Communications and Sensing Convergence

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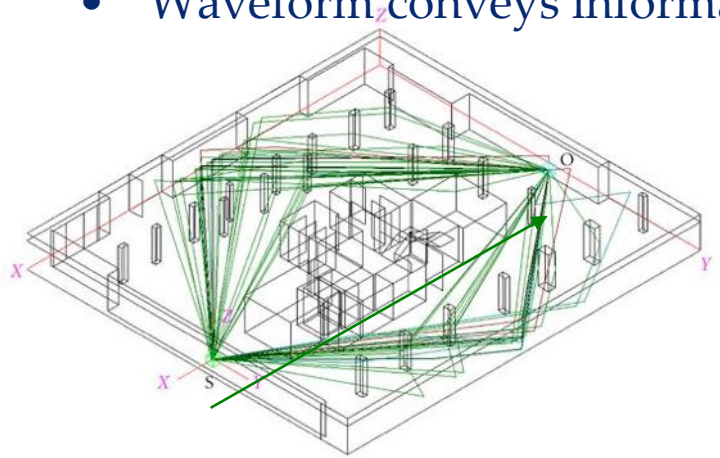
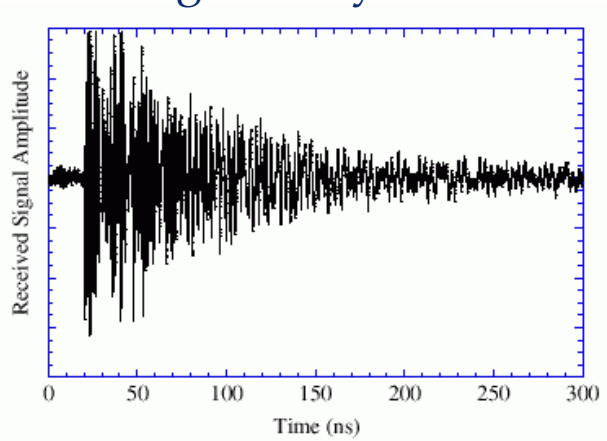
Main idea of radio-based positioning and mapping

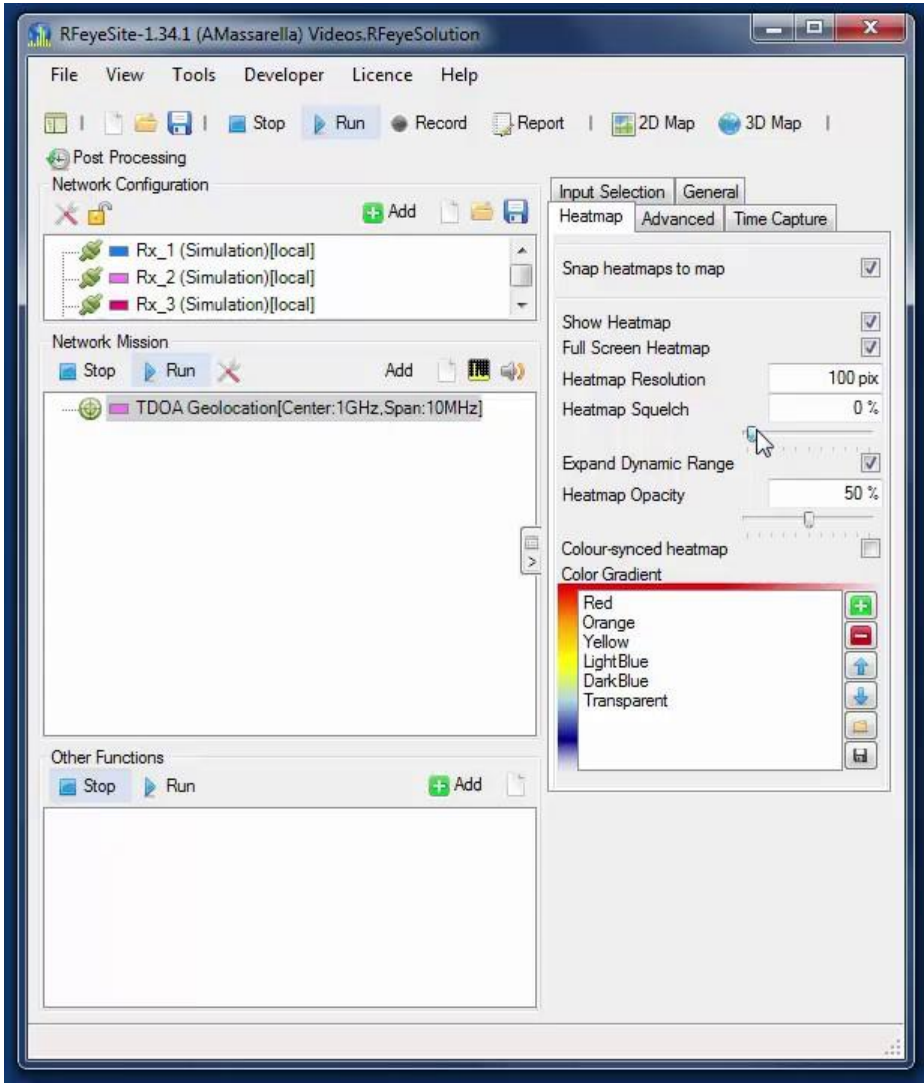
- Waveform conveys information about geometry

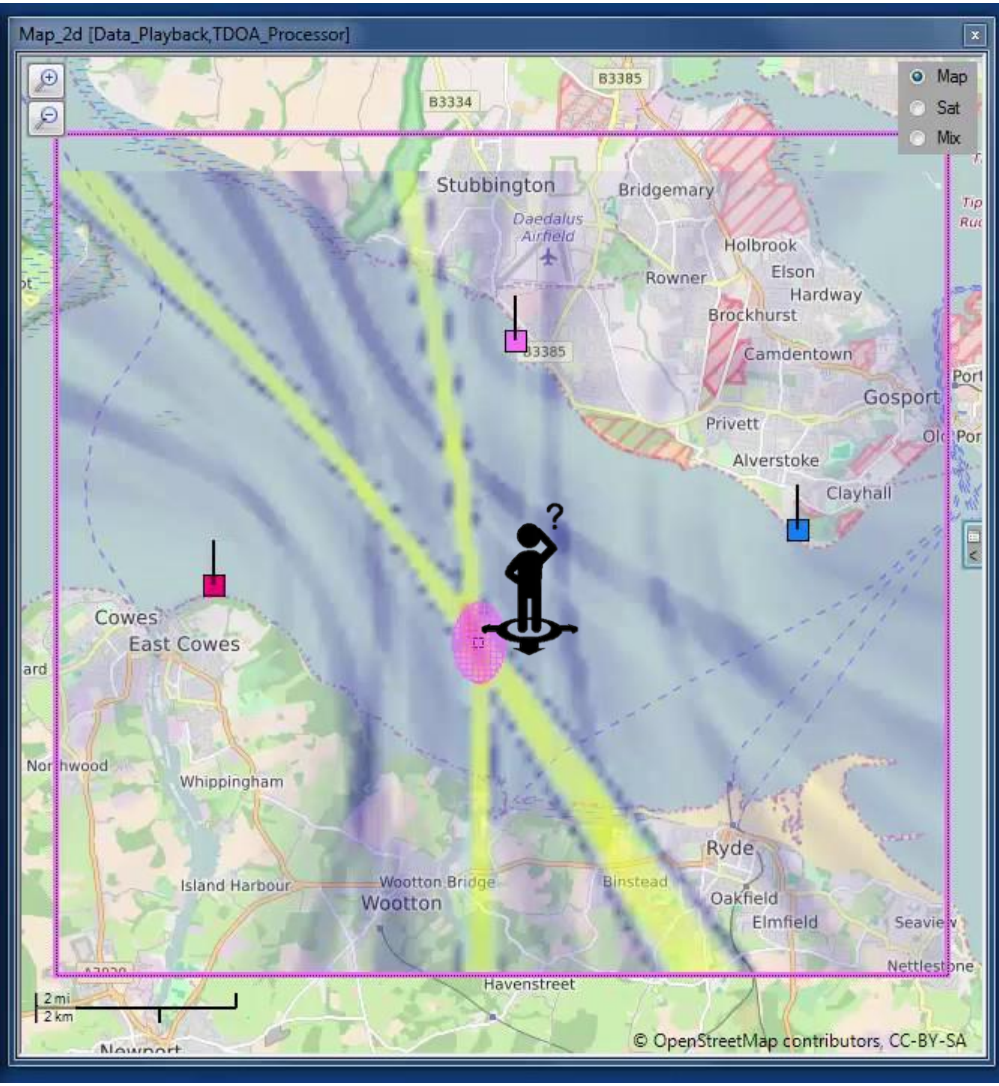




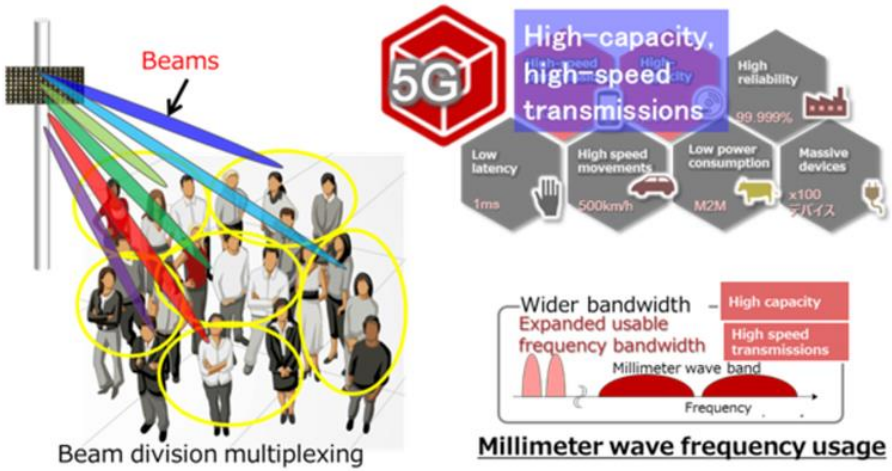
- Different measurements: signal strength (path loss, fingerprinting), time (TOA, TDOA, RTT), angle (AOA, AOD), Doppler, signal phase
- Signals should be resolvable in at least 1 dimension (distance, angle, velocity)
- Measurements converted to position and map: SLAM

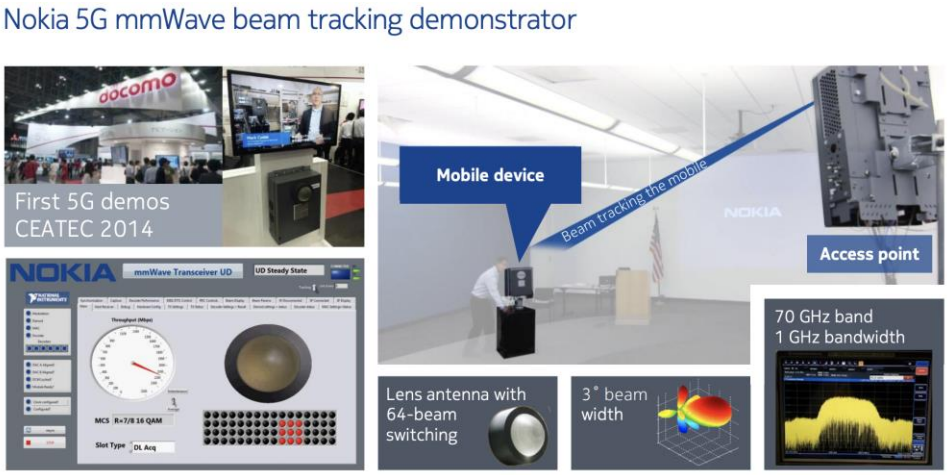
Current status: time difference-of-arrival (TDOA)





Example 1 - Beamforming





Source: https://www.zdnet.com/article/fujitsu-unveils-small-cell-mmwave-5g-tech/

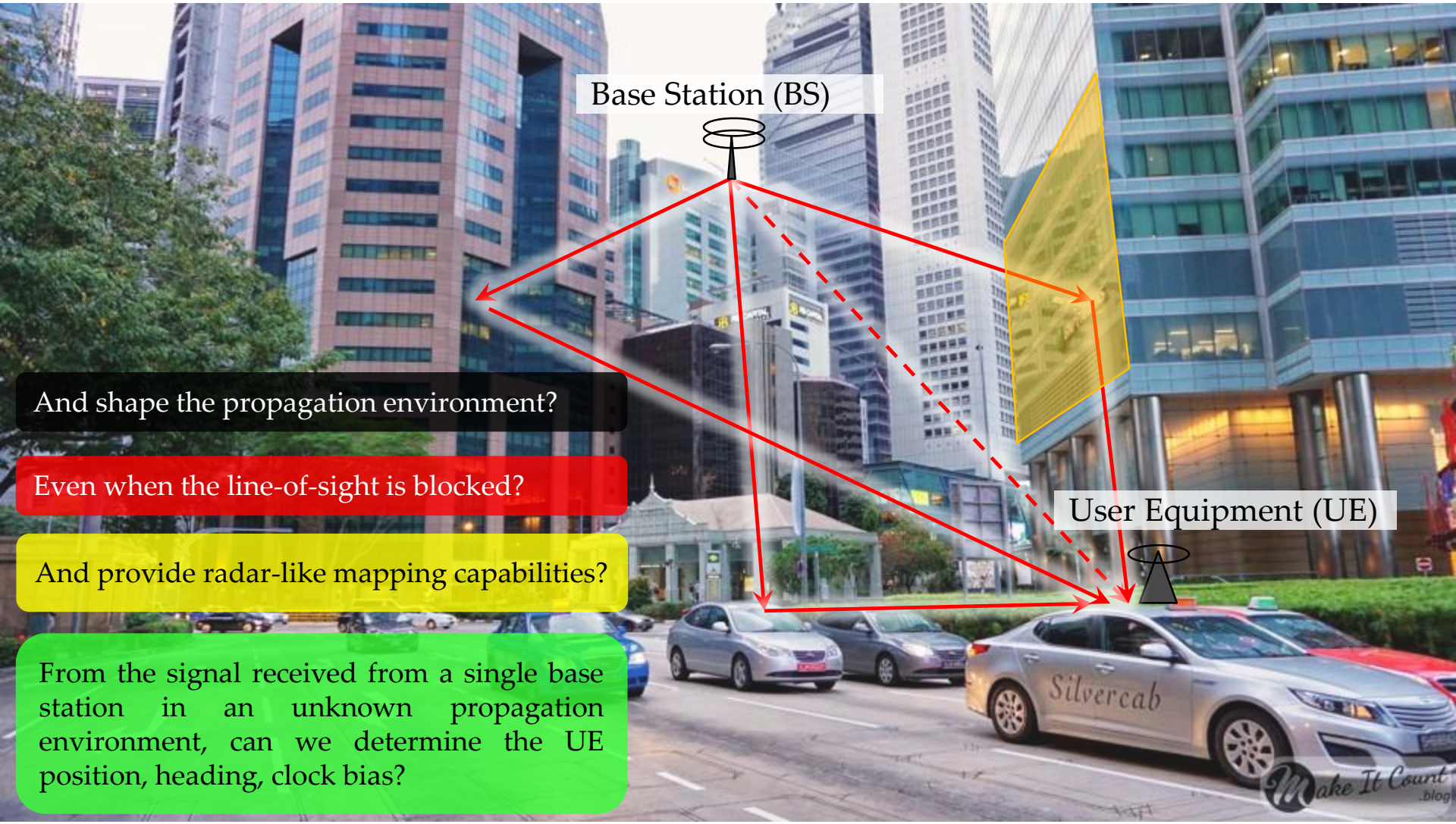
- Location information is implicitly used, in order to direct beams.
- Can be in-system or out-of-system (e.g., GNSS)

Example 2 - Radar interference

Source https://www.futurebridge.com/uncategorized/advancements-in-automotive-radars/

- Interference leads to false alarms (ghosts) and missed detections (accidents)
- Communication can help coordinate transmissions of radar

Example 3 - The Beyond 5G SLAM Challenge



And shape the propagation environment?

Even when the line-of-sight is blocked?

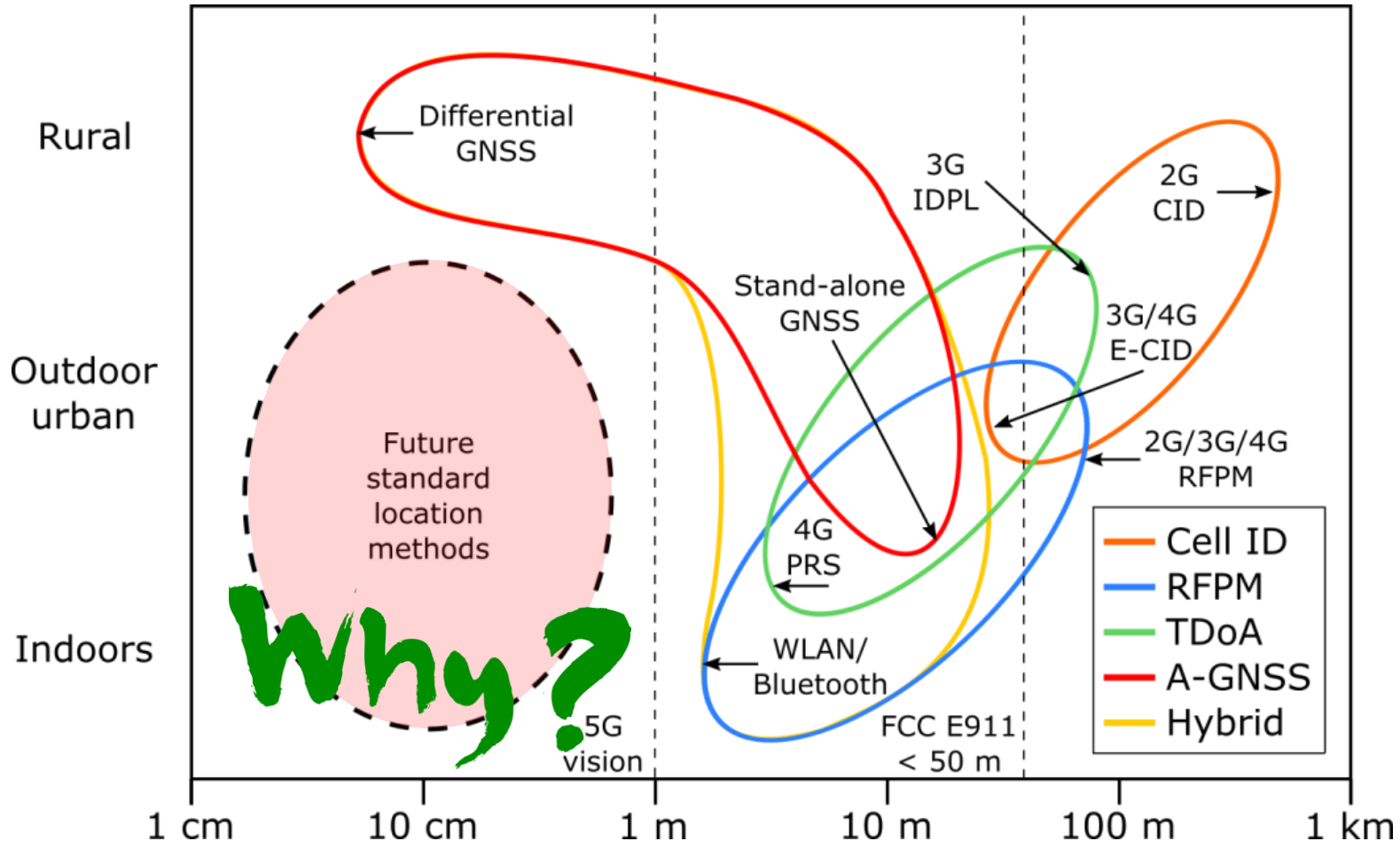
And provide radar-like mapping capabilities?

From the signal received from a single base station in an unknown propagation environment, can we determine the UE position, heading, clock bias?

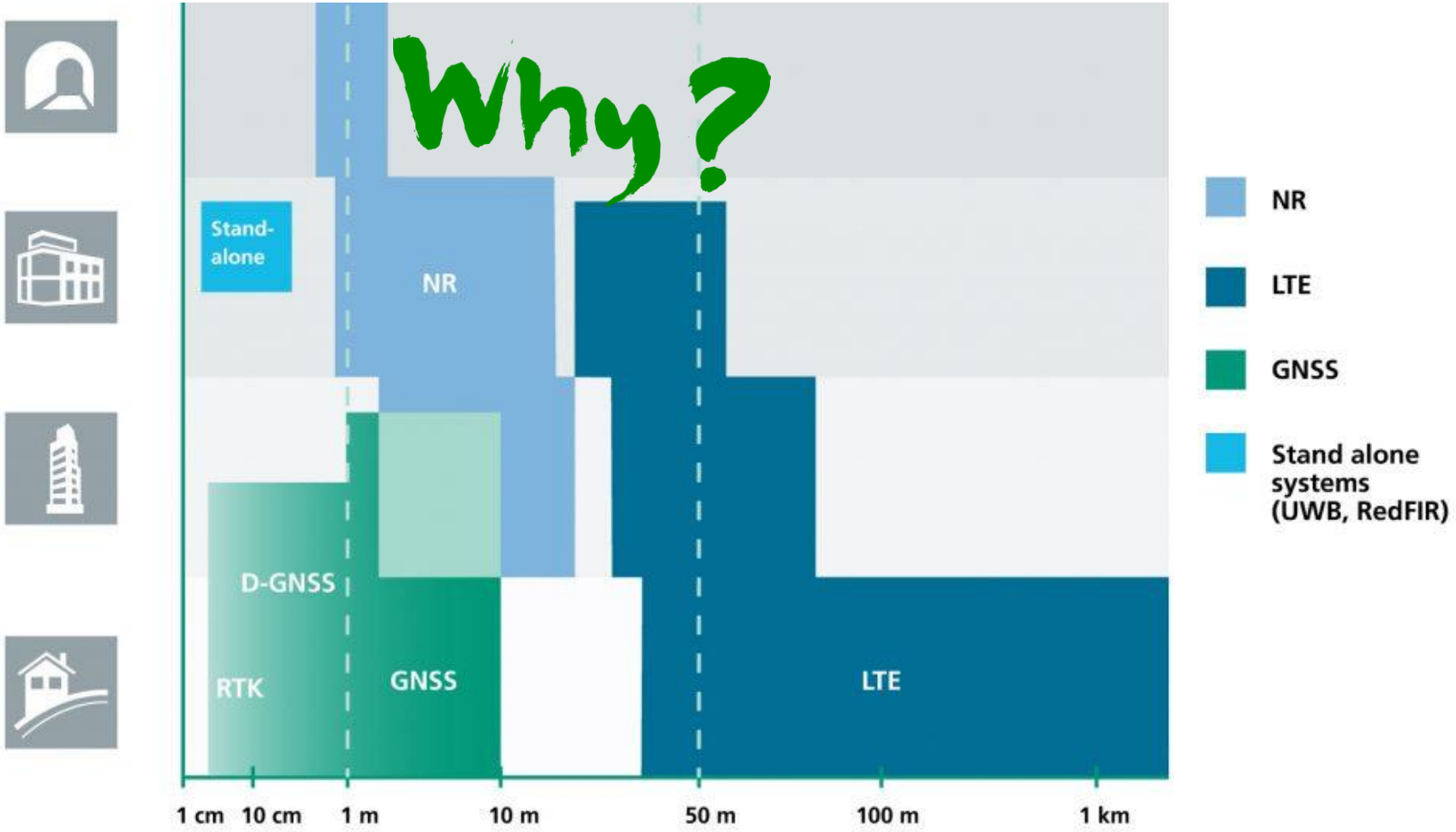
Source: https://makeitcount.blog/singapore-good-to-know/image-singapore-downtown-street-taxi/

Vision for 5G

J. A. del Peral-Rosado, et. al. "Survey of Cellular Mobile Radio Localization Methods: From 1G to 5G" in IEEE Communications Surveys & Tutorials, 2018.



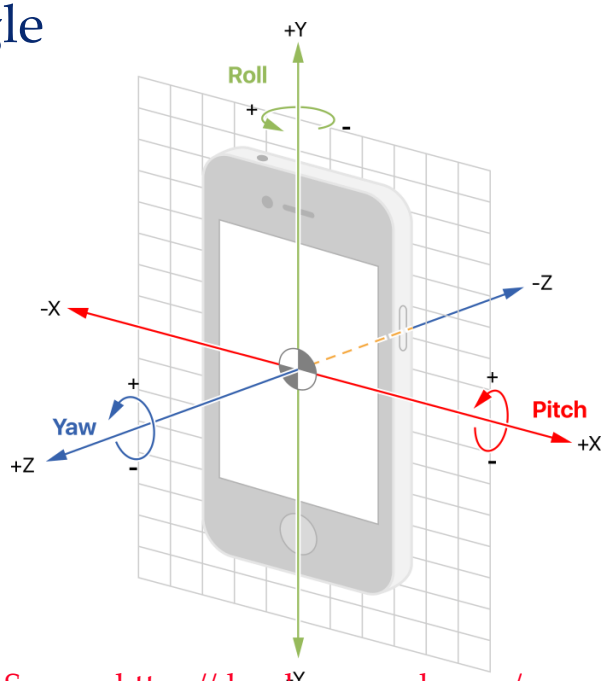
Vision for 5G



Source: https://www.iis.fraunhofer.de/en/ff/lv/lok/tech/5g.html

6 Selling Points for Beyond 5G positioning

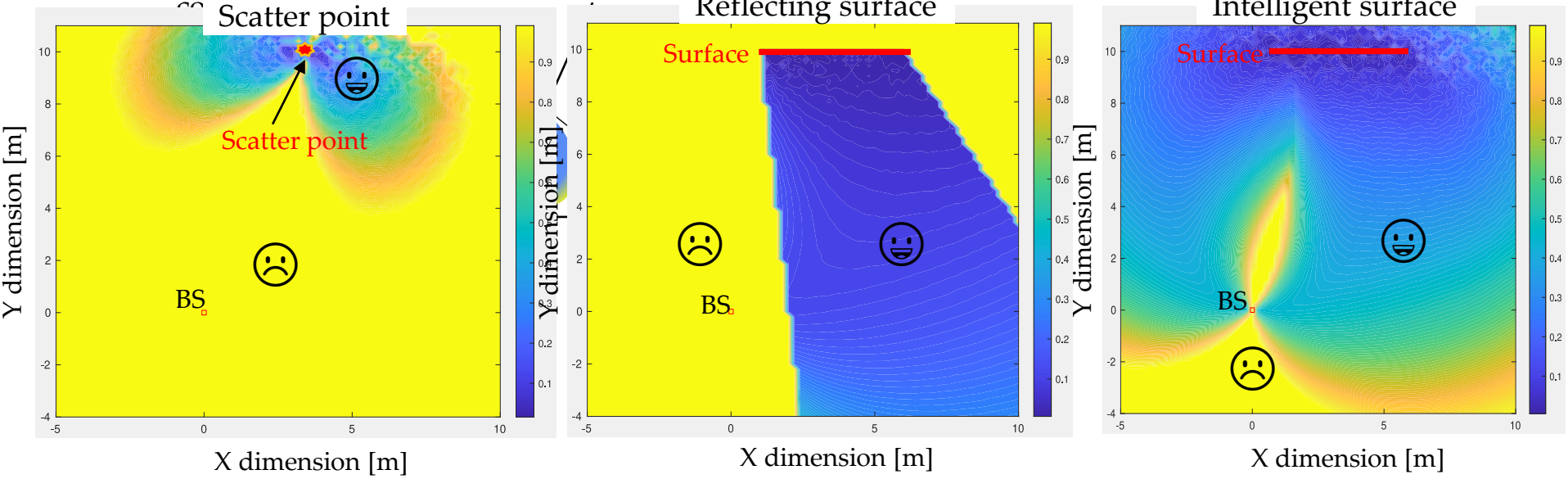
1. **High carrier frequencies** (up to THz): geometric channel
2. **Large bandwidths** (GHz): high delay resolution
3. **Large number of antennas** (100+): high angle resolution
4. **D2D** communication: relative positioning, bistatic radar
5. Network **densification**: LOS links
6. **Shaping the environment** with intelligent metasurfaces



Source: https://developer.apple.com/

Reconfigurable Intelligent Surfaces

Shaping the environment to improve communication



Environment can be optimized for positioning

Applications

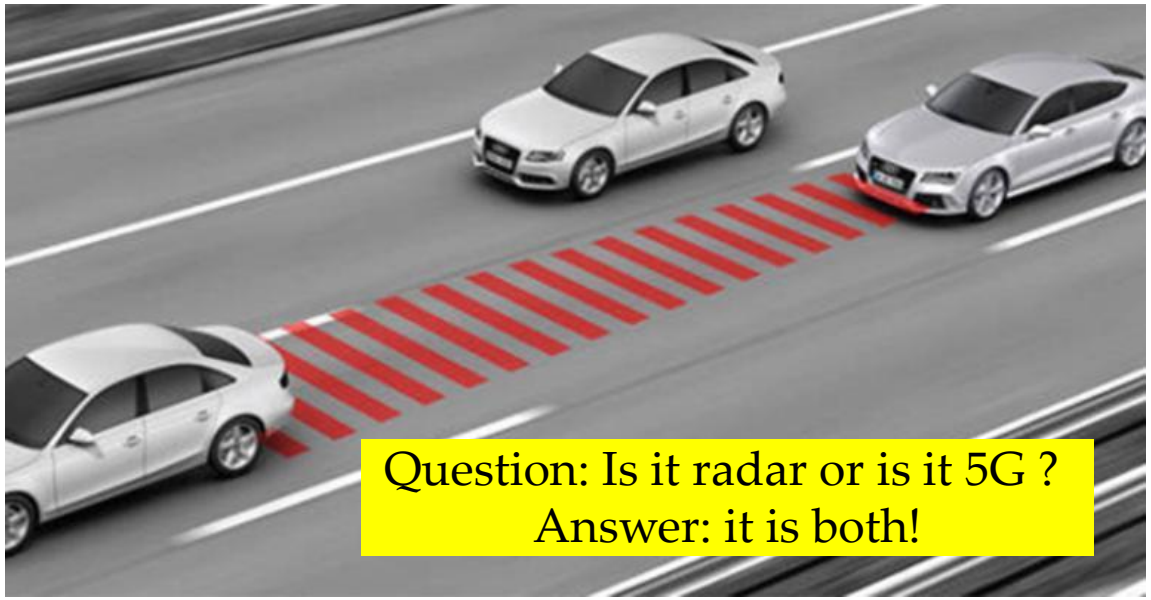
- Opportunities

- Risks

- Directed challenges

Conclusion

- Radio signals have always provided location information.
- THz frequencies, large bandwidth, smart surfaces, many antennas is an interesting regime.
- Very active in 3GPP (e.g., 3GPP TR 38.855 V16.0.0 (2019-03)) along these lines
- Many unanswered questions. Need for measurements.



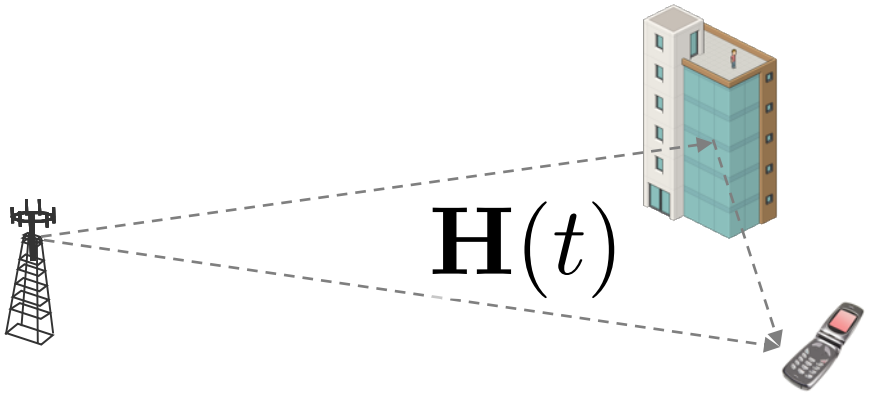
BACKUP SLIDES

Activities at 3GPP - 3GPP TR 38.855 V16.0.0 (2019-03)

- NR positioning requirements
  - 3 m xyz indoors
  - 10 m xy outdoor
- Measurements: time, phase, angle
- Enhancements:
  - Multipath
  - DL-only
  - Carrier-phase measurements
- Increasingly active topic in standardization
- Shift towards higher frequencies
- Trend towards cm-level uncertainty

1. High carrier frequencies

- Received power due to path loss, shadowing, multipath fading
- Path loss: countered by array gains
- Shadowing: severe penetration loss so no shadowing
- Multipath fading: no diffraction, limited scattering and little reflection
- Communication channel is dominated by LOS and a few location-dependent clusters



Below 6 GHz: full matrix (i.i.d., Gaussian)
Above 28 GHz: low-rank matrix

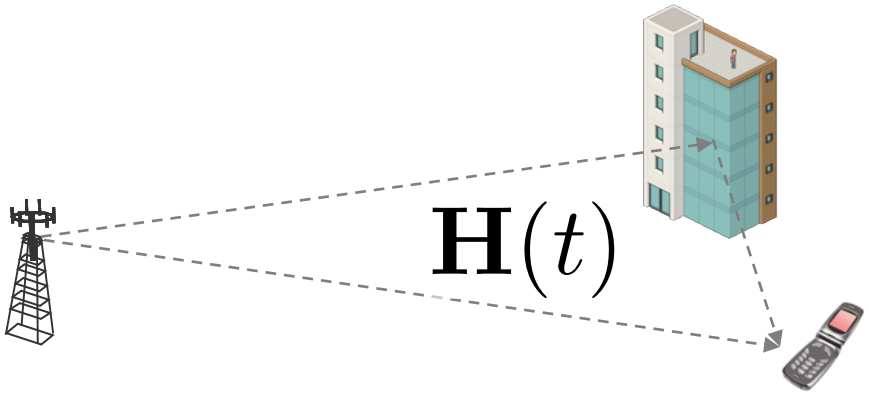
$$\mathbf{H}(t) = \sum_{l=0}^{L-1} \alpha_l \mathbf{a}(\theta_{\mathrm{rx},l})\mathbf{a}^{\mathrm{H}}(\theta_{\mathrm{tx},l})\delta(t-\tau_l)$$

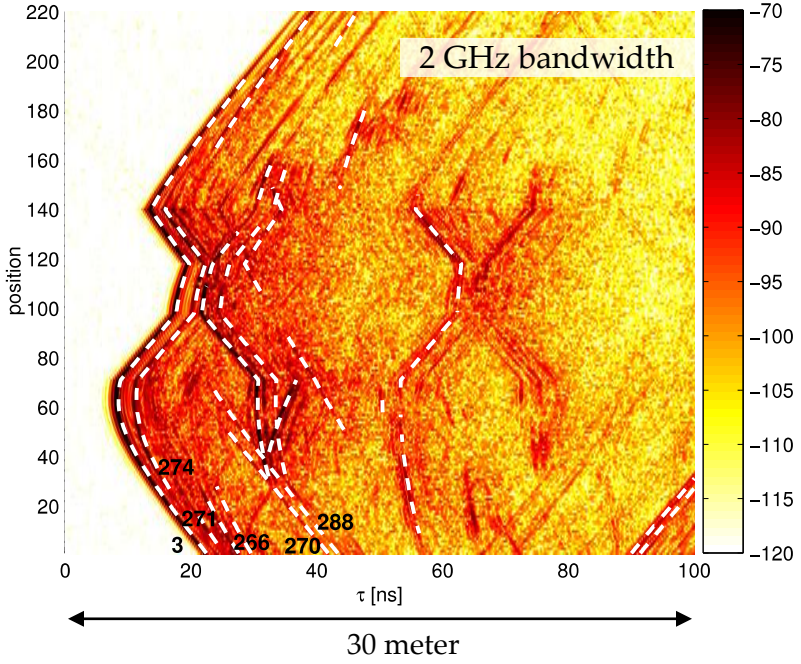
Each "effective path" corresponds to cluster

Sparse communication channel, related to the physical environment

2. Large bandwidths

1. From Fisher information: large bandwidth leads to better delay (distance) estimation accuracy
2. More resolvable multipath components: two paths are resolvable when $|\tau_1 - \tau_2| \times B \gg 1$



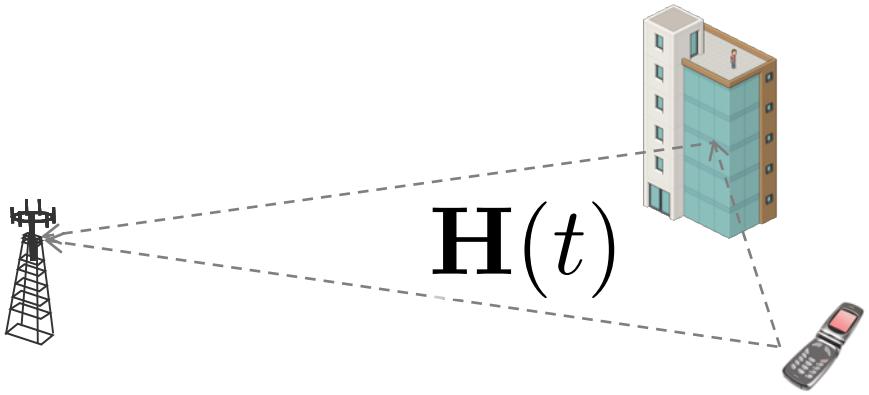


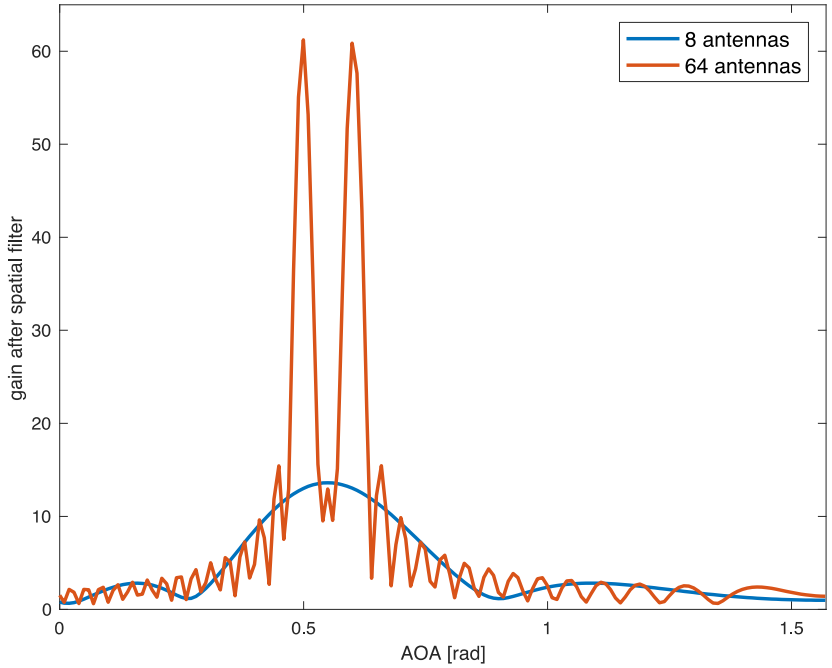
High degree of resolvability of multipath

Meissner, Paul, et al. "Accurate and robust indoor localization systems using ultra-wideband signals." arXiv preprint

3. Large number of antennas

- From Fisher information
  - large number of RX antennas: better AOA resolvability
  - Large number of TX antennas: smaller beamwidth, better AOD resolvability

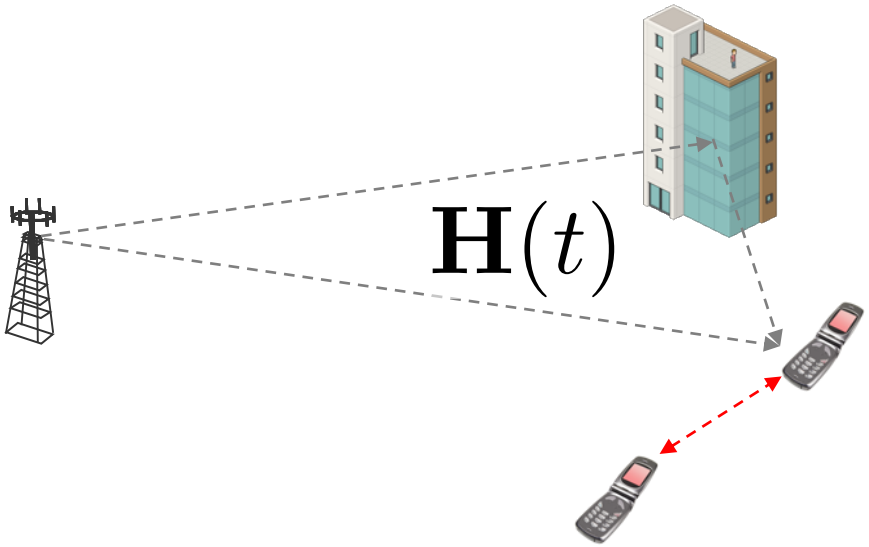


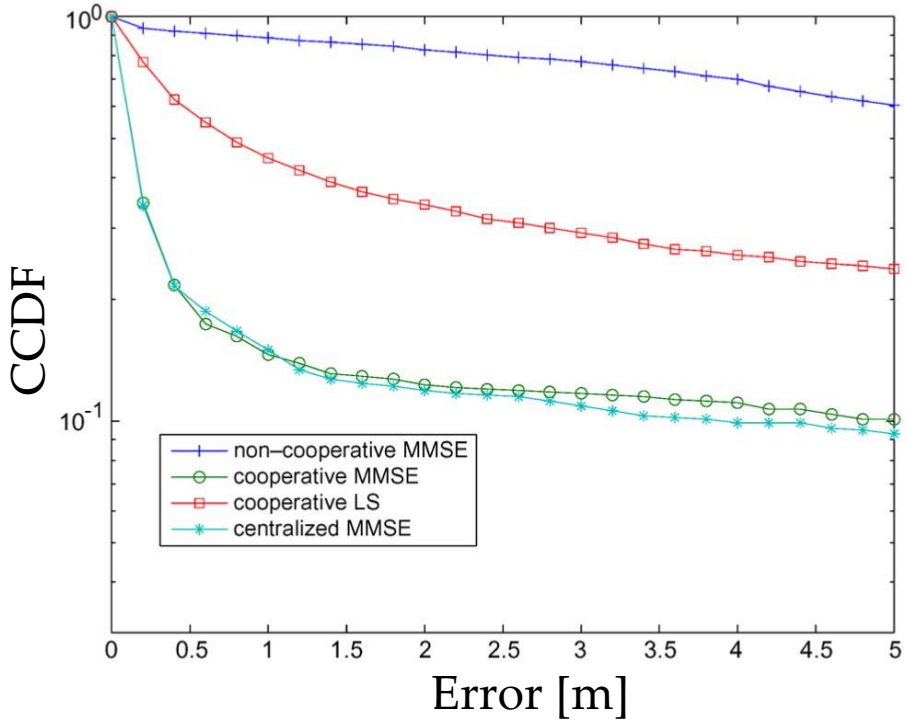


High degree of resolvability of angles

4. D2D communication

- 5G will have sidelinks
- Measurements *between* devices
- Can improve location accuracy and coverage

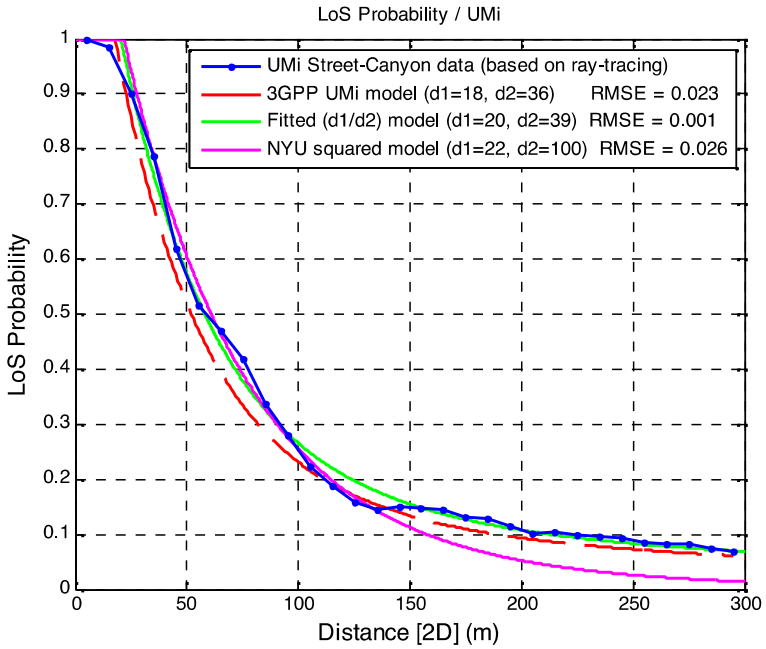


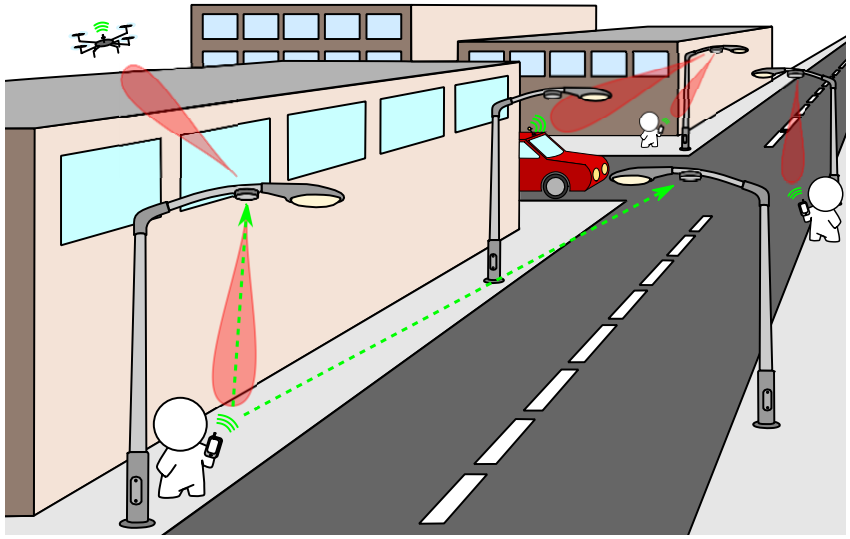


Cooperative positioning based on D2D measurements

5. Network densification

- Many access nodes
- High chance of LOS at short distances
- LOS link most useful for positioning

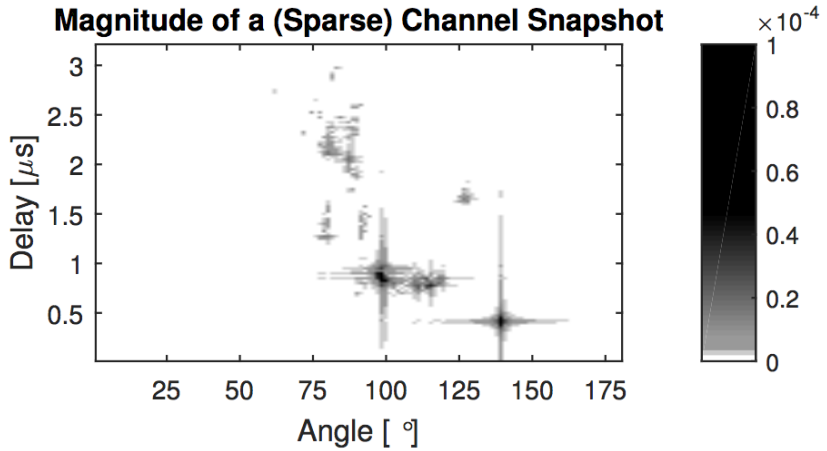




LOS link generally available for positioning

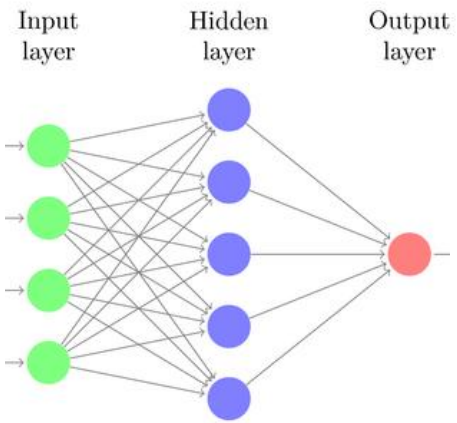
5G positioning below 6 GHz: data-driven approaches

- Idea: relation between channel at the BS and the user location
- Exploit sparsity



Vieira, J., et al, "Deep convolutional neural networks for massive MIMO fingerprint-based positioning"

- Train neural network



Channel at BS

UE location

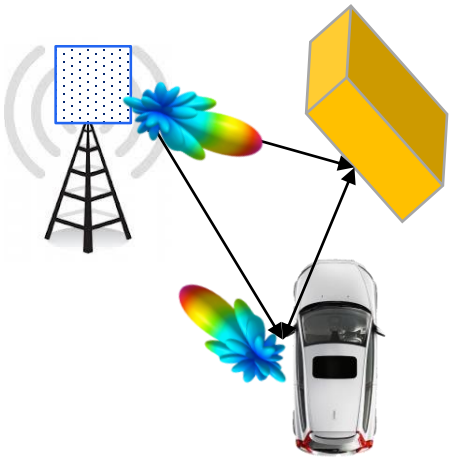
5G positioning vs automotive FMCW radar

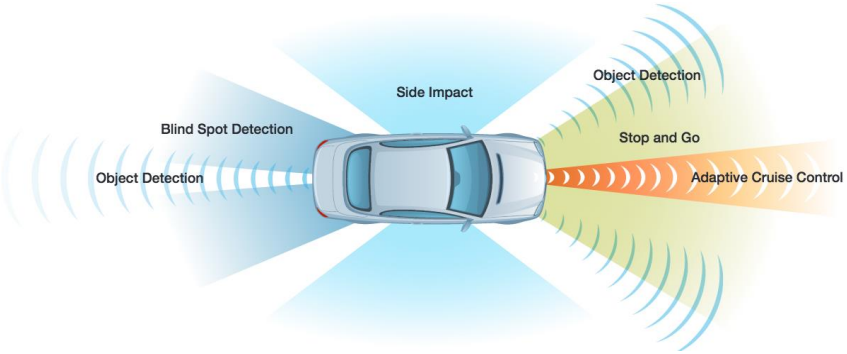
5G positioning

- Carrier above 28 GHz
- Large bandwidth (100+ MHz)
- Large antenna arrays (100+)
- Full-band ADC (100+MHz)
- Coordinated transmission
- Mainly communication
- Possible for positioning & mapping!

FMCW radar

- Carrier above 28 GHz
- Very large bandwidth (0.5-4 GHz)
- Multi-antenna arrays (2-4)
- Low-rate ADC (10-40 MHz)
- Uncoordinated transmission
- Mainly mapping
- Possible for communication?





https://www.nxp.com/docs/en/fact-sheet/AUTORADARFS.pdf

Challenges

- Good geometric mmWave channel models for positioning, including blockage, clustering and distributed sources
- Database of location-based channel measurements
- Design of precoding and combining for positioning, mapping
- Pilot design for positioning, mapping
- Fast algorithms for positioning, tracking, mapping
- Online synchronization for positioning
- Multi-user positioning, resource allocation for MU positioning
- Calibration of references (location, time)