Assessment of Urban-Scale Wireless Networks with a Small Number of Measurements

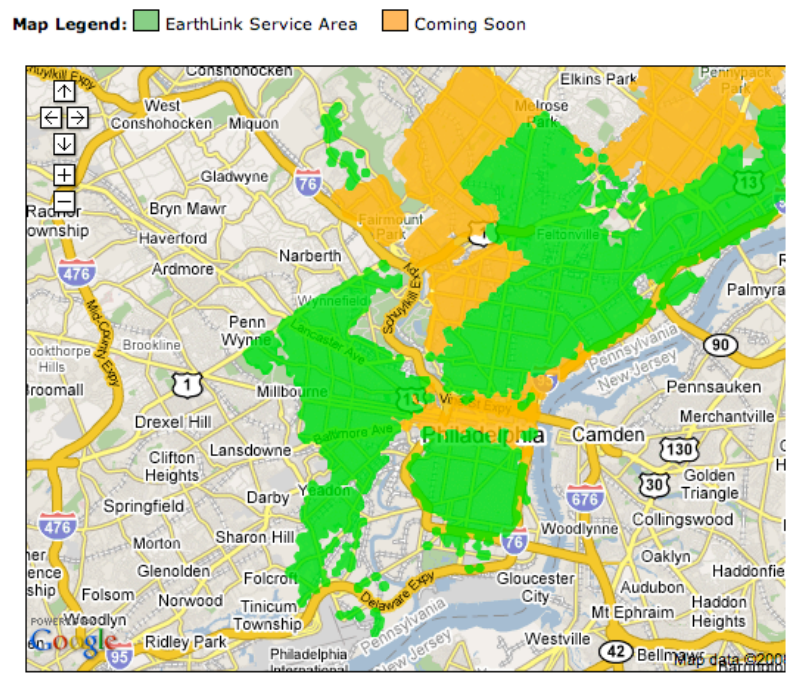
Joshua Robinson
Rice University

Ram Swaminathan
HP Labs

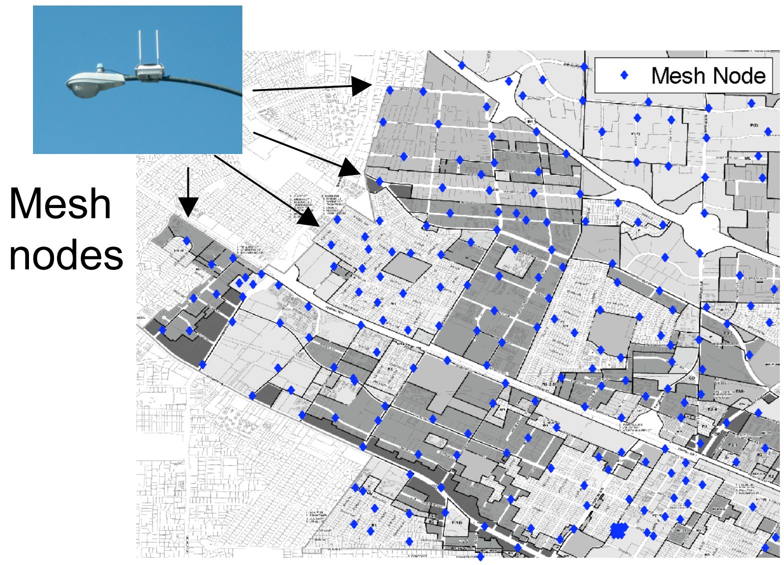
Ed Knightly
Rice University

Urban Wireless Networks

- Goal to provide wireless Internet coverage over large areas
- Low cost by leveraging WiFi/mesh technology
- Challenge: to achieve coverage and capacity subject to cost constraints
- Industry example:
  - "But soon it became clear that dependable reception required more routers than initially predicted, which drastically raised the cost of building the networks." New York Times. March 22, 2008.



Deployment Assessment Problem

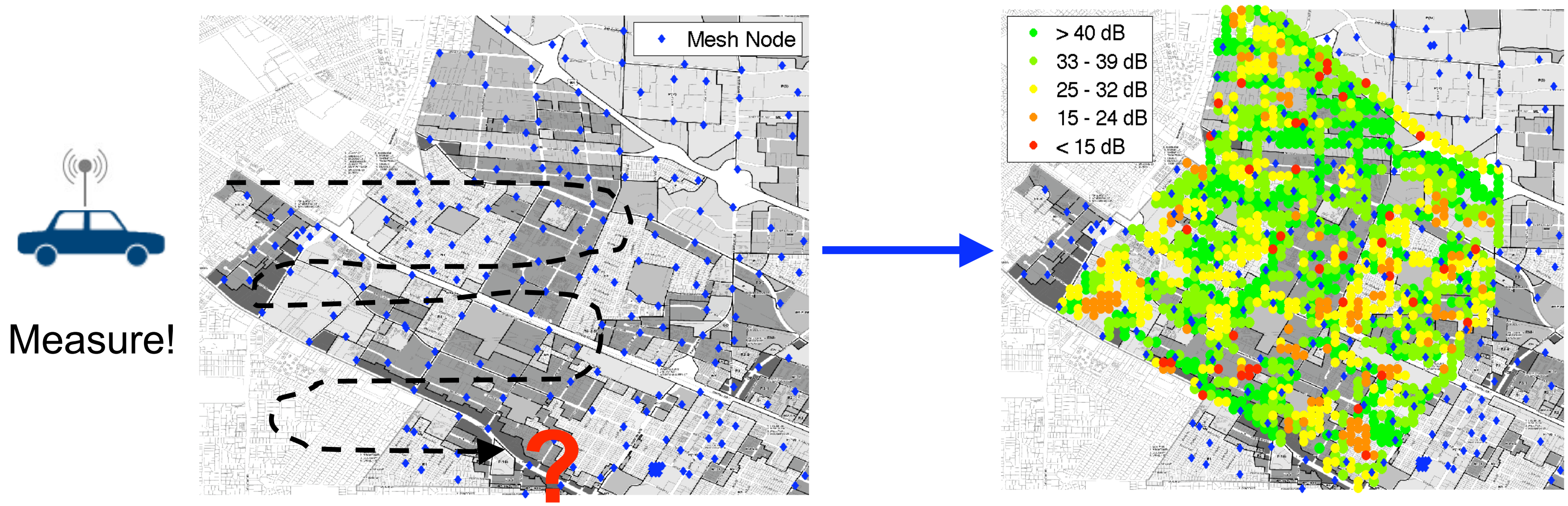


Mesh node locations in GoogleWiFi network

Challenge: Cannot determine actual network performance until network is deployed

Objective: Identify whether each client location meets a performance threshold

Exhaustive Assessment



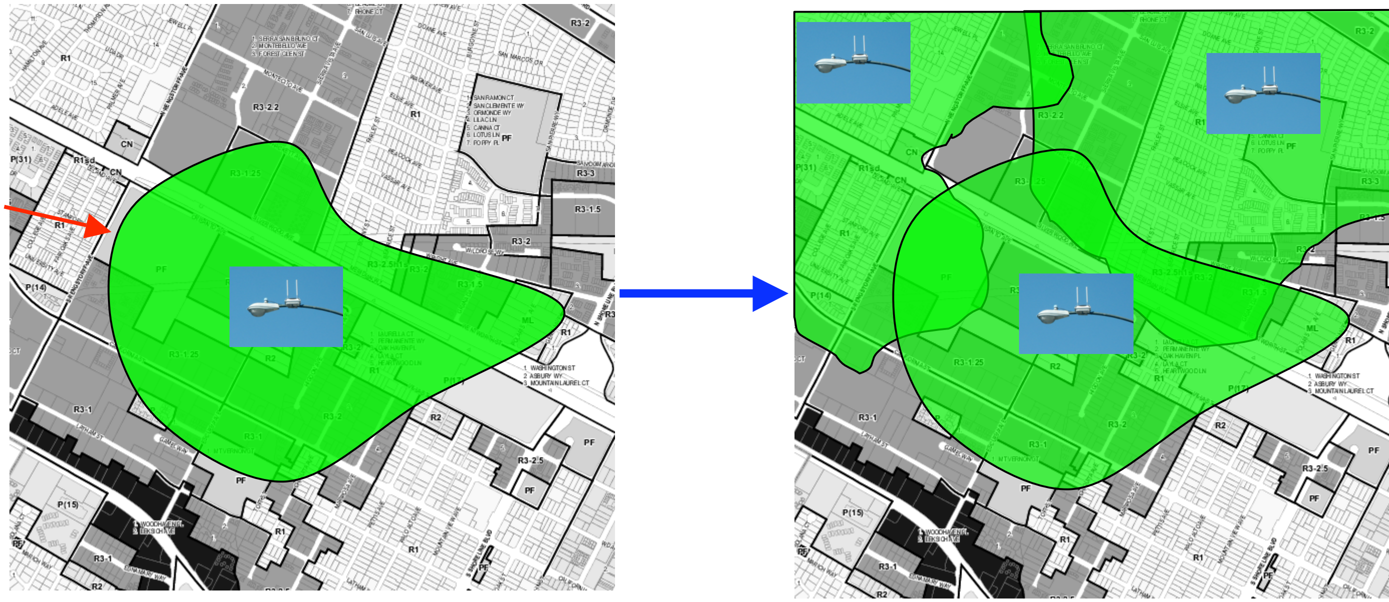
Exhaustive measurement study is prohibitively expensive

- Especially for staged assessment of newly deployed nodes

Instead: Goal is to predict each location's performance with limited measurement budget

Assessment and Estimation

Metric region

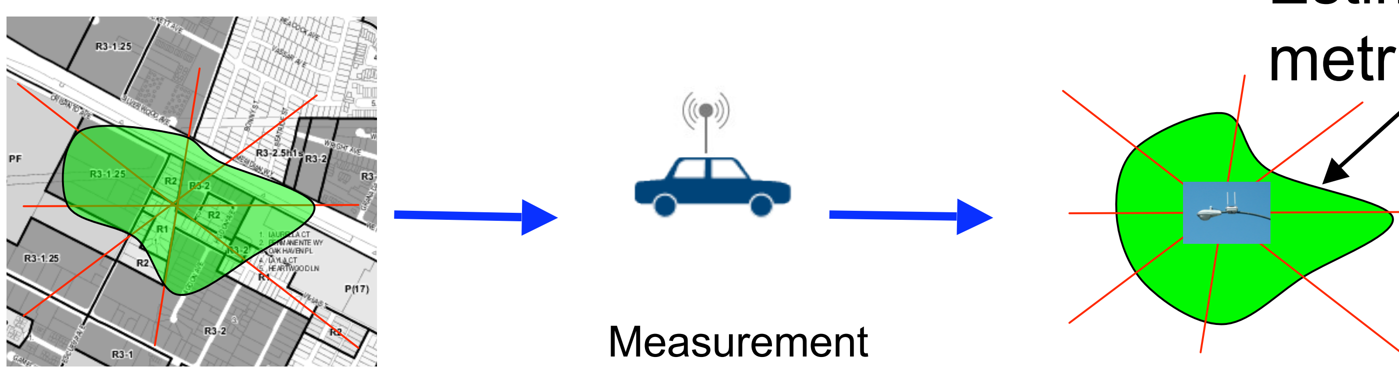


Output: mesh assessment

- To predict, we estimate a mesh node's *metric region*: the set of all locations with measurements meeting a performance threshold
- Related work: ray-tracing used to estimate physical-layer propagation, but high accuracy requires detailed environment info

Assessment Framework

- Present and validate a framework to estimate metric regions through a small number of measurements:
  - Measurement process guided by physical-layer estimation and prior measurement results
  - Metric region estimation using coarse-grained terrain maps and the construction of per-node virtual sectors



Outline

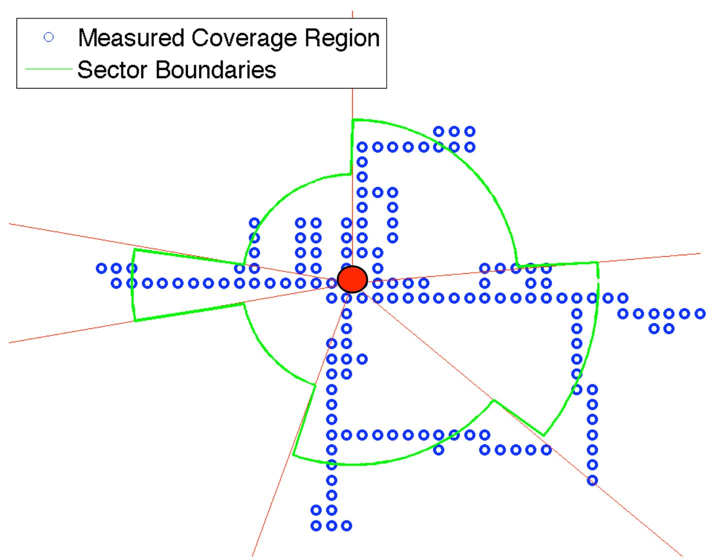
- Introduction
- Framework: Estimation and refinement description
- Validation:
  - Framework accuracy in real networks and error bounds
- Application:
  - Coverage holes in existing deployments
- Conclusion

Metric Sector Framework

Challenge: Non-uniform propagation

Framework approach: Divide metric region into virtual sectors

- Estimate the metric boundary of each sector independently



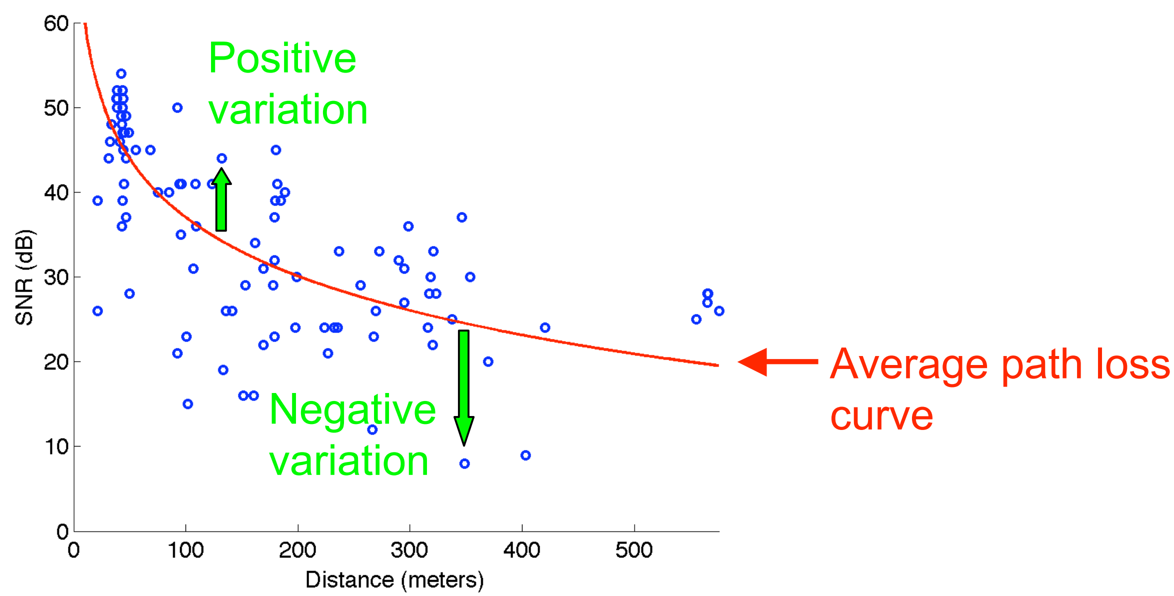
Example node metric region

Estimation of Metric Region

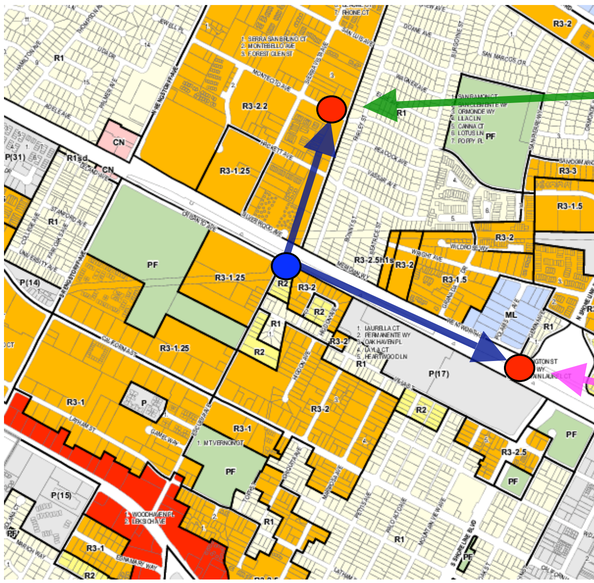
Challenge: Highly variable interactions with terrain results in irregular region boundary

Framework two-stage approach:

1. Predict propagation variations using <u>terrain maps</u> to estimate region boundaries
2. Measure to refine boundaries



Estimation via Terrain Features

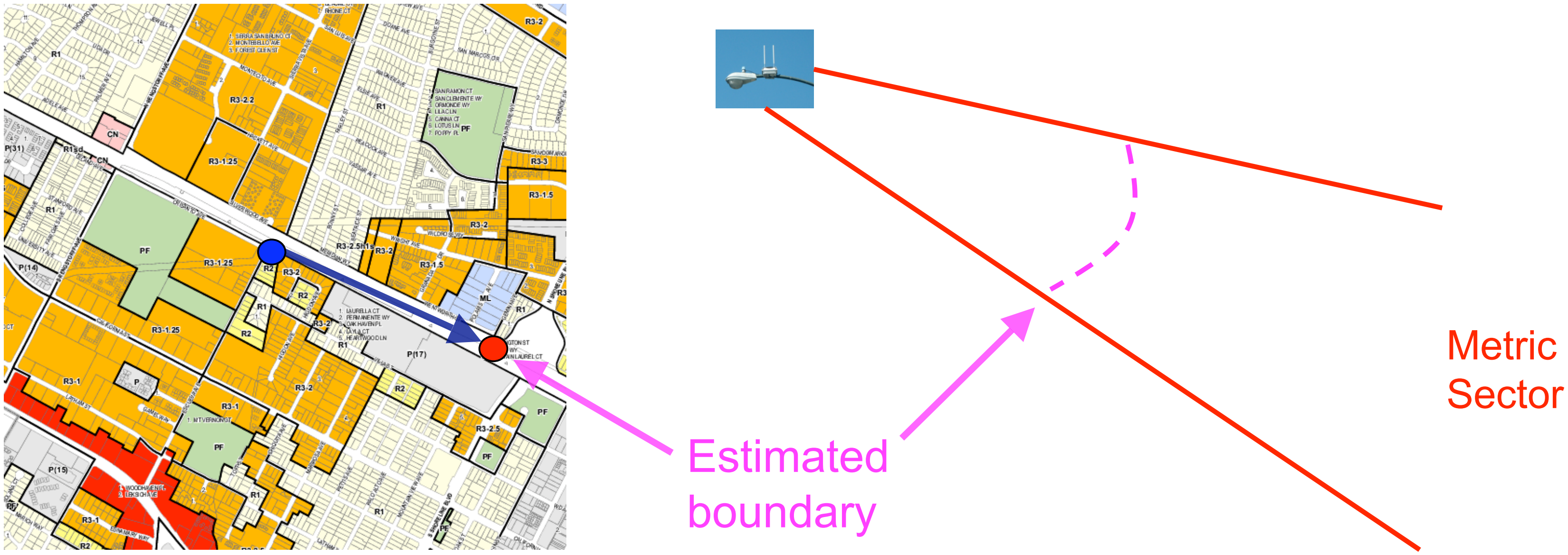


Point 1
Dense apartment buildings --> negative variation

Point 2
Line-of-sight down street --> positive variation

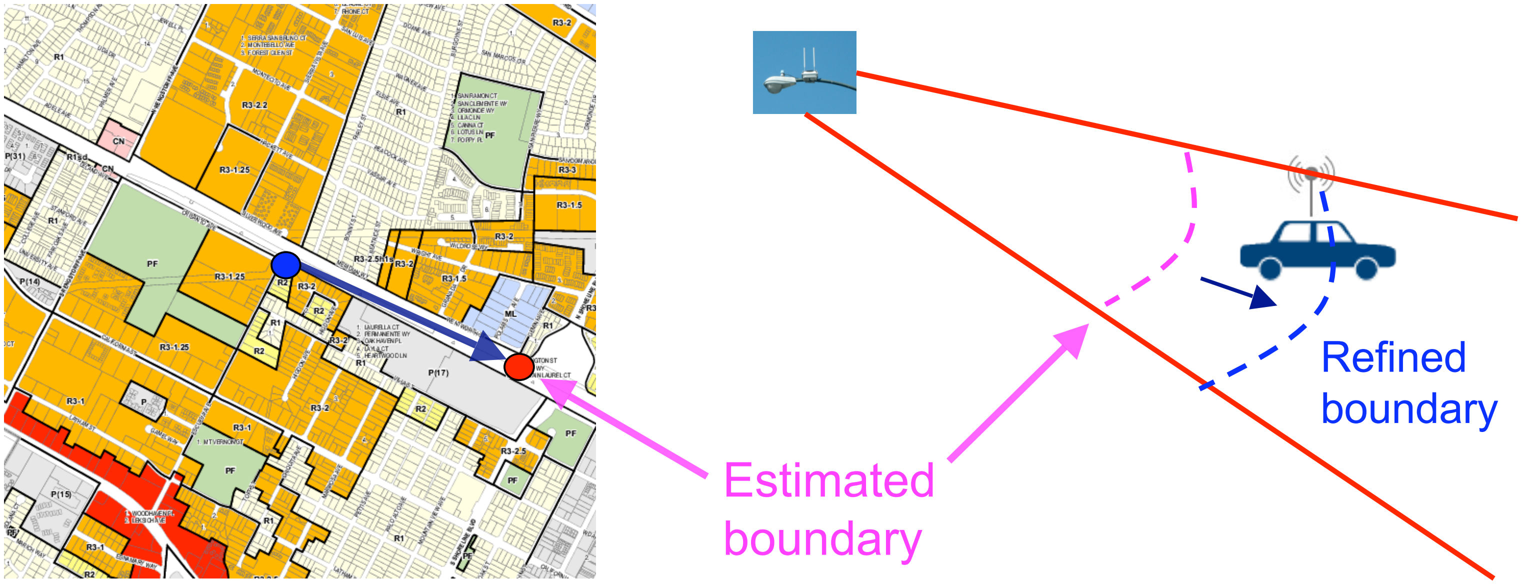
- Estimate metric region boundary using map information
  - Use coarse-grain terrain features to predict variations per link
  - Predicted variation is sum of cumulative impact of each intervening terrain feature
  - Requires training measurements to understand impact of different features

Estimating Sector Boundary



- Limit measurements by refining boundary on per sector basis
  - Number of sectors chosen based on measurement budget
  - Key technique to use estimations to choose sector widths with uniform boundary

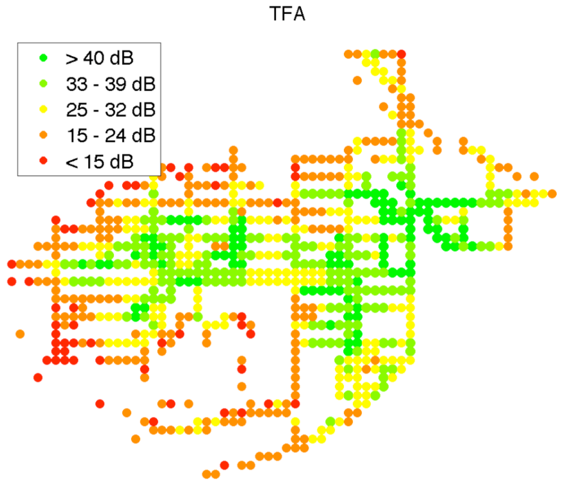
Refining Boundary Estimates

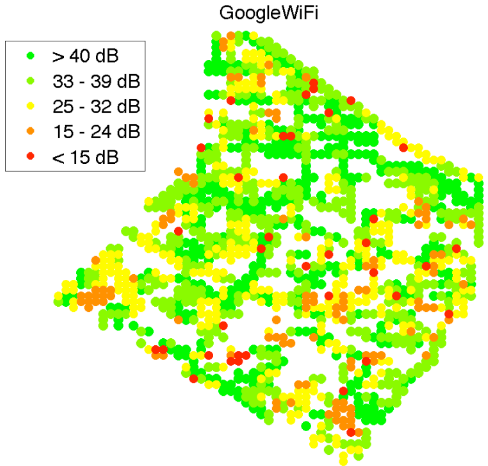


- Design simple push/pull heuristic to move each boundary closer/farther from mesh node
  - Measurement locations guided by estimations and previous measurement results
  - Little state kept to recover from noisy measurements

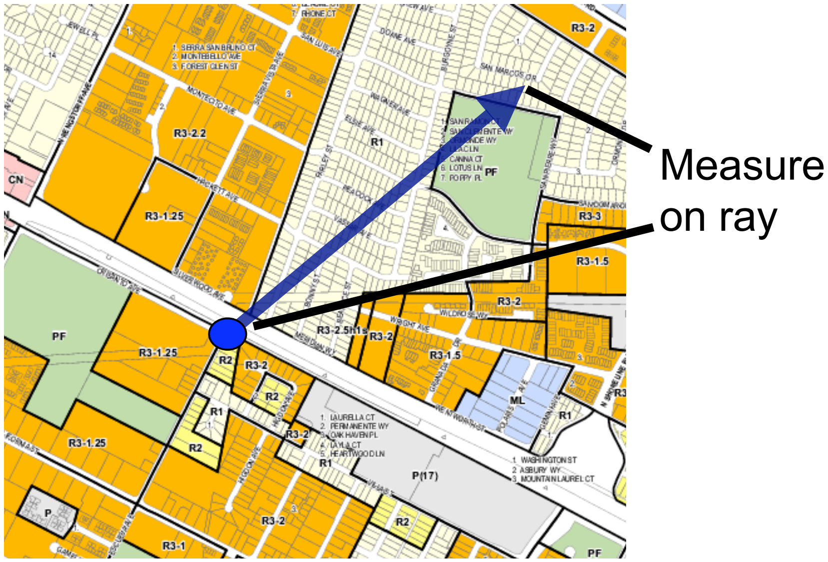
Validation on Deployed Networks

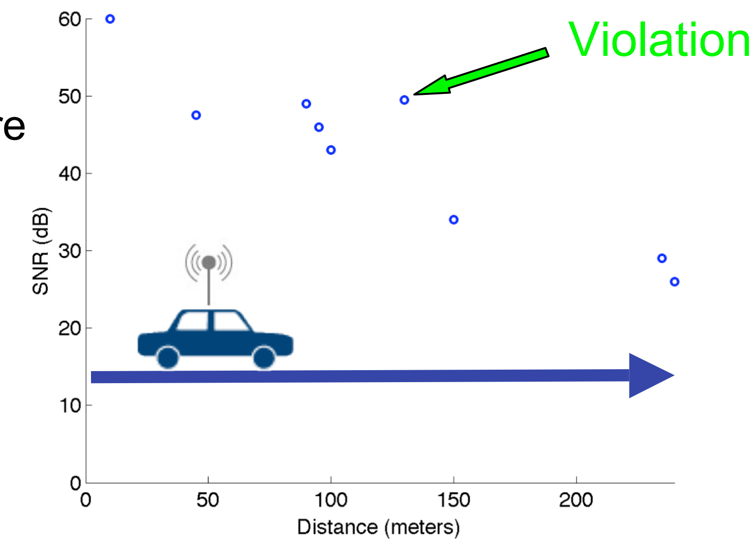
- Approximately 30,000 measured locations in the TFA and GoogleWiFi networks
- Laptop with external antenna
- Different antennas, tree cover, terrain, and target area size
- Evaluate predictive accuracy of our framework with small subset of measurements





Results: Monotonicity Property





- *Monotonicity* property:
  - For any ray from a mesh node, metric **M** is non-increasing with distance
- Allows modeling metric region as a <u>connected</u> region
- Consider metrics that (mostly) satisfy
  - Coverage (SNR) and metrics based on coverage

Coverage Monotonicity

Fig. Probability of violation

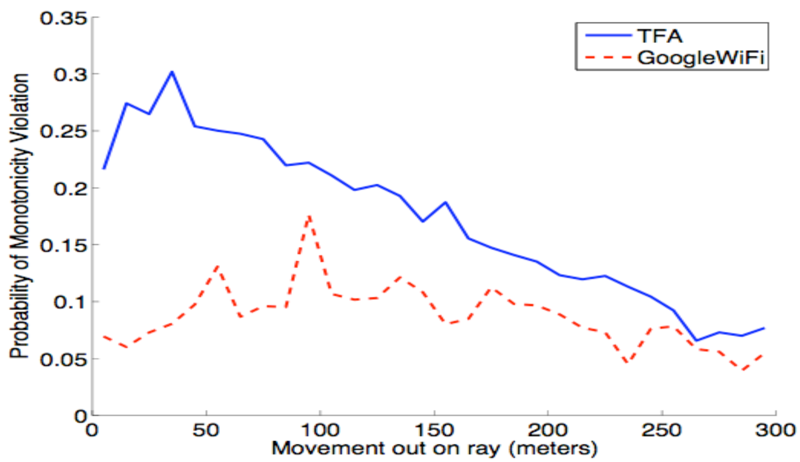
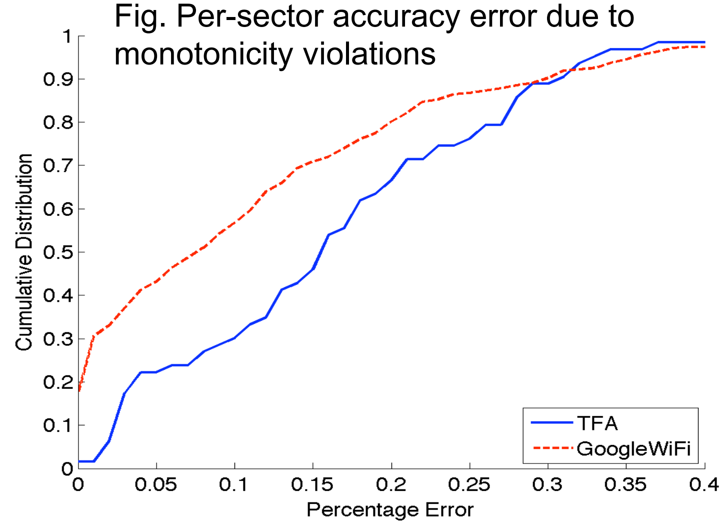


Fig. Per-sector accuracy error due to monotonicity violations



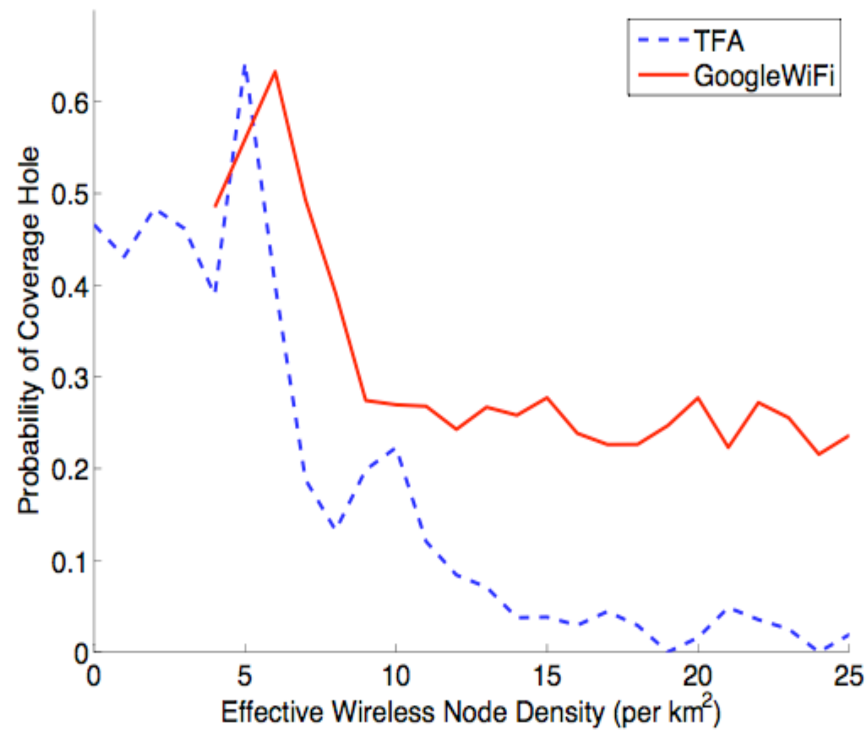
- Monotonicity violations due to multi-path
  - GoogleWiFi features stronger line-of-sight links
- Result in average error per sector of 10% for GoogleWiFi and 15% for TFA
- Results show that estimation and refinement achieve within 3% of upper bound

Application: Coverage Holes

- Coverage hole is a location outside of any coverage region
- As function of effective deployment density at client locations
- TFA and GoogleWiFi use different hardware, so same probabilities are not expected

Examining Coverage Holes

- GoogleWiFi hole probability has much weaker dependence on deployment density
- Holes likely to be in sector with worse-than-average propagation
- Indicates small “trouble” spots where increasing node density does not help
- Client-side solutions may be most cost-effective



Assessment Contributions

- Show accurate estimation by coupling terrain maps, per-node virtual sectorization, and measurement refinement
- Show that despite violations of the monotonicity property, framework attains high accuracy on real deployments
- In existing deployments, apply framework to study coverage holes and load balancing
  - Key challenge: large number of additional nodes needed to eliminate numerous small coverage holes

http://tfa.rice.edu/ -- TFA background/info

http://tfa.rice.edu/measurements/ -- measurement data

http://networks.rice.edu