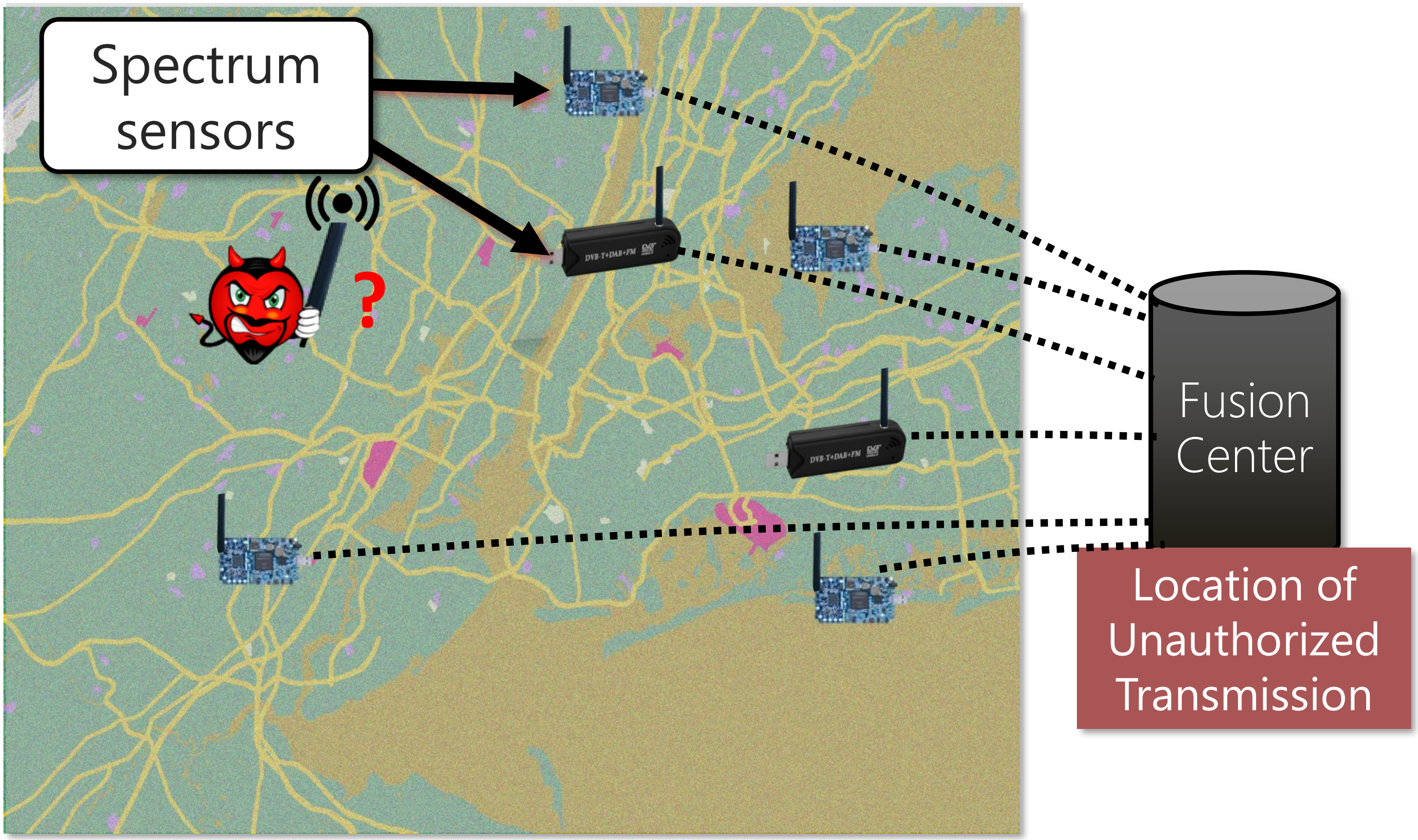
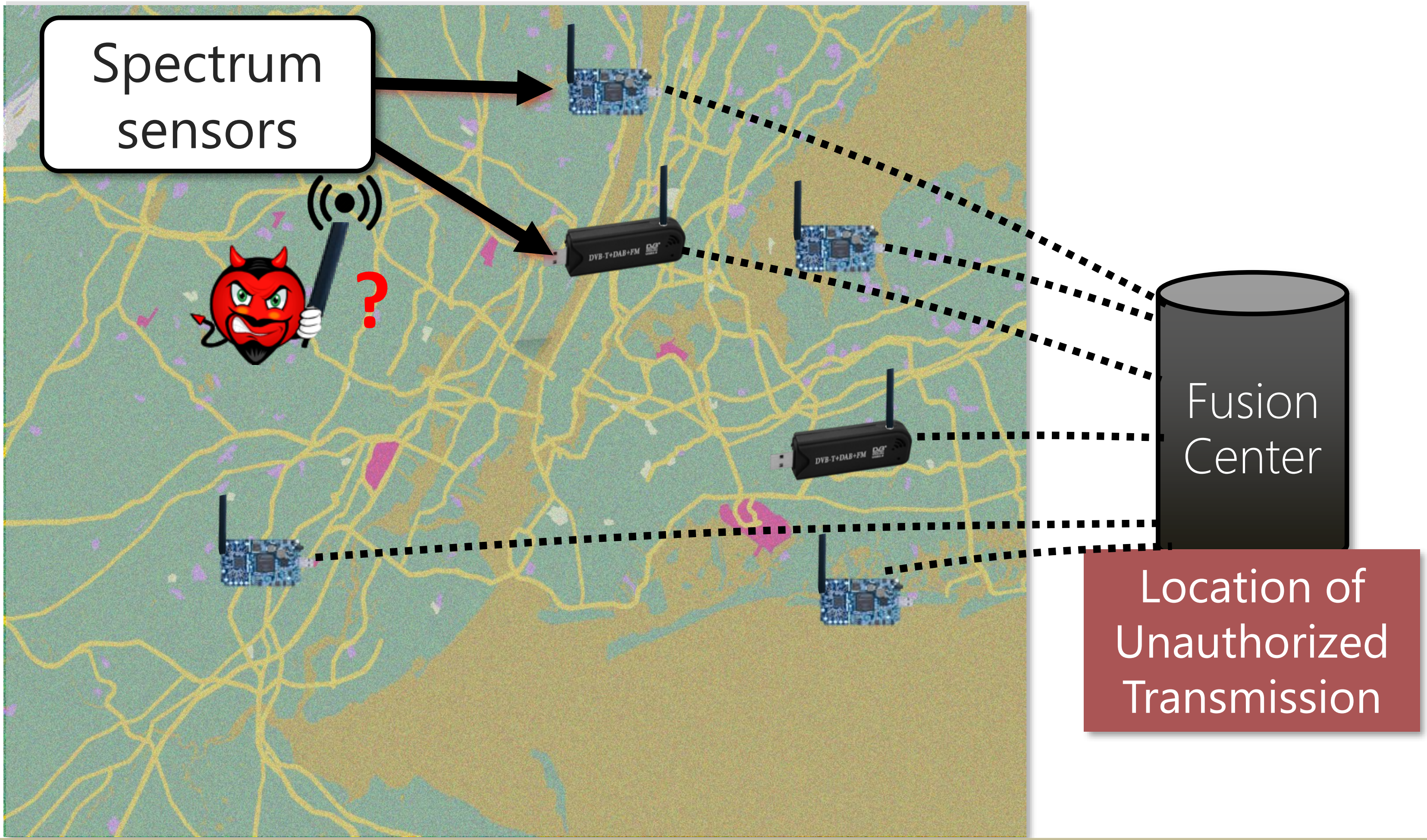
Fast and Efficient Online Selection of Sensors for Transmitter Localization

Arani Bhattacharya, Abhishek Maji,
Jaya Prakash Verma Champati, James Gross

A Distributed Spectrum Monitoring System to Identify Unauthorized Transmissions

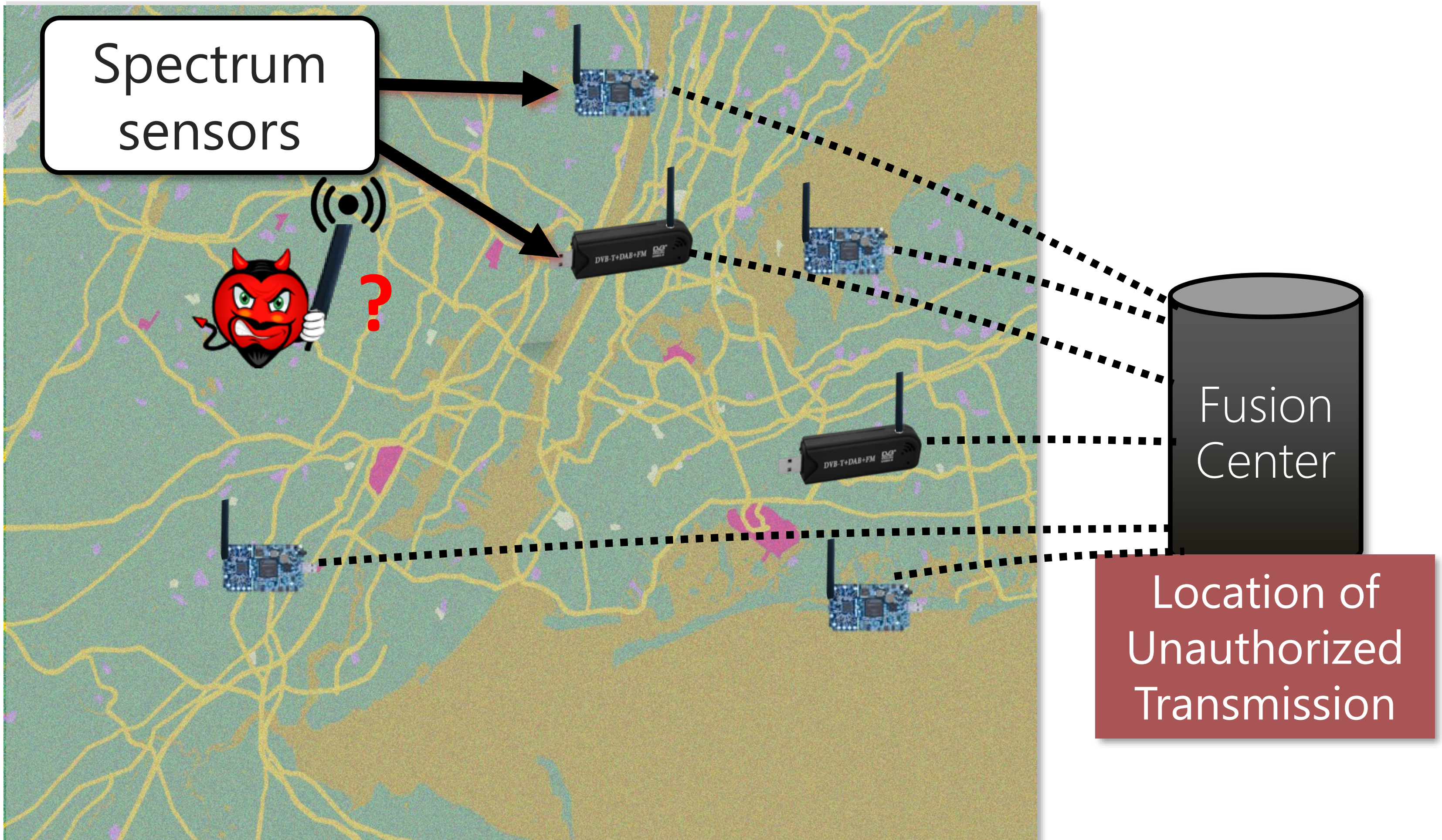


A Distributed Spectrum Monitoring System to Identify Unauthorized Transmissions



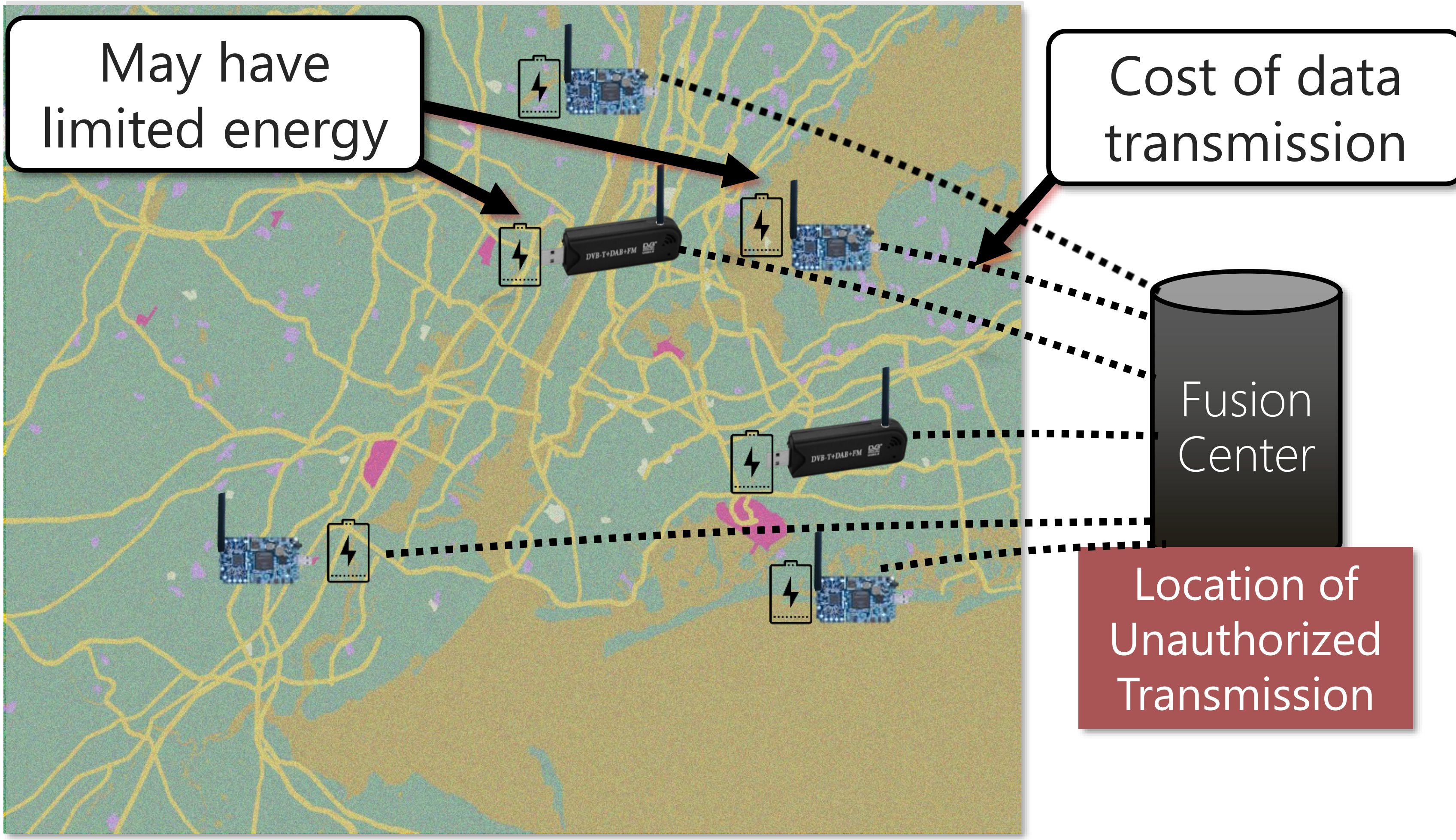
Deploy large number of cheap but noisy spectrum sensors;

A Distributed Spectrum Monitoring System to Identify Unauthorized Transmissions

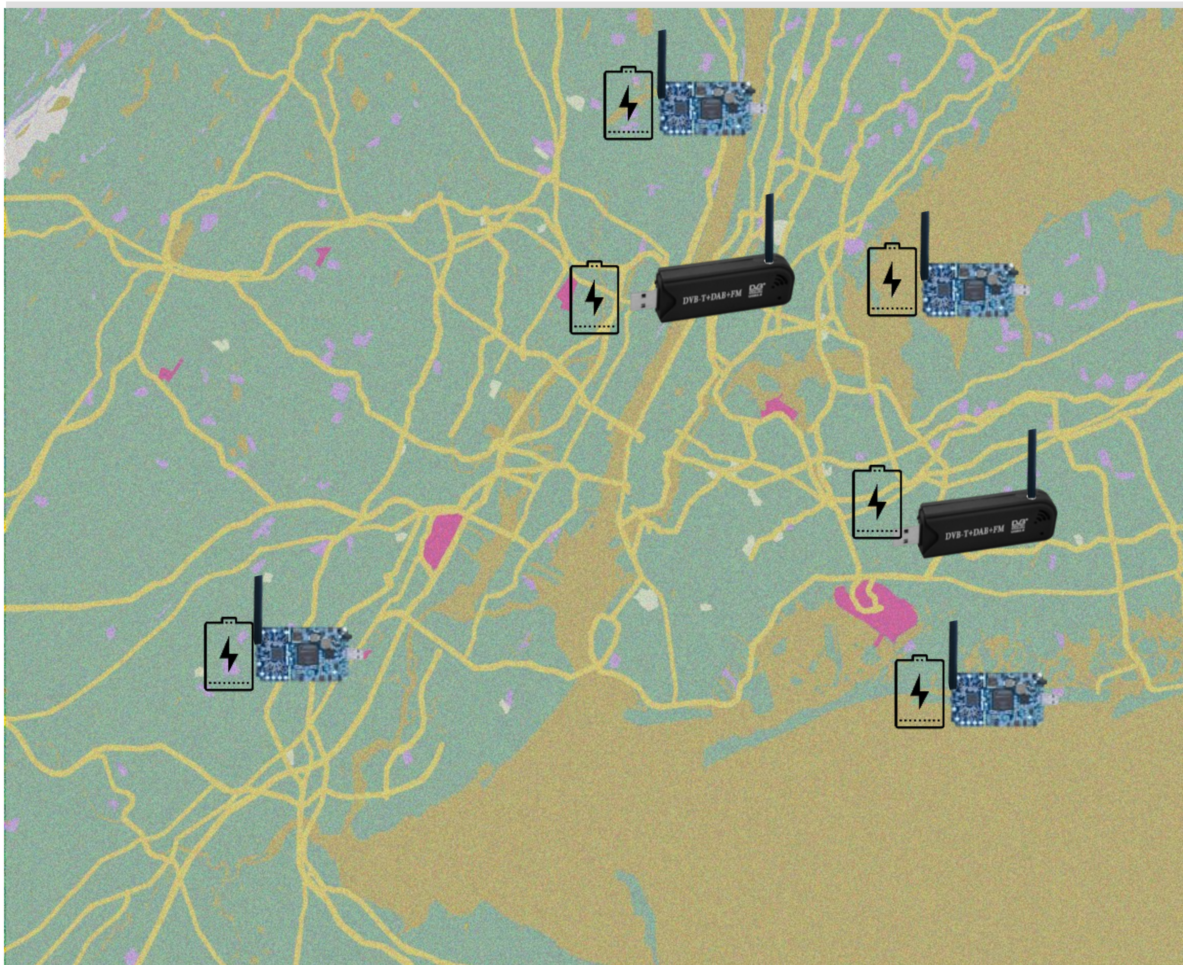


Deploy large number of cheap but noisy spectrum sensors; utilize robust localization to reduce impact of noise

Running Sensors has a Recurring Cost



A Number of Prior Works have Focused on Sensor Selection

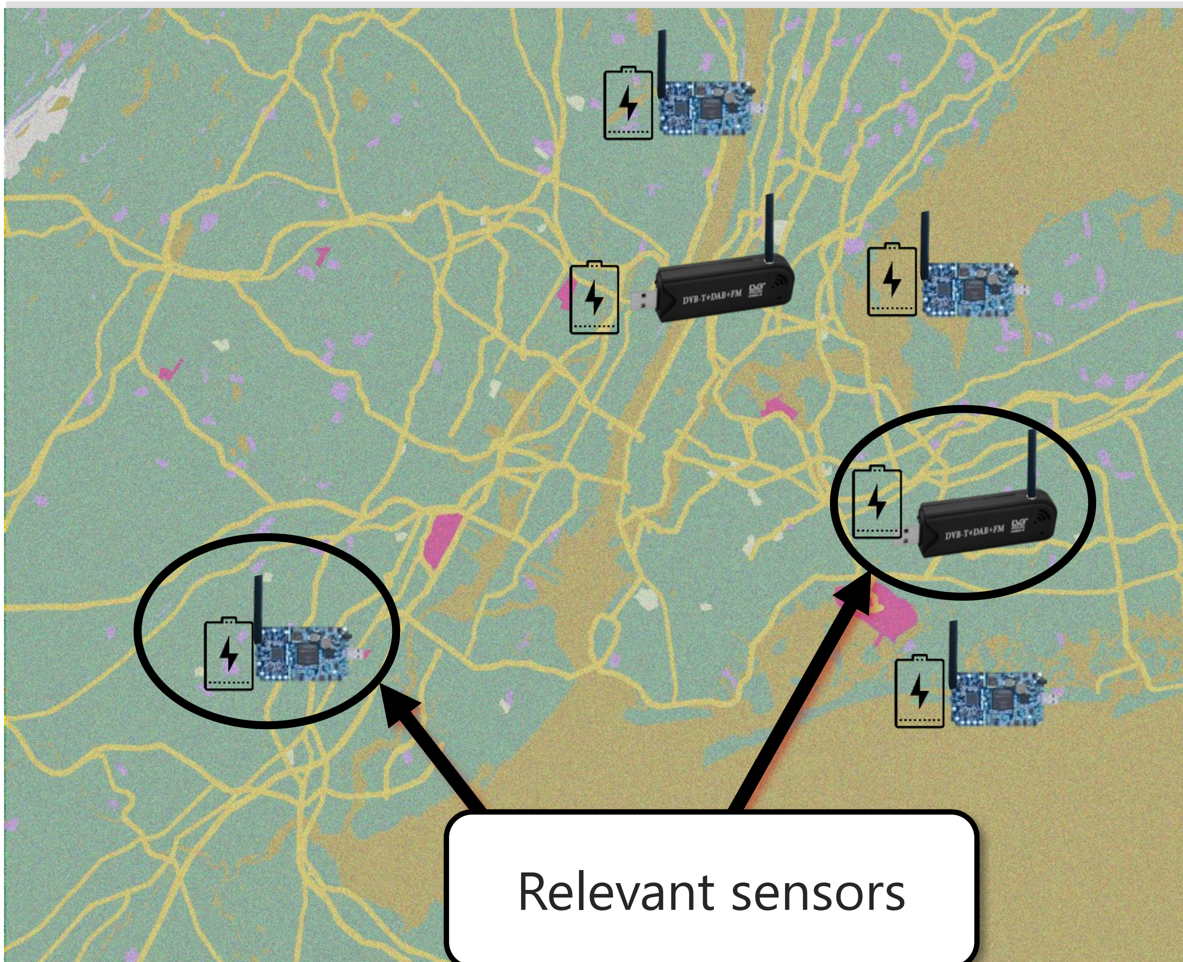


Select sensors

Bhattacharya et al., “Selection of Sensors for Efficient Transmitter Localization”, IEEE/ACM Transactions on Networking 2021

M. Khaledi et al., “Simultaneous power-based localization of transmitters for crowdsourced spectrum monitoring”, ACM Mobicom 2017

A Number of Prior Works have Focused on Sensor Selection



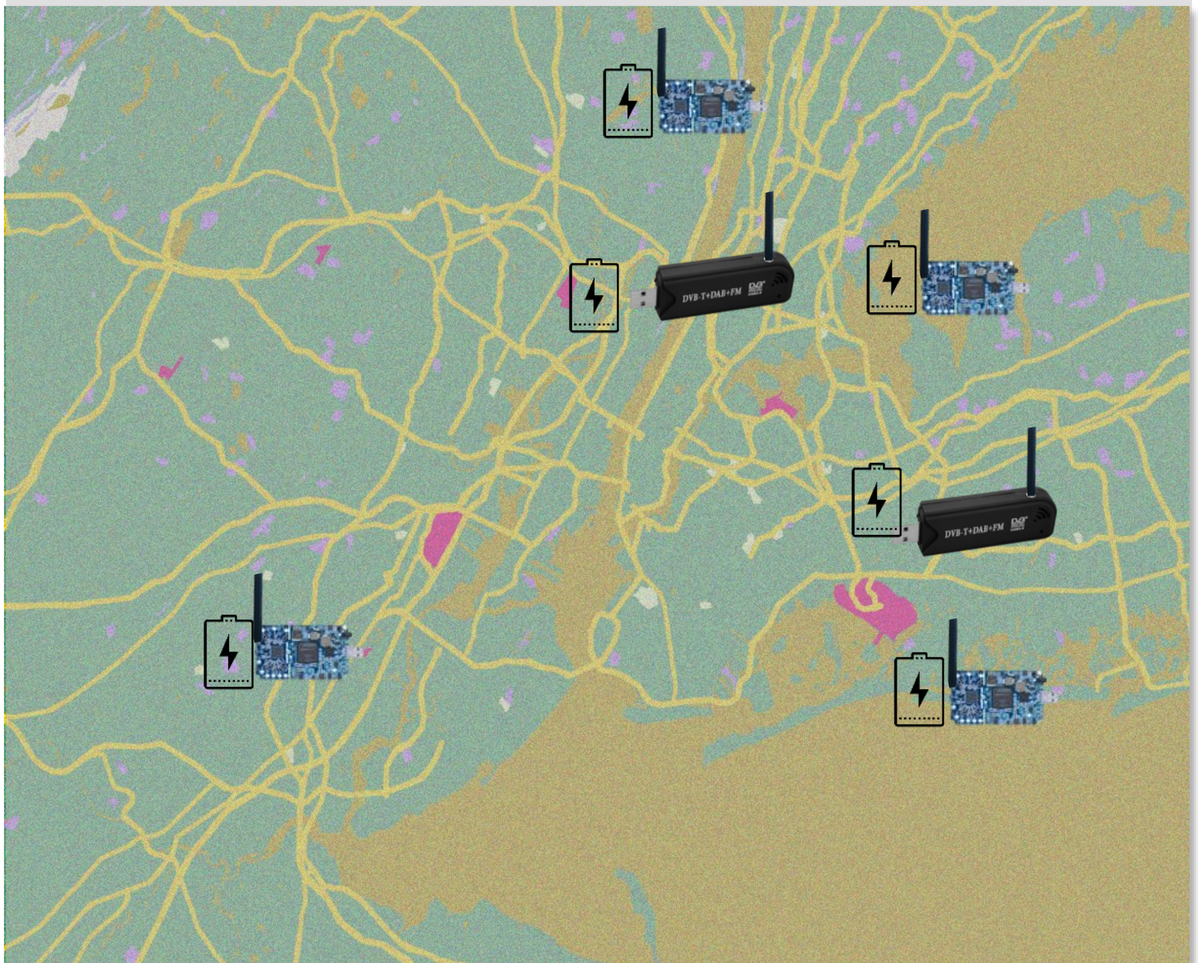
Select sensors

Bhattacharya et al., "Selection of Sensors for Efficient Transmitter Localization", IEEE/ACM Transactions on Networking 2021

M. Khaledi et al., "Simultaneous power-based localization of transmitters for crowdsourced spectrum monitoring", ACM Mobicom 2017

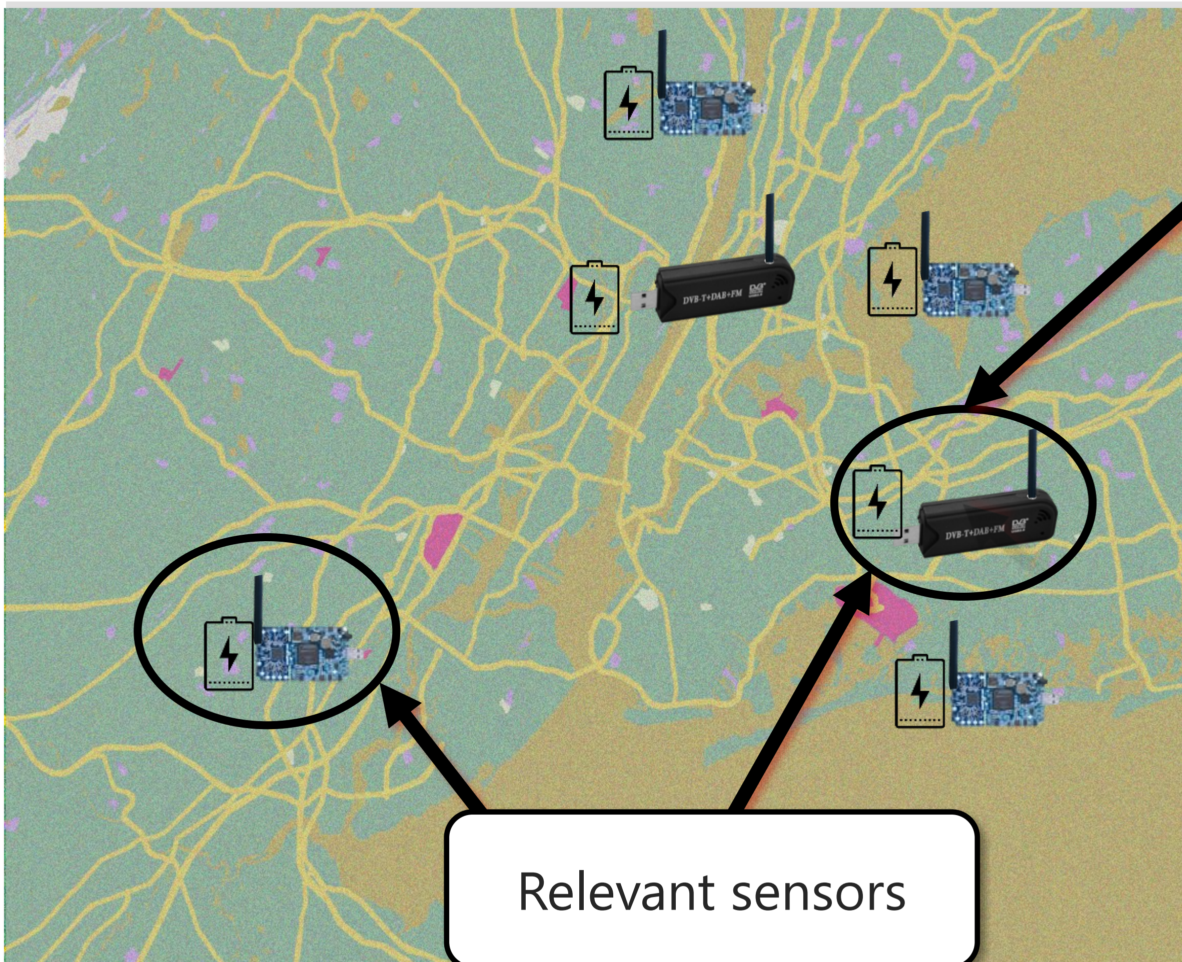
Select the most relevant sensors and keep them running to localize unauthorized transmission

Drawbacks of Standard Sensor Selection



Selected sensors keep running continuously, thus consuming bandwidth and energy

Drawbacks of Standard Sensor Selection

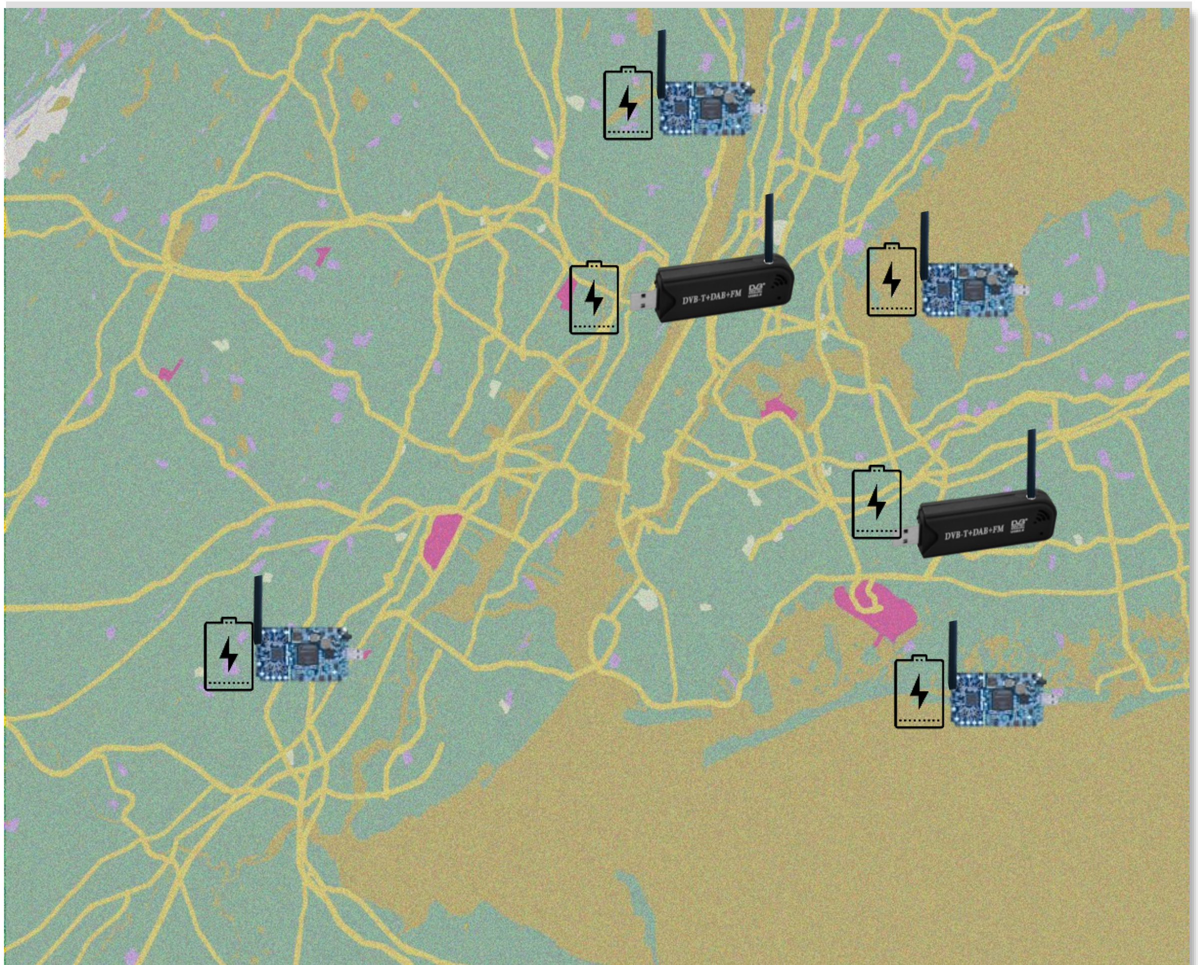


Selected sensors keep running continuously, thus consuming bandwidth and energy

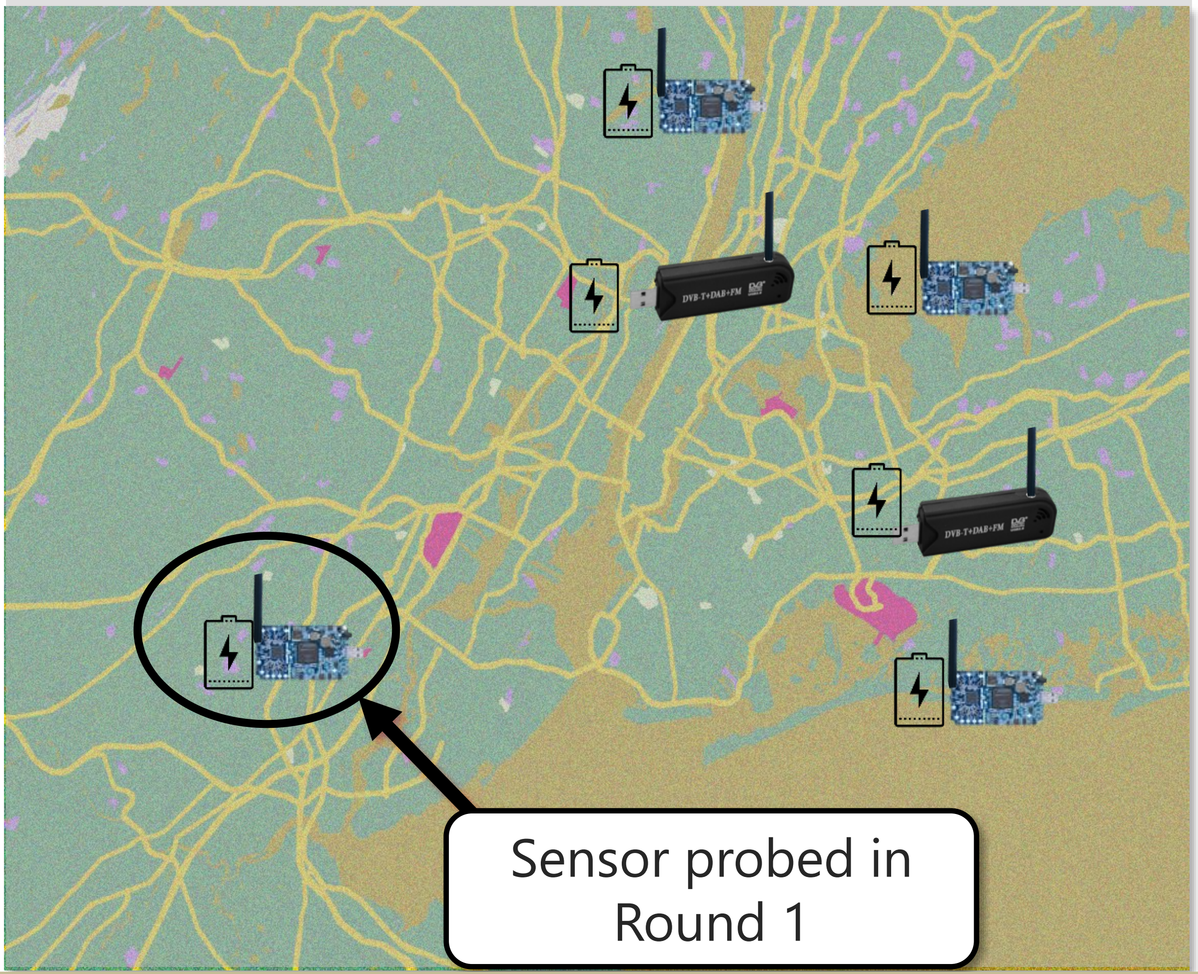
Relevant sensors

Can we reduce cost even further?

Feedback from a Few Sensors can be used to Probe Additional Sensors

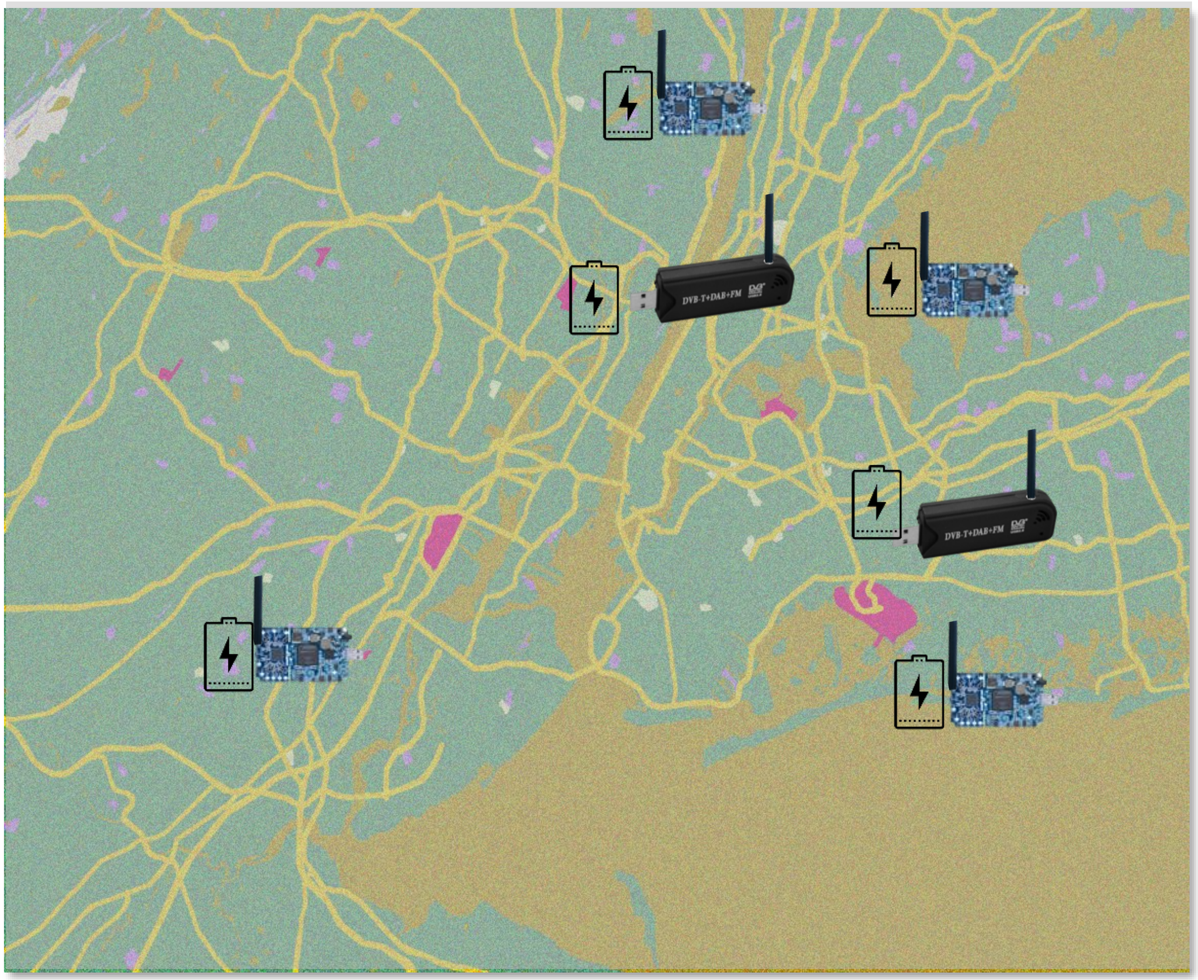


Feedback from a Few Sensors can be used to Probe Additional Sensors

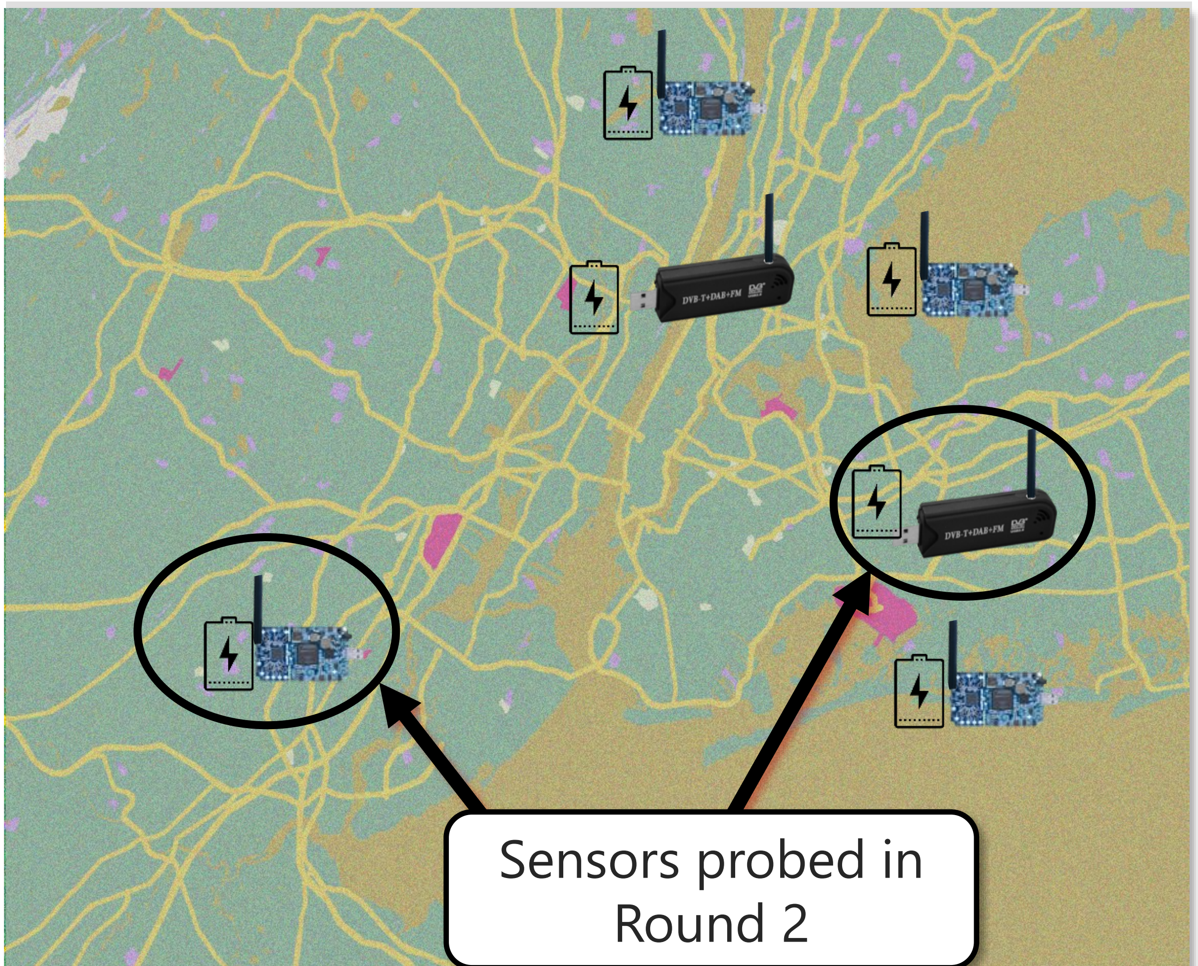


Can we reduce cost even further?

Feedback from a Few Sensors can be used to Probe Additional Sensors

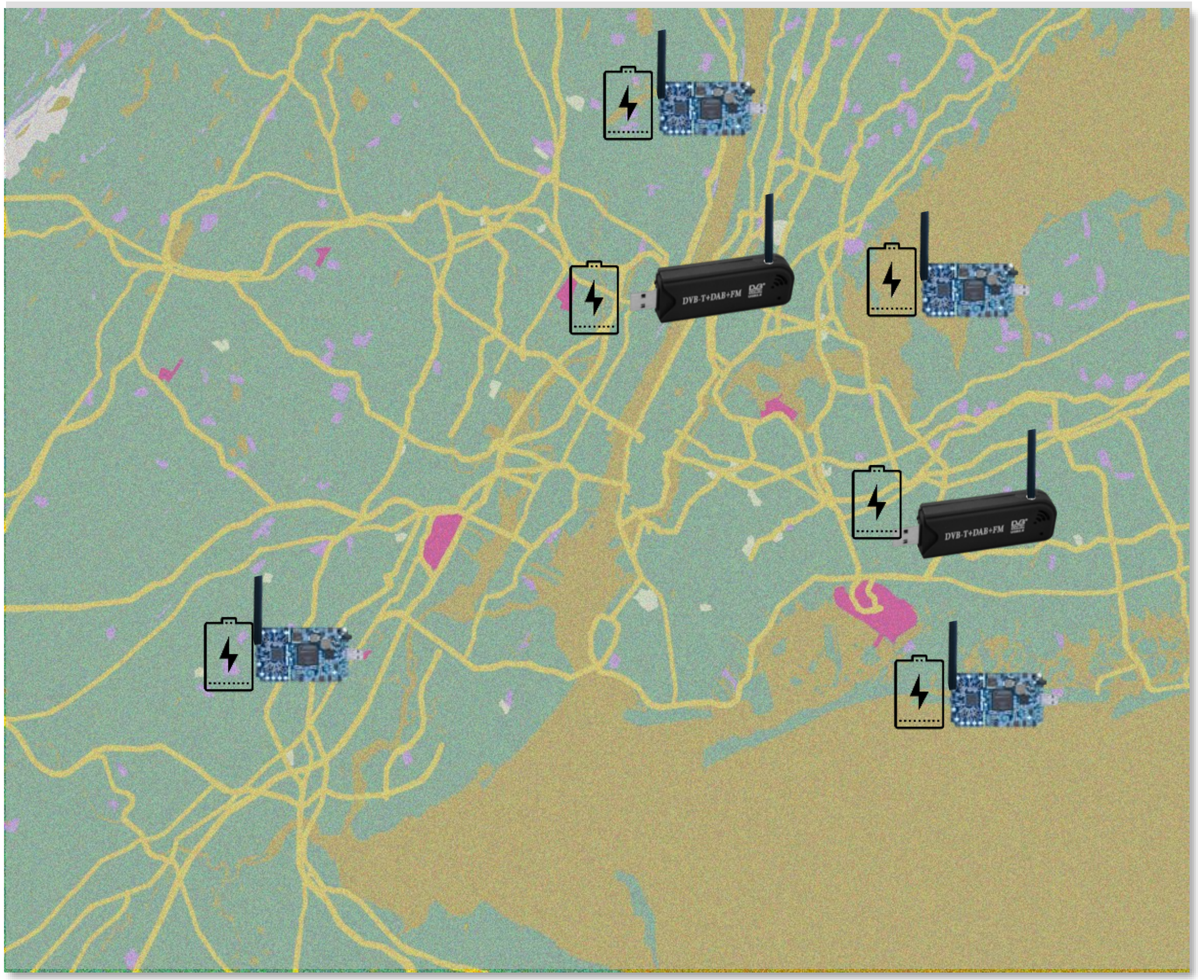


Feedback from a Few Sensors can be used to Probe Additional Sensors

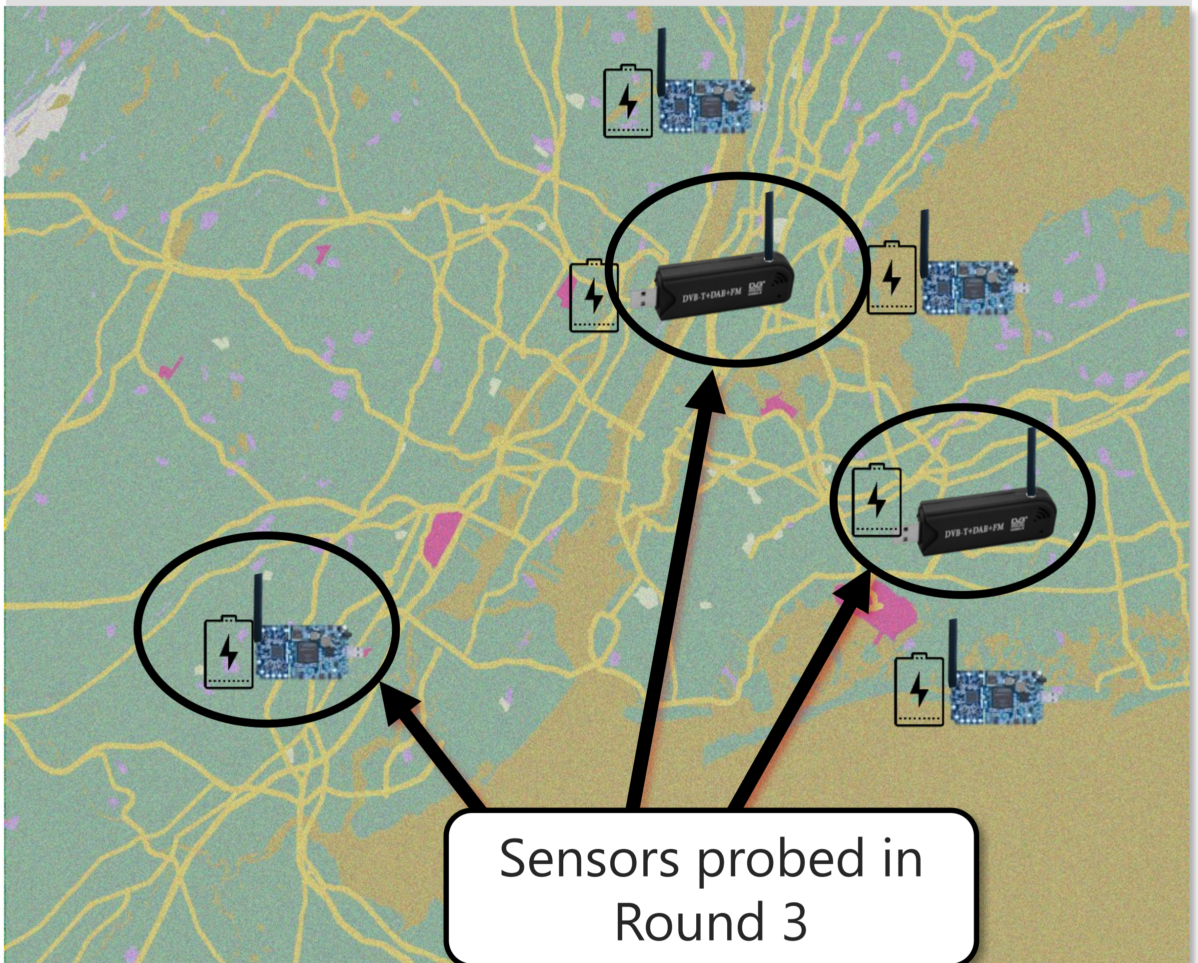


Can we reduce cost even further?

Feedback from a Few Sensors can be used to Probe Additional Sensors

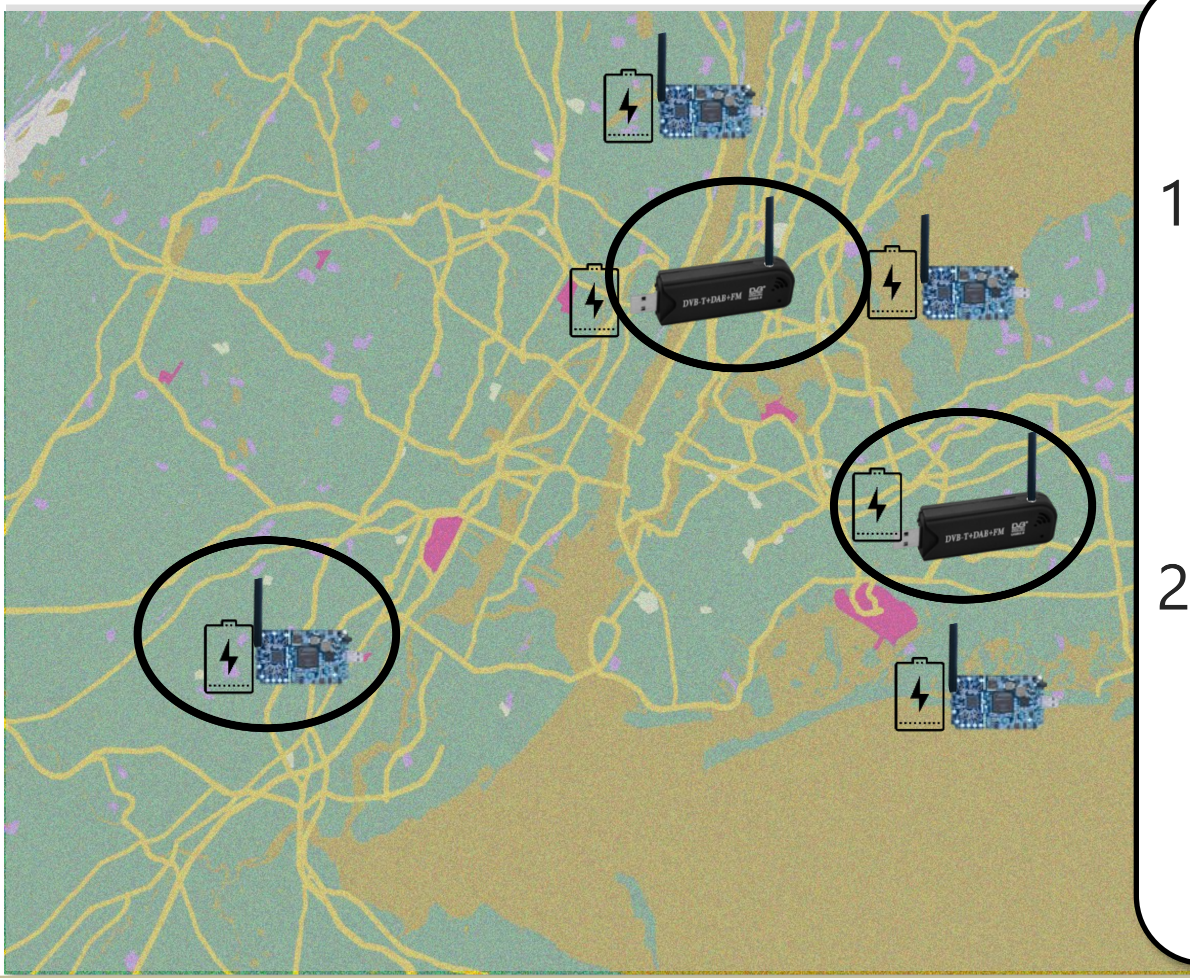


Feedback from a Few Sensors can be used to Probe Additional Sensors



Sequential sensor selection can reduce cost of spectrum monitoring by helping reduce running time of sensors

Challenges of Sequential Sensor Selection



1. Localization becomes slower as feedback needs to be incorporated
2. Greedy method is no longer the best technique

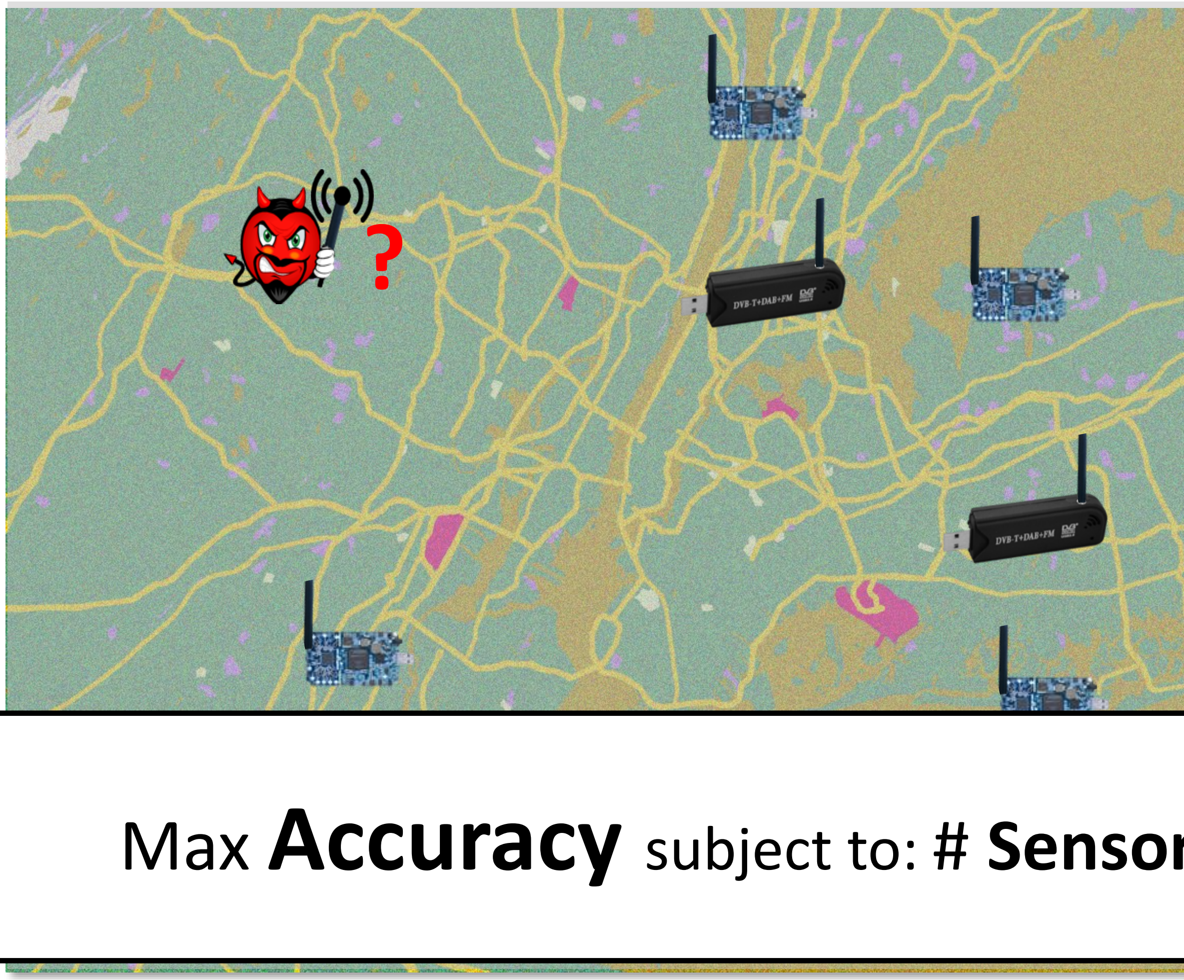
Our goal is to make sequential sensor selection feasible

Content

- Motivation of Sensor Selection
- Problem Formulation and Basic Algorithm
- Our Algorithm
- Evaluation

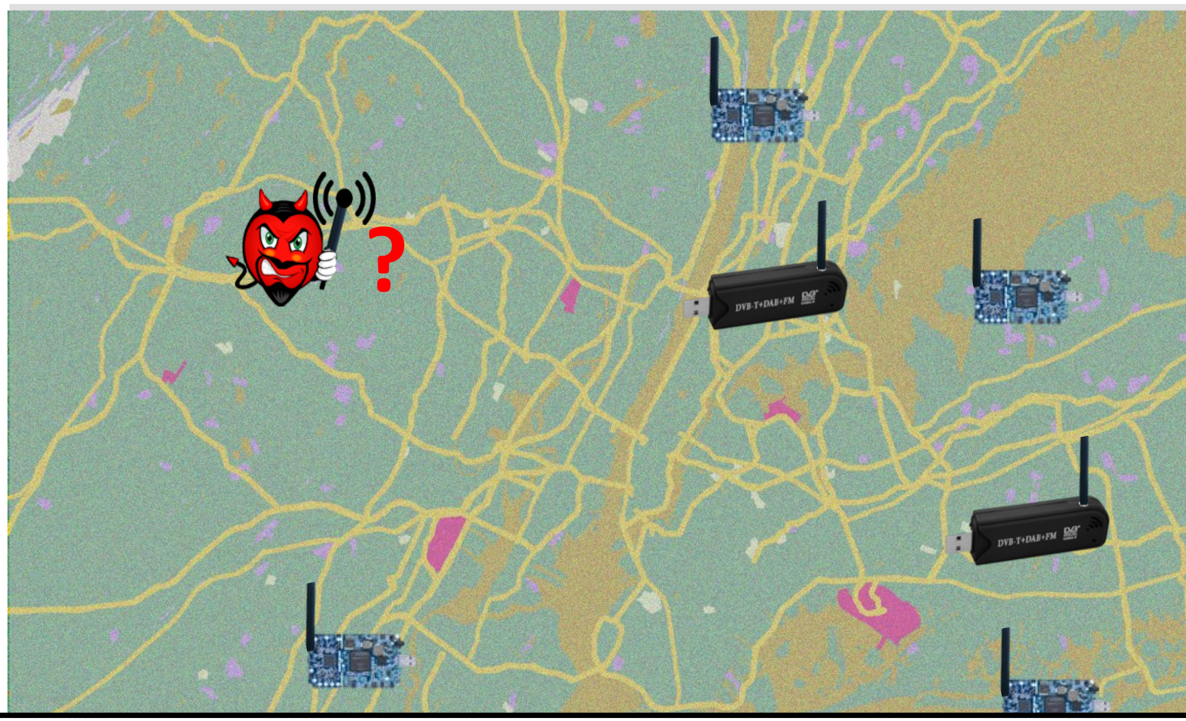
Sensor Selection: Optimization Problem

Sensor Selection: Optimization Problem



Max **Accuracy** subject to: # **Sensors** ≤ **Budget**

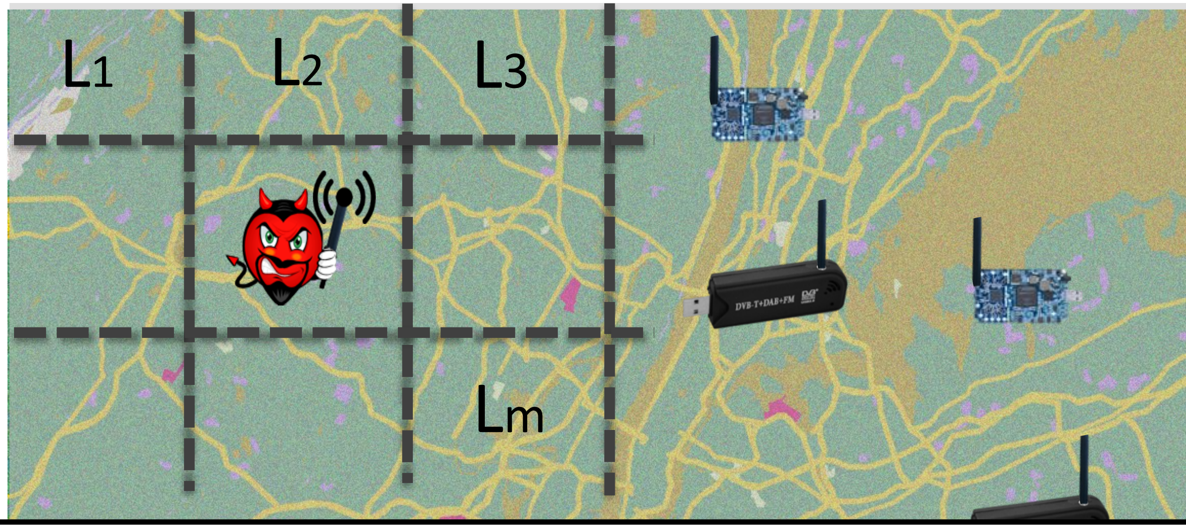
Sensor Selection: Optimization Problem



Max **Accuracy** subject to: # **Sensors** ≤ **Budget**

Accuracy = Posterior probability of ground truth

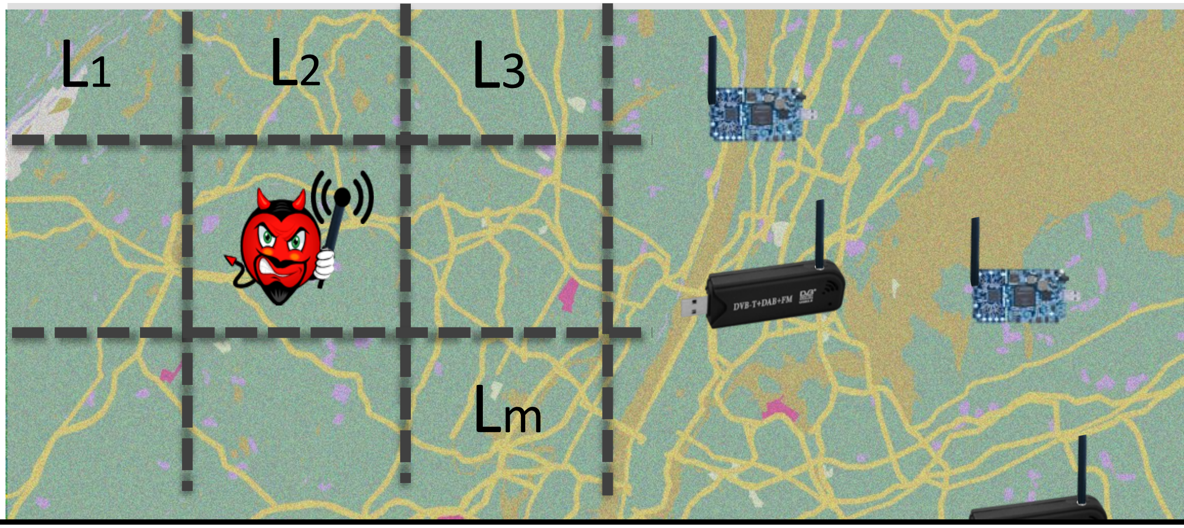
Sensor Selection as an Optimization Problem



Max $\sum_{\mathbf{i}} \mathbf{P}(\boldsymbol{H_i}|\mathbf{L_i})\mathbf{P}(\mathbf{L_i})$ subject to: $\boldsymbol{T} = \cup_{\boldsymbol{k=1}}^{\boldsymbol{K}} \boldsymbol{T_i}$; $|\boldsymbol{T}| \le \mathbf{B}$; $\mathbf{T} \subseteq \mathbf{S}$

$\boldsymbol{T_i}$ = sensor subset in stage i; S = available sensors; B = budget

Sensor Selection as an Optimization Problem



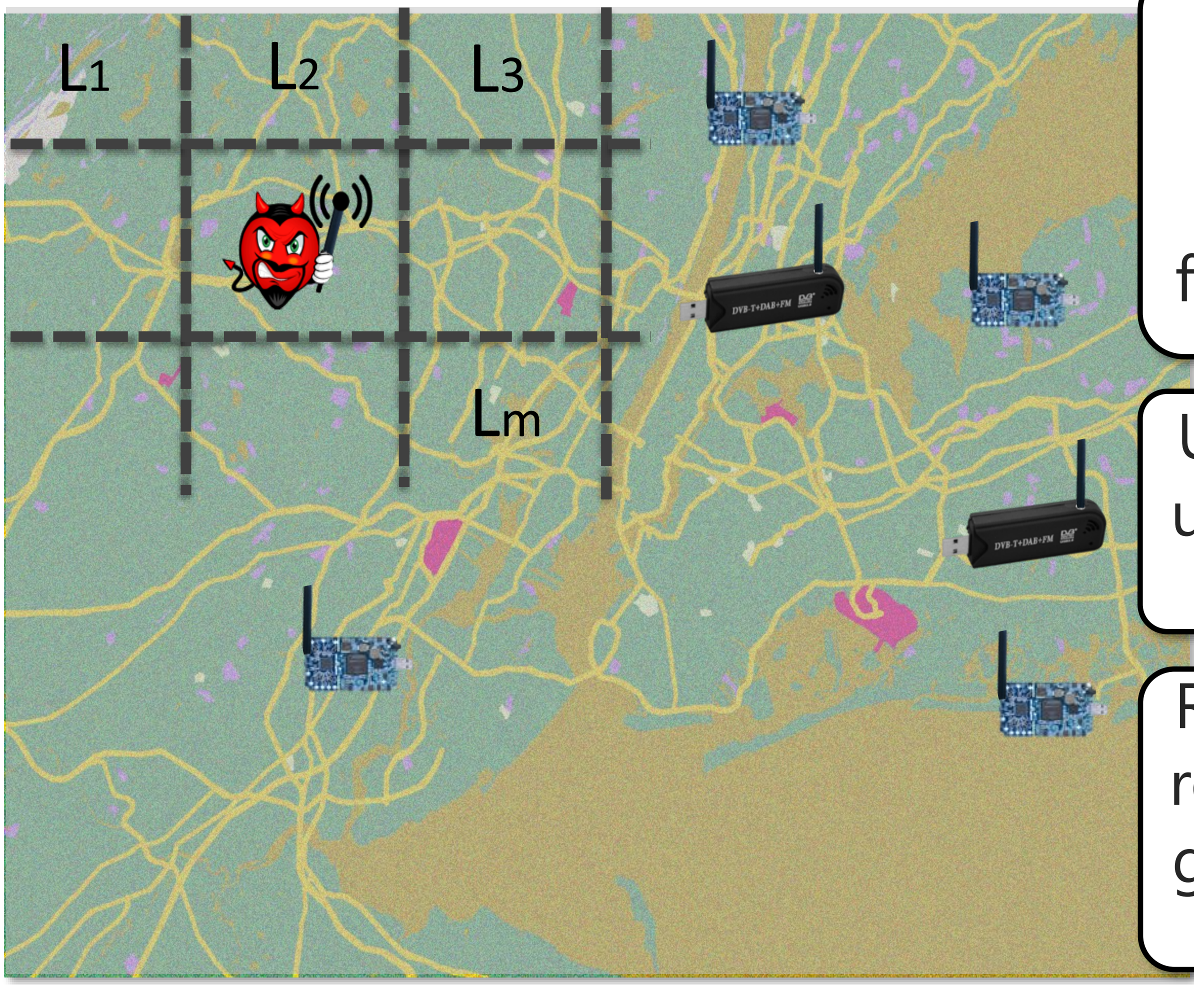
Max $\sum_{\mathbf{i}} \mathbf{P}(\boldsymbol{H_i}|\mathbf{L_i})\mathbf{P}(\mathbf{L_i})$ subject to: $\boldsymbol{T} = \cup_{\boldsymbol{k=1}}^{\boldsymbol{K}} \boldsymbol{T_i}$; $|\boldsymbol{T}| \leq \mathbf{B}$; $\mathbf{T} \subseteq \mathbf{S}$

$\boldsymbol{T_i}$ = sensor subset in stage i; S = available sensors; B = budget

NP-Hard Problem; variant of stochastic set cover.

Our goal is to find an approximate solution

Baseline Strategy: Greedy Approach



Select the sensor with the highest probability of finding transmitter

Update the beliefs using Bayes rule at the fusion center

Return if budget is reached; otherwise go back and select next sensor

Baseline Strategy: Greedy Approach

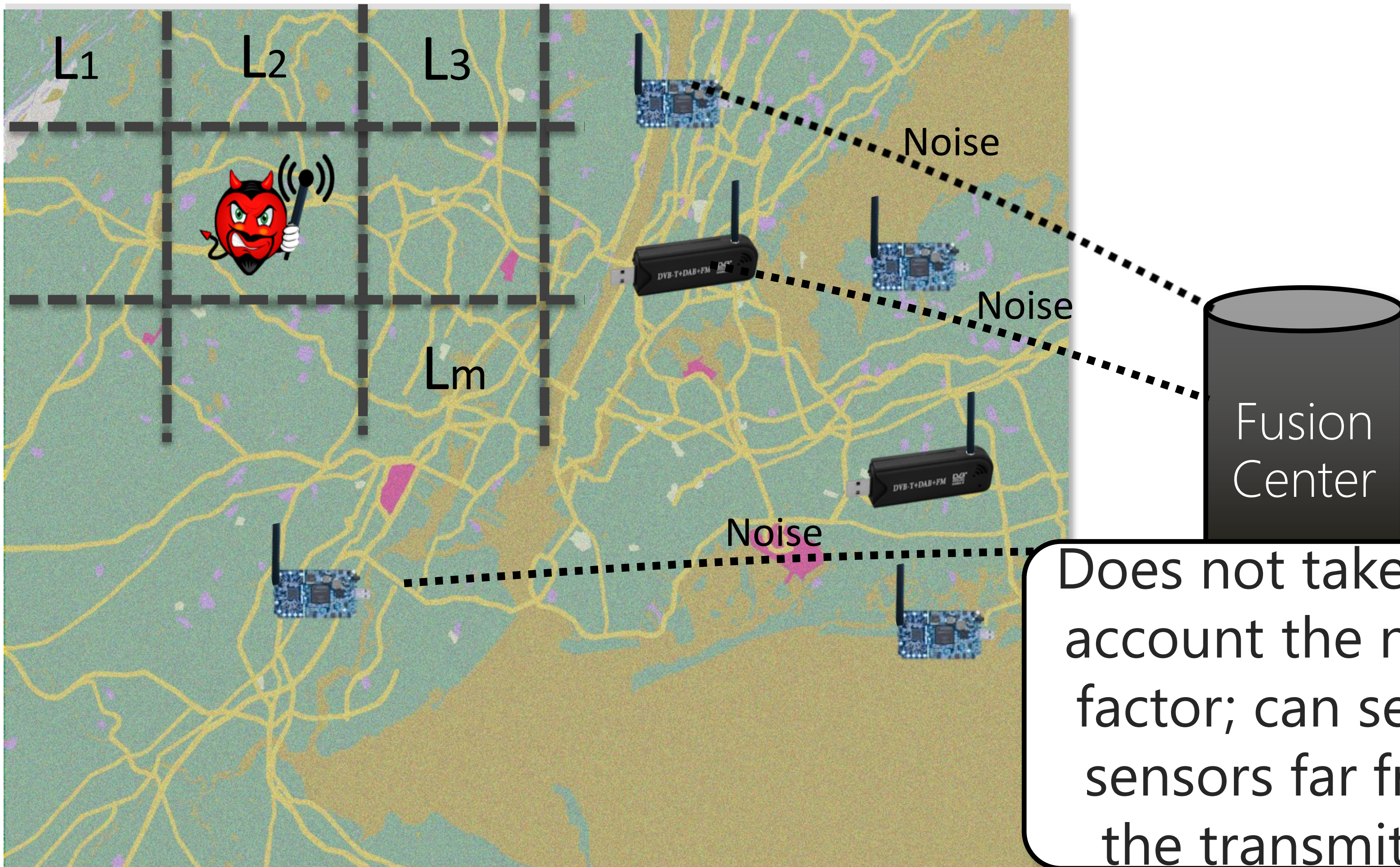
Select the sensor with the highest probability of finding transmitter

Update the beliefs using Bayes rule at the fusion center

Return if budget is reached; otherwise go back and select next sensor

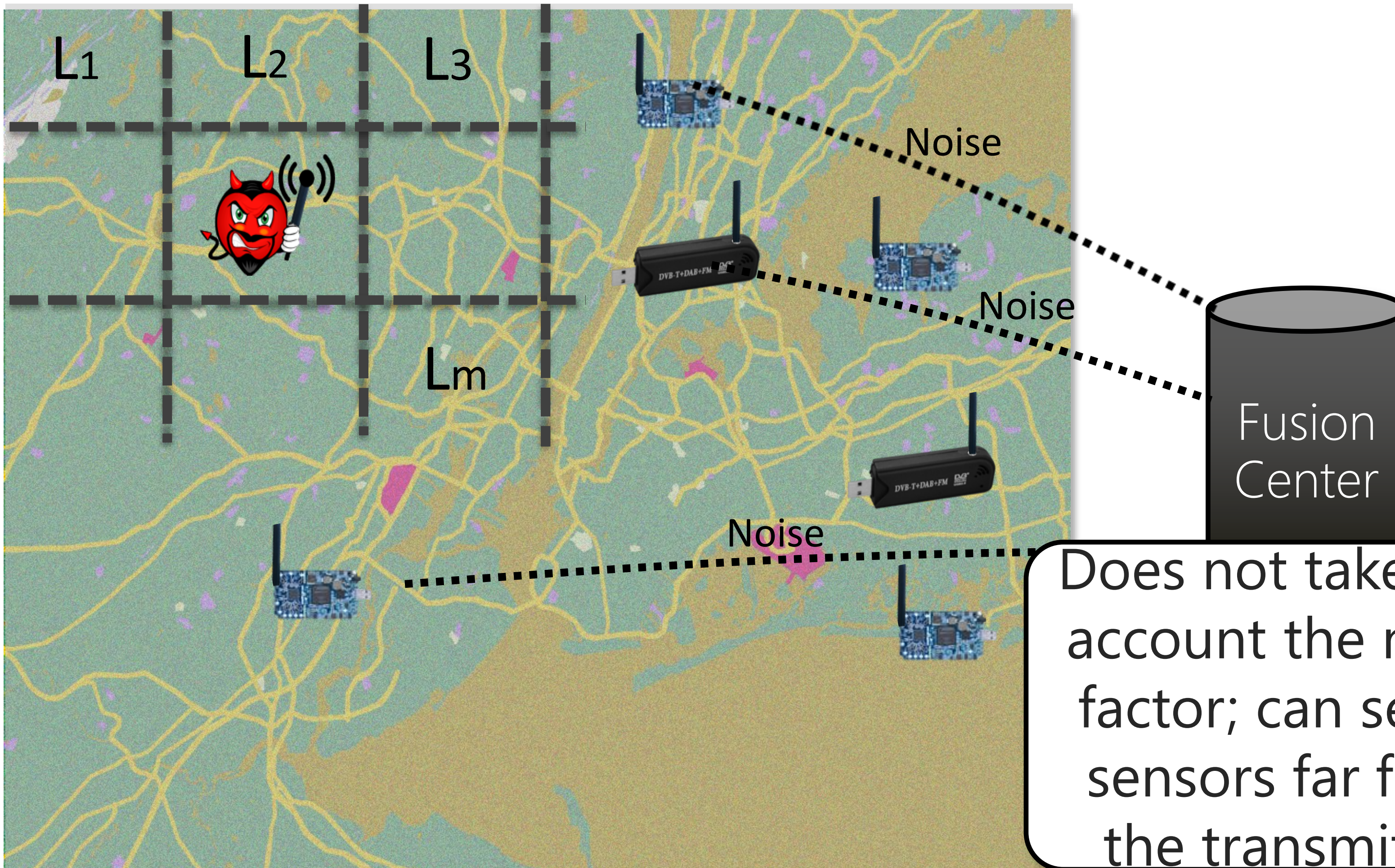
Greedy approach has no performance guarantees

Disadvantages of Greedy Strategy



Does not take into account the noise factor; can select sensors far from the transmitter

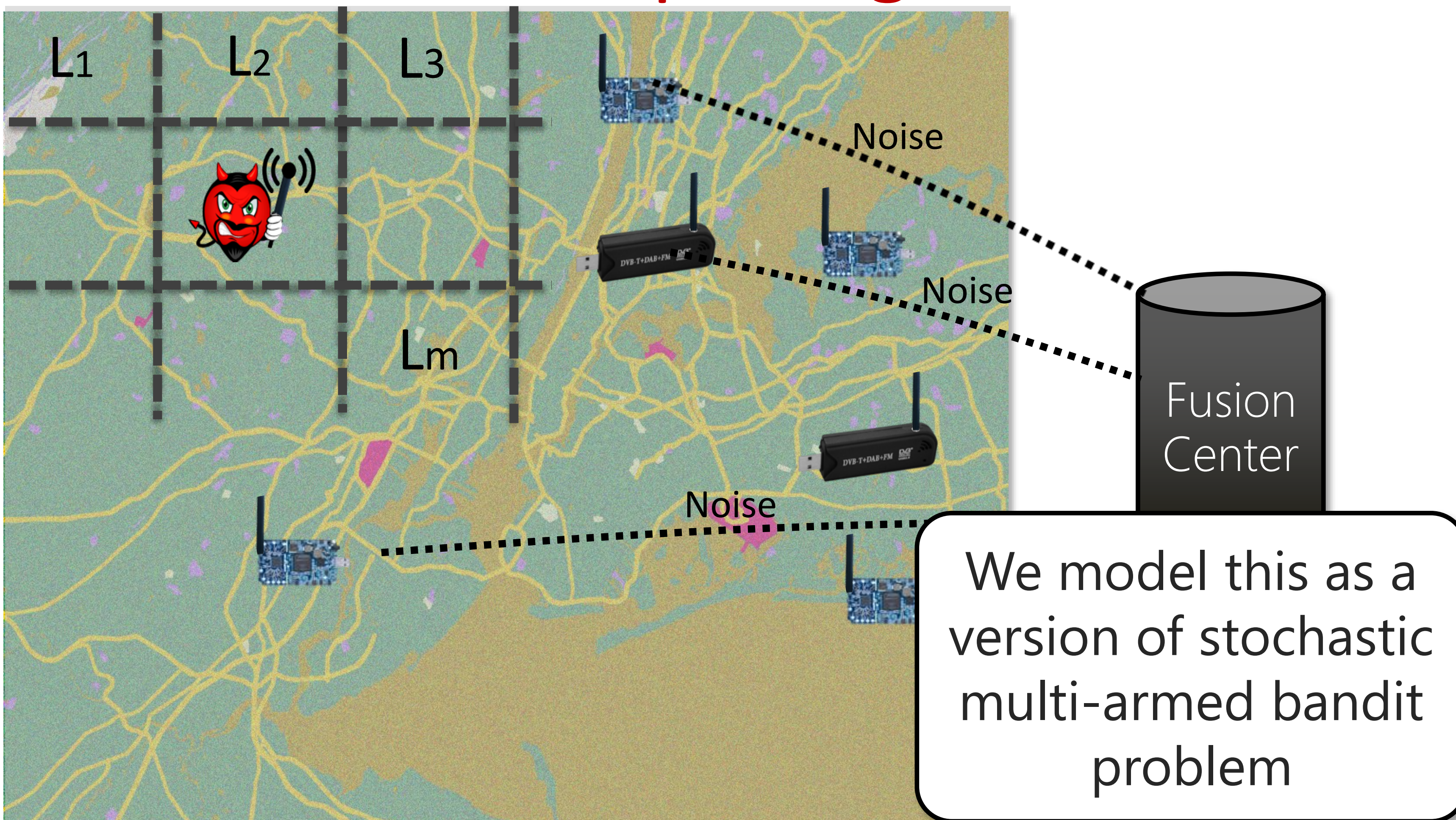
Disadvantages of Greedy Strategy



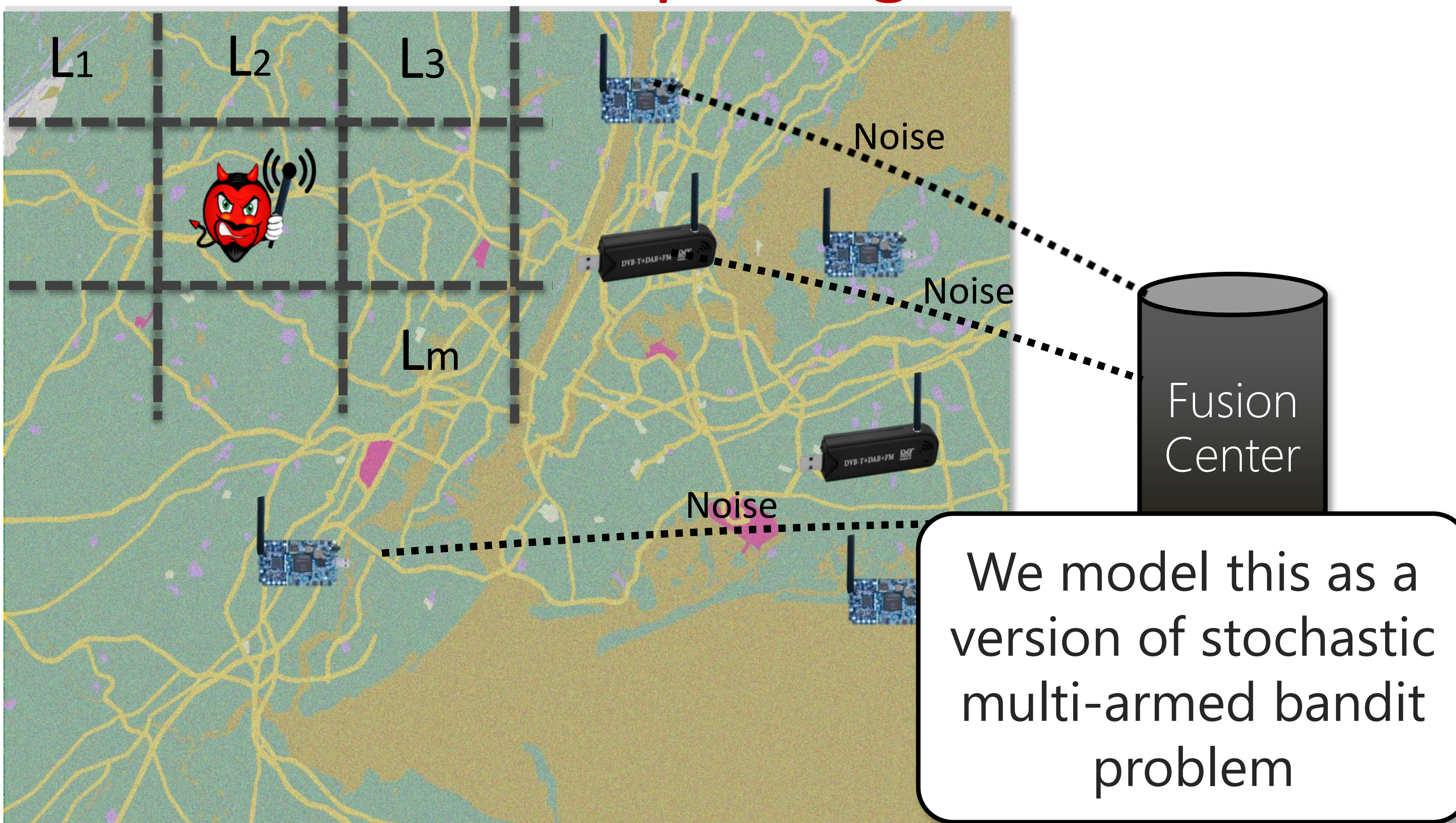
Does not take into account the noise factor; can select sensors far from the transmitter

A strategy that considers the impact of noise needs to be considered

Strategy: Balance between Exploiting Prior Observations and Exploring New Sensors

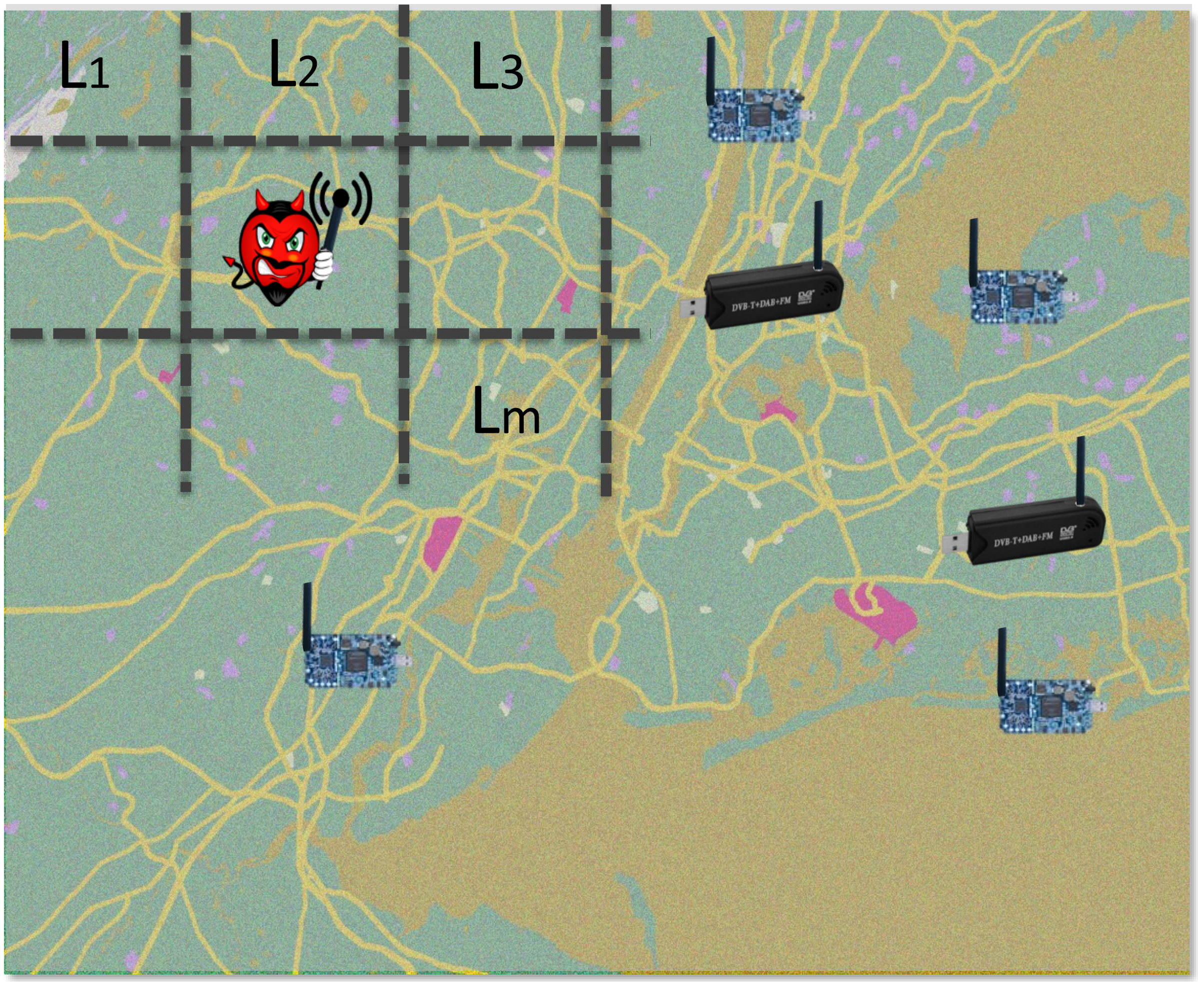


Strategy: Balance between Exploiting Prior Observations and Exploring New Sensors



We use a common strategy Thompson Sampling to select sensors, call it Hypothesis-based Thompson Sampling

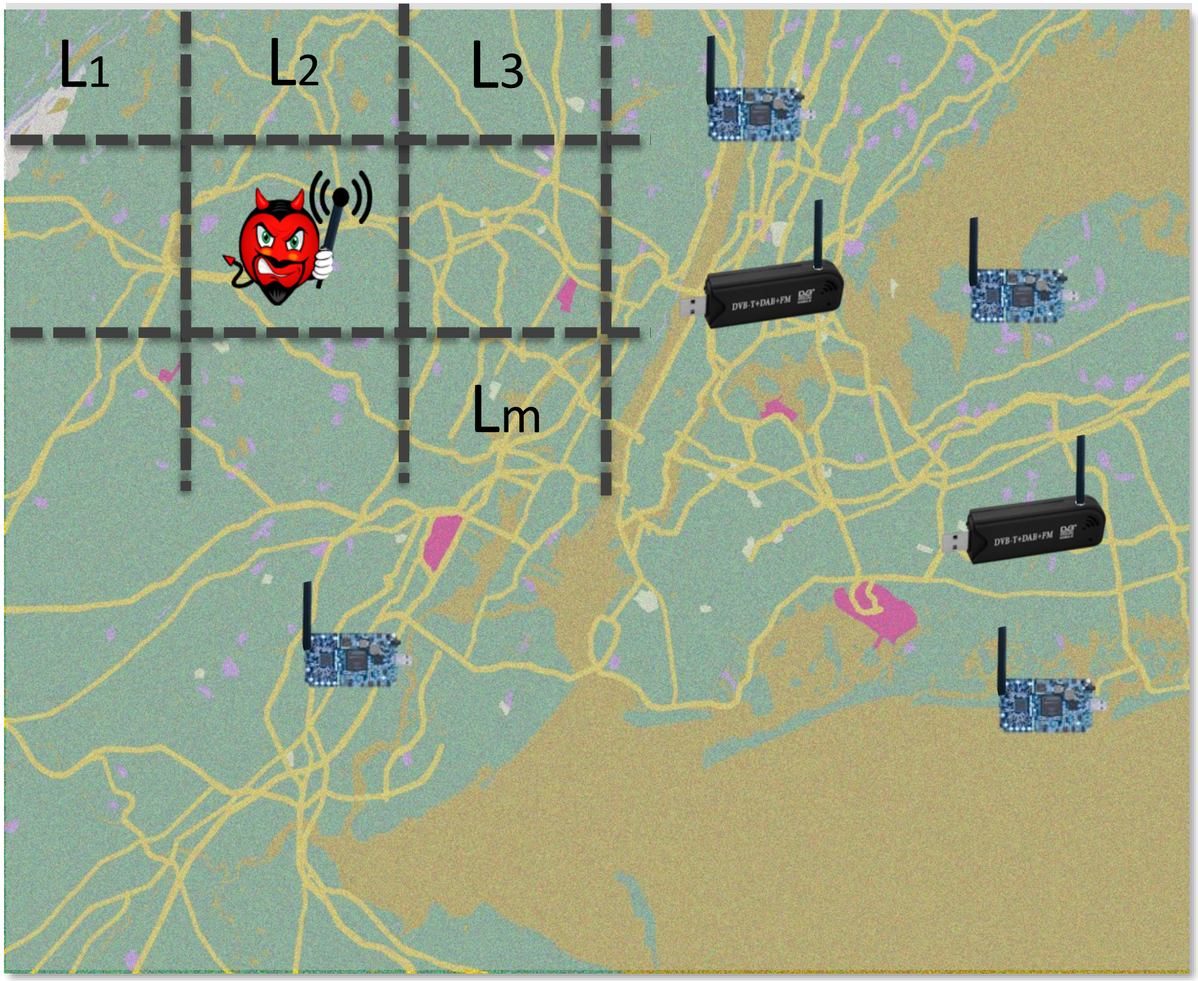
Evaluation Technique



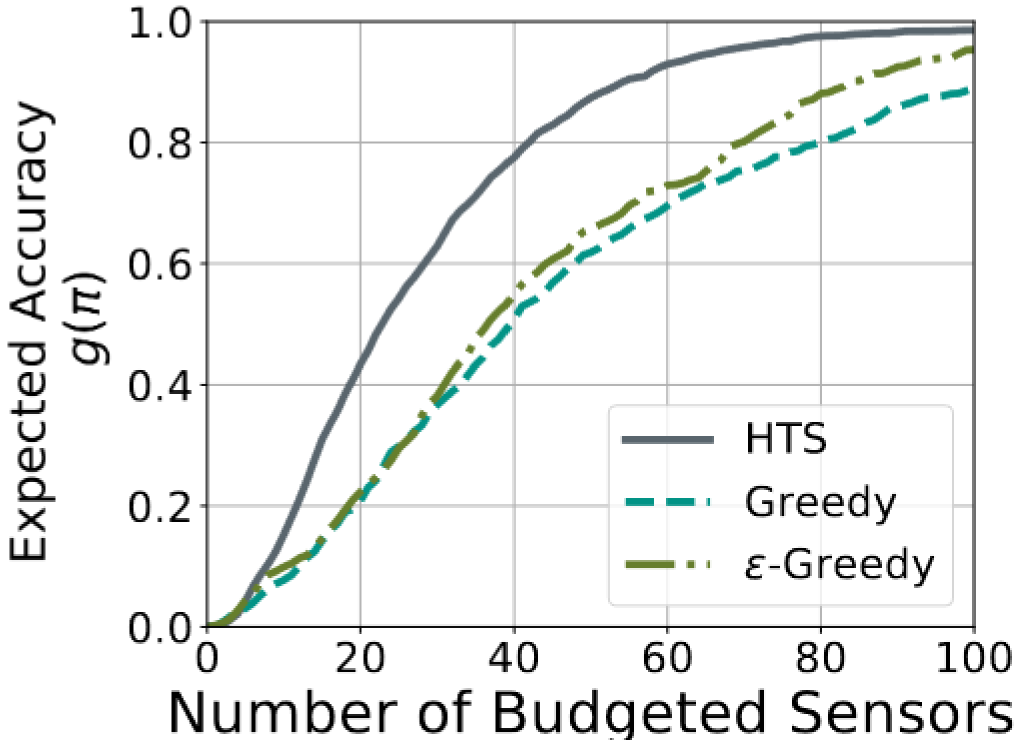
200 sensors simulated in an area of 40x40 sq km

Simulation using SPLAT tool, which uses Longley-Rice model

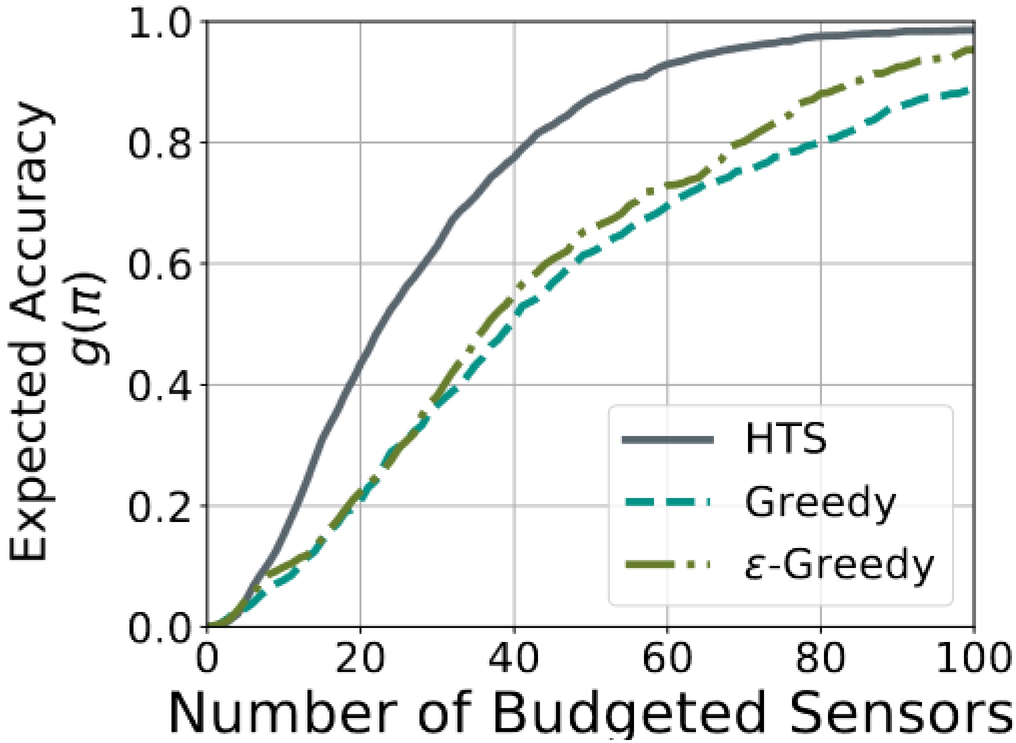
Evaluation Results



Evaluation Result



Evaluation Result



Thompson Sampling outperforms greedy by up to 22%

Drawbacks of Sequential Sensor Selection

- Higher latency, to incorporate feedback
  - Can be important for low-latency transmitter identification, required in cognitive radio applications
- Solution:
  - Optimized implementation of fusion technique on GPU-based server (systems approach)
  - Select sensors in batches, instead of using fully sequential approach

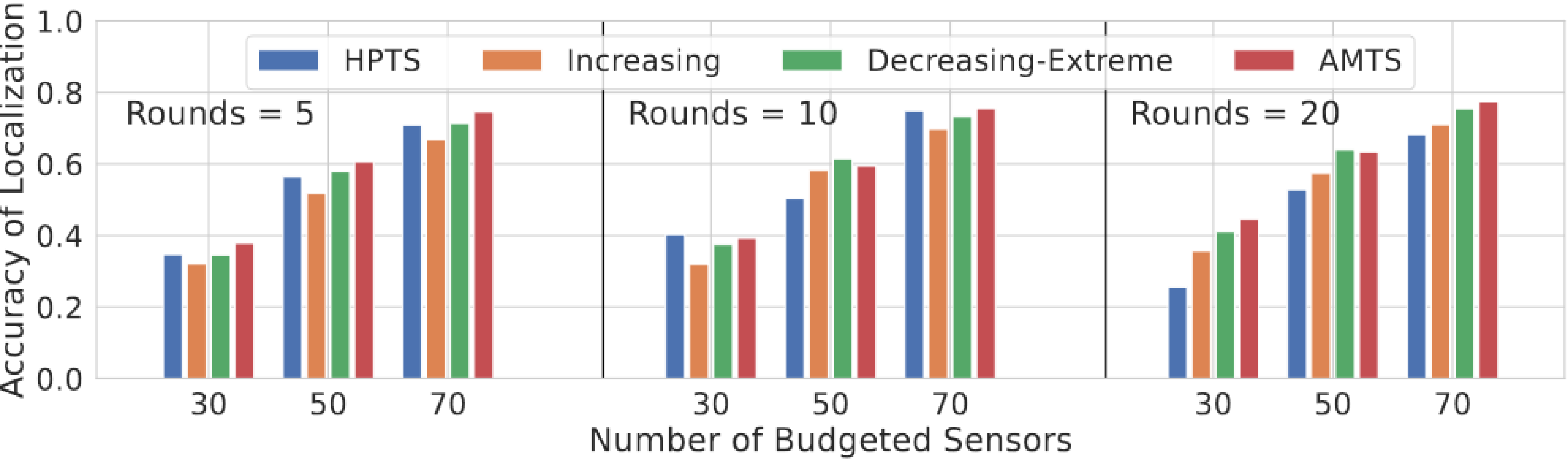
Batched Sensor Selection

- Additional constraint on the number of batches or *rounds*
- How many sensors to select in each batch?
- Open problem; we propose a heuristic based on empirical observations
  - Selecting highest number of sensors in the first round and then gradually decreasing the batch size is the best strategy

Batched Sensor Selection

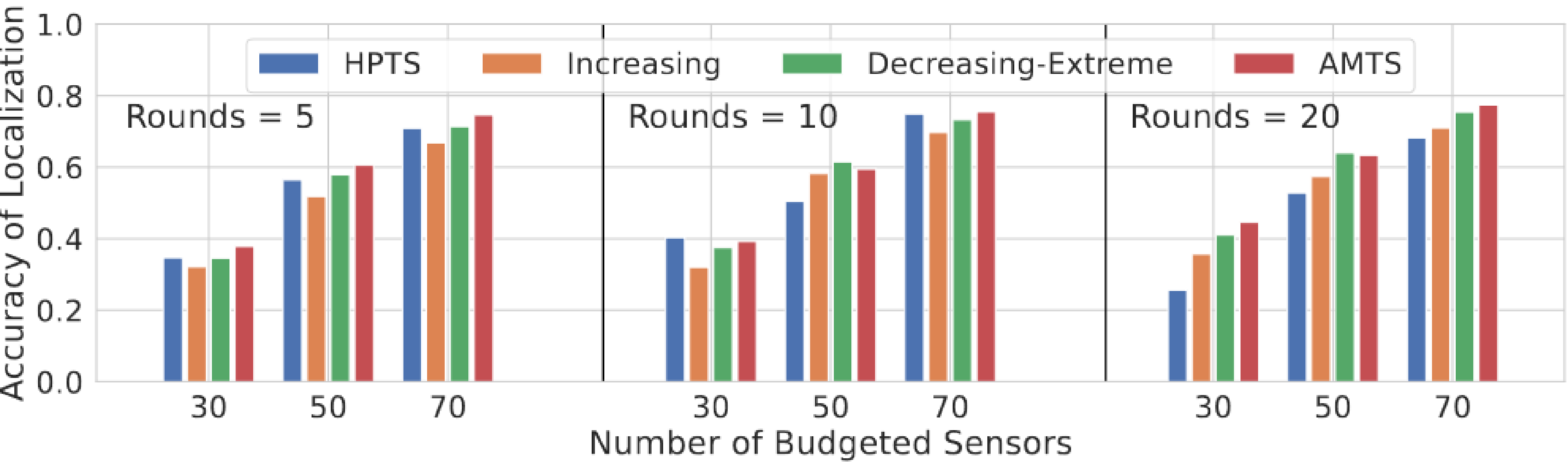
- Additional constraint on the number of batches or *rounds*
- How many sensors to select in each batch?
- Open problem; we propose a heuristic based on empirical observations
  - Selecting highest number of sensors in the first round and then gradually decreasing the batch size is the best strategy
  - We call this heuristic as AMTS (Asymmetric Modified Thompson Sampling)

Evaluation



HPTS
Increasing
Decreasing-Extreme
AMTS
Rounds = 5
Rounds = 10
Rounds = 20
Accuracy of Localization
1.0
0.8
0.6
0.4
0.2
0.0
30
50
70
Number of Budgeted Sensors

Evaluation



AMTS beats other baseline strategies by up to 20%

Takeaways

Takeaways

- Sequential sensor selection to localize transmitter

Takeaways

- Sequential sensor selection to localize transmitter
- Formulated it as a stochastic multi-armed bandit problem, and used Thompson Sampling

Takeaways

- Sequential sensor selection to localize transmitter
- Formulated it as a stochastic multi-armed bandit problem, and used Thompson Sampling
- Used a batched version to reduce latency

Takeaways

- Sequential sensor selection to localize transmitter
- Formulated it as a stochastic multi-armed bandit problem, and used Thompson Sampling
- Used a batched version to reduce latency
- Proposed a heuristic for the batched version