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Large-Scale Cellular Coverage Analyses for UAV Data Relay via Channel Modeling

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IoT4Ag
The Internet of Things for Precision Agriculture
an NSF Engineering Research Center

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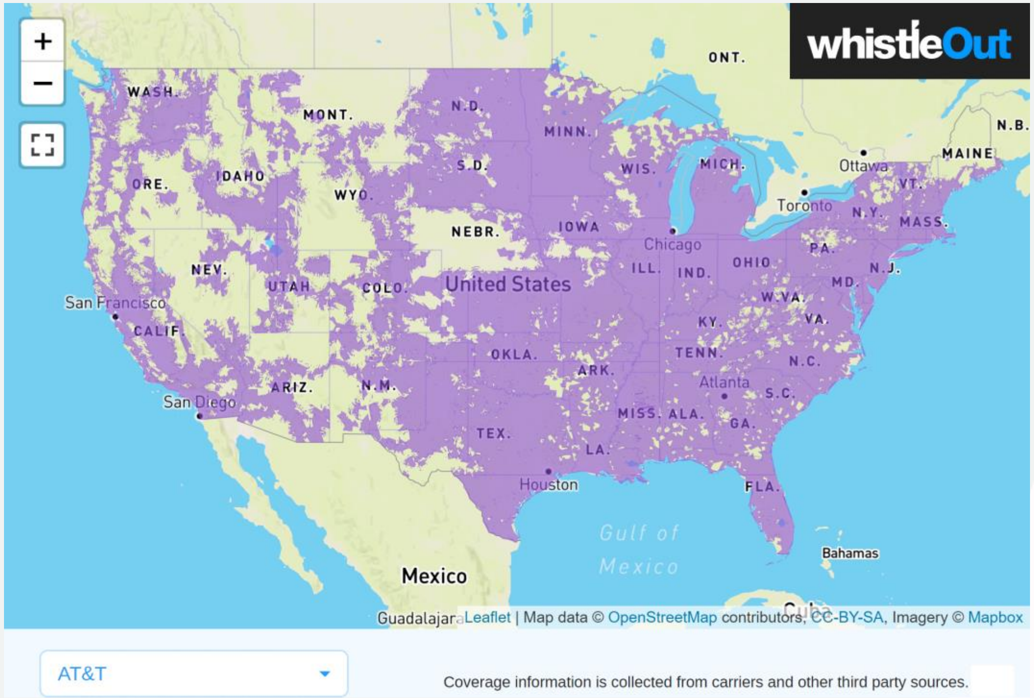
Rural Cellular Coverage

Demand for broadband in rural areas

- Low population density
  - Not yet economically viable



Rural Cellular Coverage

Demand for broadband in rural areas

- Not economically viable
  - Low user density, high customizability, and high infrastructure costs
- Digital agriculture
  - Over a vast low-population area
  - Basic data connection needed for sensors
  - High-speed connection for cameras
  - Intermittent connectivity requirement

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“Dawn of Drones”

A vast array of new possibilities

- Extremely flexible
  - Aerial mobility
  - On-demand deployment
  - UAV-aided networks
  - Multi-tier architecture
  - Placement optimization
  - Route planning
  - …
- Uncertainties
  - Battery life
  - Safety
  - Legislation
  - Privacy
  - …

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Real-life deployment?

A series of quantitative analyses
for large geographic areas
based on real-life data

- Key findings
  - Upper bounds on system-level coverage gains
    - For example, ~45% cellular coverage ratio gain in IN with UAVs@100 m (baseline: 1.5 m)

$$\text{Coverage Ratio Gain} = \underbrace{\frac{\text{Coverage Area}}{\text{Total Area}}}_{\text{Coverage Ratio}} - \underbrace{\frac{\text{Baseline Coverage Area}}{\text{Total Area}}}_{\text{Baseline Coverage Ratio}}$$

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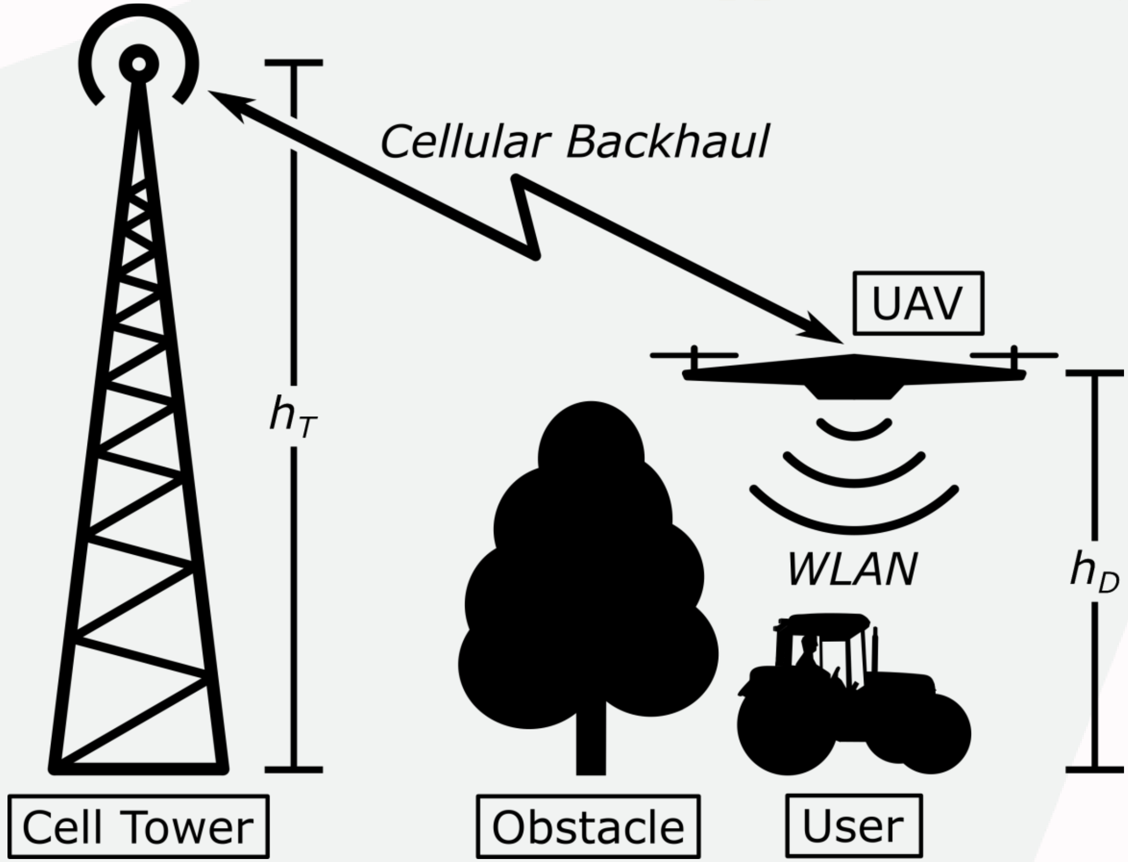
Data Relay Scenario

An application in agriculture



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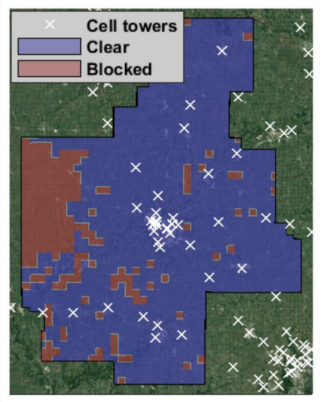
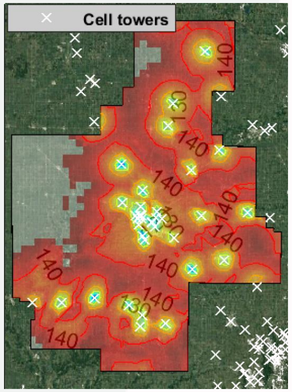
Goals

Coverage analysis and visualization

- Blockage maps
  - Simple and intuitive
  - LiDAR data



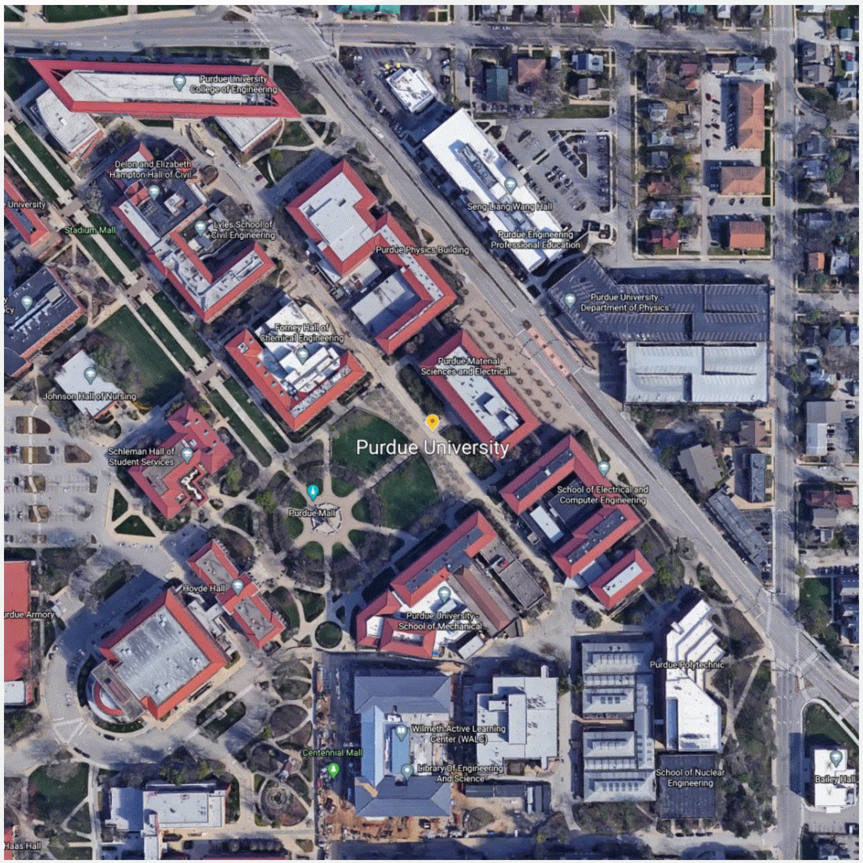


- Path loss maps
  - Based on the NTIA* eHata model
  - Terrain elevation data
  - Take into consideration more factors like reflection, refraction, terrain profile, obstacle clutter type…

* National Telecommunications and Information Administration

Large-Scale

All about computation



- Areas of interest
  - ACRE (a Purdue research farm)
  - Tippecanoe County
  - WHIN (10 counties)
  - Indiana State

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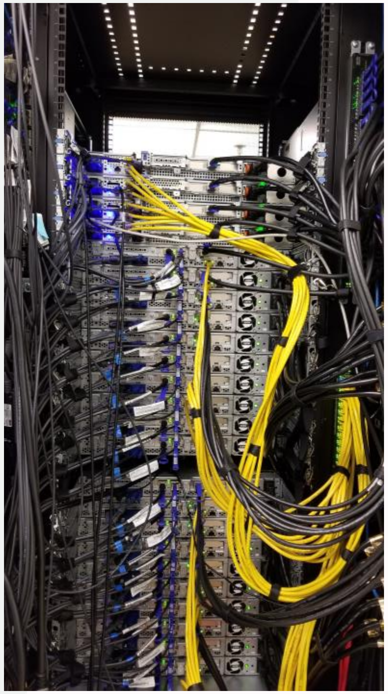
Large-Scale

All about computation

- Indiana State
  - On-demand elevation
  - 322 GB LiDAR

  => 939 GB locally cached data (as .mat files)
- Cluster
  - 36 cores
  - 216 GB RAM
  - >2 TB hard drive
  - ~285 GFLOPS

(a) Front view



(b) Back view

Simulator Structure

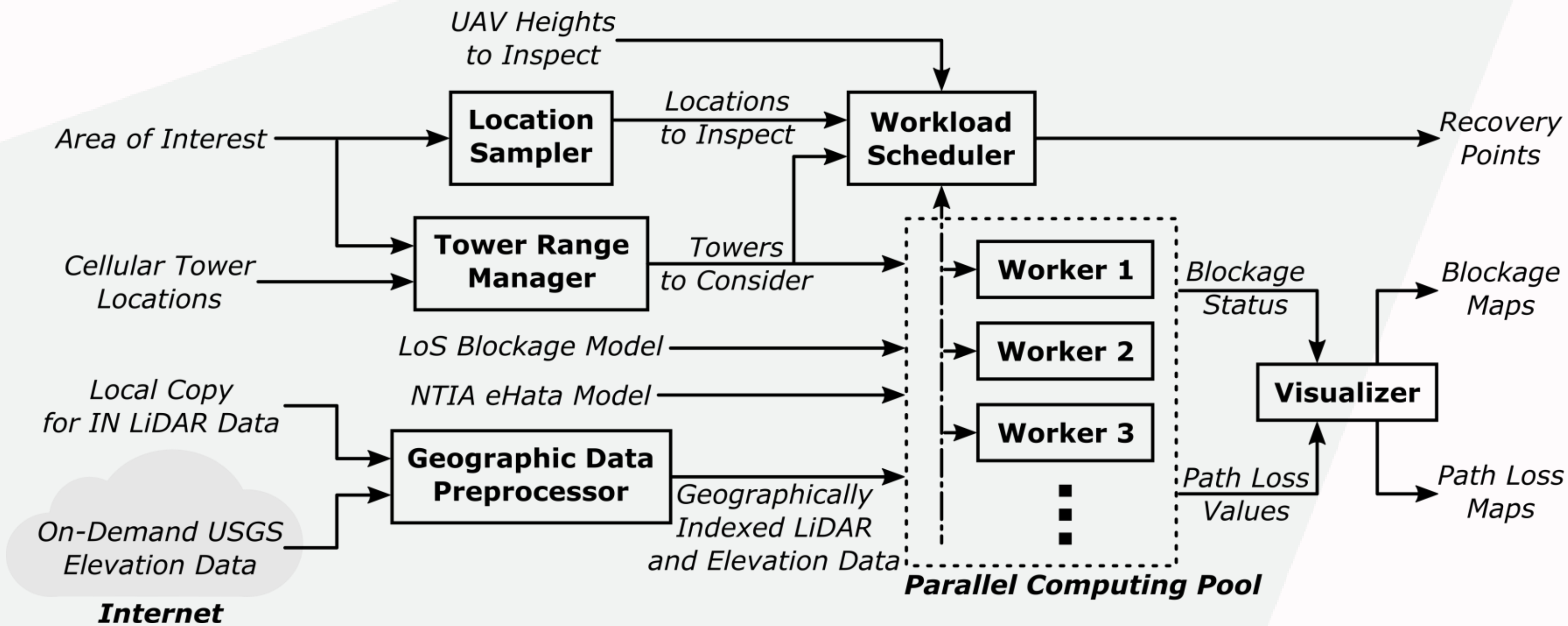
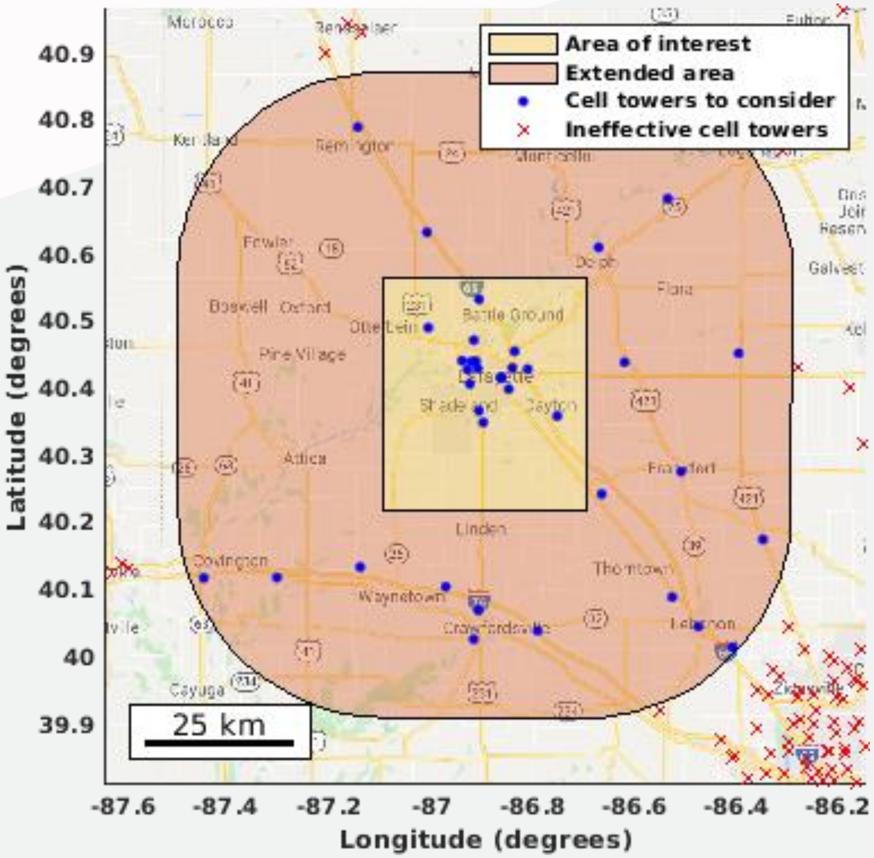
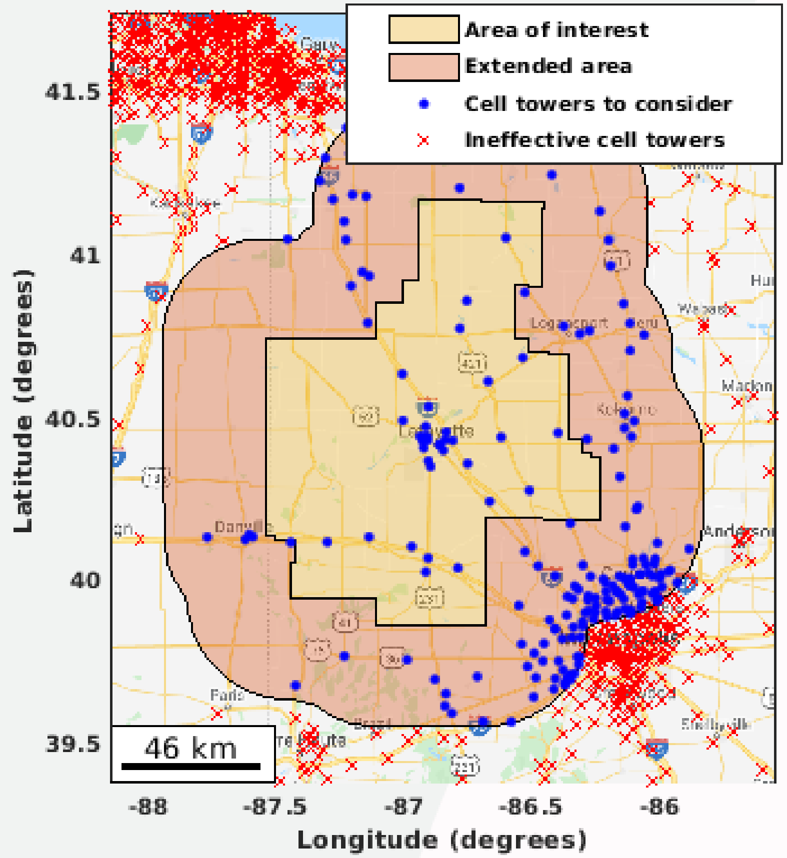


Fig. Illustration diagram for the structure of the simulator

Cellular Towers



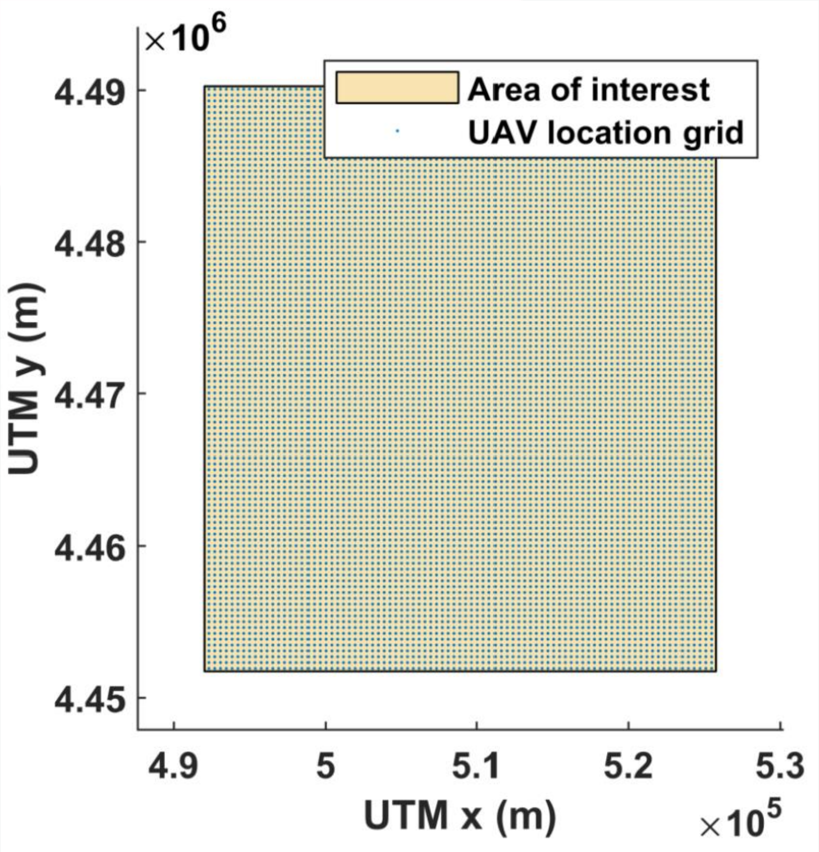
(a) For Tippecanoe County



(b) For WHIN

Cellular tower locations obtained from the Commerce Spectrum Management Advisory Committee (CSMAC)

Inspected Locations



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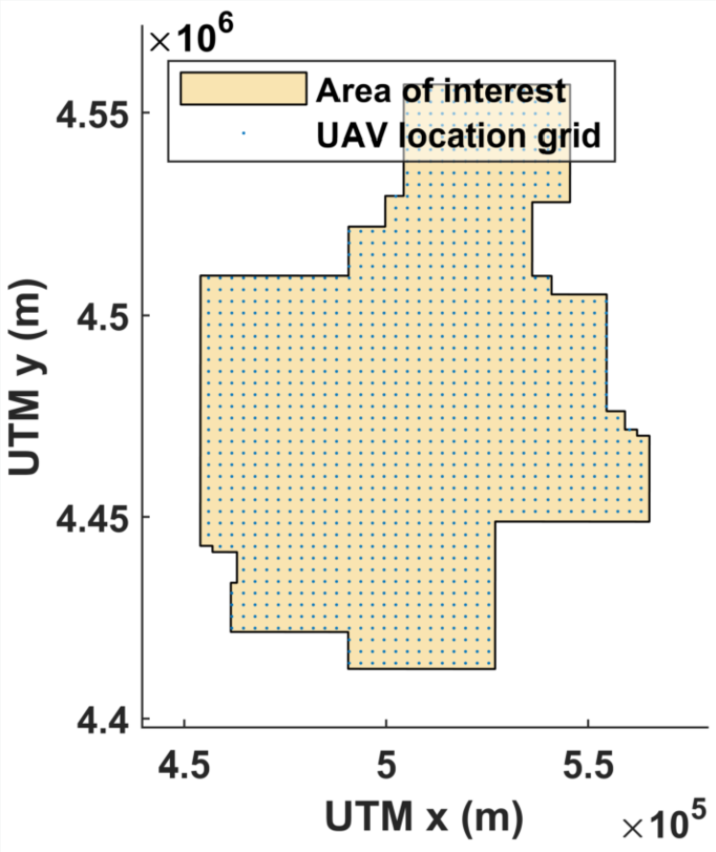


(b) For WHIN

Channel Modeling

The LoS blockage case as an example

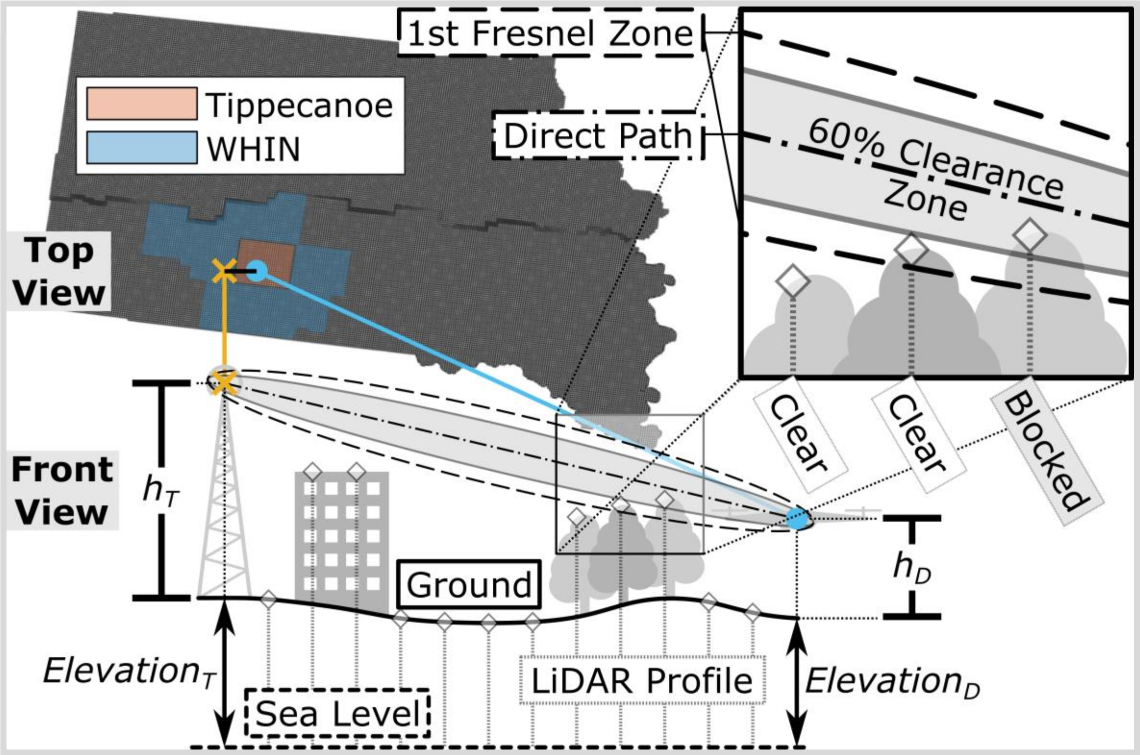
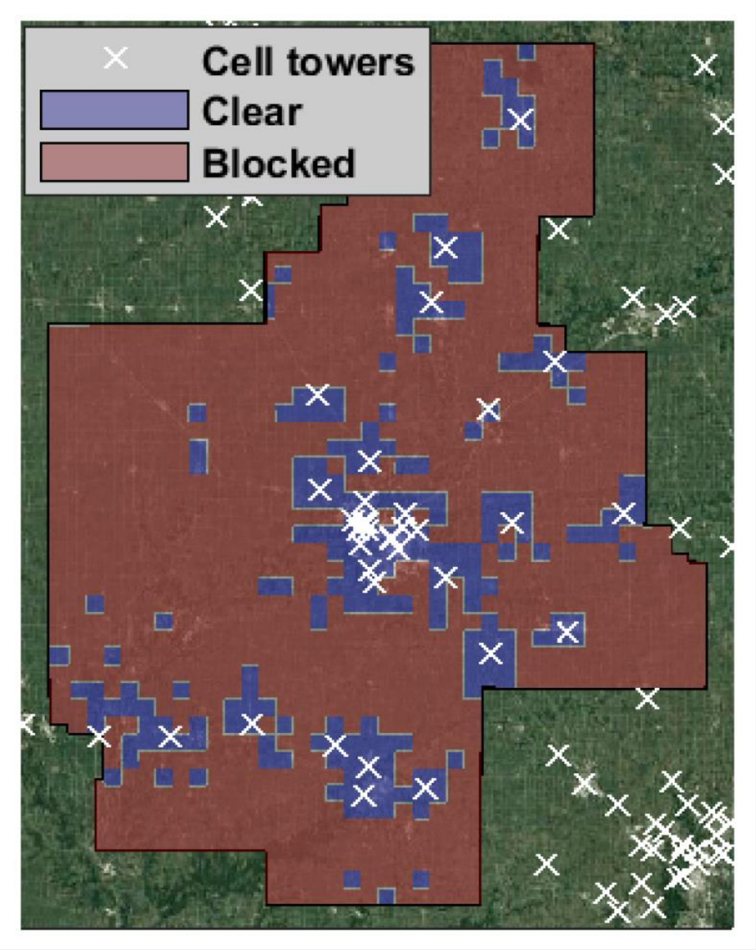


Fig. Determining blockage status

We used the raster LiDAR dataset (5 feet resolution) from the Indiana Statewide Imagery and LiDAR Program.

Blockage Maps



Animation for the WHIN area, showing UAV flying at heights of

- 1.5 m,
- 10 m, and
- 100m.

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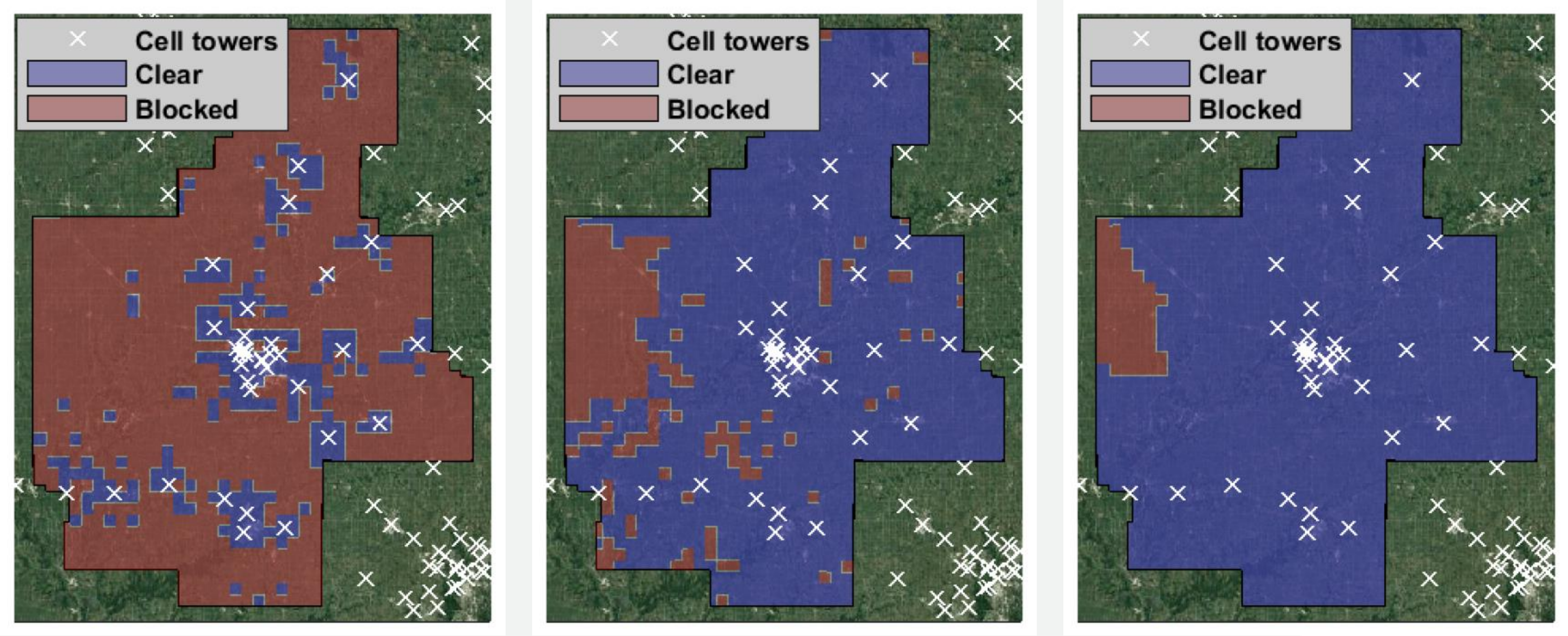
Blockage Maps



(a) UAV height = 1.5 m (b) UAV height = 10 m (c) UAV height = 100 m

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Blockage Maps

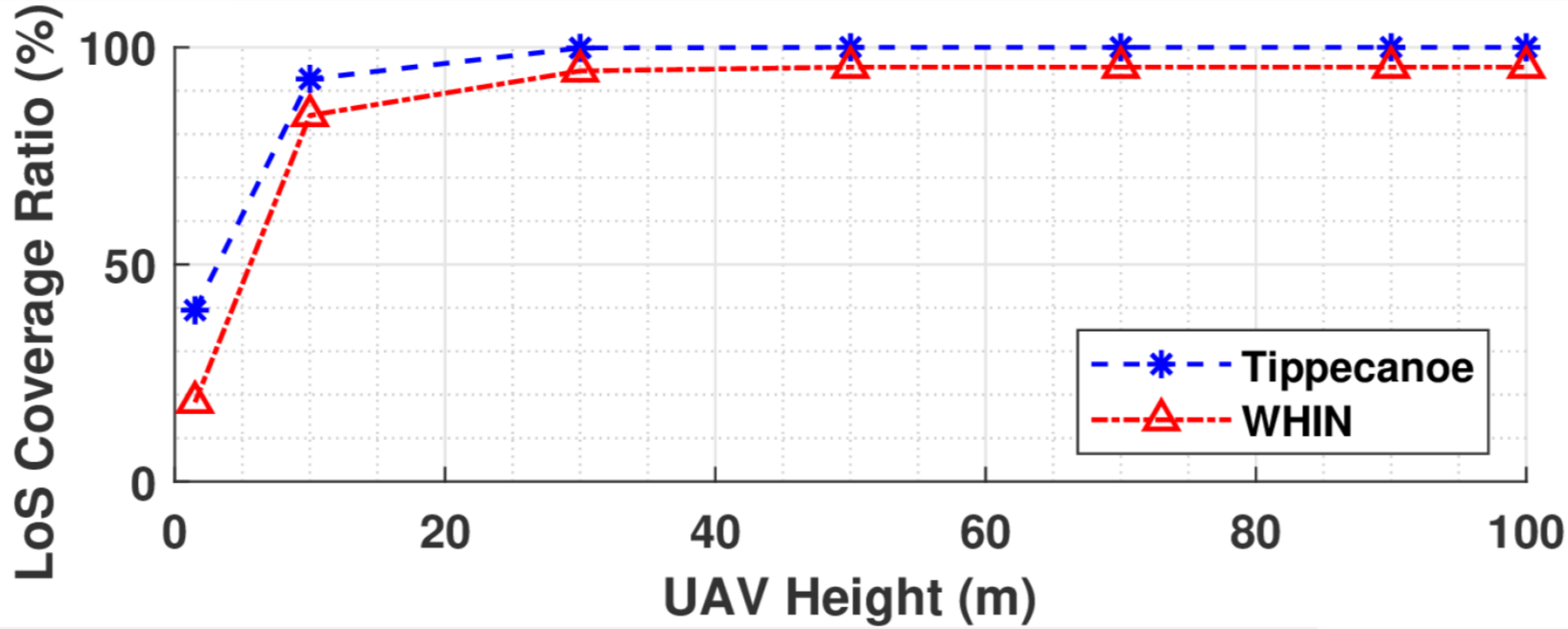
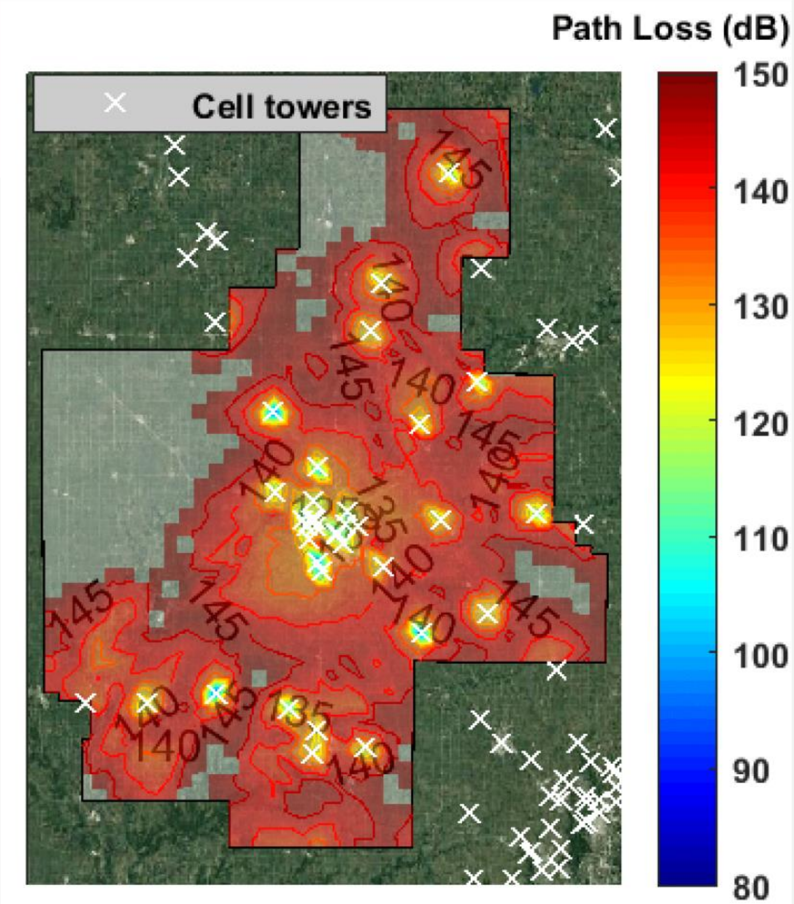


Fig. Clear LoS coverage ratio based on blockage maps

Coverage Maps



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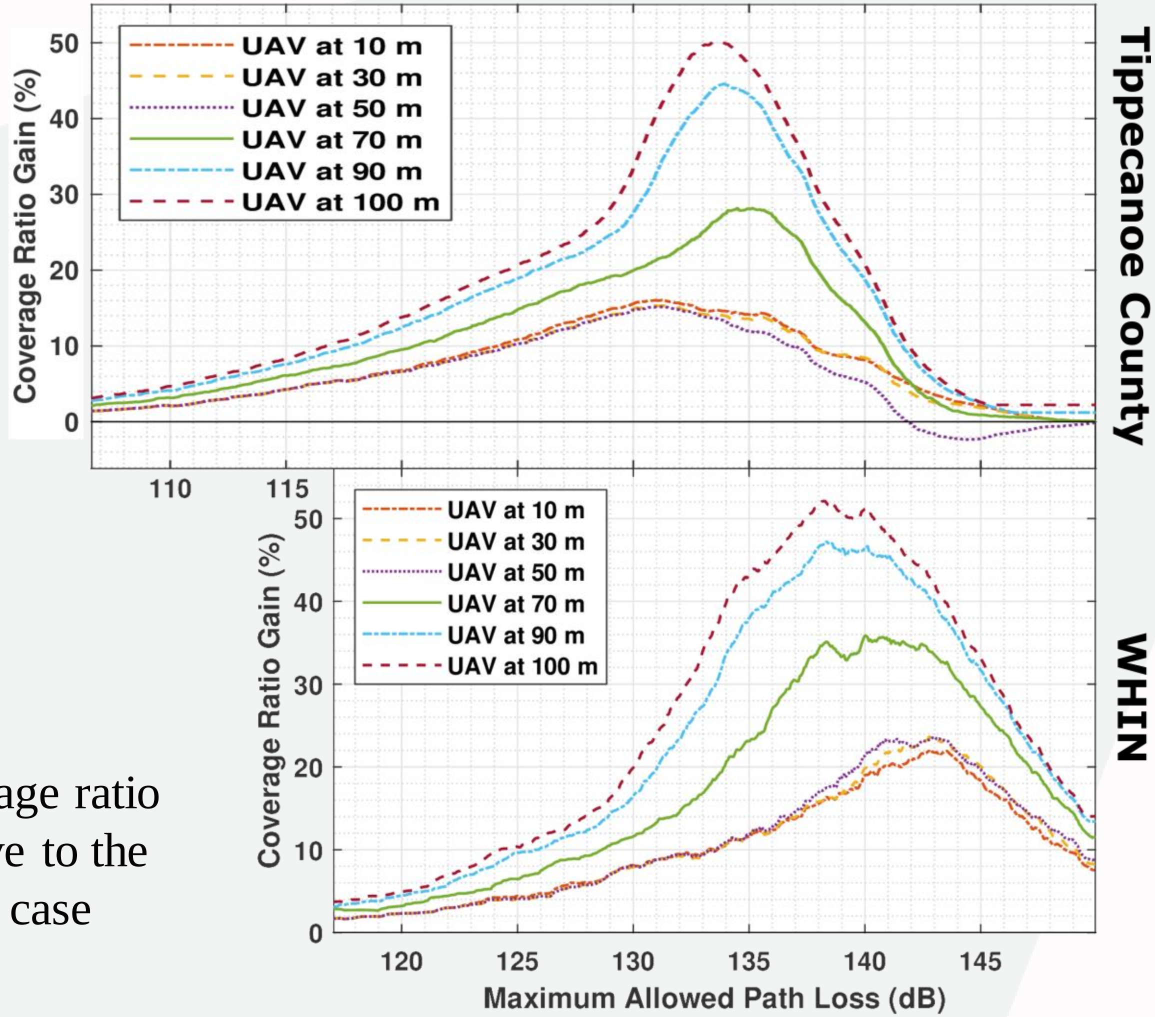
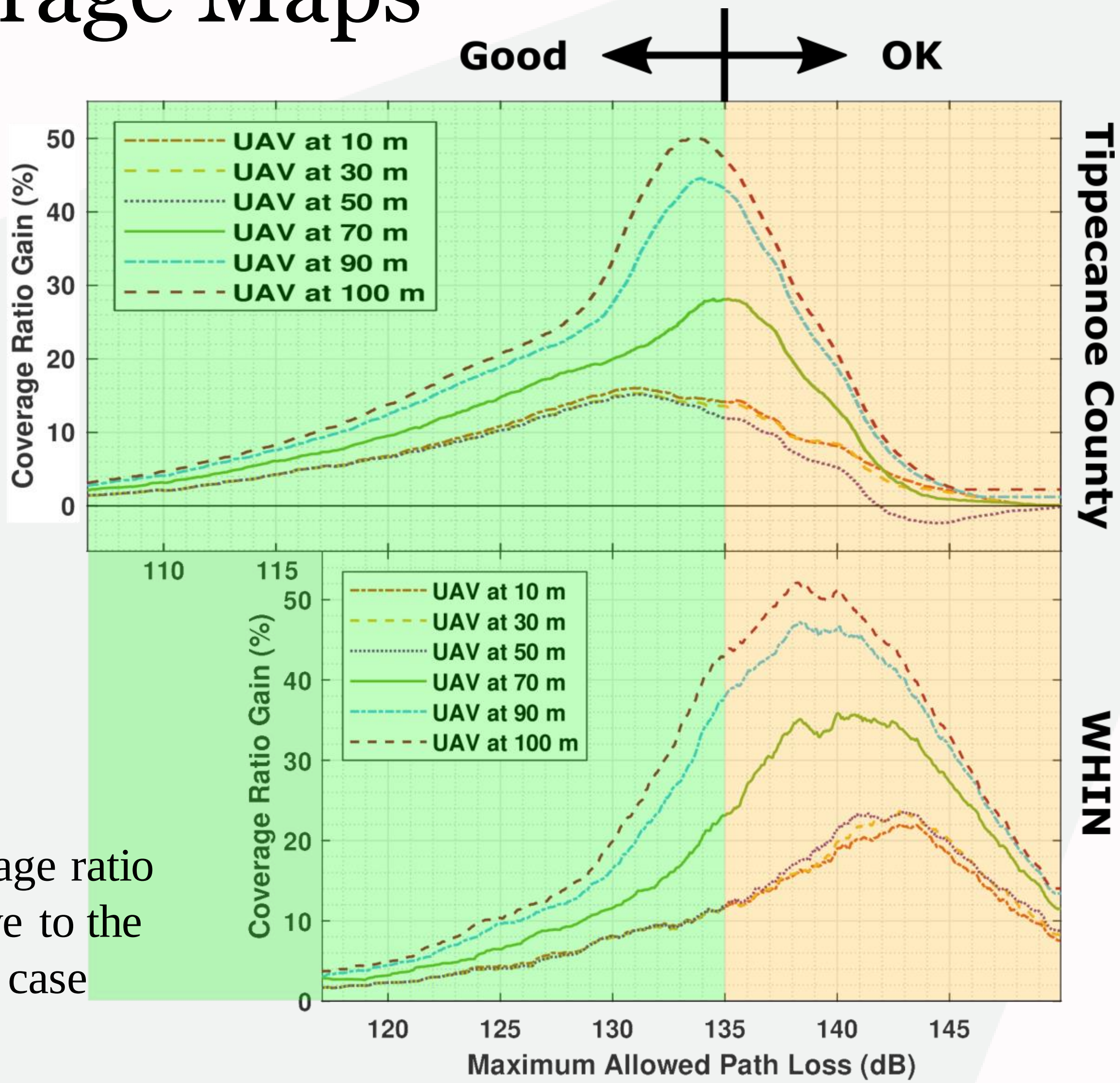


Fig. Coverage ratio gain relative to the h_D = 1.5 m case

Coverage Maps



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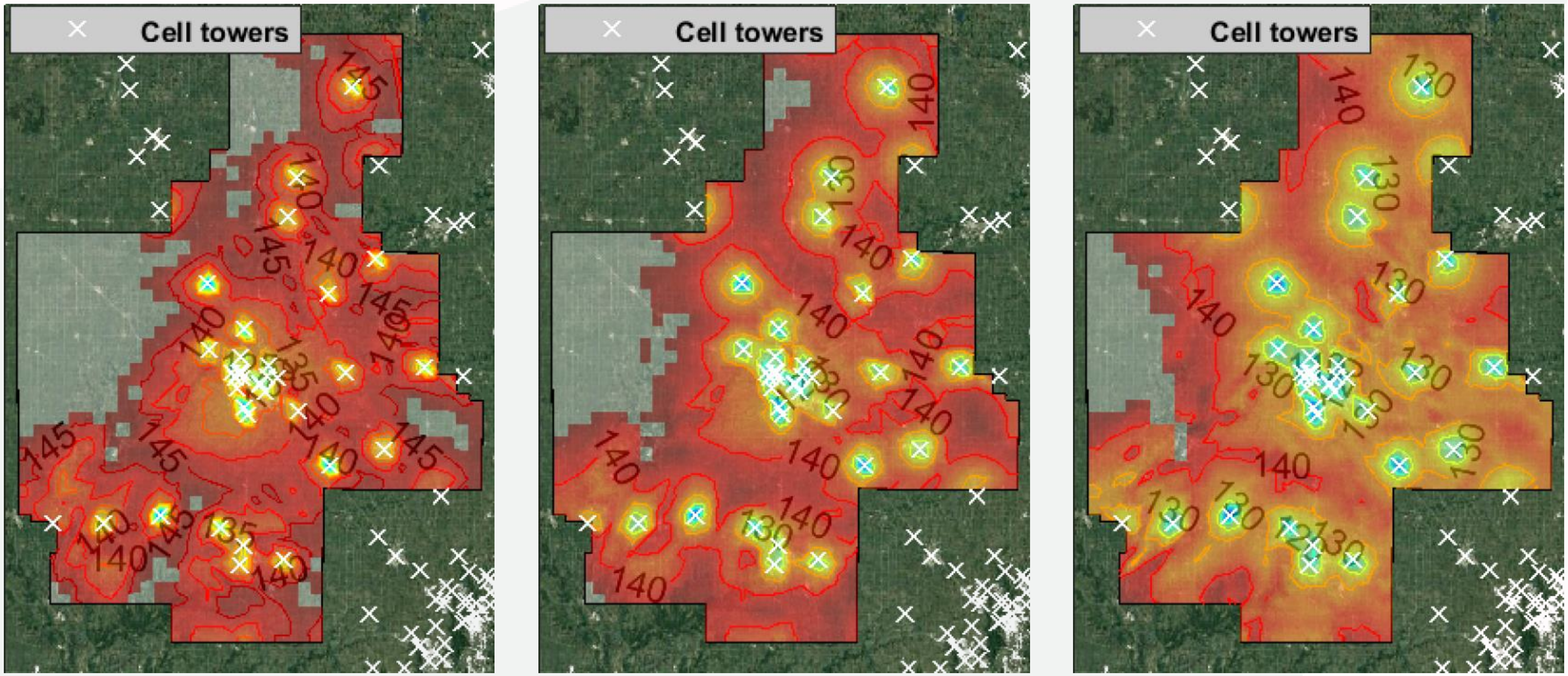

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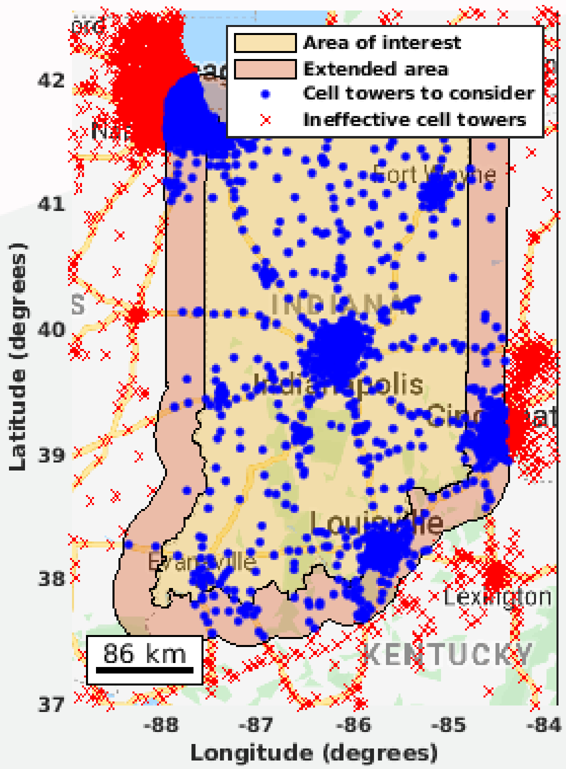
Preliminary Results for IN



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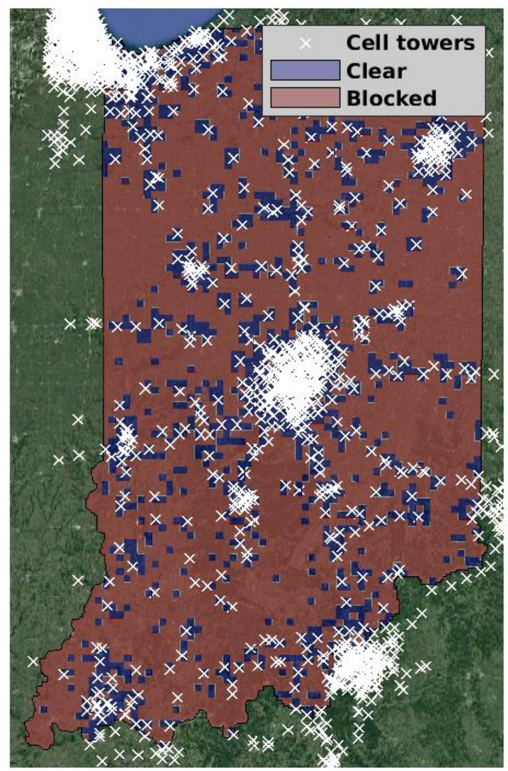
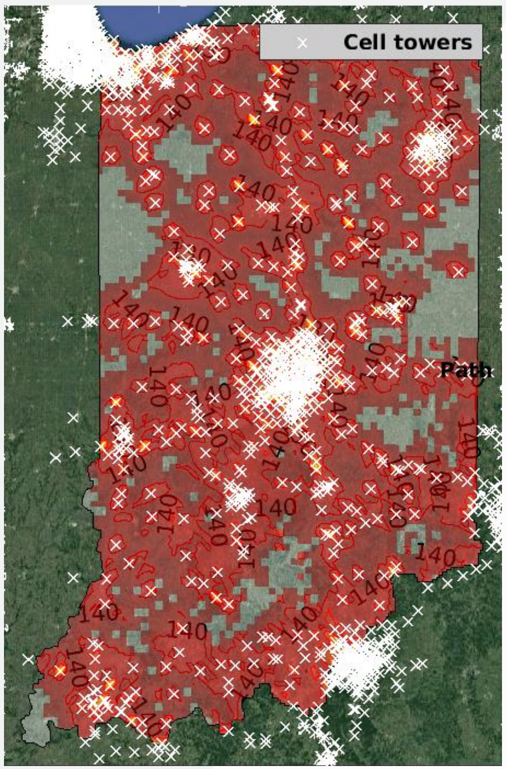


(b) Blockage maps



(c) Coverage maps

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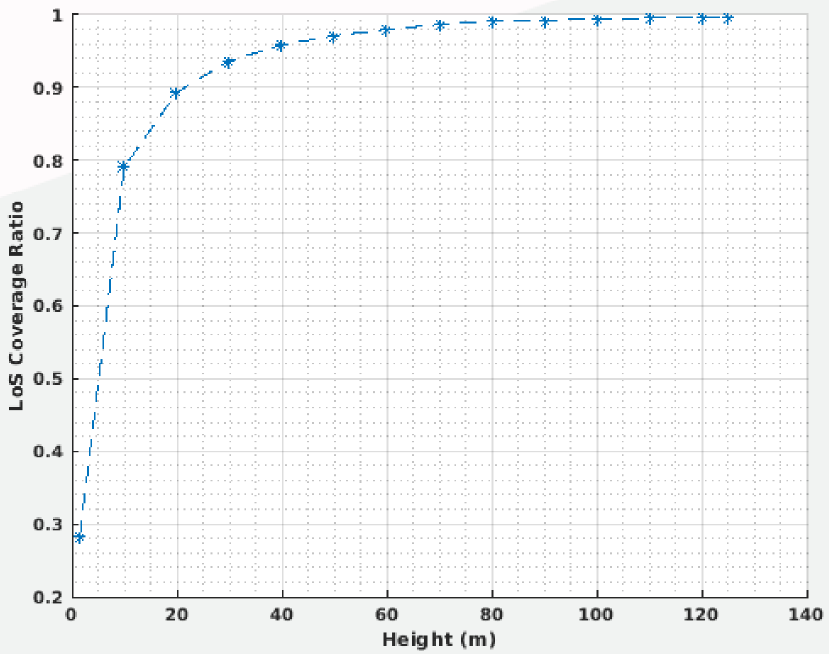

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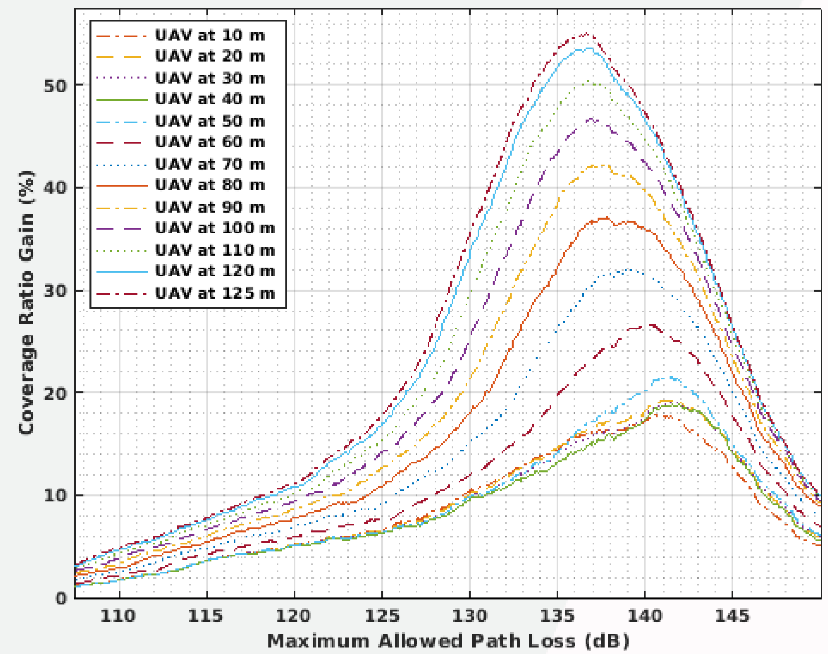

(b) Coverage ratio gain based on coverage maps

Contributions

A series of quantitative analyses
for large geographic areas
based on real-life data

- Key findings
  - Upper bounds on system-level coverage gains
    - For example, ~45% coverage ratio gain in IN with UAVs@100 m (baseline: 1.5 m)
  - More improvement expected for areas with larger elevation variation

Thank you!

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