6G sensing and communication convergence

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Localization and Sensing – Technologies, Opportunities and Challenges
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Outline

- Why 6G needs localization and sensing
- 6G as a sensor for localization and sensing (bistatic view)
- Communication and sensing convergence (monostatic view)
- Location-aided communication
- What is next?
Why 6G needs localization and sensing

Status in 5G mmWave
- Beam alignment and beam tracking
- Blockage avoidance by beam search
- Proactive resource allocation
- 5G can benefit from location and map information

Vision in 6G
- Finer beams: even more overhead
- Environment maps for discovery of propagation paths
- 3D orientation and 3D location information needed
- New sensor: a communicating 6G radar
- 6G must harness location and map information
6G as a sensor for localization and sensing

**Status in 5G mmW**
- Localization with TDOA, AOD, RTT
- Multipath: foe to friend
- 5G as bistatic radar: allows mapping the environment (SLAM) and tracking passive objects (SLAT)
- Ability to share location, map, object information

**Vision for 6G**
1. High carrier frequencies (above 0.1 THz): fewer paths
2. Large bandwidths (above 1 GHz): better delay resolution
3. Large number of antennas (> 100 for SNR gain): better angle resolution
4. D2D communication: relative positioning, bistatic radar
5. Network densification: short LOS links
6. Intelligent metasurfaces: shaping the environment for improved positioning quality
7. AI/ML: solve hard problems with data-driven approach

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“3GPP TR 38.855 V16.0.0; study on nr positioning support,” Tech. Rep., 2019.
6G as a sensor for localization and sensing

- **Channel charting and AI**
  - When channel is described by too many parameters
  - Data-driven approach and dimensionality reduction
  - Generates a pseudo-map that can be used as an unsupervised replacement for radio maps

- **Intelligent surfaces**
  - Multipath: from foe to friend to partner
  - New reference points
  - Can provide automatic synchronization and AoD value
  - Wavefront curvature and near-field propagation effects


Communication and sensing convergence

5G as radar
- Process backscattered signal to estimate range, velocity, and angle
- Needs full-duplex operation but automatic synchronization
- OFDM waveform vs tailored waveforms (FMCW, PMCW)
- Fundamental parameters:
  - Bandwidth for range
  - Coherent integration time for Doppler
  - Array aperture for angle

How 6G is an enhanced radar system
- Bandwidth on par with automotive radar, so can replace FMCW
- Full-duplex OFDM vs new waveforms (e.g., OTFS)
- Power consumption and guaranteed radar performance issues
- Main benefit: ability to share information between radars
- Joint radar and communication (JRC): spectrum sharing

Question: Is it radar or is it 6G?
Answer: it is both!


Location-aided communication

- **Path Loss**: $d = |x - x_s|^{-\eta}$
- **Doppler Velocity**: $f_D = |\dot{x}(t)|/\lambda$
- **Shadowing**: $\exp\left(-\frac{|x_i - x_j|}{d_c}\right)$
- **Spatial Correlation**: $\rho(x, x_s)$
- **Interference**: $|x_i - x_s| < R$
- **Spatial Reuse**: $|x_i - x_j| > R_{\text{int}}$
- **MIMO**: $h(x, x_s)$
- **Angle of Arrival**: $\theta(x, x_s)$
- **Routing**: $\min_j |x_j - x_d|$
- **Propagation Delay**: $\tau = |x - x_s|/c$
- **Proactive Allocation**: $p(x(t))$
- **Predictable Behavior**: $\rho(x(t))$

THz Sensing vs 6G?

- Sensing deeply integrated into 6G wireless communications networks
  - Uses the same infrastructure, tailor-made sensing signals part of the 6G air interface design, sensing reusing the communications signals, …
  - Mobile networks operators might be the provider of the sensing service

- Sensing enabled by 6G connectivity, but where the sensing part is not co-designed with the 6G air interface
  - Cooperative sensing that inherently needs 6G connectivity capabilities between the cooperative sensors
  - Sensing whose data is (ML/AI) processed in a cloud, in particular when low latency/high capacity/very reliable wireless connectivity is needed to the cloud, e.g. tight control on the communications and computing in the (distributed) cloud is required for the sensing system

- Non-connected sensing/ sensing not connected via 6G, that benefits from the HW and SW developments in the 6G eco system
  - Benefitting from the R&D and efficient manufacturing and testing capabilities of 6G industry
  - 6G could drive availability of low cost and high performing THz HW enabling sensing in so far not economically viable domains
antennas, so that small devices can be packed with tens or hundreds of antennas, which will be beneficial for angle estimation. In addition, the high-rate communication links offered by 6G will be able to be leveraged to quickly and reliably share map and location information between different sensing devices. This is beneficial for both active and passive sensing. To harness these benefits, chip technologies must be available that sufficiently support economies of scale. In addition, to support the development of new solutions and algorithms, suitable channel models that properly characterize the propagation of 6G waves over the hardware and the air are needed as well.

Future chip technologies:
Having defined the broad initial range of relevant (new) spectrum for 6G to be as large as 0.3 - 3 THz, while regulatory bodies have recently started to enable R&D up to 250 GHz, there is a clear need for further development of technology which will be able to support the said frequency bands in a cost-effective manner. One key aspect is the integration of the required technology. Currently, radio systems operating in the range of multiple 100 GHz typically include antennas and signal processing equipment, for example, which is unreasonably large to integrate into typical user equipment (UE). As we start to migrate towards 5G systems in the world, we see that silicon products for UE purposes have been in development for a few years while the network roll-out has started in a limited geographical scope only during 2019 and 2020. This is in no small part due to the complexity of the added air interface at mmWave...

What is next?

![Diagram](https://arxiv.org/abs/2006.01779)