved MIMO detection, reducing RS overhead.

HW impairments

Compensating for hardware impairments is today, in many cases, performed in a non-ideal way and there is a model deficiency in modeling the non-linear effects from hardware where data-driven approaches can improve performance.

Learning the wireless channel

Accurate predictions of complex dynamics in spatial-temporal-frequency dimension and for example understanding the underlying channel opens up for improved beam management, precoding, positioning channel compression lower RS overhead, etc

Rx opt.

To what extent can ML/AI compensate for the loss in performance when operating under non-ideal conditions, e.g. high speed UEs, high frequency offsets, colored noise, interference, low SNR operation etc?

AI for PHY

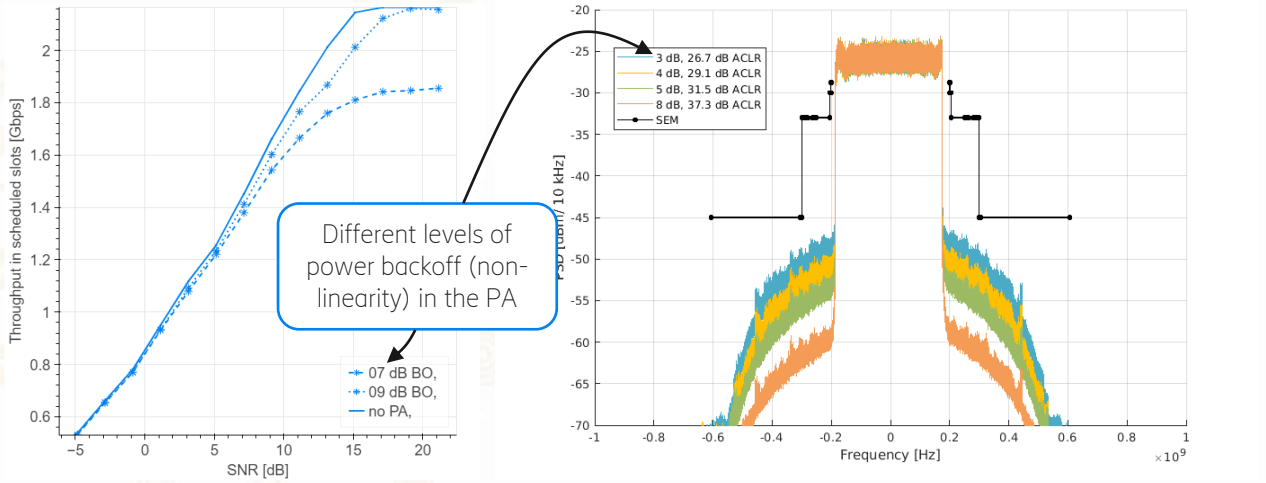
Digital Post-Distortion (DPoD)

One of the main components of both UE energy consumption and added signal impairments is the transmitter power amplifier (PA)

To keep impairments low, the point of operation in a power amplifier need to operate in a linear enough region, negatively impacting **power efficiency** and **maximum output power achievable**

Can we allow more impairments at the Tx and use AI/ML at the Rx to improve performance?

Assuming current EVM requirements can be violated but regulatory requirements, such as ACLR, spectrum mask, are still to be complied with



AI for PHY - DPoD Scenario 1

Fixed Transmit Conditions

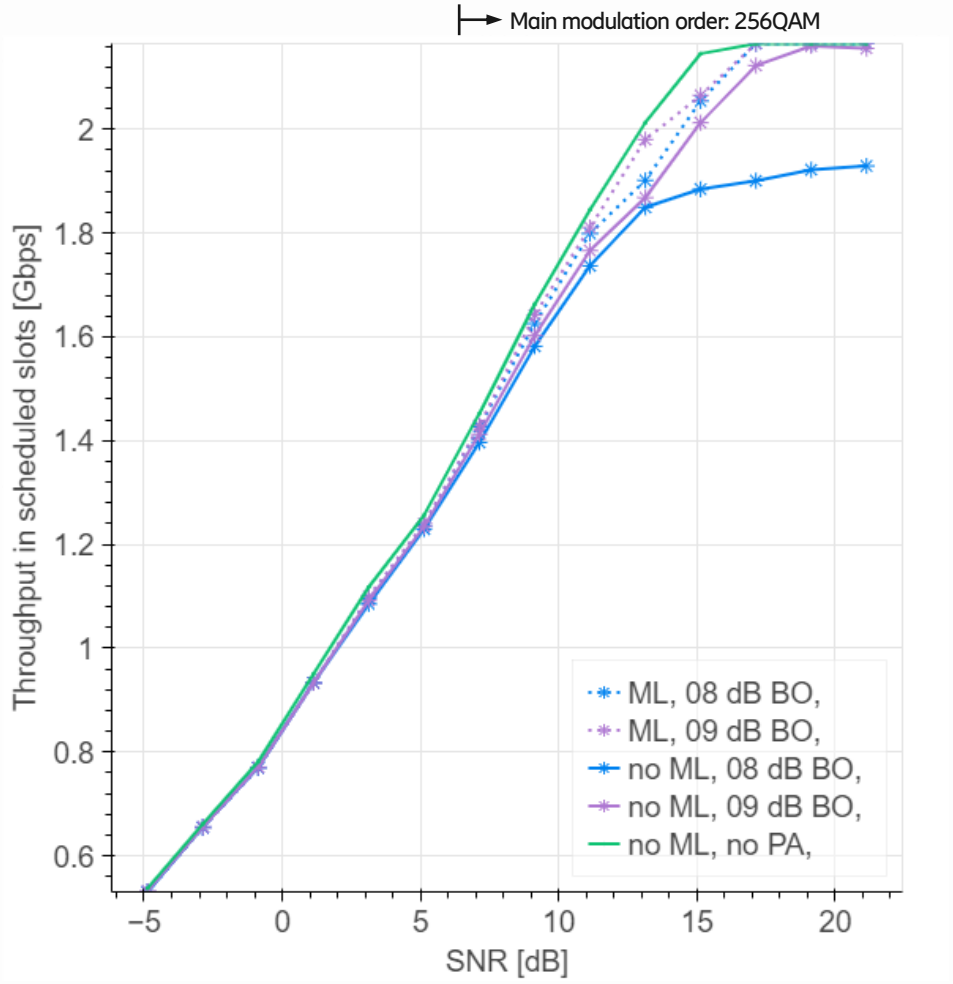
Scenario description

- The UE transmit conditions (e.g., PA back-off) are fixed and performance is compared at a certain SNR in terms of throughput
  - The intention is to investigate what happens if we simply turn on an AI/ML based receiver with current transmitters

Key results

- Throughput gains at SNR=13 dB and 17 dB are shown in the table

Backoff [dB]	SNR [dB]	Gain [%]
8	13	3 %
	17	14%
9	13	6%
	17	2%



AI for PHY - DPoD Scenario 2

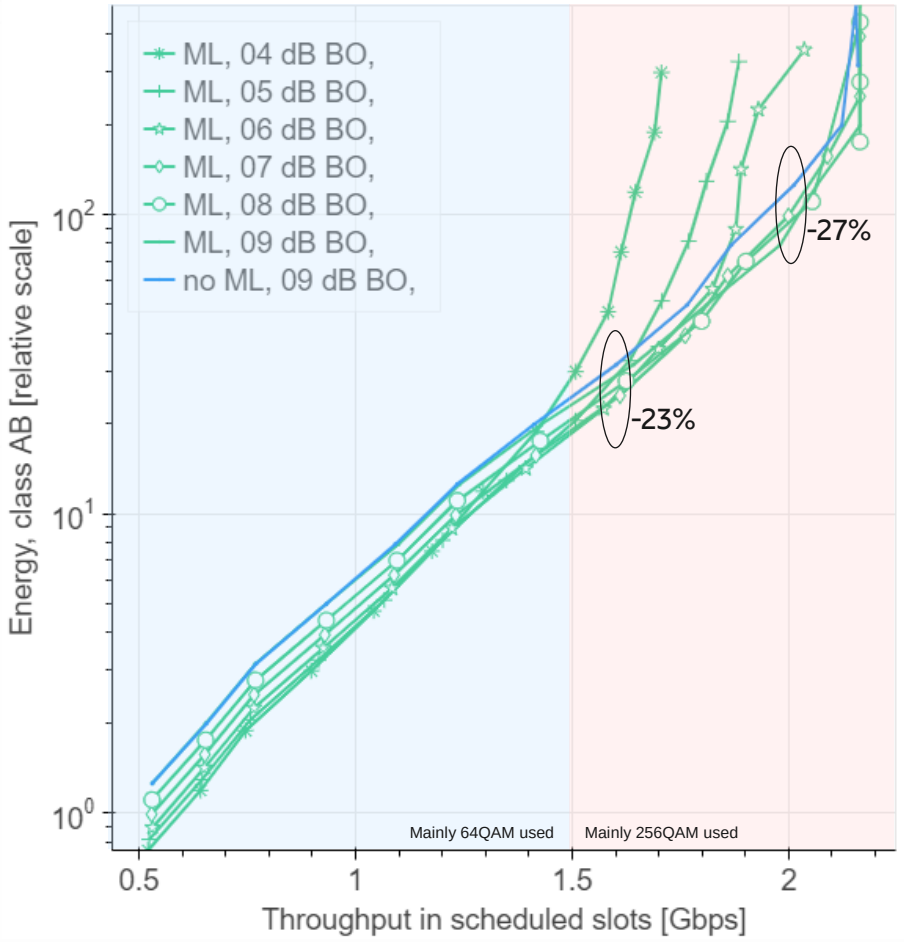
Fixed Throughput

Scenario description

- Assuming that the system is not power limited, the UE operates at an as efficient operating point as possible in the network to reach a given throughput level
  - The intention is to investigate how energy efficient the UE can operate with a new standard specification including this feature

Key results

- Energy efficiency gains between 23%-27% are observed between the PA models and throughput levels 1.6-2.0 Gbps
  - The gain in energy efficiency is very much dependent on the assumed power efficiency profile of the PA and the operated throughput level



Thank You

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