Cellular Network Localization: Current Challenges and Future Directions

Christos Laoudias

Senior Researcher
KIOS Research and Innovation Center of Excellence
University of Cyprus

Funded by:

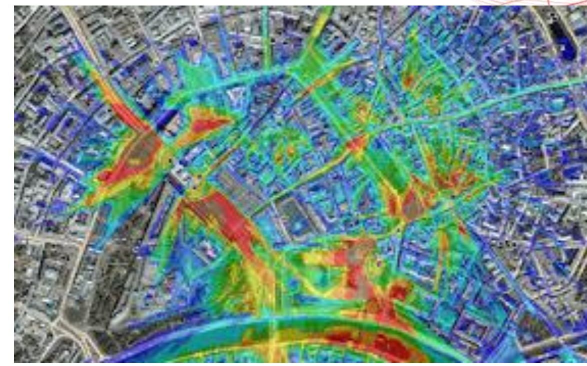
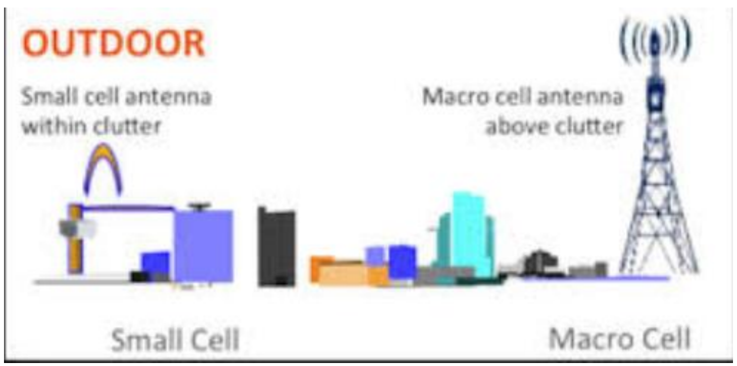
IEEE ICC Workshop on ANLN, May 25, 2017

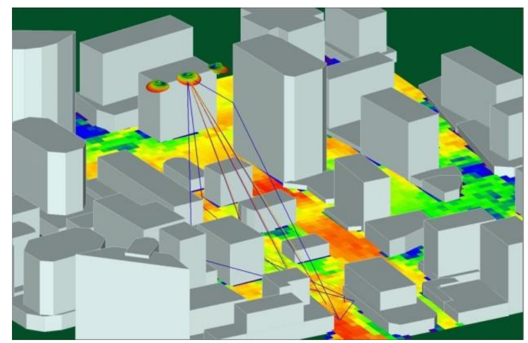
Outline

- **Industry interests**
  - Network Operators localization needs
- **Technology landscape**
  - Commercial solutions and LBS platforms for Network Operators
- **Technical challenges**
  - Using the high volume of data recorded at the network side for localization and tracking
- **Future directions**

Industry interests
Network planning and optimization





- **Location-dependent network analytics & diagnostics**
  - Identify traffic hotspots and poor coverage areas
- **Root cause analysis:** dropped calls, low KPI/KQI
  - Customer Experience Management (CEM) with location-tagged data
- **Optimal small/macro cell deployment**

Industry interests
Reducing the cost of Drive Tests

- **Traditional network optimization relies on Drive Tests (DT)**
  - Professional testers drive along target routes and collect network data
  - Needs vehicles, test instruments, testing skills, analysis tools
  - Initially used on roads accessible by vehicles, now also applied indoors
  - Accounts for ~45% of the network optimization cost
- **Example:** Analysis and optimization of LTE network with 3,051 eNBs*
  - Drive Tests: 8 tests/cluster/month for 3 months
  - Manpower: 3 person-months
  - Cost: ~EUR9,000 per month
- **How to utilize user network data to reproduce DT scenarios?**

*Source: ZTE, Virtual DT: An Innovation in Drive Test for Cost-Efficiency, 2016.

Technology landscape
Key players

Source: ABI Research

Ericsson | TCS | Cisco

Nokia Siemens Networks | JDSU | Tektronix communications | intrado | Groundhog Technologies Inc.

Polaris Wireless | TruePosition | Qualcomm | GloPos | NextNav | Invisitrack

intersec | Mobile Arts

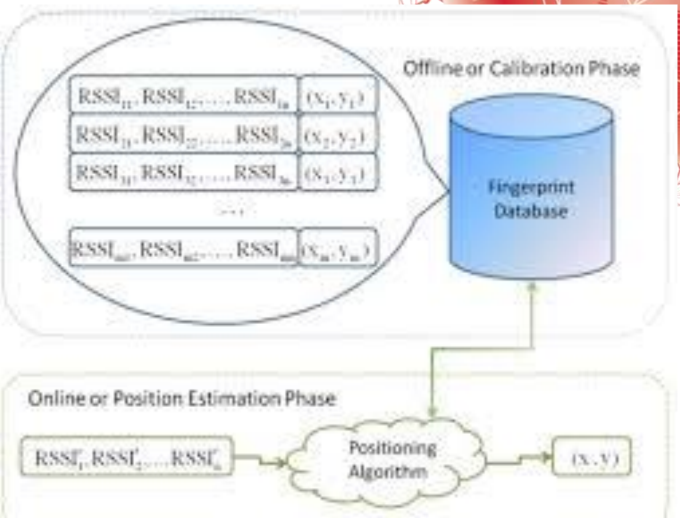
- **1st tier:** Traditional network operator location platform vendors
- **2nd tier:** LBS providers
- **3rd tier:** Localization technology providers
- **4th tier:** Network operator data analytics and advertising
- **Recent trend:** Platform vendors join forces with data analytics companies
    - TCS – Intersec strategic partnership to expand precise LBS solutions (2016)

Technology landscape
Where we stand in terms of accuracy

Company	Technology Solution	Indoor Accuracy
TruePosition	U-TDOA Hybrid A-GPS/U-TDOA	57.1m* 48.8m
Qualcomm	Hybrid A-GPS/AFLT (Advance Forward Link Trilateration, similar to O-TDOA)	226.8m**
Polaris Wireless	RF Pattern Matching*** (signal strengths, signal-to-interference ratios, time delays)	198.4m**
GloPos	Software-only, self-learning probabilistic models based on signals and network parameters, models of cell area and shape	6-13m
InvisiTrack (PoLTE)	LTE Sounding Reference Signals (uplink)	1-10m (horizontal) < 3m (vertical)
NextNav	Terrestrial Beacon System*** (GPS-like signals transmitted at 920-928 MHz band)	63m (horizontal)** 1.9m (vertical)

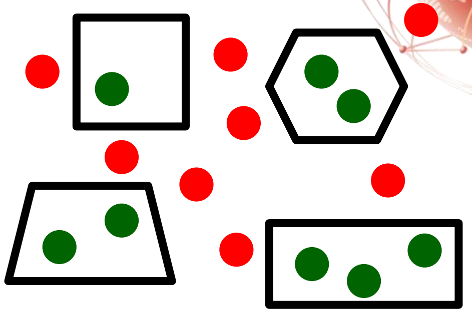
* "TruePosition indoor test report," TechnoCom, Jun. 2014. 67th percentile error in urban area.
** "E9-1-1 location accuracy: Indoor location test bed report", CSRIC III WG 3, Mar. 2013. 67th percentile error in urban area.
*** Provisioned in 3GPP LTE Positioning Protocol (LPP).

Technical challenges
Arena & game rules



- **Fingerprint database construction**
  - Network Measurement Reports (MR)
    - High volume, no location, only cell IDs and signal strengths, # of cell IDs differs in GSM, UMTS, LTE
  - AGPS MRs
    - Moderate volume, location-tagged, introduce network overhead during collection, available in GSM/UMTS (but not LTE)
  - DT MRs
    - Low volume, location-tagged, increase operational cost
  - Over-The-Top (OTT) data
    - Variable volume, produced by LBS web/phone applications, location-tagged, can be associated with user-specific MRs
  - Signal strengths generated by a radio propagation model
    - High volume, require fine-tuning with field measurements
- **Localization**
  - Use the Fingerprint database to localize new MRs

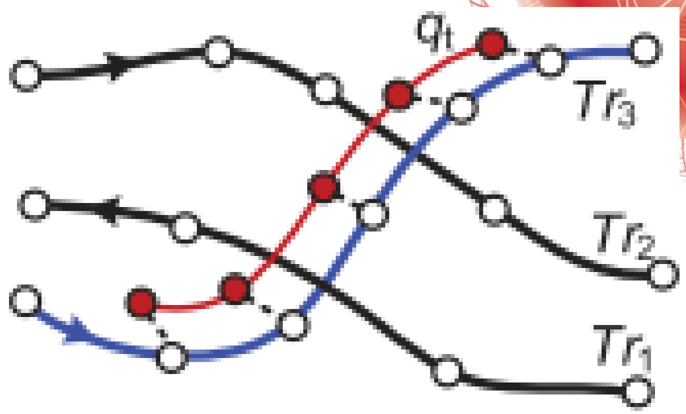
Technical challenges
Indoor/Outdoor identification



- **Why is it important?**
  - Fingerprint database: Avoid "polluting" fingerprints at outdoor locations with signal strengths measured indoors and vice versa
  - Localization: Useful hint for improving accuracy
- **Solutions**
  - Naïve approach
    - If the user is served by an indoor cell then he/she is located indoors
    - Not always true under real network conditions
  - *Machine learning approach (Alcatel-Lucent/Nokia)
    - Feature engineering with combination of Reference Signal Received Power (RSRP) and Received Signal Strength Indicator (RSSI) pairs
    - Supervised training of SVM/logistic regression classifier using extensive Drive Tests (outdoor) and Walk Tests (indoor)
    - 95-98% classification accuracy depending on the ratio of WT/DT data
  - Network operators are looking for unsupervised solutions
    - Combine signal strength features with network layout knowledge (indoor/outdoor cells, sectors, antenna heights and tilts)

* A. Ray et al., "Localization of LTE measurement records with missing information", in INFOCOM, 2016.

Technical challenges
OTT-MR data association



- **OTT data wave**
  - A cellphone running an LBS application generates a MR data stream (at the network) and an OTT data stream (at the LBS server)
  - OTT data contain location from cellphone's location API (GPS, Wi-Fi, etc.)
  - Associated OTT-MR data can be used for:
    - Building the Fingerprint database
    - Reducing costly Drive Tests
- **OTT data acquisition**
  - Through business agreements with OTT providers
- **How to do the association?**
  - Straightforward if user IMSIs are present in both OTT and MR data
    - *City-scale OTT-MR fingerprint system reports 80m median error (Huawei)
    - OTT providers raise privacy concerns
  - Employ spatiotemporal data processing and trajectory matching techniques if user IMSIs are not present

* F. Zhu et al., "City-Scale Localization with Telco Big Data", in CIKM, 2016.

Technical challenges
1-2cell MR localization

- **Facts**
  - * >50% of the observations in Sprint's commercial CDMA2000 network contain only one base station
  - **Alcatel-Lucent/Nokia report that most of the observations in a 4G LTE commercial network contain only signal strength information from the serving cell and (in some cases) from the strongest neighbor cell
  - Triangulation/trilateration cannot be performed
  - Low-dimensional fingerprints degrade accuracy of fingerprinting
- **Solutions**
  - *Bayesian inference method using network layout information together with RTT (i.e., distance to base station) and SINR measurements
    - 20% accuracy improvement over standard Cell ID-RTT localization
    - Requires field measurements for parameter tuning: SINR thresholds, interference from non-neighboring base stations, RTT measurement error
  - **Supervised training of Random Forest with labeled DT data to learn the signal strength values at different locations, combined with HMM
    - 20-30m median error
    - Requires extensive DT data for training

* H. Zang et al., "Bayesian Inference for Localization in Cellular Networks", in INFOCOM, 2010.
** A. Ray et al., "Localization of LTE measurement records with missing information", in INFOCOM, 2016.

Technical challenges
3D location

- **Motivation**
  - Indoor network optimization and small cell deployment
  - Indoor E911: 50m horizontal accuracy for 40%–80% of calls within 2–6 years, <u>proposal for a vertical accuracy metric</u> to be approved and comply with within 6 years (FCC, 2015)
- **Current situation**
  - A few commercial systems provide height (floor) information
  - Fingerprinting suffers the cost of building/maintaining the 3D database
  - O-TDOA
    - *1m vertical error for 25% of the tests (Ericsson, outdoor-indoor simulation)
  - CID provides high vertical accuracy in dense indoor small cell networks
    - *1m vertical error in 99% of the tests (Ericsson, outdoor-indoor simulation)
    - **1.79m RMS vertical error (JRC/ESA, 2-floor 4 LTE femtocell experimental)
- **Way forward: Complement cellular with Wi-Fi and barometer**
  - Wi-Fi can be used for height estimation if no indoor cells are present
  - Barometer is not reliable for absolute height estimation (w/o reference pressure stations), but can detect floor changes and classify vertical activities (taking escalators, stairs or elevators)

* H. Ryden et al., “Baseline Performance of LTE Positioning in 3GPP 3D MIMO Indoor User Scenarios”, in ICL-GNSS, 2015.
** J.A. Peral-Rosado et al., “Floor Detection with Indoor Vertical Positioning in LTE Femtocell Networks”, in GC Workshops, 2015.

Future directions

- **Channel state information versus signal strength**
  - Knowledge of the channel properties can improve accuracy
    - Exploit multipath components, e.g. for 1-2cell MR localization
  - Access to the measurements is a limitation
    - Should be readily reported by the cellphone similar to signal strength
- **Optimal measurement data fusion**
  - *Layered fusion for positioning in radio networks (Ericsson)
    - Radio measurements (TOA, TDOA, RTT, AOA, RSS), algorithms (lateration, triangulation, fingerprinting), statistical processing and temporal filtering
  - Complement cellular with Wi-Fi, BLE, inertial, and barometric sensors
    - Available at the network through LTE Positioning Protocol extensions (LPPe)
- **Data-driven algorithms**
  - **Positioning:** Machine learning together with radio propagation principles
  - **LBS platforms:** Exploit the volume of MR and OTT data
    - Social-Location-Mobile data analytics for targeted ads (IBM)
- **Radio communication ←→ location estimation**
  - Exploit low-latency communication for enabling accurate localization
  - Switch among protocols in HetNets, while ensuring accurate location
  - Location-aided communication: beamforming, CSI estimation, etc.

* K. Radnostrati et al., "New trends in radio network positioning", in FUSION, 2015.

Key takeaways

- Operators are interested in positioning technology mainly for network planning and optimization, CEM, and reducing DTs
- (Big-) Data will drive the development of positioning algorithms and LBS platforms
- Sensor data fusion will push the limit of 2D location and enable reliable 3D location
- Shift from how to compute (accurate) location towards how to use (inaccurate) location for improving radio communication
- Positioning accuracy will become an important metric for the design of new PHY/MAC, and overall network operation

THANK YOU!

Q & A