uNavChip:
Ultimate Navigation Chip

Chip-Scale Personal Navigation System Integrating Deterministic Localization and Probabilistic Signals of Opportunity

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Yusheng Wang yushengw@uci.edu	Algorithmic support (deterministic navigation)
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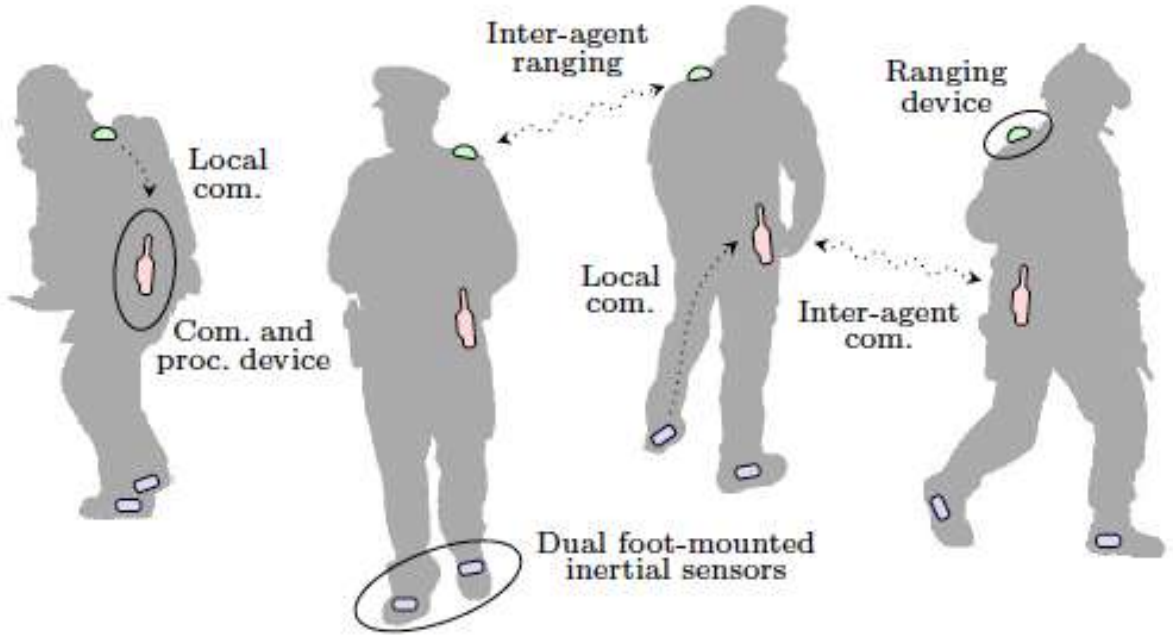
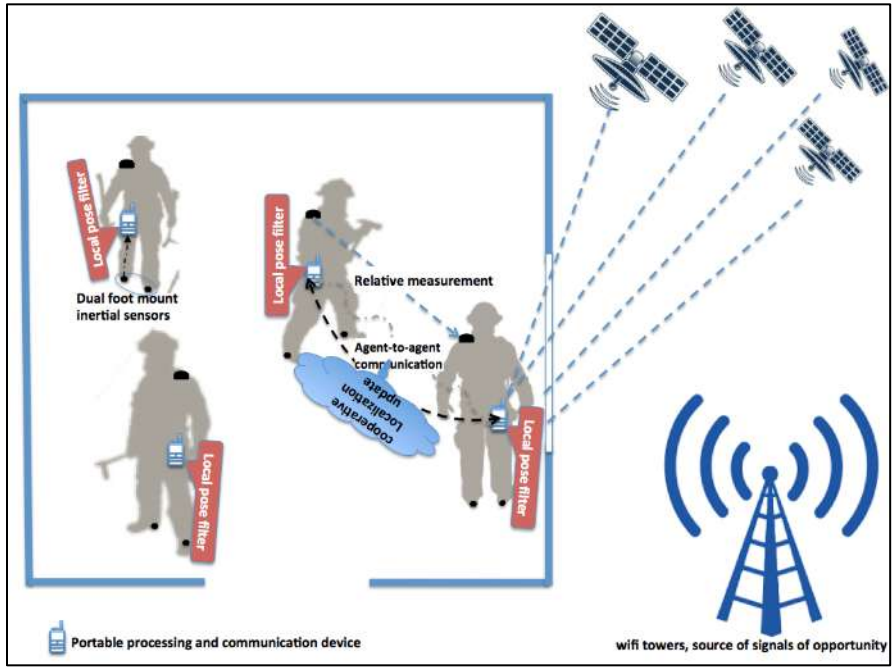
Sina Askari askaris@uci.edu	Electronics design
Ali Abdallah abdalla2@uci.edu	Algorithmic support (signals of opportunity)
Jianan Zhu jiananz1@uci.edu	Algorithmic support (cooperative localization)

The Problem Statement



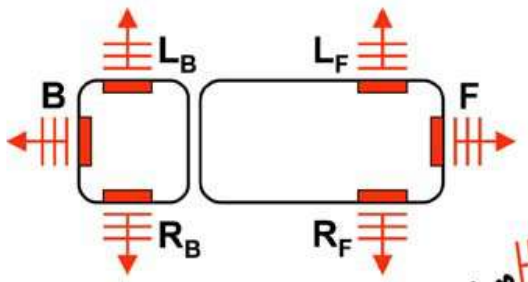


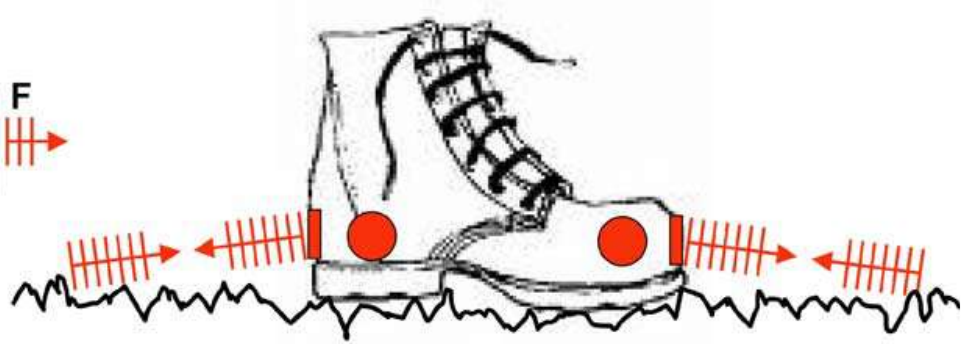
- Localization + Communication
- Situation awareness, coordination, support
- Localization w/o any infrastructure

Our Approach

Deterministic + Probabilistic + Cooperative

Deterministic

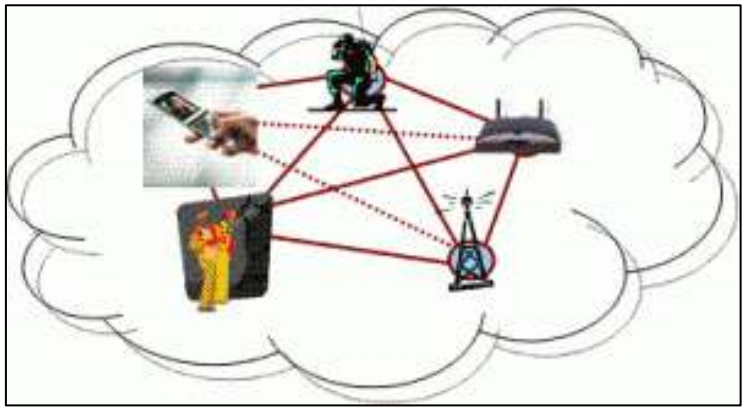


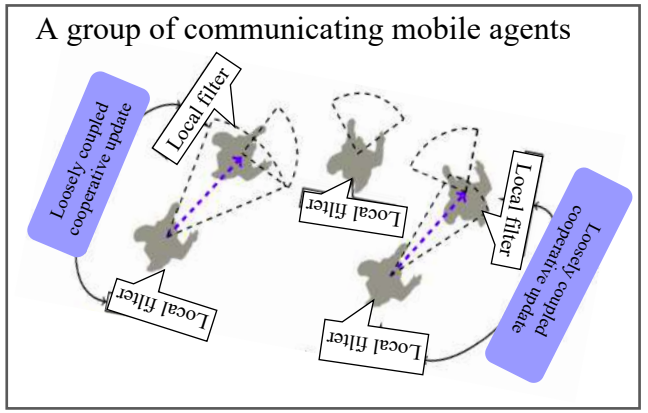


- **Inertial navigation**
- **Foot-to-foot ranging**
- **Altimetry**
- **Magnetometry**
- **Zero-velocity-update (ZUPT)**

Probabilistic

- **Cloud of signals of opportunity**





- **Cooperative localization**

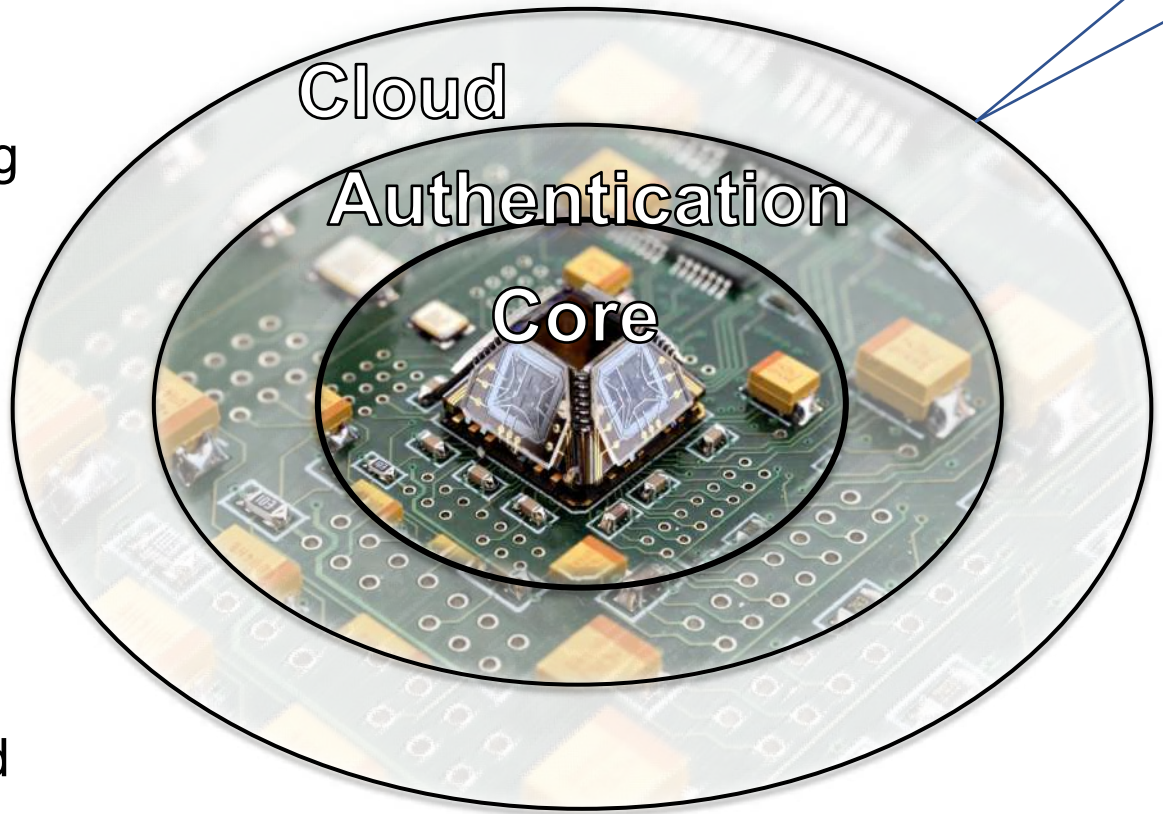
The Concept of *uNavChip*

size of
an apple seed

- **Deterministic**
self-contained sensing core

- **Probabilistic**
listening to the cloud of signals of opportunity

- **Cooperative**
leveraging distributed sensor nodes



- **Deterministic**
on-chip gyro/accel, CMUT, clock, altimeter, magnetometer

- **Probabilistic**
on-chip spectrum analyzer based on RF MEMS banks

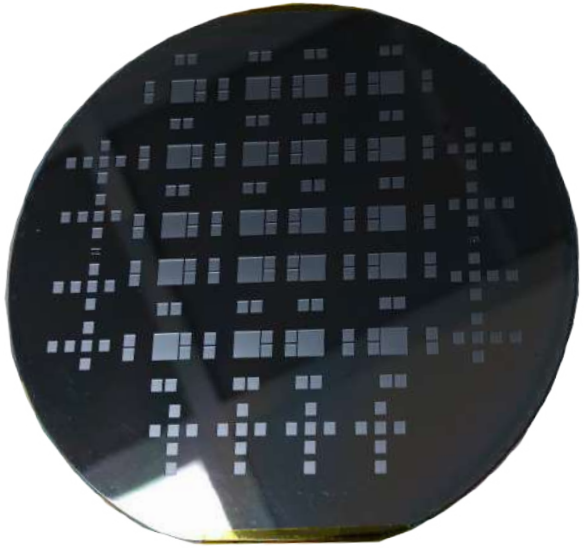
- **Cooperative**
on-chip UWB wireless transceiver

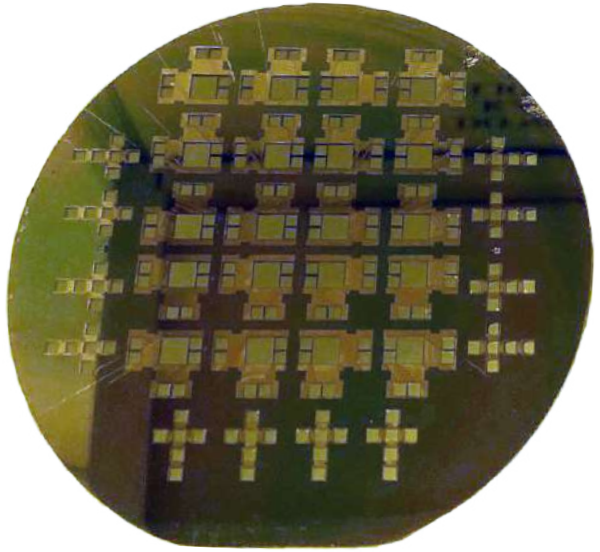
Provide maximum autonomy, security, precision

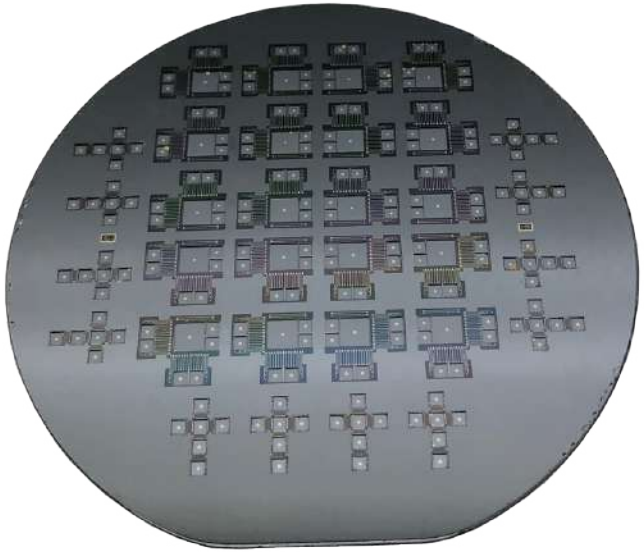
uNavChip fabrication

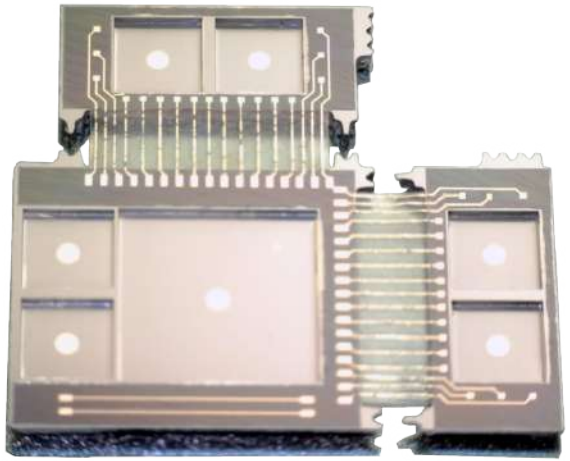
US Patent 9,696,340
US Patent 9,611,138
US Patent 8,567,247 B2
US Patent 8,368,154 B2

Deterministic





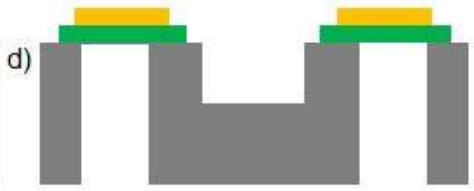




Sensor cavity & structure pre-etch

Perylene flexible hinge

Metal interconnects

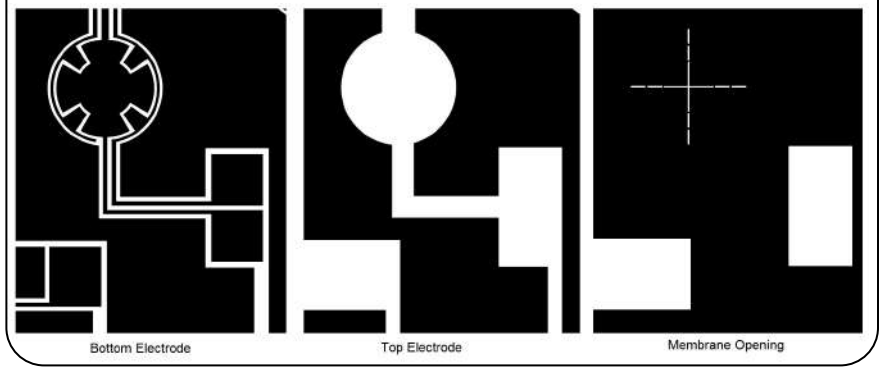


uNavChip structure

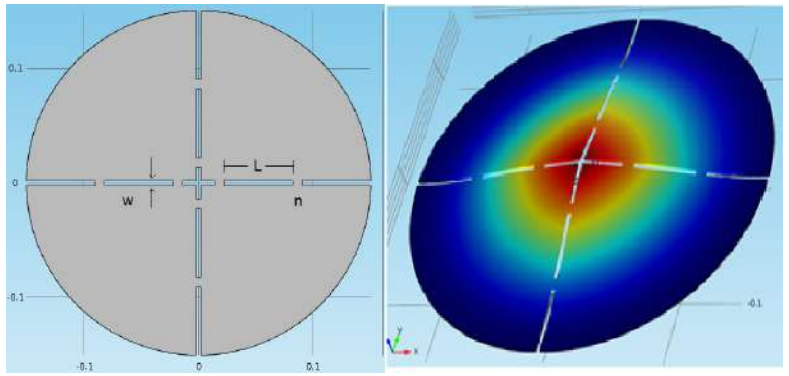
Ultrasonic Ranger (CMUT) fabrication

Deterministic

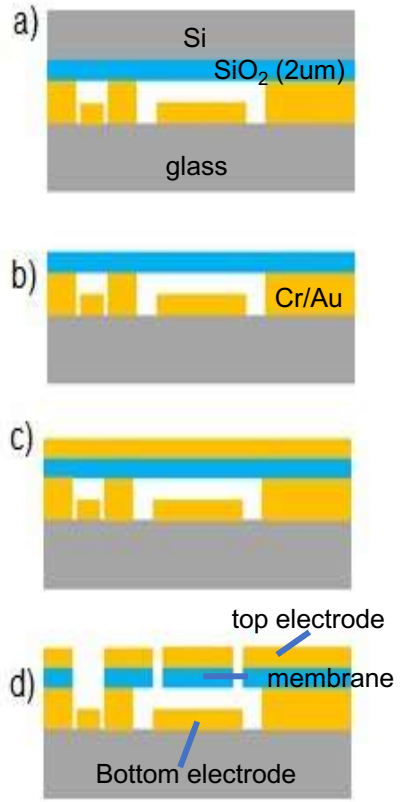
Design

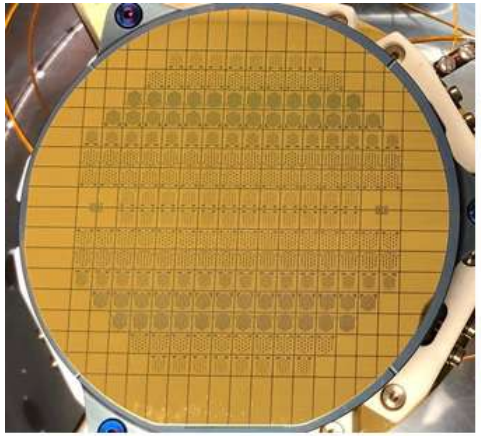


Simulation

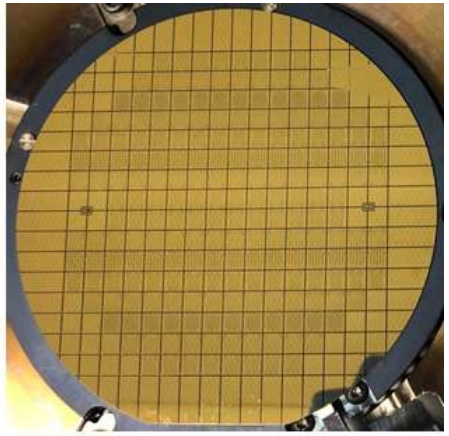


Fabrication

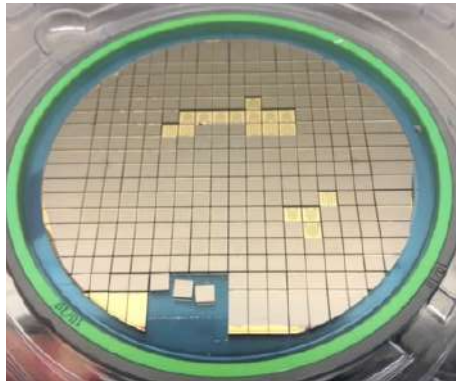


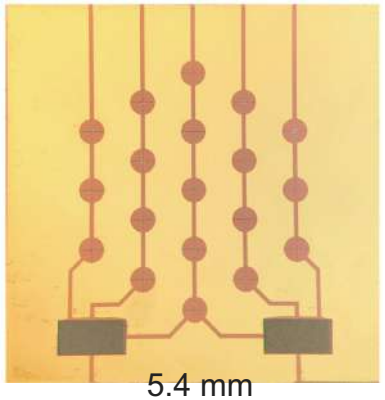


Bottom electrode



Top electrode





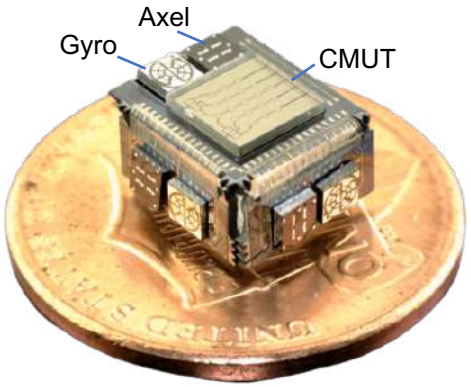
5.4 mm

Prototyping of *uNavChip*

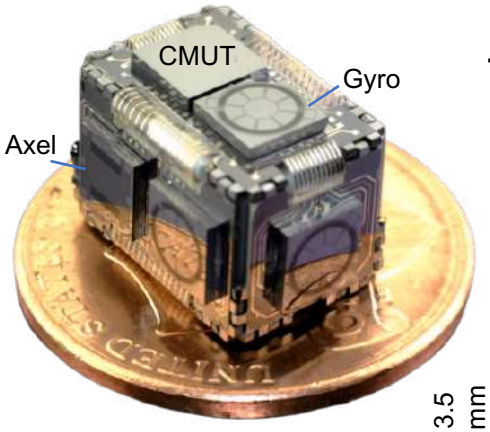
Deterministic

uNavChip Sensors

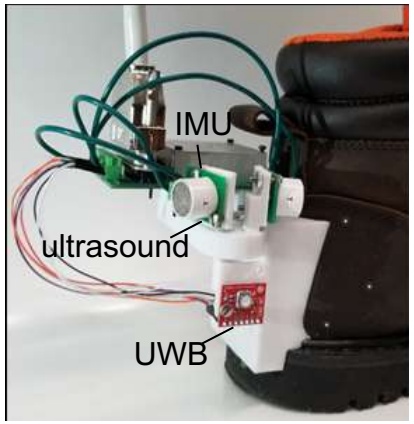
- Accelerometers
- Gyroscopes
- Magnetometer
- Altimeter
- Ultrasonic ranger
- Tunable radio



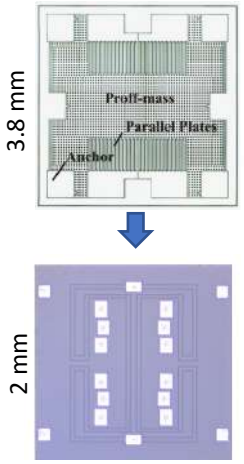
uNavChip_v2
(150mm^3)

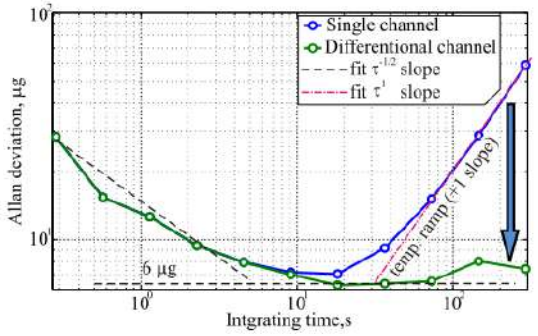


uNavChip_v1
(450mm^3)



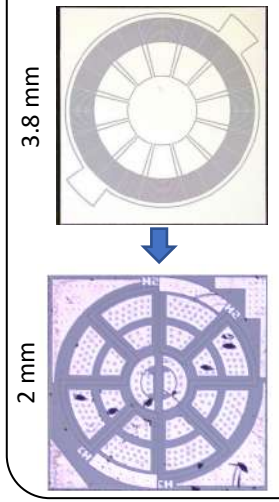
Accelerometer

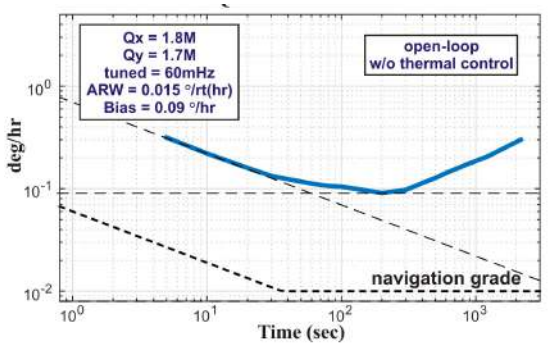




Zotov, Sergei A., et al. "High quality factor resonant MEMS accelerometer with continuous thermal compensation." *IEEE Sensors Journal* 15.9 (2015): 5045-5052.

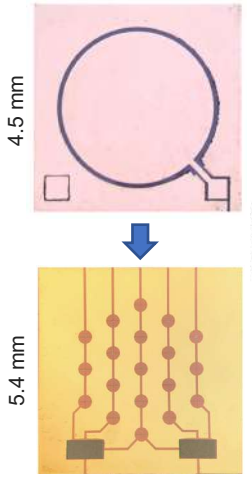
Gyroscope

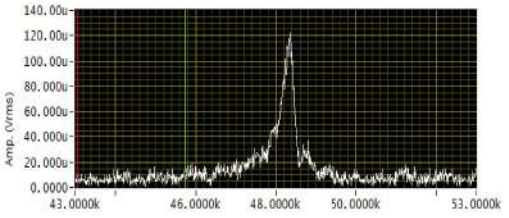




Askari, S., Asadian, M., Kakavand, K., and Shkel, AM. "Near-Navigation Grade Quad Mass Gyroscope with Q-factor Limited by Thermo-Elastic Damping", Hilton Head 2016

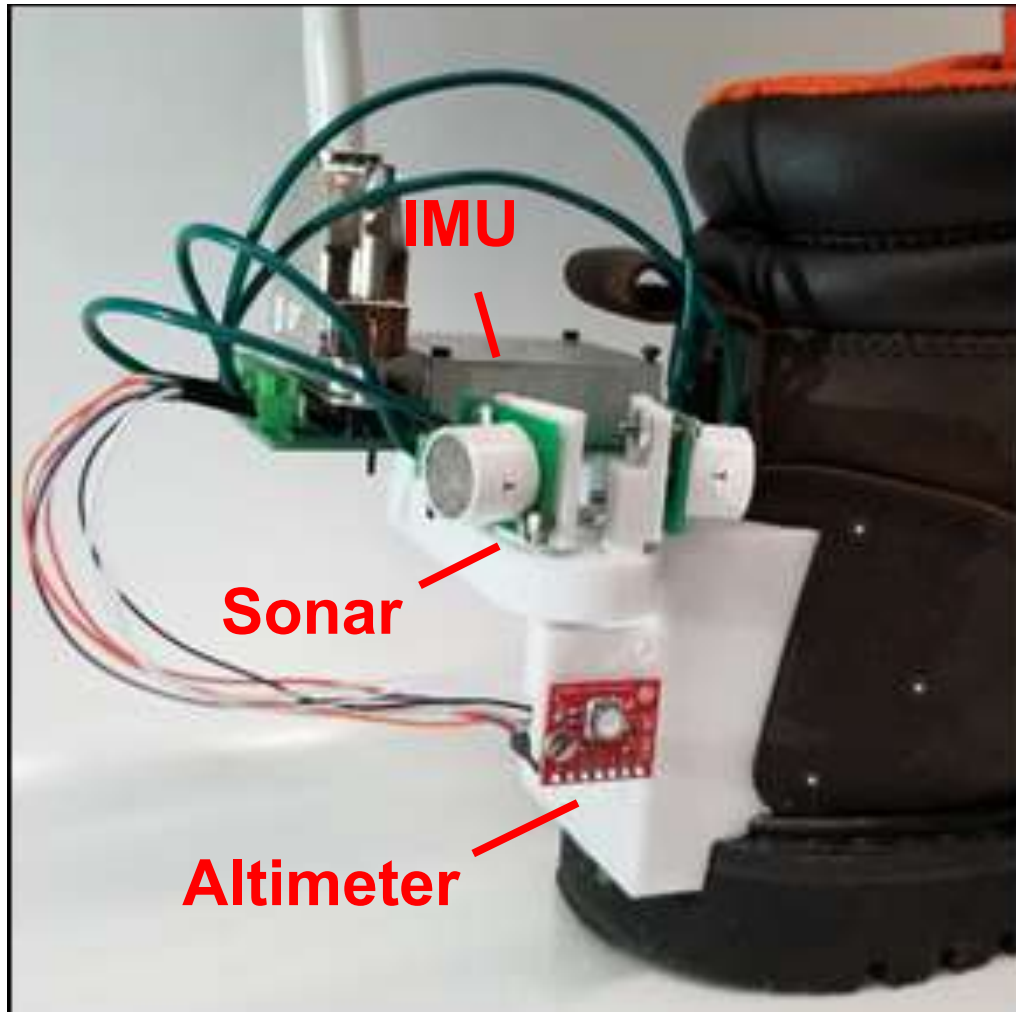
Ultrasonic Ranger (CMUT)



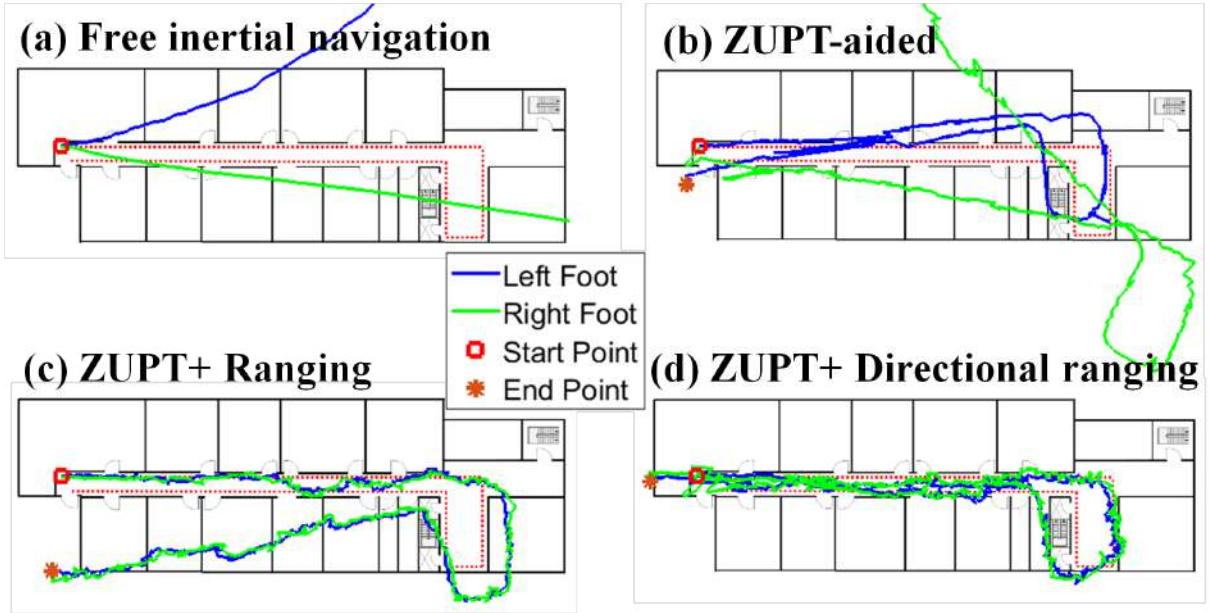


Algorithmic developments

Deterministic



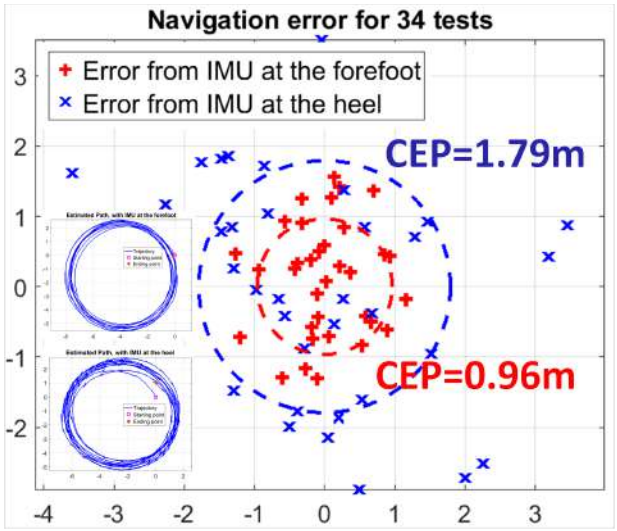
- ZUPT-aided inertial navigation (IMU)
- foot-to-foot directional ranging (Sonar)
- altitude compensation (Altimeter)



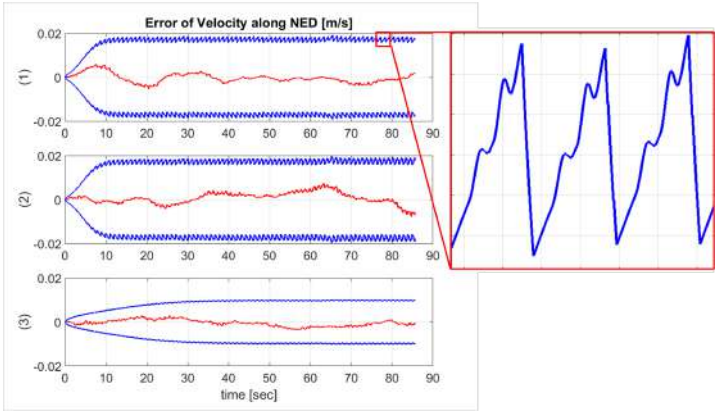
Nontrivial considerations

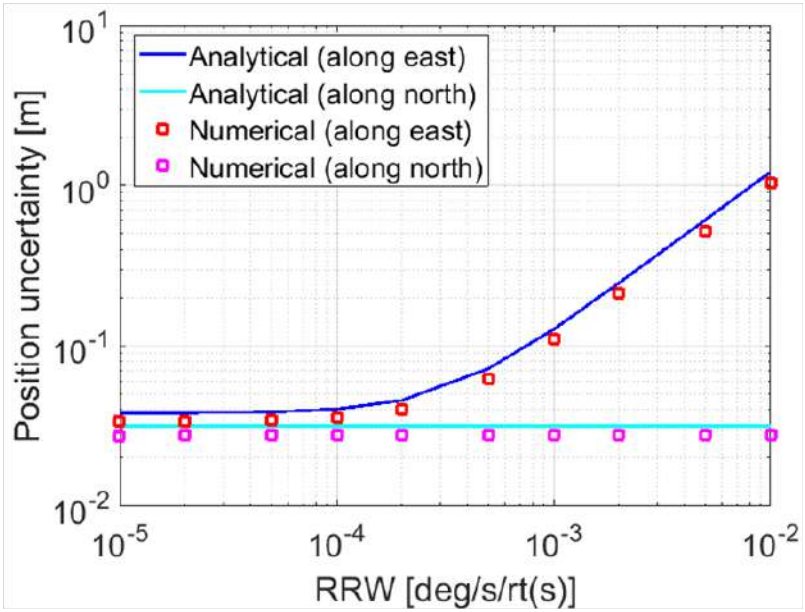
Deterministic

IMU mounting position

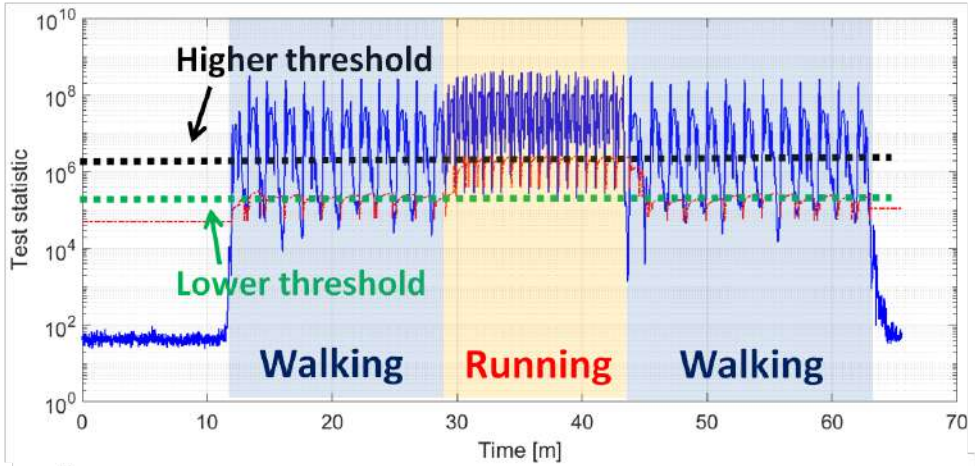


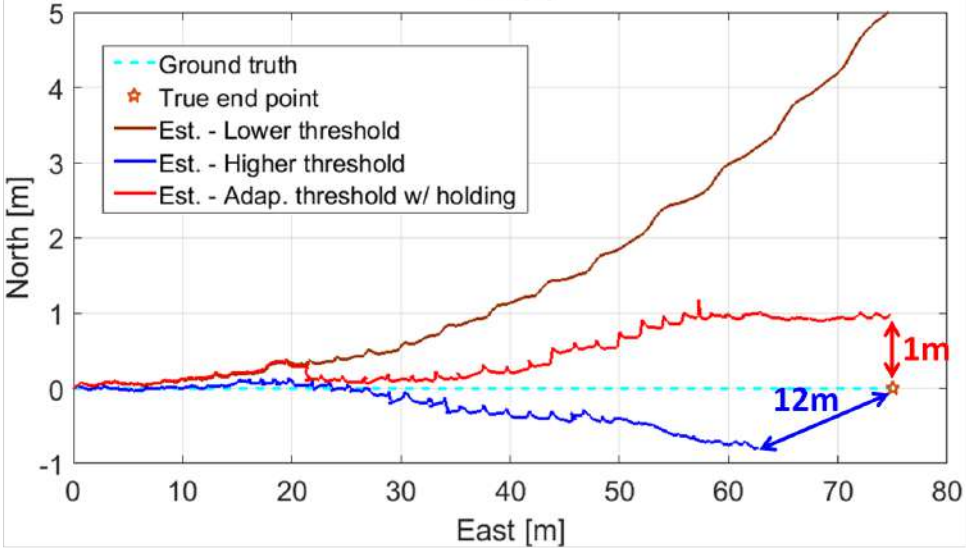
Navigation error analysis





Adaptive ZUPT detector

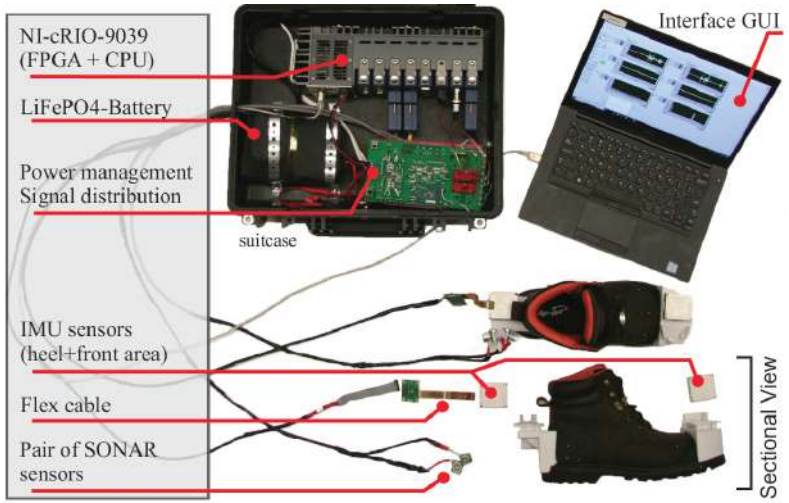




Platform for field demonstrations

Deterministic

Hardware

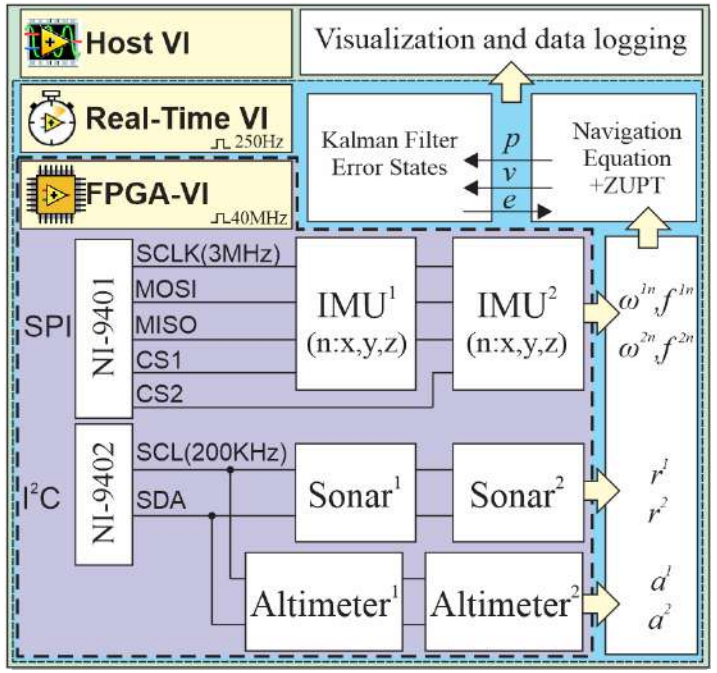


(IMU)
Analog Devices
- ADIS16485

(Sonar)
Devantech Ltd
- SRF08

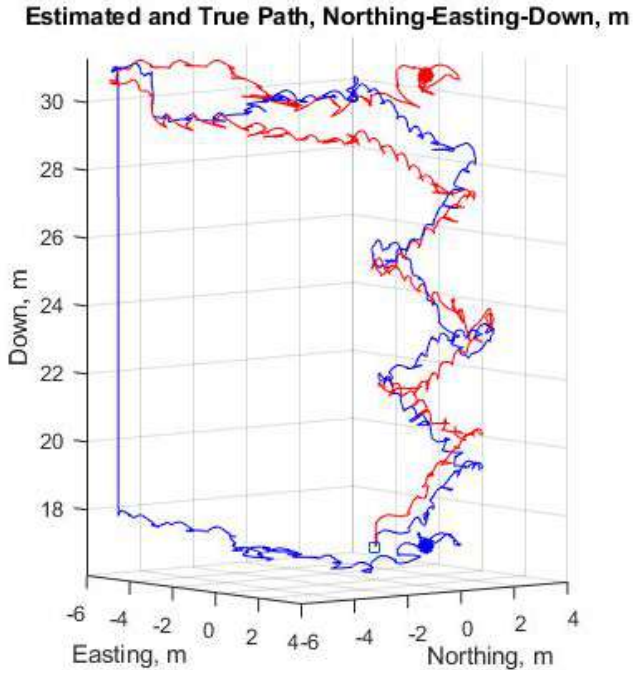
(Altimeter)
TE connectivity
- MS5803-01BA

Architecture



Field demonstrations

ZUPT with IMU + Sonar + Altimeter

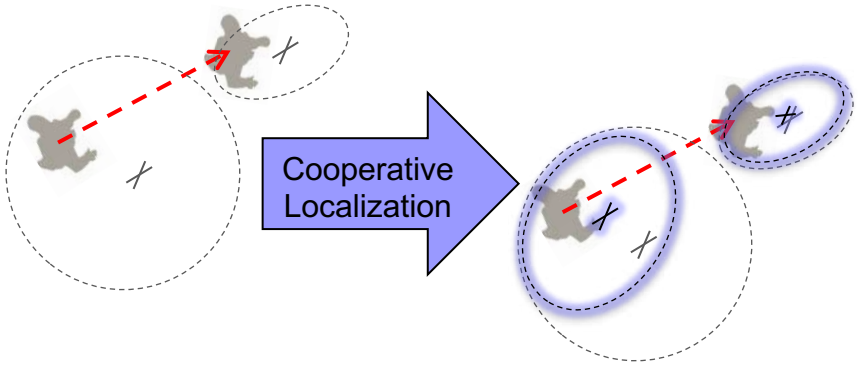


- Navigation time: 212 s
- Trajectory length (z): 142.6 m
- ZUPT+ALT error: 2.021 m
- ZUPT only error: 13.45 m

Developed flexible platform for self-contained localization

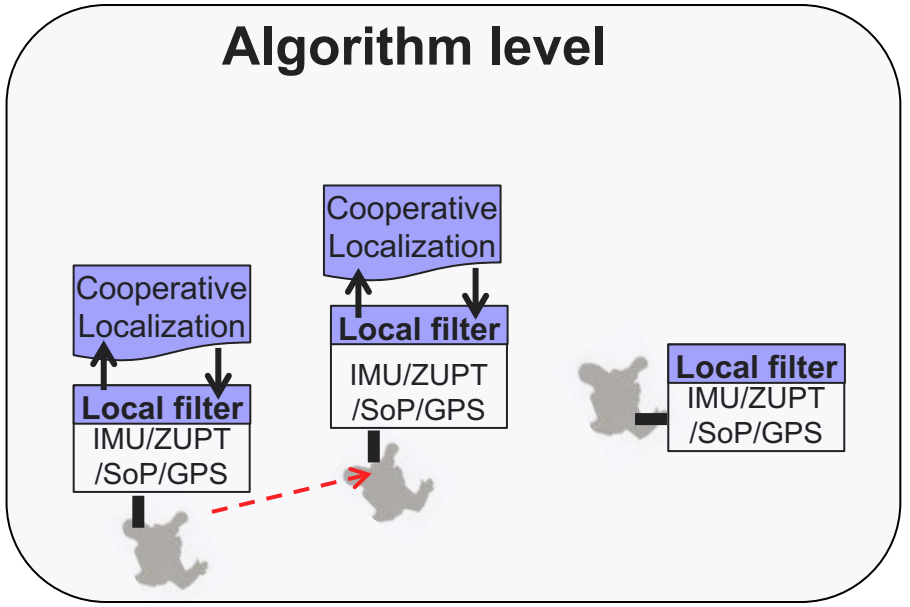
Cooperative Localization

Cooperative

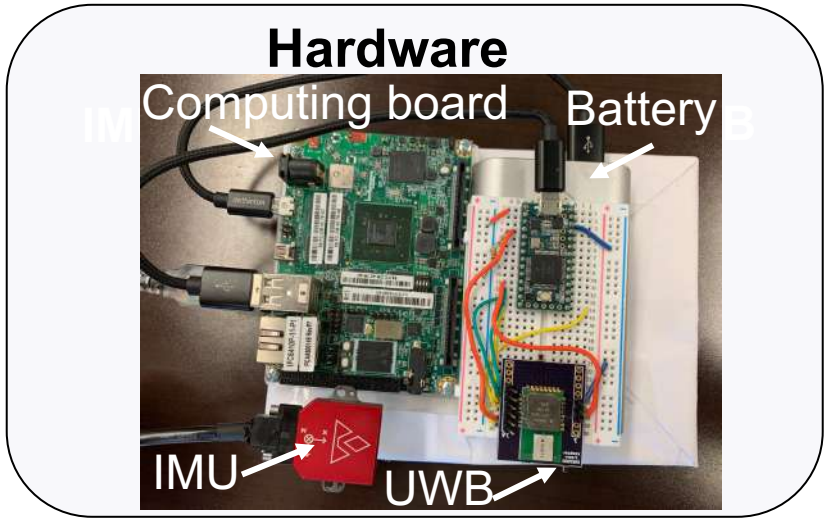


$$\hat{\boldsymbol{x}}_i^+ = \hat{\boldsymbol{x}}_i^- + \boldsymbol{K}_x\left(r - \sqrt{\left(\hat{x}_i^- - \hat{x}_j^-\right)^2 + \left(\hat{y}_i^- - \hat{y}_j^-\right)^2}\right)$$

$$\boldsymbol{P}^- = \begin{bmatrix} \boldsymbol{P}_i^- & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{P}_j^- \end{bmatrix} \rightarrow \boldsymbol{P}^+ = \begin{bmatrix} \boldsymbol{P}_i^+ & \boldsymbol{P}_{ij}^+ \\ \boldsymbol{P}_{ji}^+ & \boldsymbol{P}_j^+ \end{bmatrix}$$

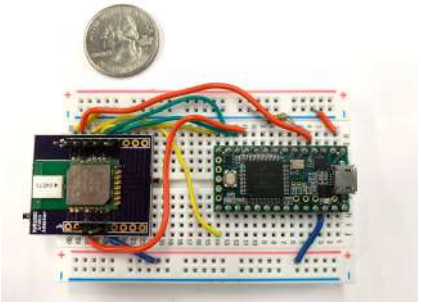


- **Challenge**: - strong correlations that cannot be ignored
  - limited communication
- **Objective**: - Communication time = relative measurement time
- **Solution**: - upper-bound the join covariance
  - estimate unknown correlations



Cooperative localization

Cooperative



UWB

- Ranging sensor
- Communication module

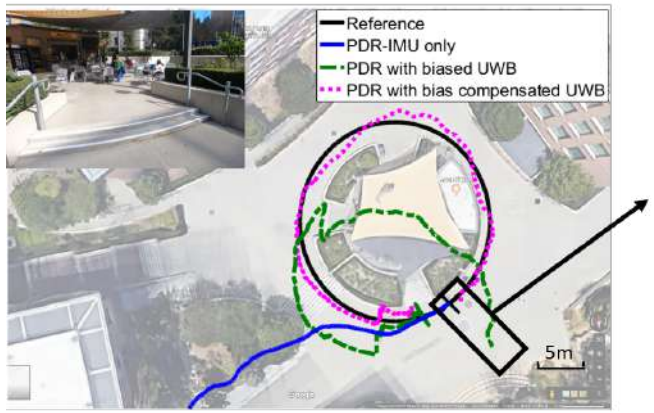
- **UWB Ranging**
  - Main challenge: bias removal in NLoS and long range LoS ranging
  - Our solution: algorithmic bias removal
    - No need for obstacle identification/classification
    - Low cost computation

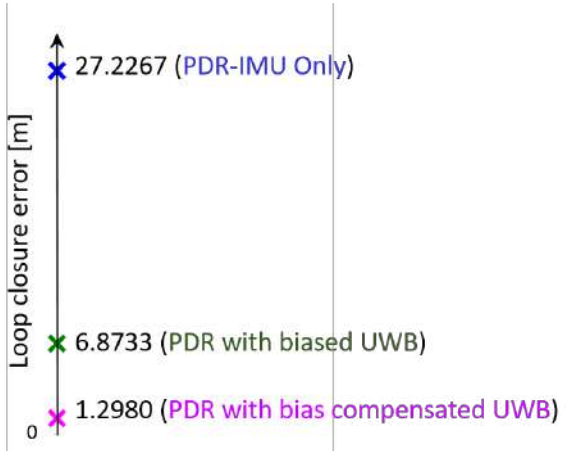
- **UWB for Inter-agent Communication**
  - Infrastructure free, stand alone communication
  - No need to maintain any network-wide connectivity between the firefighters

Experiment

Algorithmic bias removal: PDR with a low grade IMU and UWB ranging with respect to a beacon

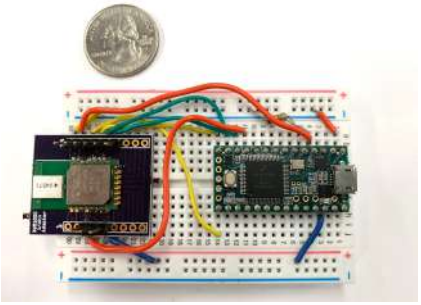
Obstructions: walls, café equipment, chairs and tables, bushes, trees, people





Cooperative localization

Cooperative



UWB

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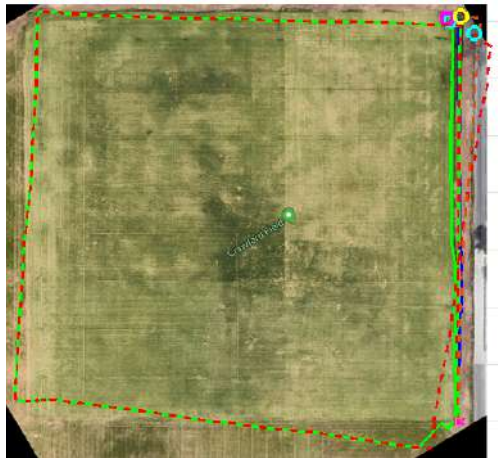
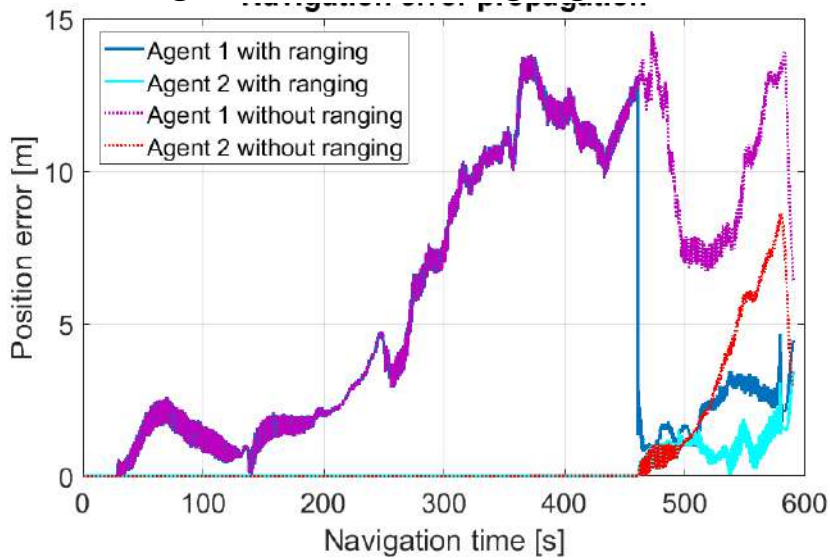
Experiment

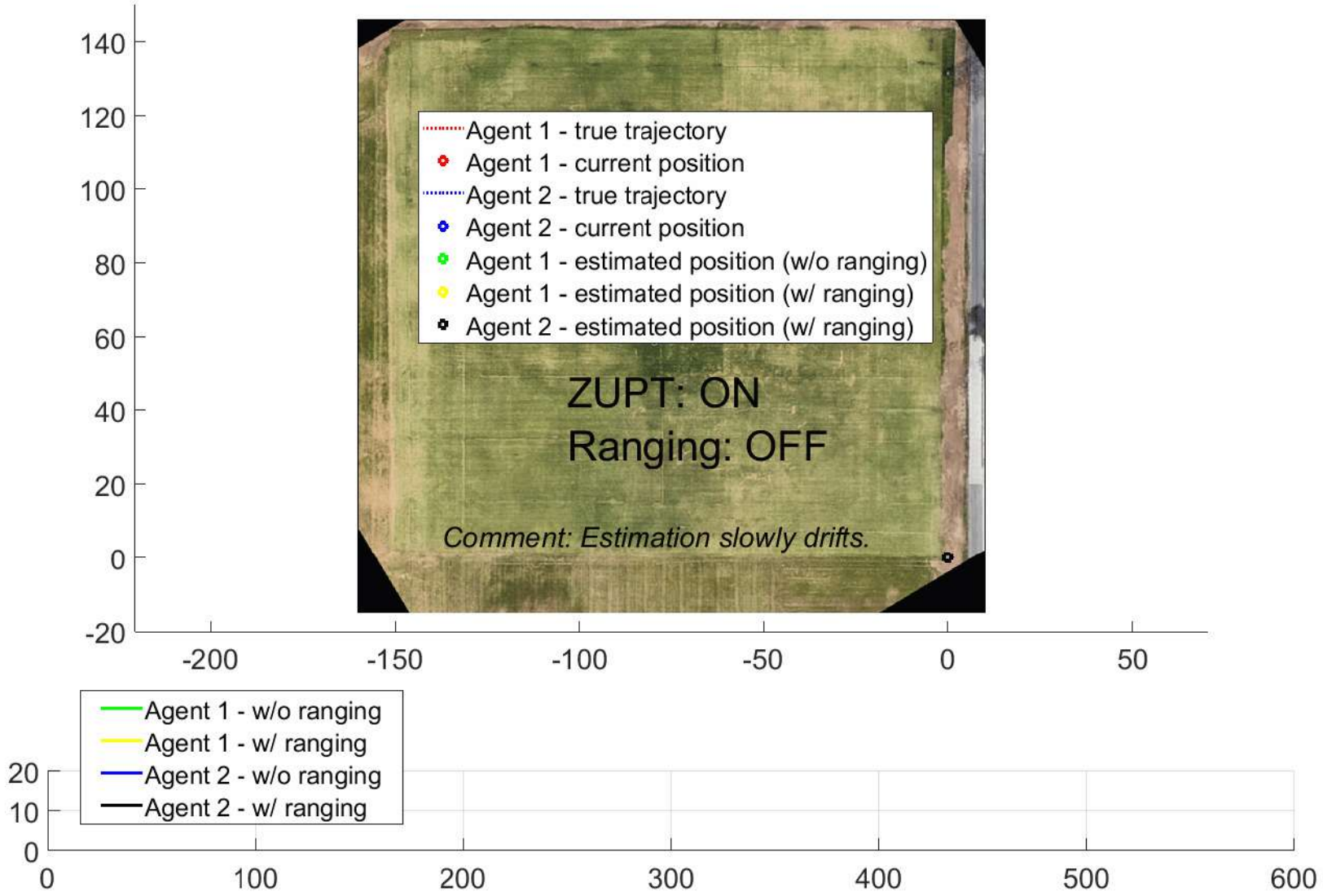
- Cooperative localization using LoS UWB ranging





- Cooperative localization with NLoS UWB ranging

Cooperative

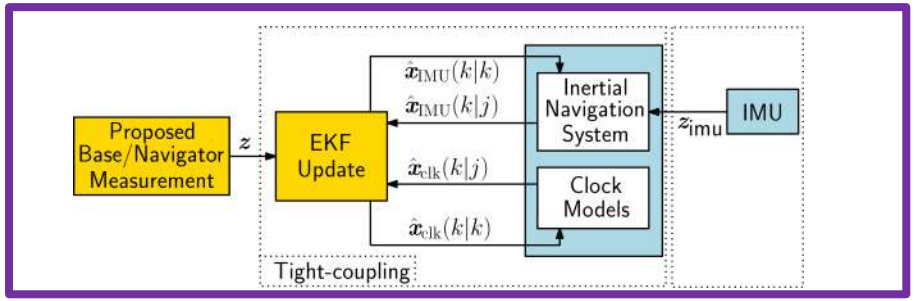


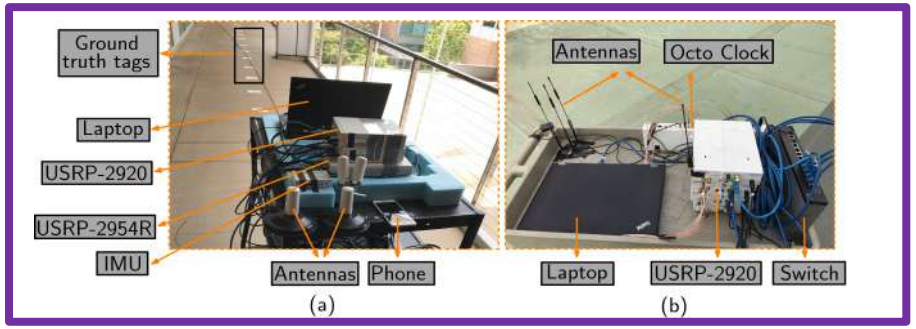
Self-contained cooperative localization improves accuracy by over 50%

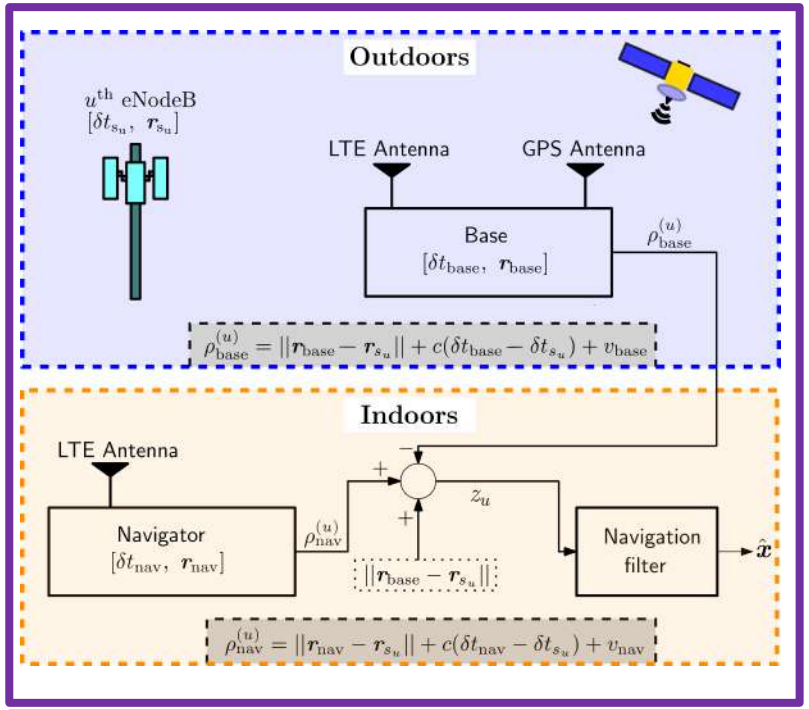
Signals of opportunity

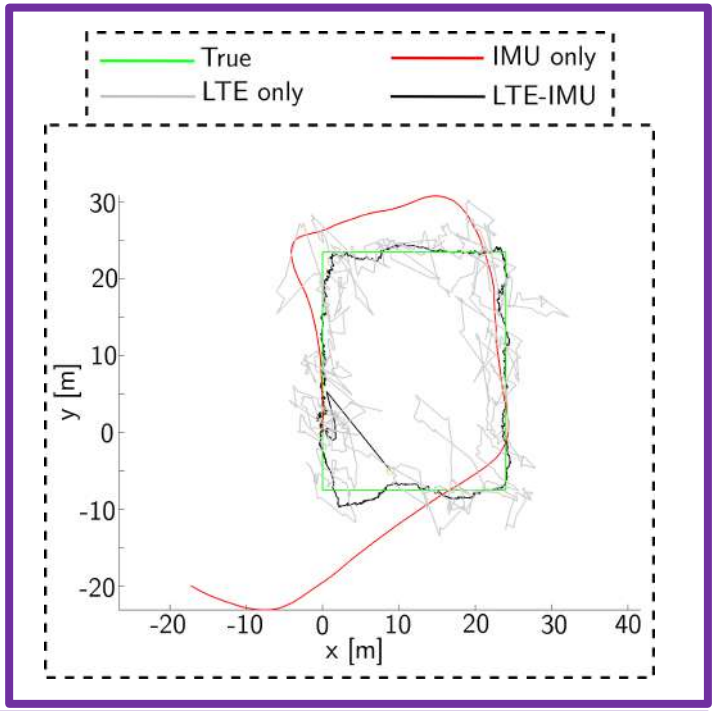
Probabilistic

- Graduate student: A. Abdallah







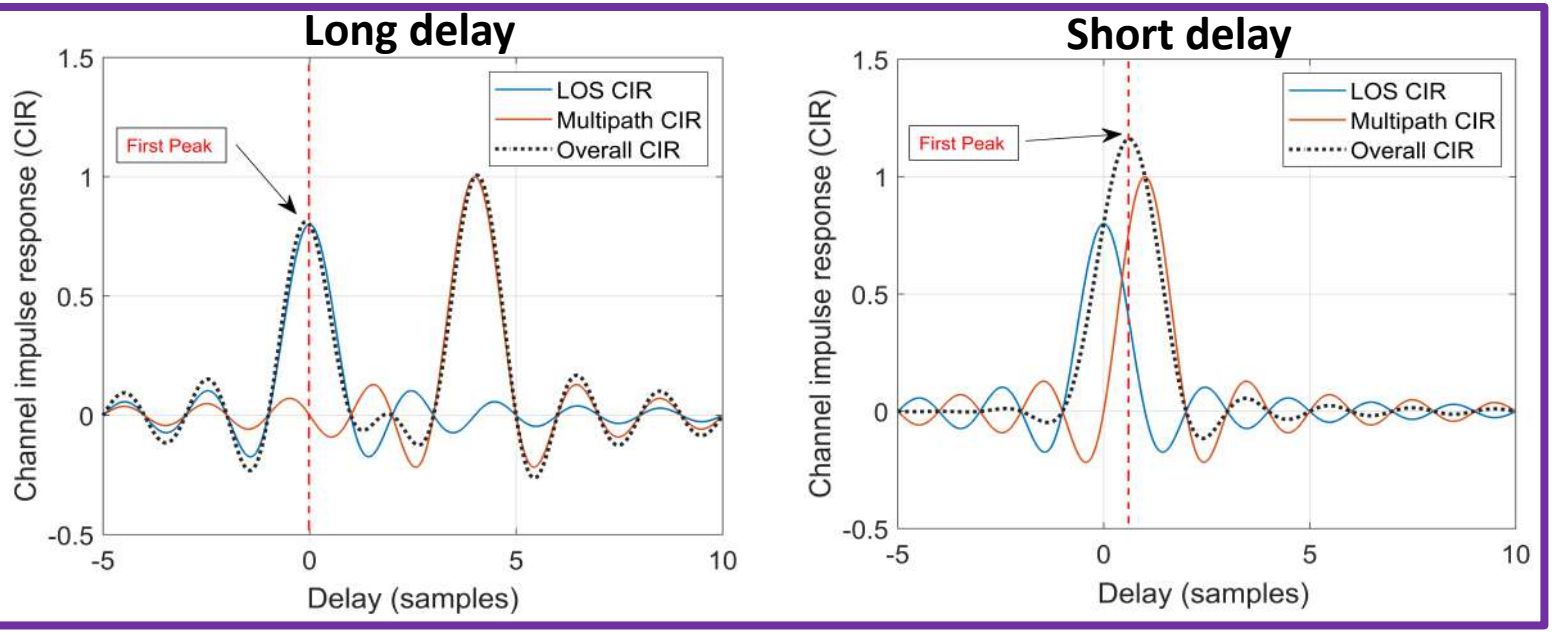


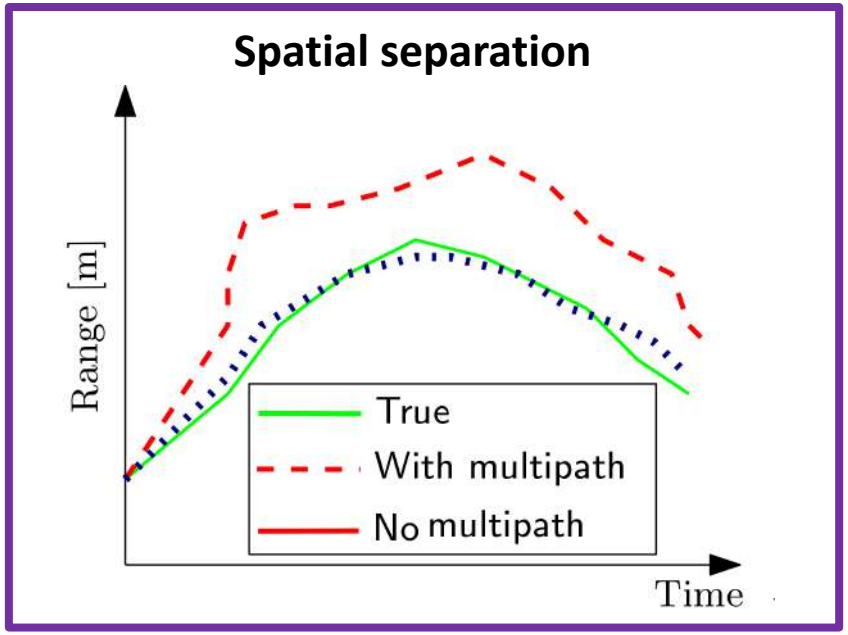
Performance Measure [m]	LTE-IMU	IMU Only	LTE Only
RMSE	2.92	9.48	5.09
Standard deviation	2.74	10.36	5.66
Maximum error	5.6	22.53	14.24

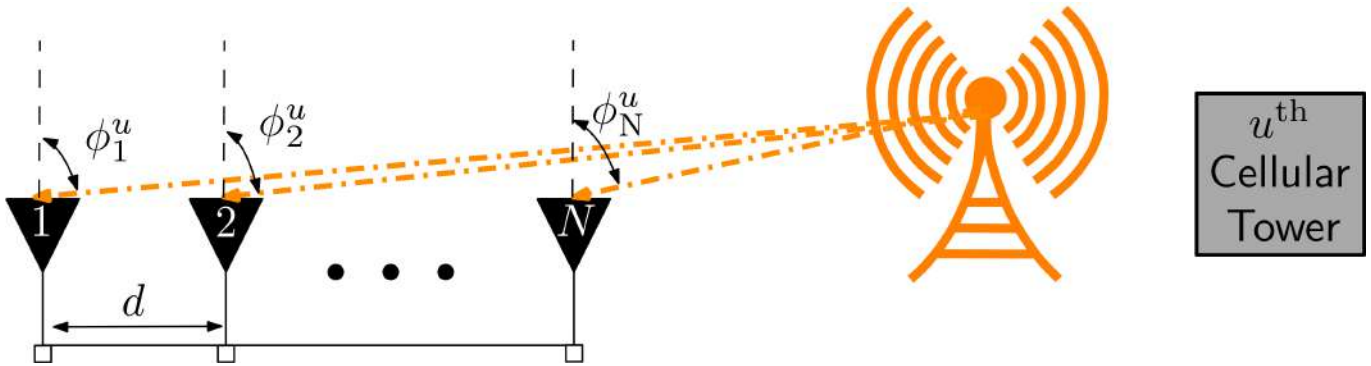
Signals of opportunity

Probabilistic

- Graduate student: A. Abdallah







u^{th} Cellular Tower

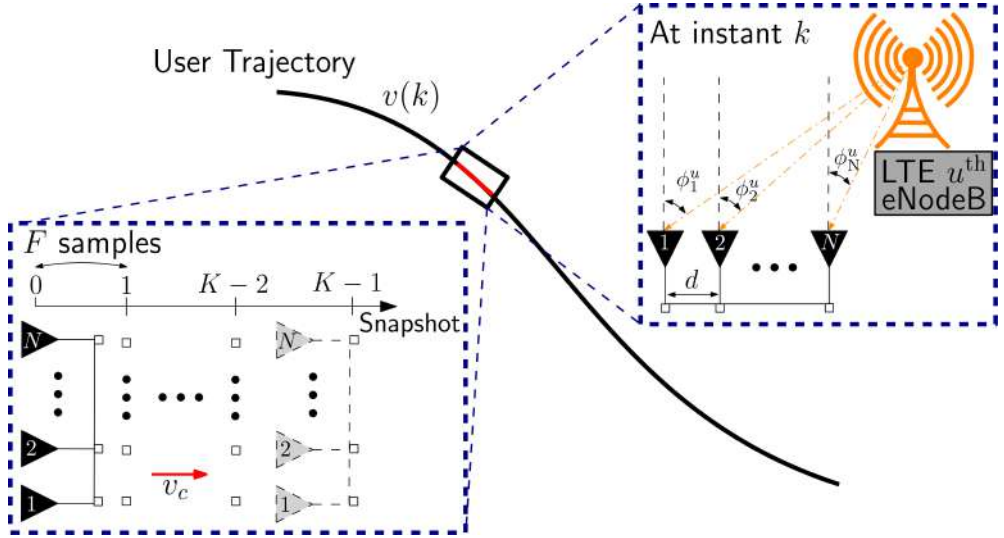
Limitations of physical antenna arrays

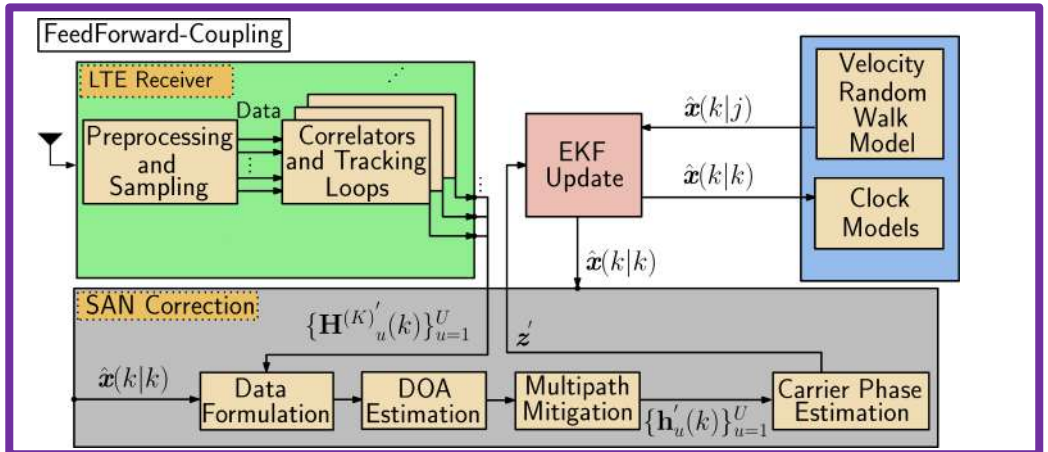
- Size
- Cost
- Limited number of resolved signals

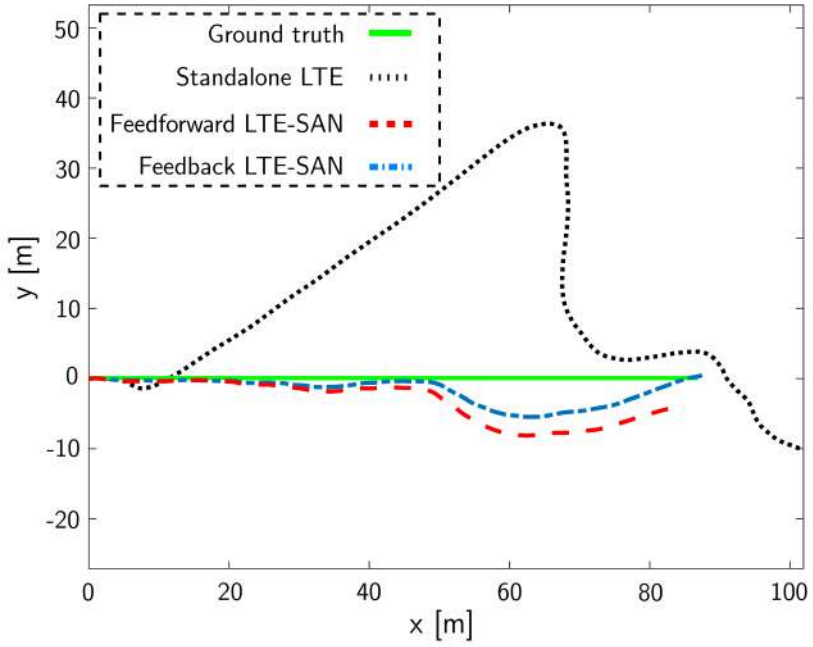
Signals of opportunity

Probabilistic

- Graduate student: A. Abdallah







Performance Measure [m]	Standalone LTE	Feedforward LTE-SAN	Feedback LTE-SAN
RMSE	23.00	4.50	2.62
Standard deviation	12.22	2.92	1.76
Maximum error	45.07	8.40	5.56

Expected Impact

- *uNavChip*
  - a single-chip integrating deterministic, probabilistic, cooperative capabilities
- Miniaturized Personal Navigation Technology for GPS-challenged environment
- Achieve the localization accuracy on the level of 1 meter
- Hours of self-contained localization

Acknowledgements

This work was performed under the following financial assistance award 70NANB17H192 from U.S. Department of Commerce, National Institute of Standards and Technology. Program Manager Jeb Benson.

#PSCR2019

Break for

Lunch

BACK AT

1:00PM