CRII: Towards Optimal Information Gathering in Unknown Stochastic Environments

PI: Zak M. Kassas

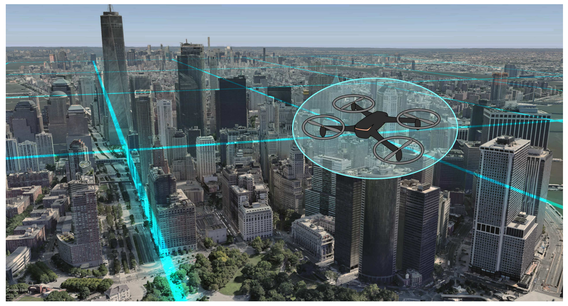
Background and Motivation

Objective:

Exploit the abundance of signals of opportunity for CPS situational awareness.

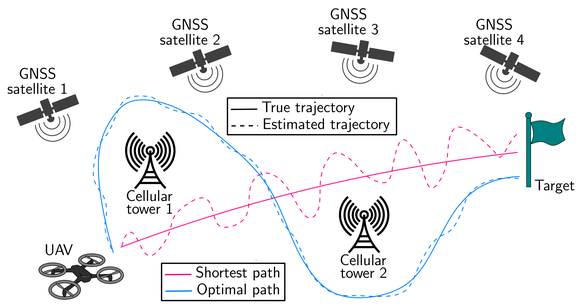
Challenges:

Measurements extracted from these signals suffer from large errors due to line-of-sight (LOS) blockage and multipath.



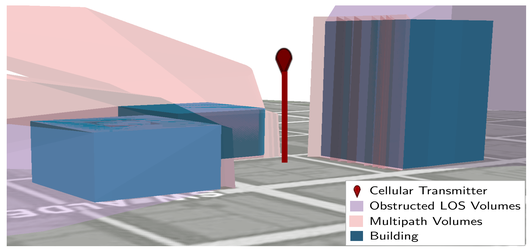
Approach

Develop an efficient path planning framework to constrain multipath-induced biases.

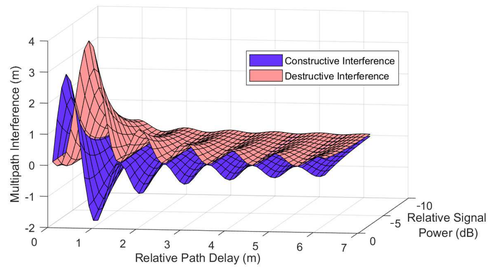


Error Prediction

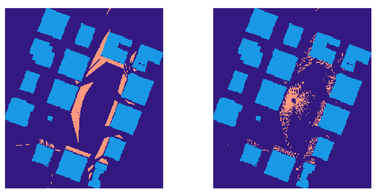
Multipath volumes and obstructed LOS volumes for a cellular transmitter.



Multipath envelopes for constructive and destructive interference (one multipath component).



Areas where the multipath bias is larger than 1 m (left) match with the areas where the relative path delay is between 6 and 24 m (right).



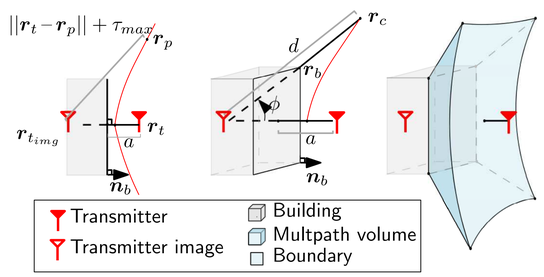
High-fidelity multipath map (computationally expensive)

Path delay map (computationally efficient)

Trajectory Planning

Algorithm Populate table with boolean values for receiver locations being inside an obstructed LOS or multipath volume

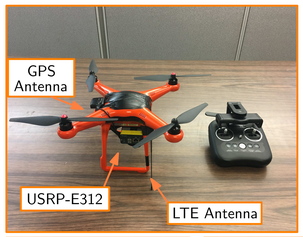
Input: Buildings, transmitter positions, pts
Output: Table of boolean values
Initialize table to $false$ for all $2M$ columns
For each m cellular transmitter in the environment
  For each building
    Calculate obstructed LOS volume corner
    For each point p in pts that is inside the building
      Label the p-th row and m-th column as $true$
  For each building surface with unobstructed LOS
    Calculate multipath volume corners
    For each point p in pts inside the multipath volume
      Label the p-th row and $(m+M)$-th column as $true$

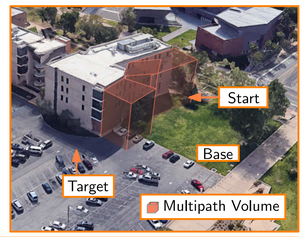


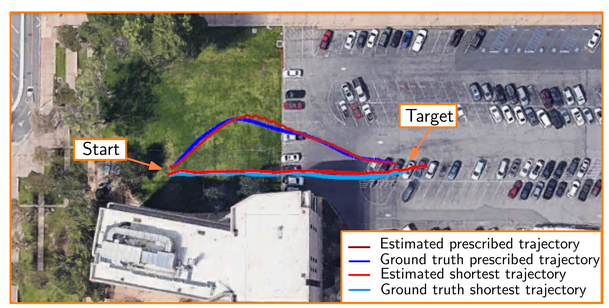
$$\boldsymbol{r}_c = \boldsymbol{r}_{t_{img}} + d\frac{\boldsymbol{r}_b \quad \boldsymbol{r}_{t_{img}}}{\|\boldsymbol{r}_b \quad \boldsymbol{r}_{t_{img}}\|}, \qquad d = \frac{4a^2 \quad \tau^2_{max}}{4\text{acos}(\phi) \quad 2\tau_{max}},$$

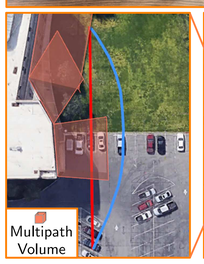
$\boldsymbol{r}_p$: receiver location
$\boldsymbol{r}_b$: building surface corner
d: distance between $\boldsymbol{r}_{t_{img}}$ and $\boldsymbol{r}_c$
$\boldsymbol{r}_{t_{img}}$: transmitter image
$\boldsymbol{r}_c$: boundary surface corner
$\boldsymbol{n}_b$: normal of surface

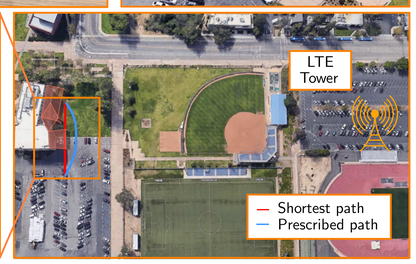
Experimental Demo

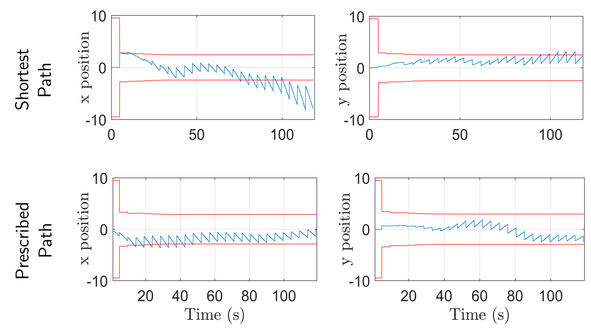






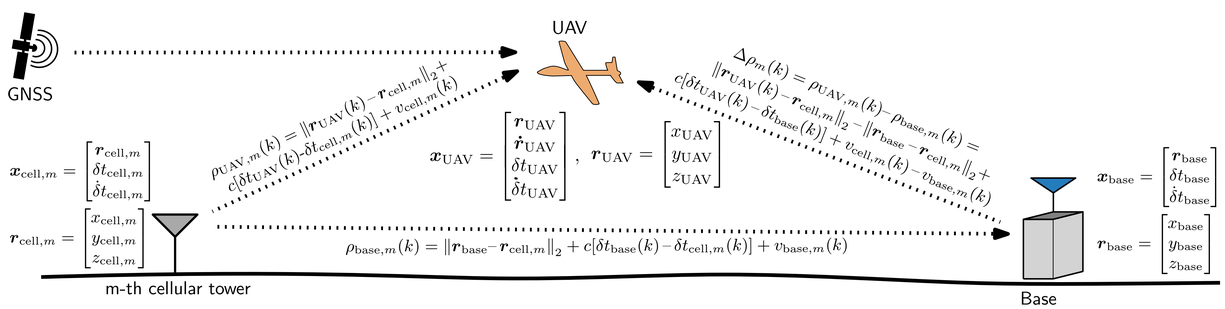






Trajectory	2-D RMSE [m]	2-D Max. error [m]
Shortest	3.03	8.92
Prescribed	2.10	3.67
Reduction	30.69%	58.86%

Base/UAV Framework



$\boldsymbol{r}$: 3–D position vector; δt: clock bias; $\dot{\delta t}$: clock drift; c: speed of light; v: measurement noise;
ρ: pseudorange measurements; $k = 0, 1, \ldots$: time index; $m = 1, \ldots, M$; M: number of cellular towers.

Acknowledgment and References

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[1] S. Ragothaman, M. Maaref, and Z. Kassas, "Autonomous ground vehicle path planning in urban environments using GNSS and cellular signals reliability maps: models and algorithms," *IEEE Transactions on Aerospace and Electronic Systems*, 2021, accepted.

[2] S. Ragothaman, M. Maaref, and Z. Kassas, "Multipath-optimal UAV trajectory planning for urban UAV navigation with cellular signals," *In Proceedings of IEEE Vehicular Technology Conference*, September 2019, pp. 1–6.

[3] S. Ragothaman, "Path planning for autonomous ground vehicles using GNSS and cellular LTE dignal reliability maps and GIS 3-D maps," Master's Thesis, University of California, Riverside, USA, 2018.