High-Efficiency Device Localization in 5G Ultra-Dense Networks: Prospects and Enabling Technologies

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Scope and Outline:

**Scope:** 5G user node localization, tracking and location prediction
Exploiting location information

**Outline:**
- Properties of 5G ultra-dense networks:
  - Technical enablers
  - Accurate measurements
- Fusion of measurements:
  - Collaborative localization
- Exploiting location-awareness:
  - New location-based services
Properties of 5G Ultra-Dense Networks
Ultra-Dense 5G Networks

- Access nodes (ANs) are deployed with a very high density
  → user nodes (UNs) can see/hear multiple ANs

* Values from Madrid model [1]
** Similar to density in [2]

Ultra-Dense 5G Networks

- High density
  → High probability for line of sight (LoS) conditions

Figure: LoS probability in METIS’ stochastic channel model [1].

5G Small Cell Radio Frames Provide Frequent UL Beacons

Proposal [1] (frame duration 163.7 µs):

Proposal [2] (frame duration 500 µs):

Proposal [3] (frame duration 250 µs):

- Use UL beacons/reference symbols for network-centric localization

Properties of 5G Networks

→ Accurate Measurements

• **Ultra-dense network:**
  High probability for line of sight

• **Radio frames:**
  Frequent uplink pilot signals for uplink channel estimation

• **Bandwidths:**
  Bandwidths are expected to be in the order of 100 MHz and beyond

• **Antenna types:**
  ANs are likely to have antenna arrays or other directional antennas

- Time of arrival (ToA)
- Time difference of arrival (TDoA)
- Direction of arrival (DoA)
- Received signal strength (RSS)
Example: Direction of Arrival Estimation in a 5G AN

Figure: Cramer Rao bound (CRB) on direction of arrival (DoA) estimation with a circular array and 100 samples. Based on the results in [1].

Fusion of the Measurements
Measurements from ANs are fused into a location estimate

\[ \ell = [x, y]^T \]

\[ \ell_1 = [x_1, y_1]^T \]

\[ \ell_2 = [x_2, y_2]^T \]

\[ \ell_K = [x_K, y_K]^T \]

\[ \sum \]

Rx pre-processing

Directional antenna

\[ \Psi_1 \]

\[ \Psi_2 \]

\[ \Psi_K \]

\[ \hat{x} \]

\[ \hat{y} \]

Location estimate

Fusion Center
5G Ultra-Dense Networks → High Localization Accuracy

• Fusion of various accurate measurements across multiple measurement/observation points
  → extremely high localization accuracy is expected (even in sub-meter range [1-2])

• Compare to the accuracies of the existing localization systems
  – OTDoA* in LTE: a few tens of meters [3]
  – GNSS: around 5 meters [4]
  – WLAN fingerprinting: 3-4 meters [5]

*OTDoA = Observed time difference of arrival

Example: Fusion of DoA Estimates from 4 ANs

Figure: Example geometry.

Figure: Localization CRB on the localization RMSE for example geometry. 4 ANs, each equipped with 10 antennas.

\[ \text{RMSE} \geq \sqrt{\text{CRB}_x + \text{CRB}_y} = \frac{D\sigma_\varphi}{\sqrt{2}} \]
Tracking and Location Prediction

- Accurate, fast and “always on” UN localization enables UN tracking

- Tracking, combined with predictive estimation algorithms, such as extended Kalman filters, enables UN location prediction
Time for a short video clip...

- Video available in:
  http://www.tut.fi/5G/VTC15
Prospects of 5G Localization
Prospects of 5G Localization

• Localization can be carried out on the network side using UN/uplink reference signals
  → “always on” network-centric localization without heavy load on UN batteries

• Tracking and prediction of UN positions
  → environment learning

• New markets for network operators: self driving cars, VTX, robots, intelligent traffic systems, …

• Advanced radio network functionalities: e.g. proactive radio resource management and mobility management
Radio environment maps can be used, e.g., for proactive radio resource management.
Prospects #2
Prediction and Cognitive Localization

- Human mobility depends highly on historical behavior and is predictable up to 88% [1]

→ mobility database

Prospects #3
Predictive Radio Resource Management

• Assume that we are tracking a car and can predict it’s movement
• Then it is possible to allocate radio resources proactively
Prospects #4

Content Prefetching

- Video streaming in a car with a predicted route
- ANs 3 and 4 are congested because of a match in a stadium  
  → this would result in a poor quality of service (QoS)
- However, the user can be prioritized while still under ANs 1 and 2 with free resources  
  → proactive content delivery to a buffer  → good user experience
Prospects #5
Routing in the Backhaul

- Network observes a truck which would block the visibility from AN 1 to the user in a car
  - proactive re-routing of the user data to AN 2
  - seamless service and better user experience
Conclusions

• Properties of 5G ultra-dense networks enable
  – network-centric UN localization with a very high accuracy
  – frequently updated UN tracking
  – UN location prediction

• This location-awareness can be utilized in the UN, ANs or by third parties to provide new location-based services such as
  – Radio environment maps
  – Cognitive localization and prediction
  – Proactive radio resource management
  – Content prefetching
  – Routing in the backhaul
Thank You!

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