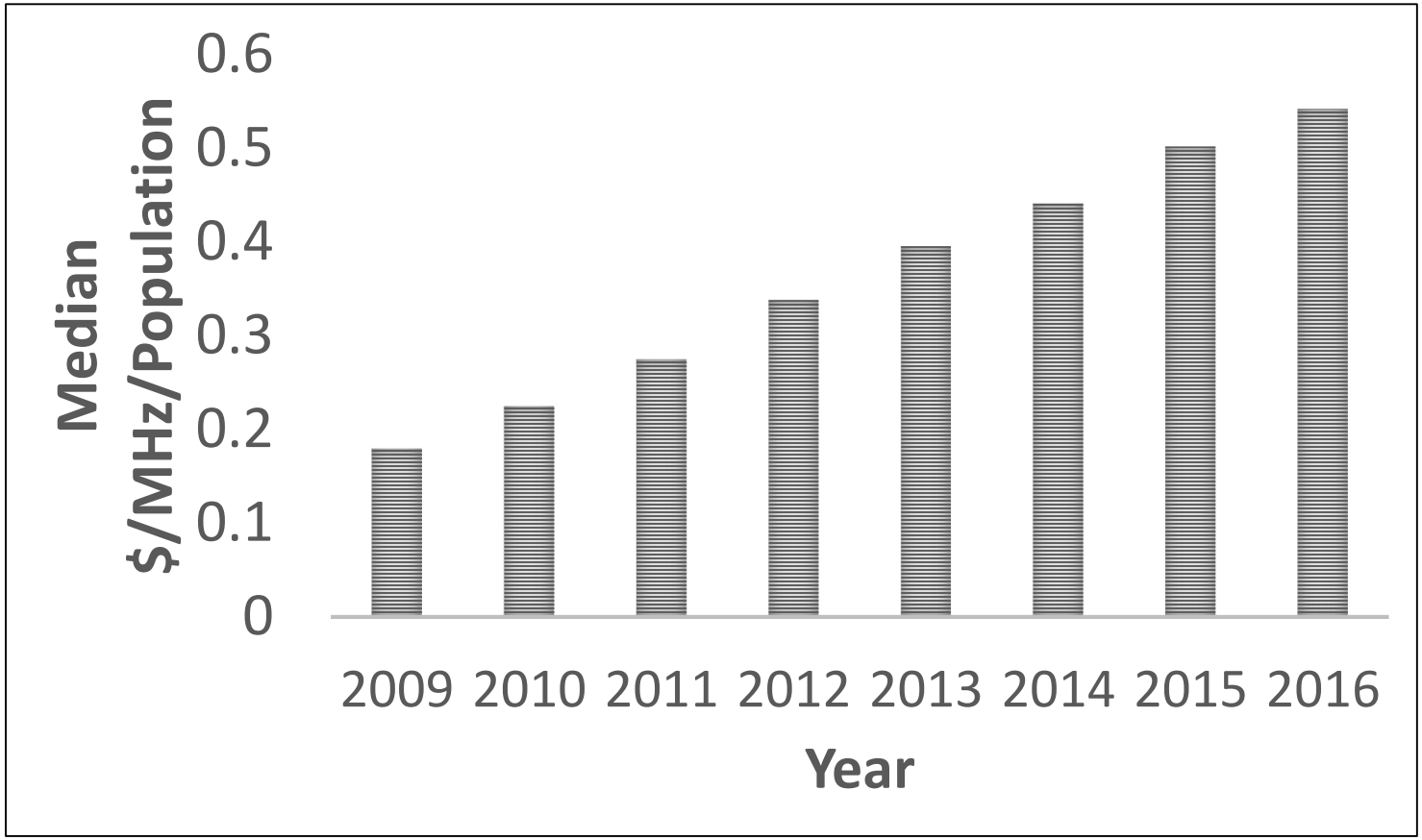
Spectrum Patrolling with Crowdsourced Spectrum Sensors

Ayon Chakraborty, Arani Bhattacharya, Snigdha Kamal, Samir R. Das, Himanshu Gupta and Petar M. Djuric

Stony Brook University

Spectrum Increasingly a Scarce Resource



Data Courtesy: *Effective Spectrum Pricing: Supporting better quality and more affordable mobile services*, Full Report, February 2017, Nera Economic Consulting

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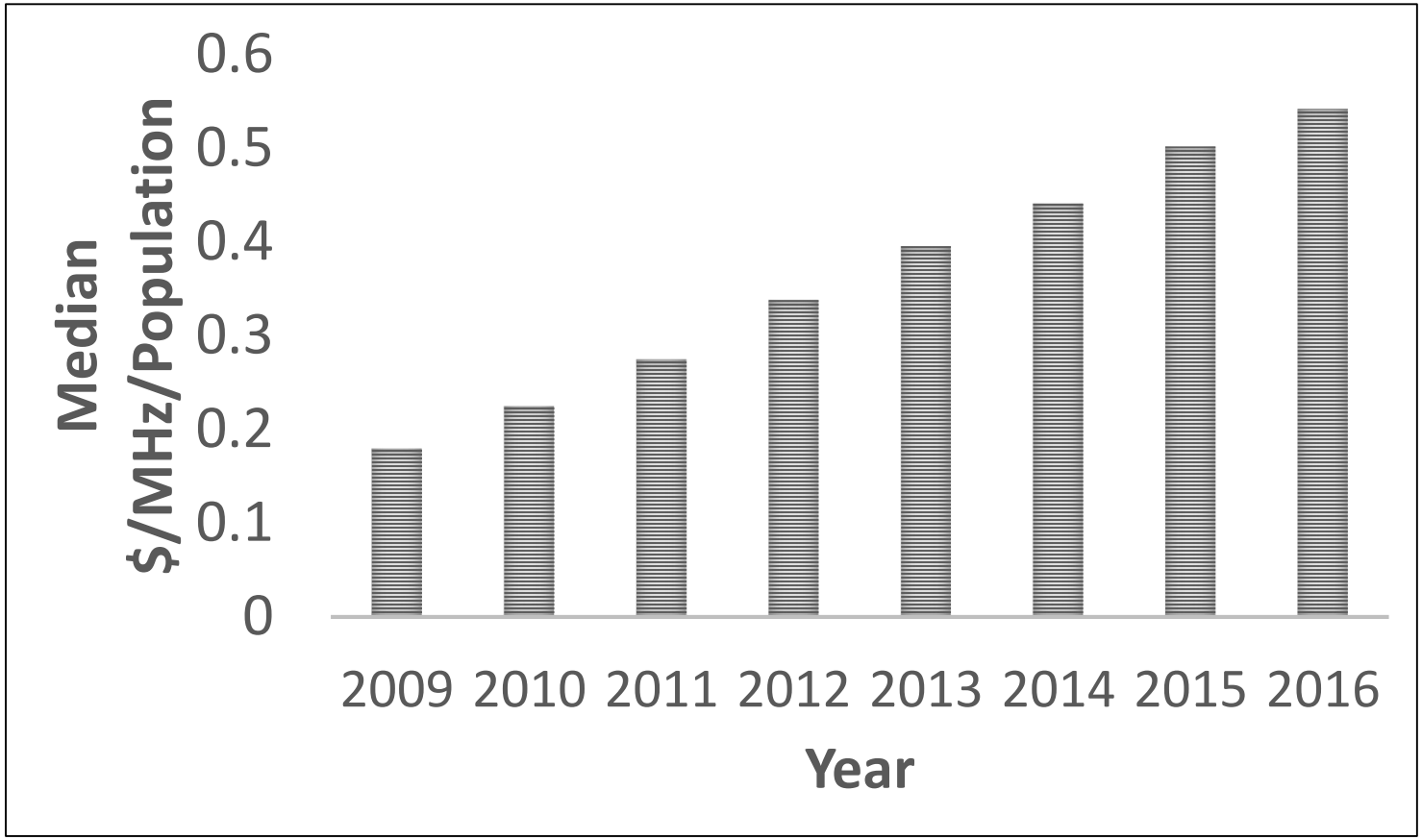

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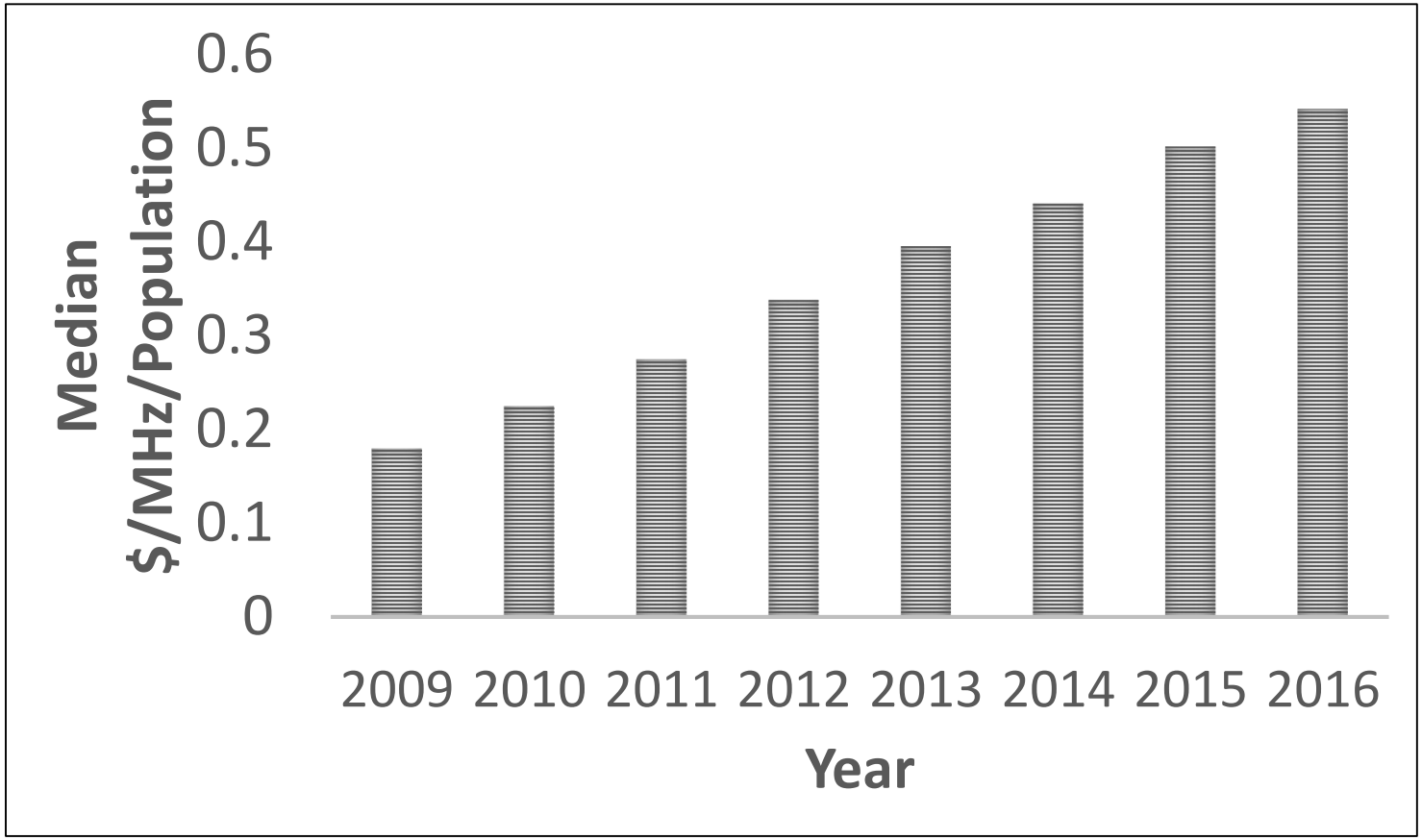

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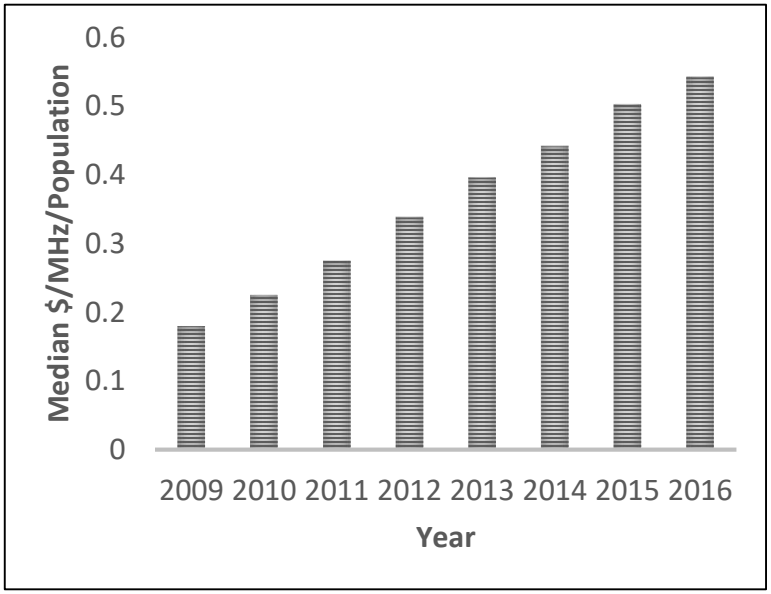
Cost of spectrum increased 3x in 7 years

Illegal Spectrum use Becoming More Lucrative



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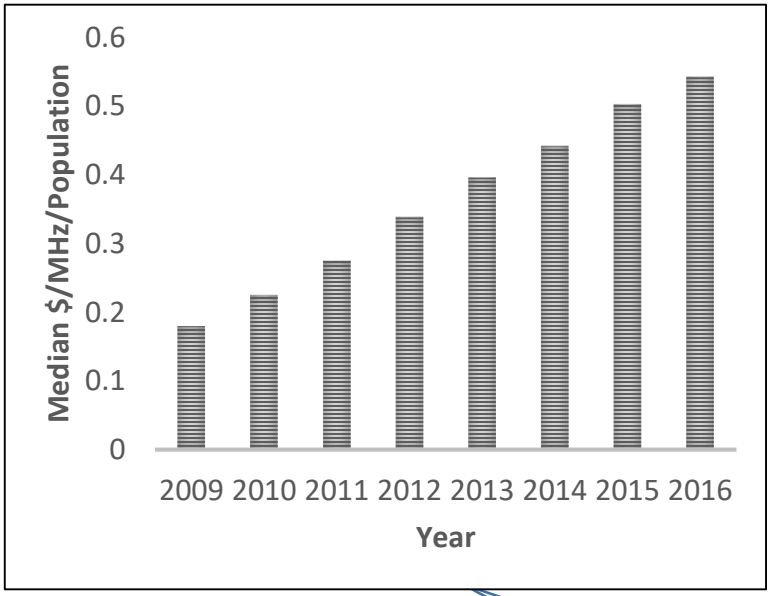
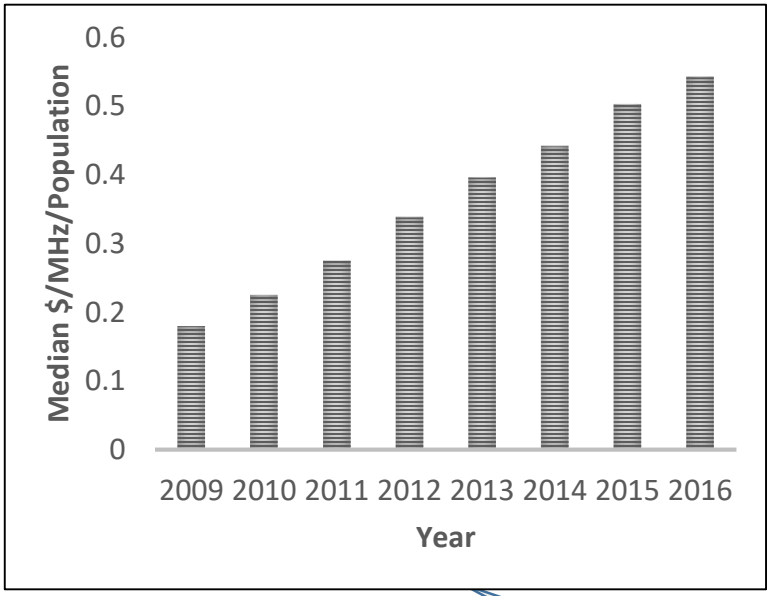


Rising gain from illegal use

Illegal Spectrum use Becoming More Lucrative



Low-cost SDRs becoming more available

Rising gain from illegal use

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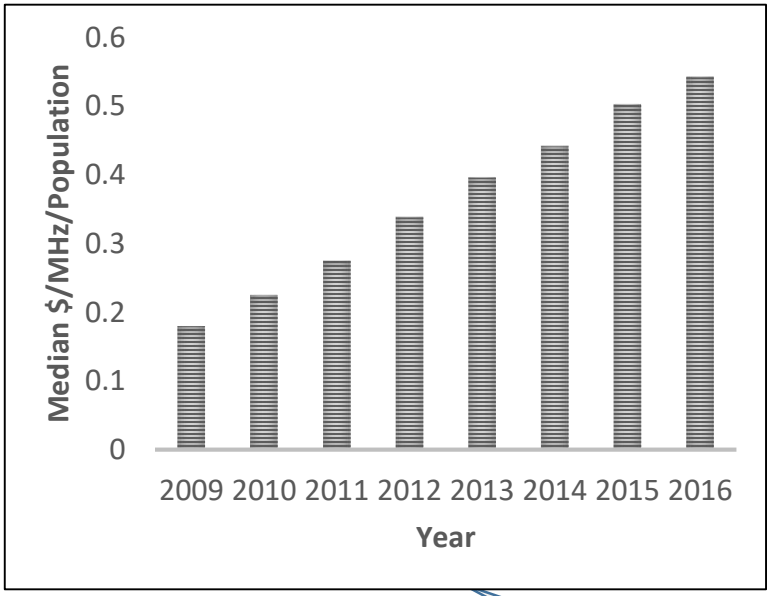

Low-cost SDRs becoming more available

Easier to illegally use spectrum

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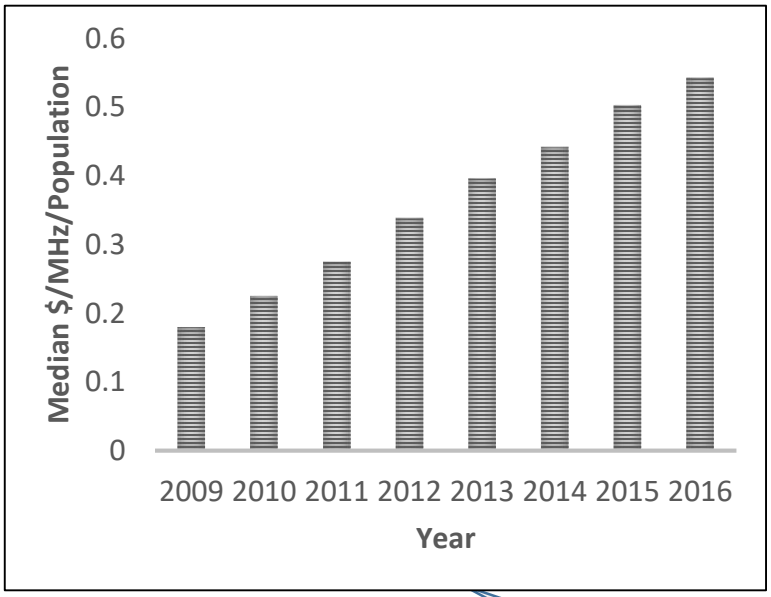

Low-cost SDRs becoming more available

Easier to illegally use spectrum

Rising gain from illegal use

Both opportunity and gain of illegal spectrum use rising

Anecdotal Evidence Suggests Rising Threat

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Shanghai wants law on radio spectrum

Ke Jiayun

00:54 UTC+8, 2018-03-06

2018 Two Sessions

SHANGHAI delegates at the first session of the 13th National People's Congress in Beijing have called for a national law on the management of radio spectrum to crack down on its misuse.

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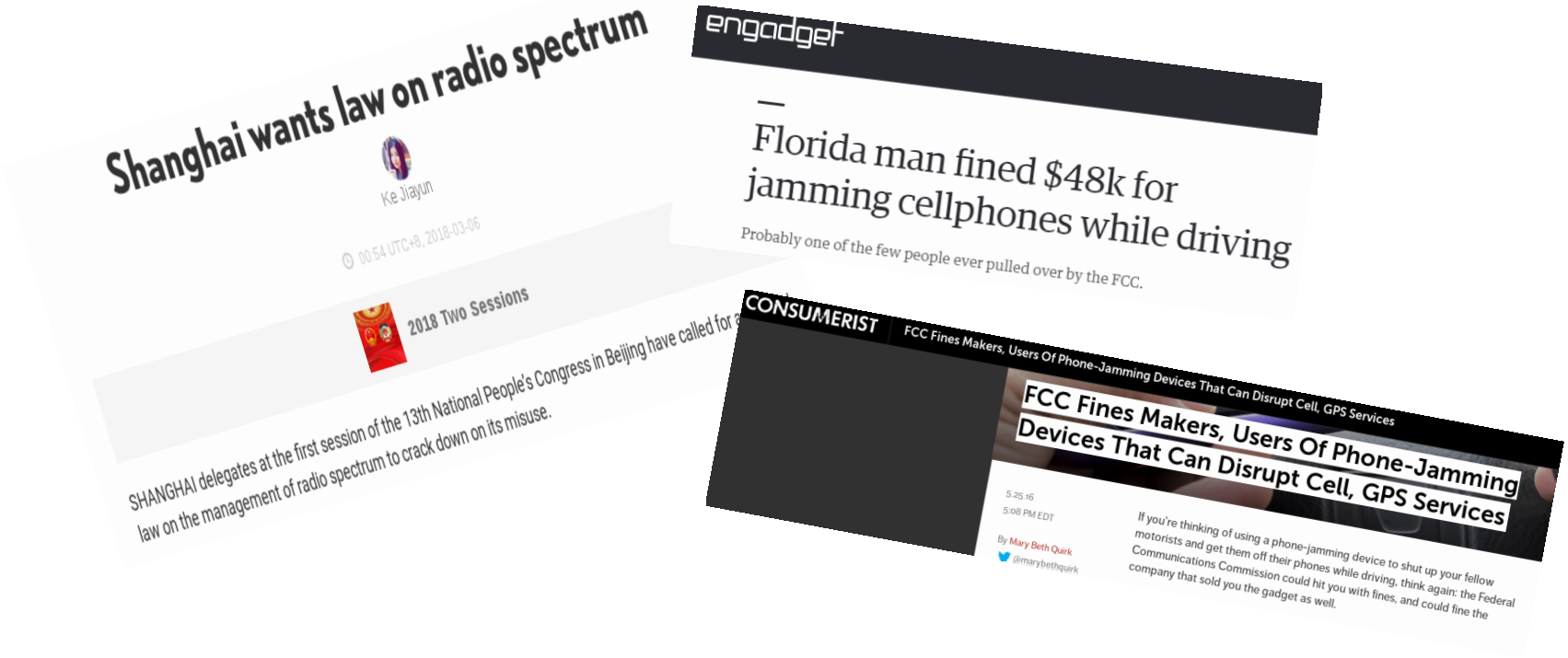
engadget

Florida man fined $48k for jamming cellphones while driving

Probably one of the few people ever pulled over by the FCC.

Anecdotal Evidence Suggests Rising Threat



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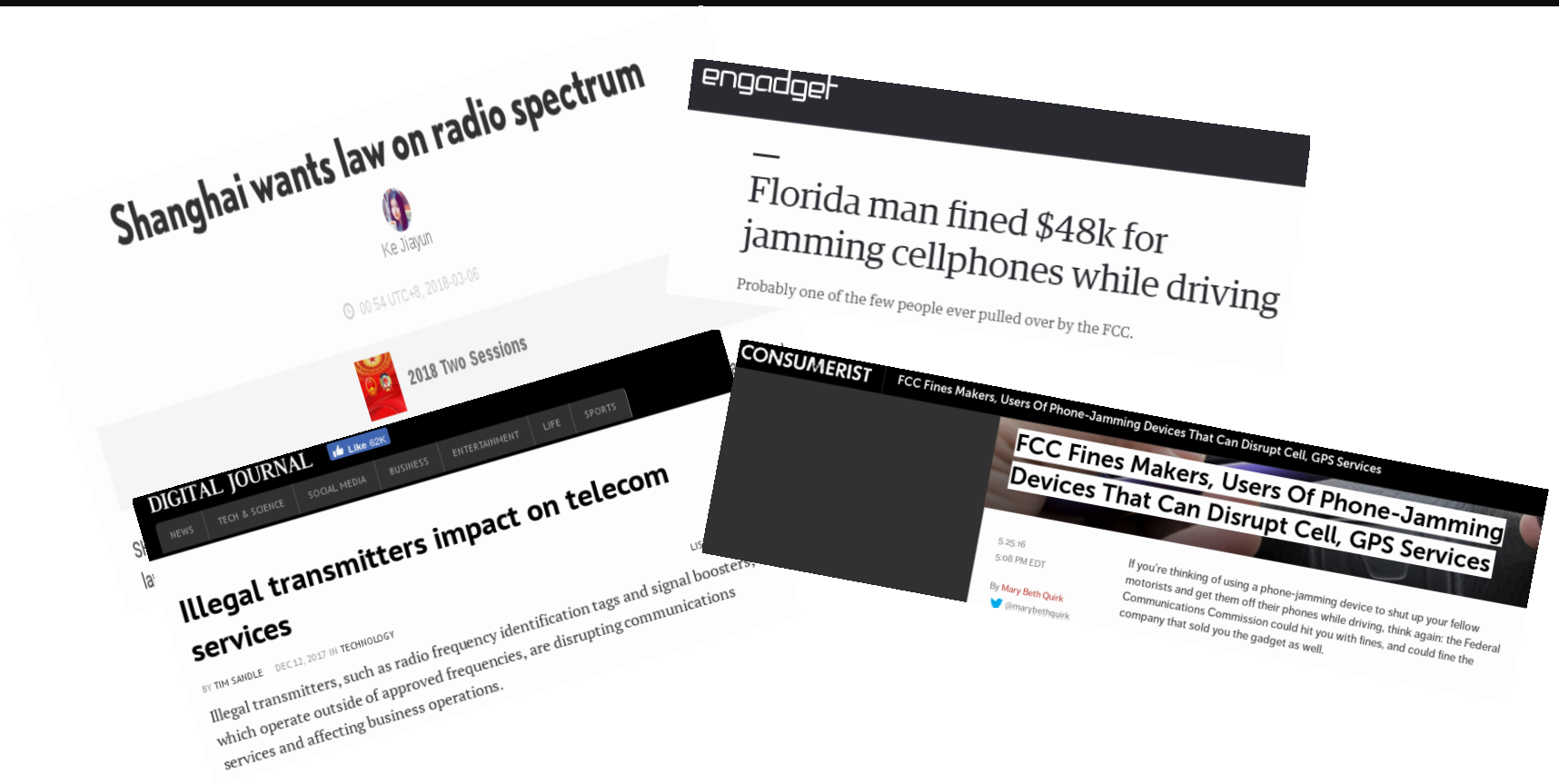

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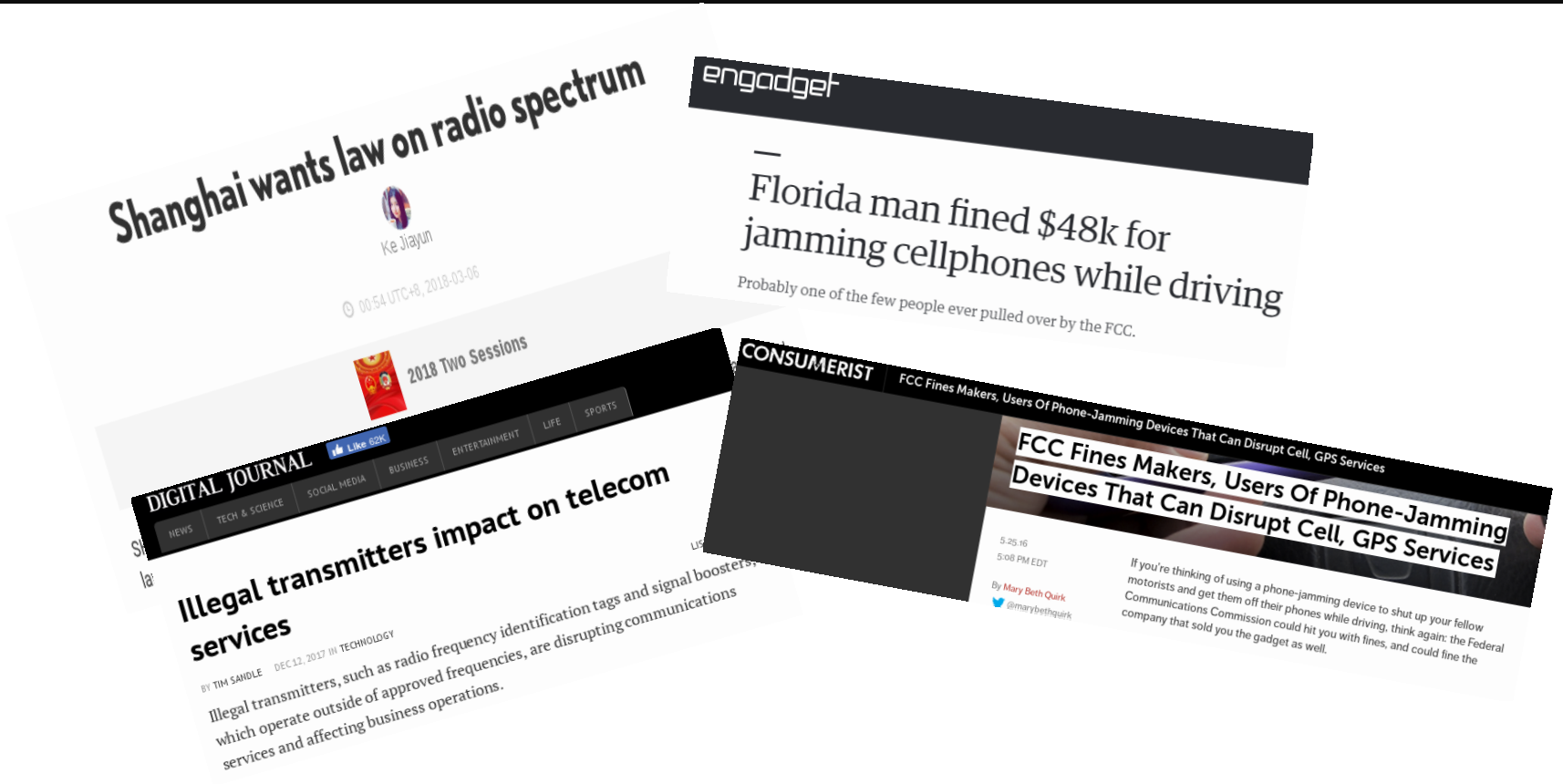
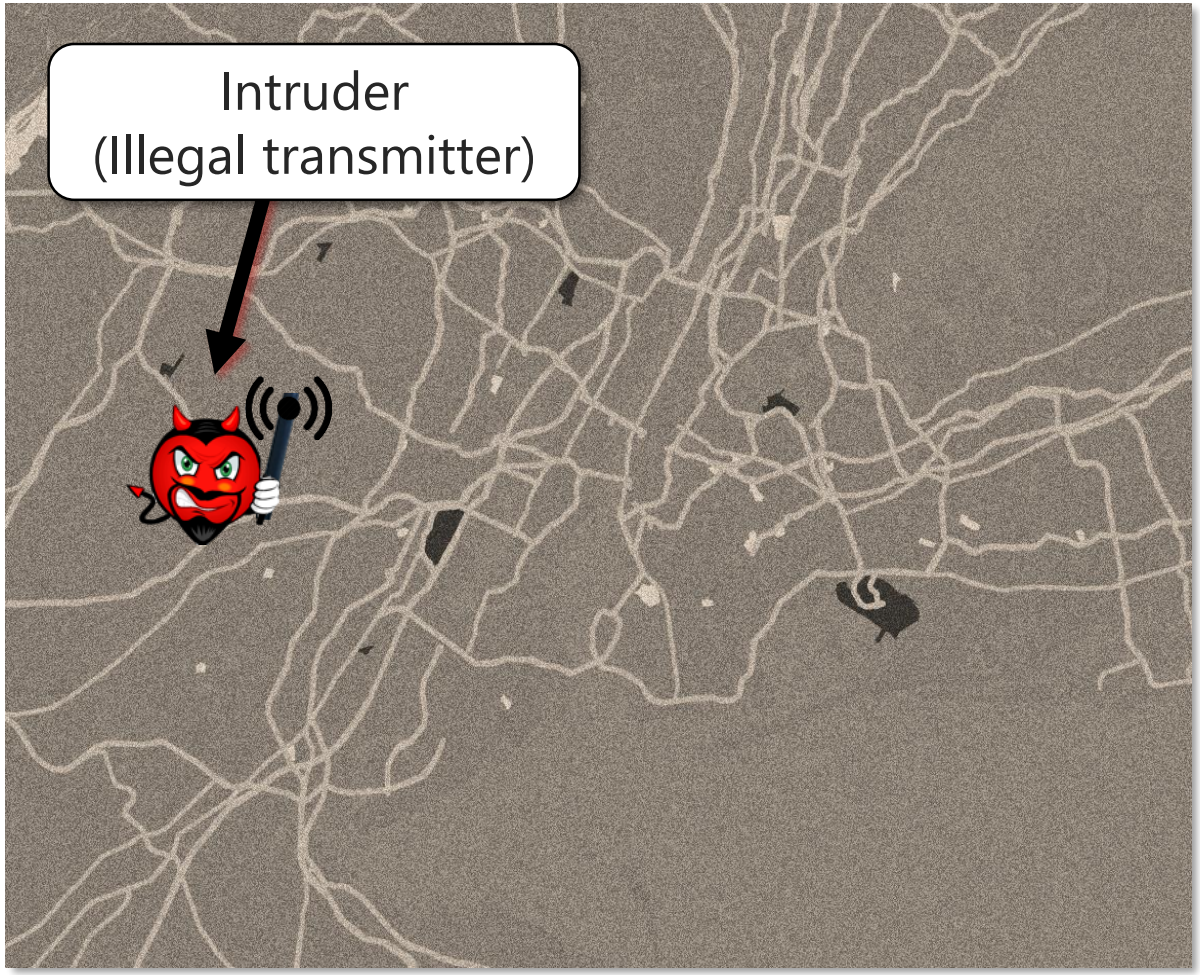


Regulators are getting worried

How can Regulators Protect Spectrum?



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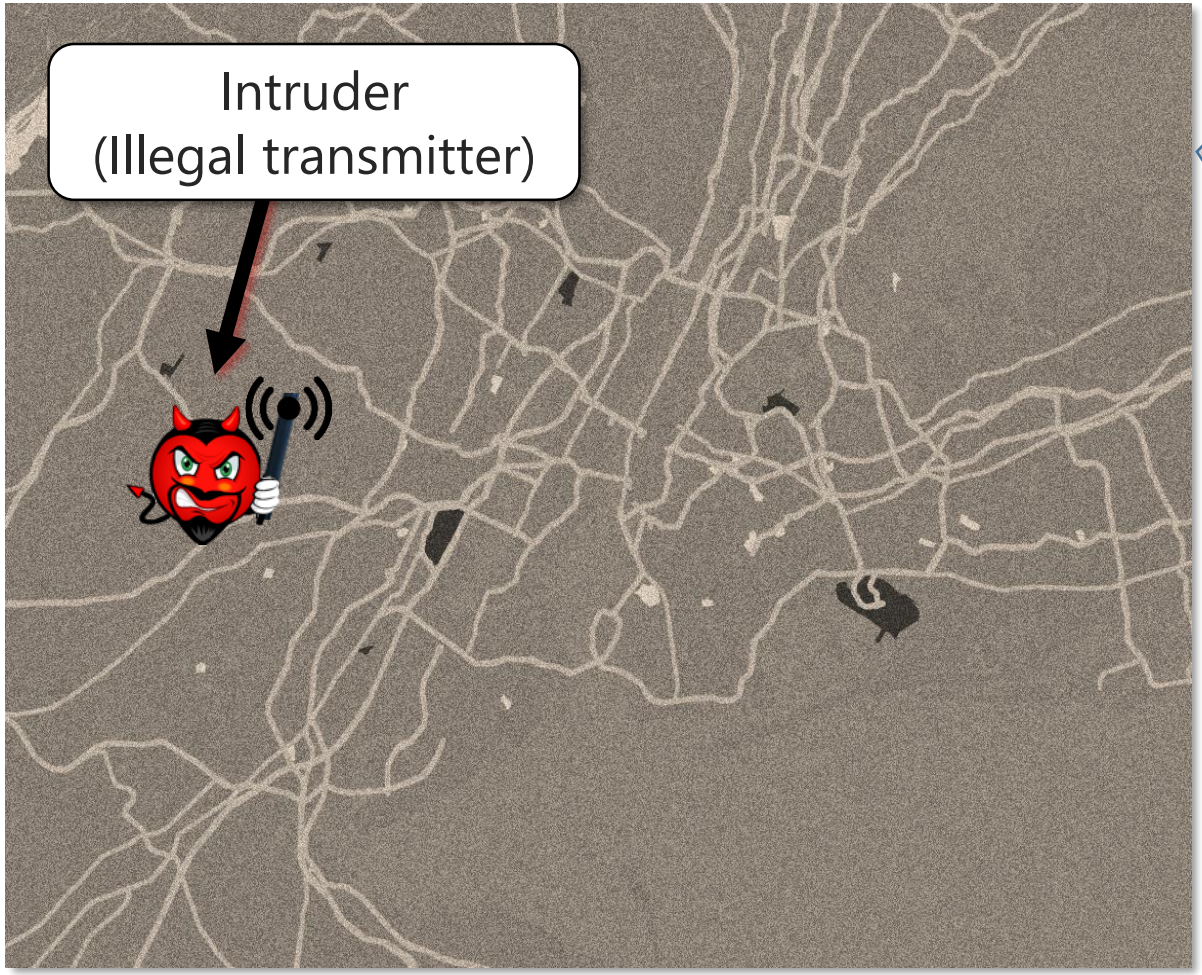

Illegal transmitters must be detected:
1) With high accuracy,
2) by cheap sensors
3) incurring low cost

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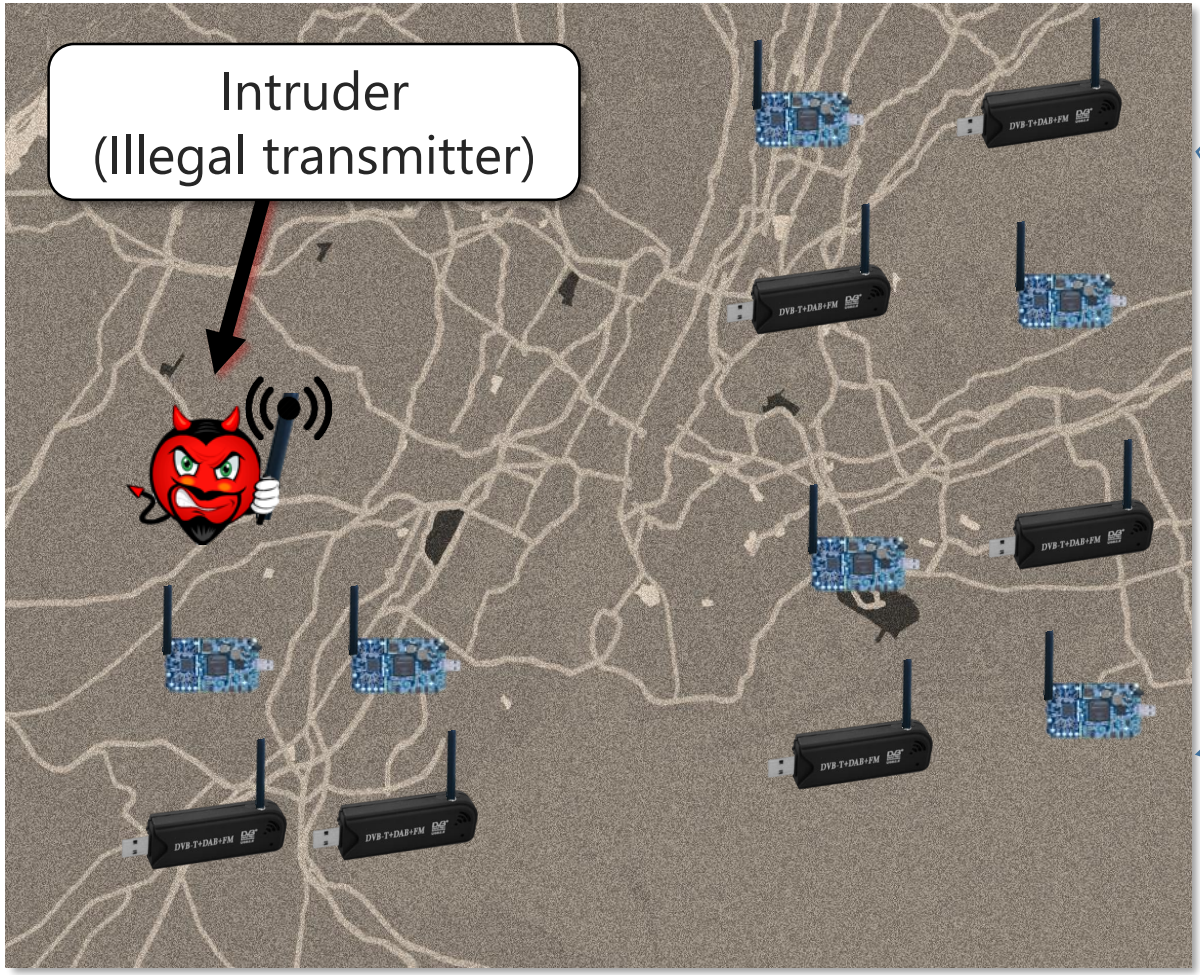

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Deploys a large number of sensors belonging to different users

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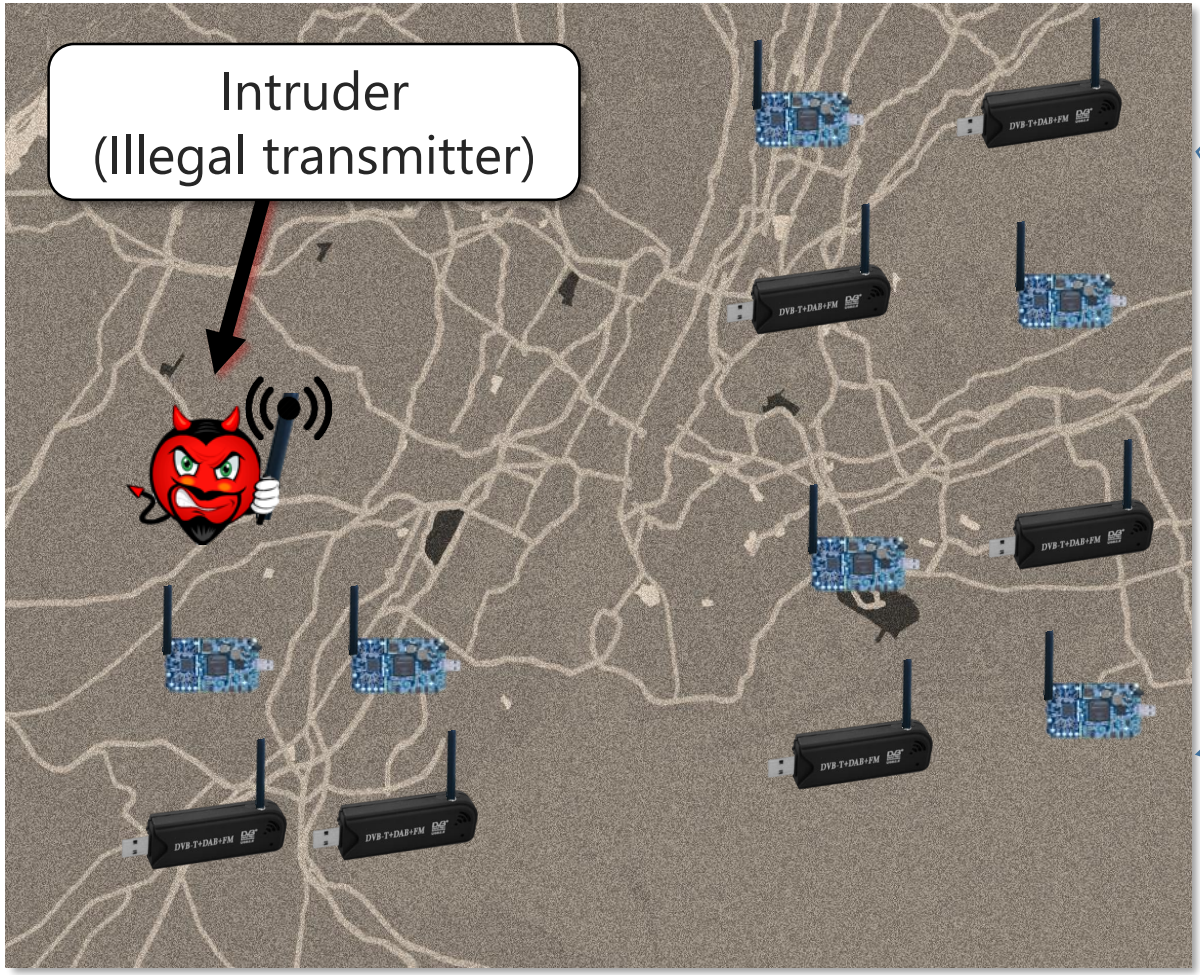

Illegal transmitters must be detected:
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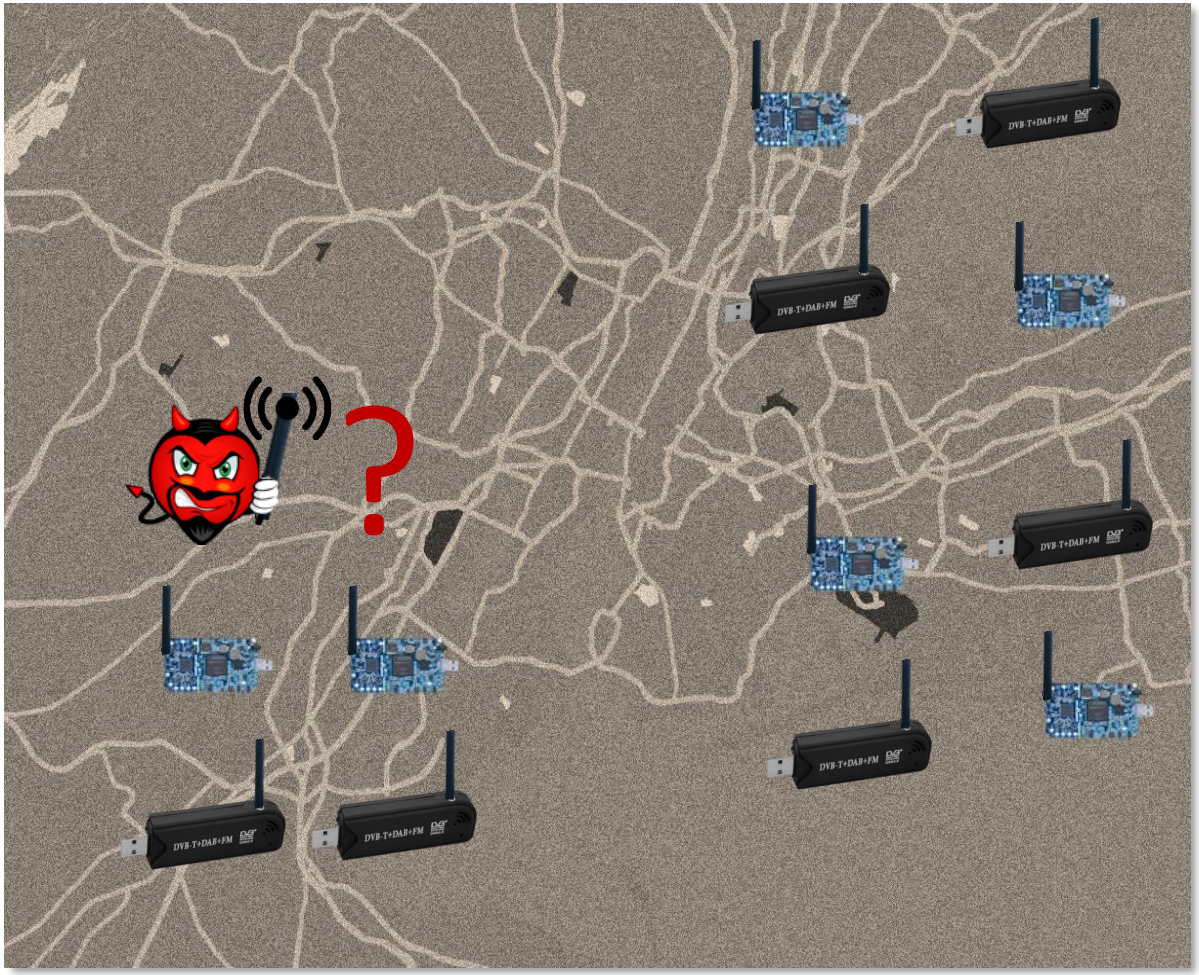
Crowdsourcing promises to satisfy accuracy and cost requirements

Challenges of Crowdsourcing



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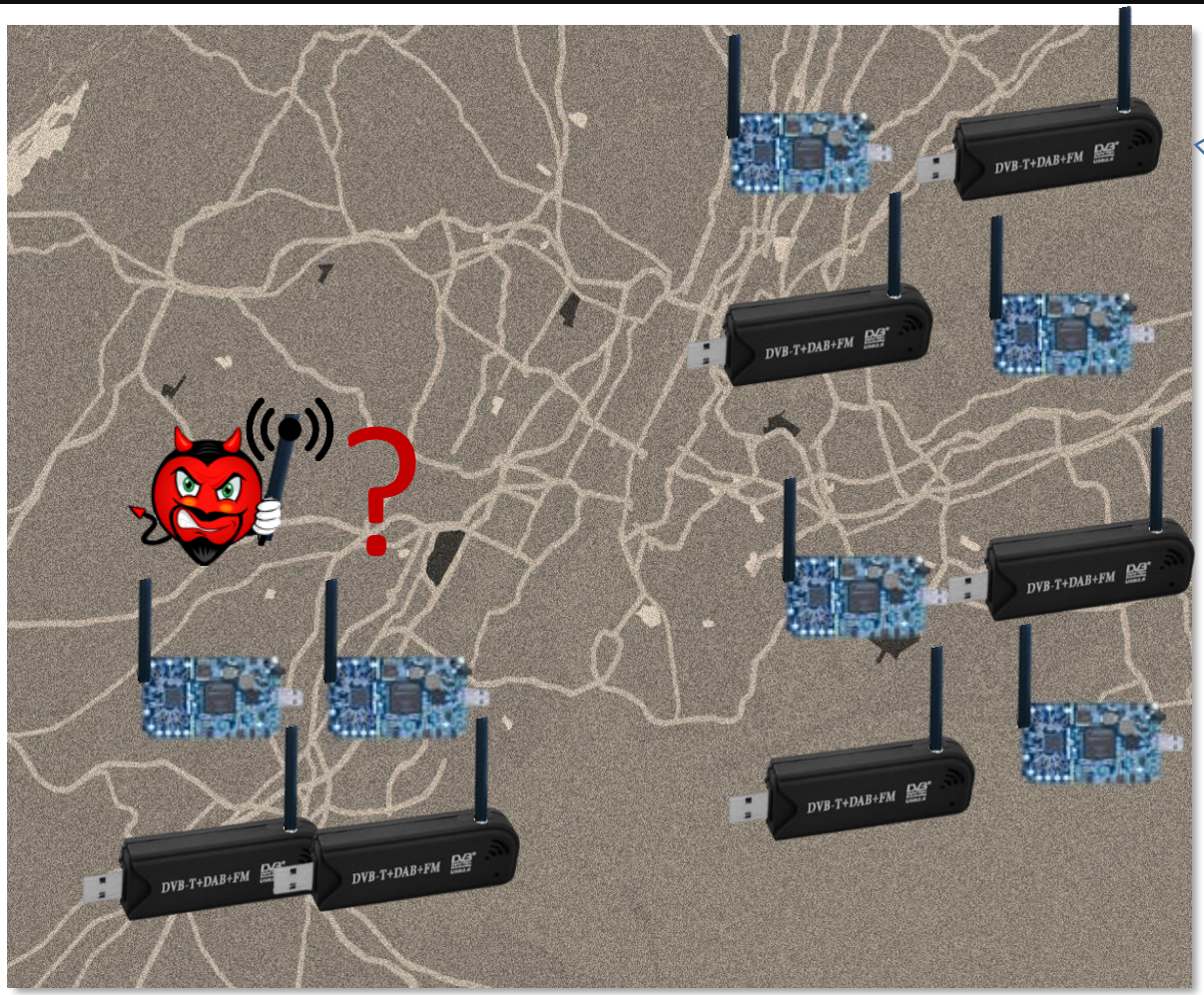
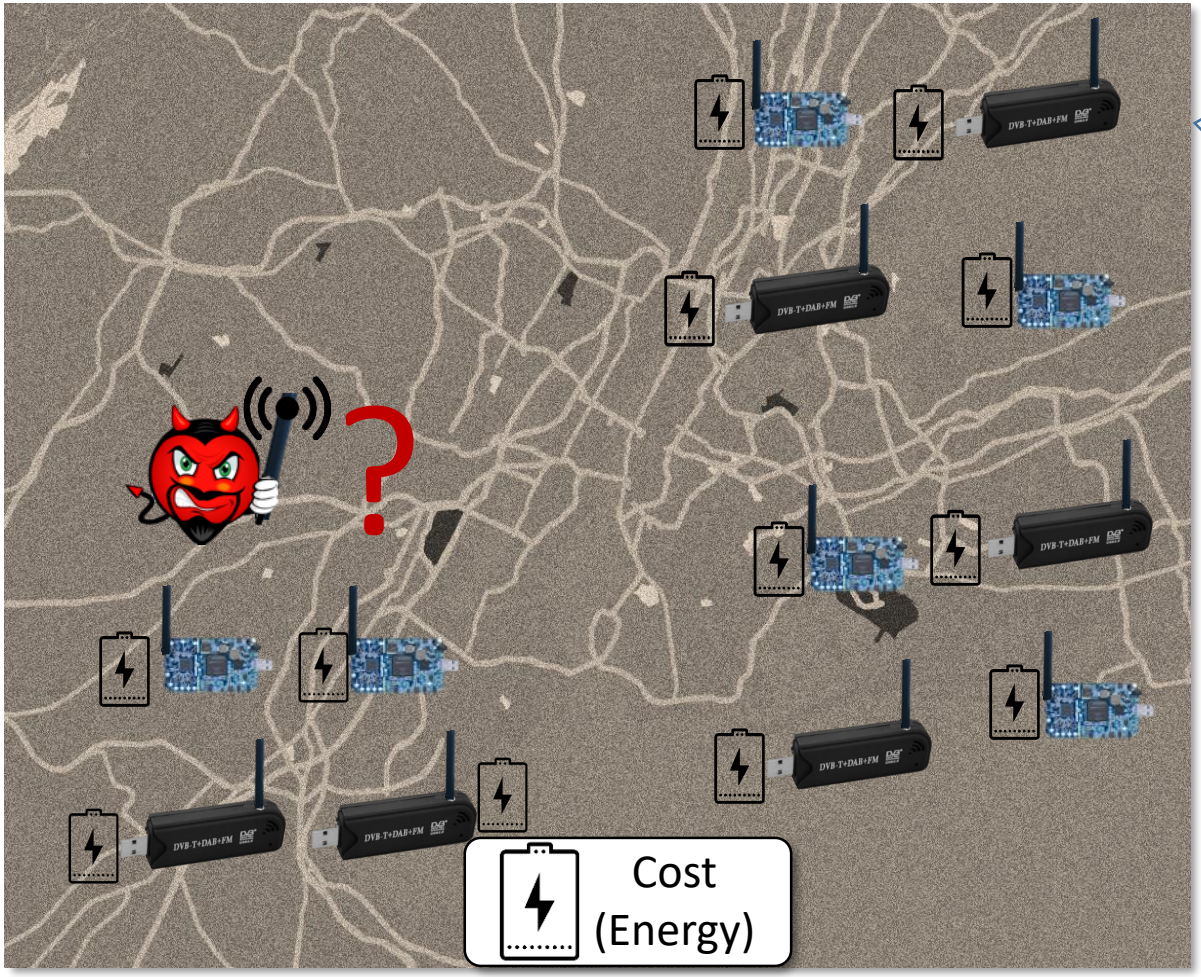


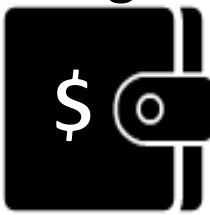
1) Handle sensor heterogeneity?

Challenges of Crowdsourcing



1) Handle sensor heterogeneity?

Budget



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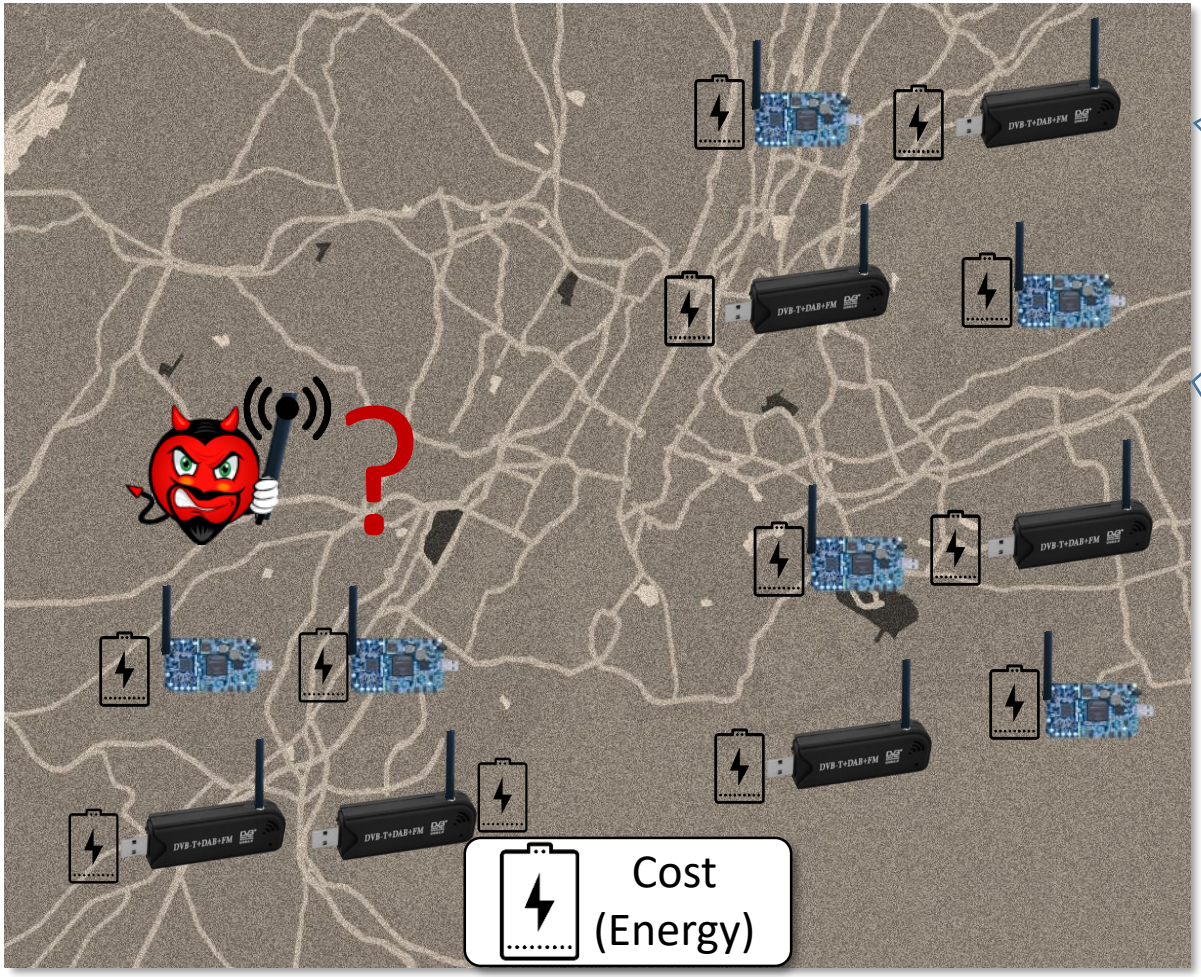
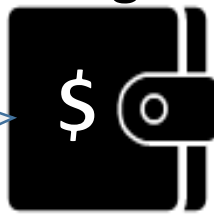


1) Handle sensor heterogeneity?

Budget

2) Select sensors



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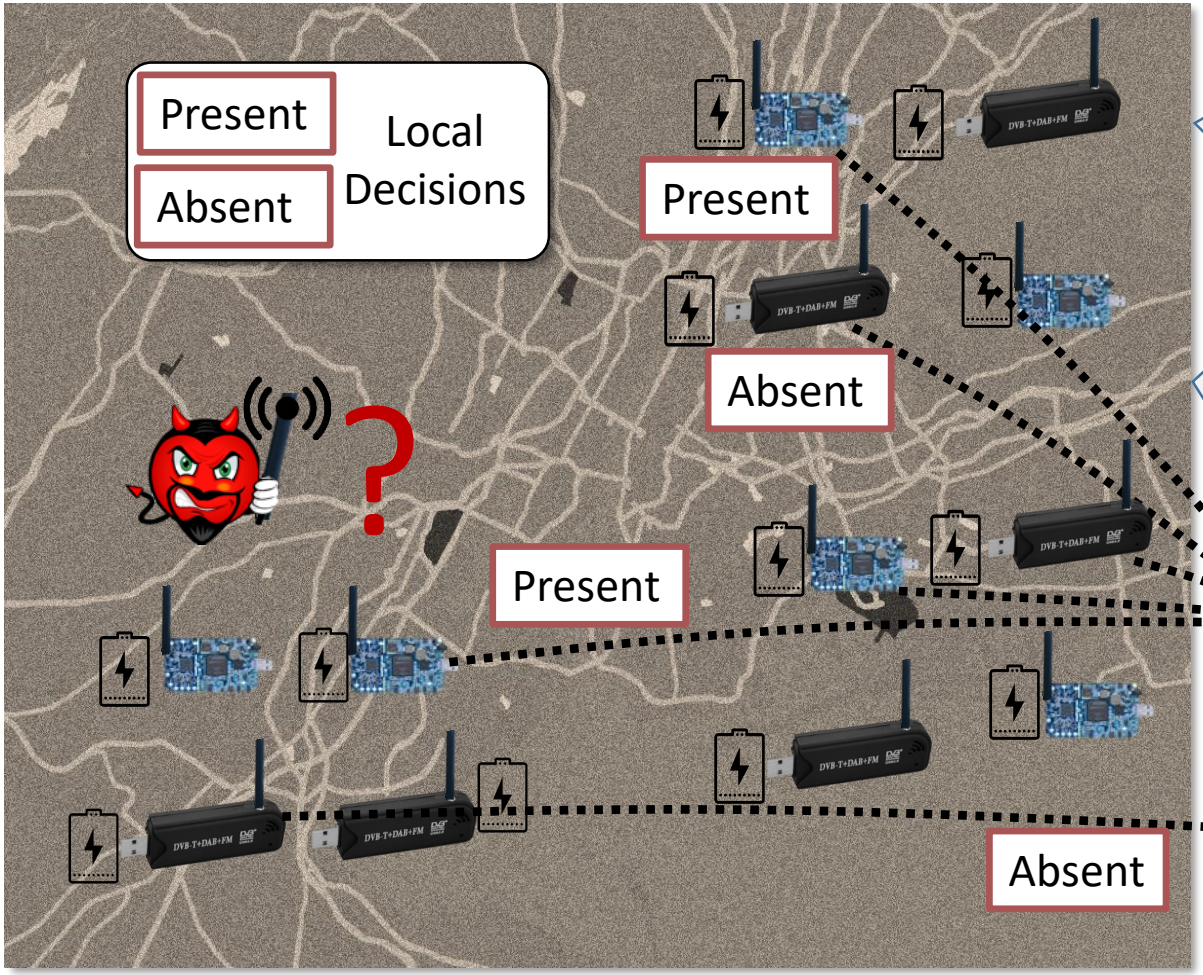

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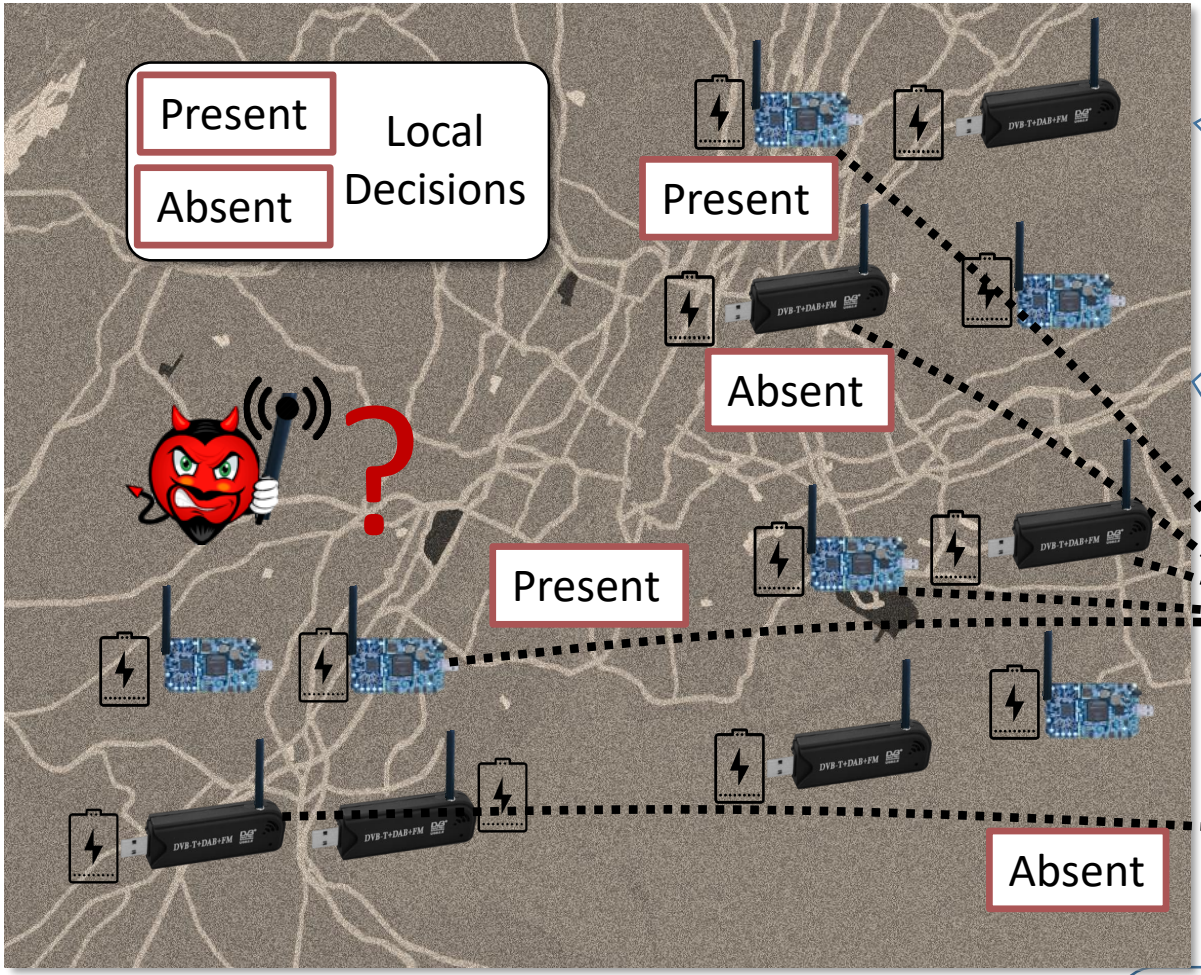

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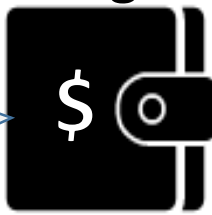


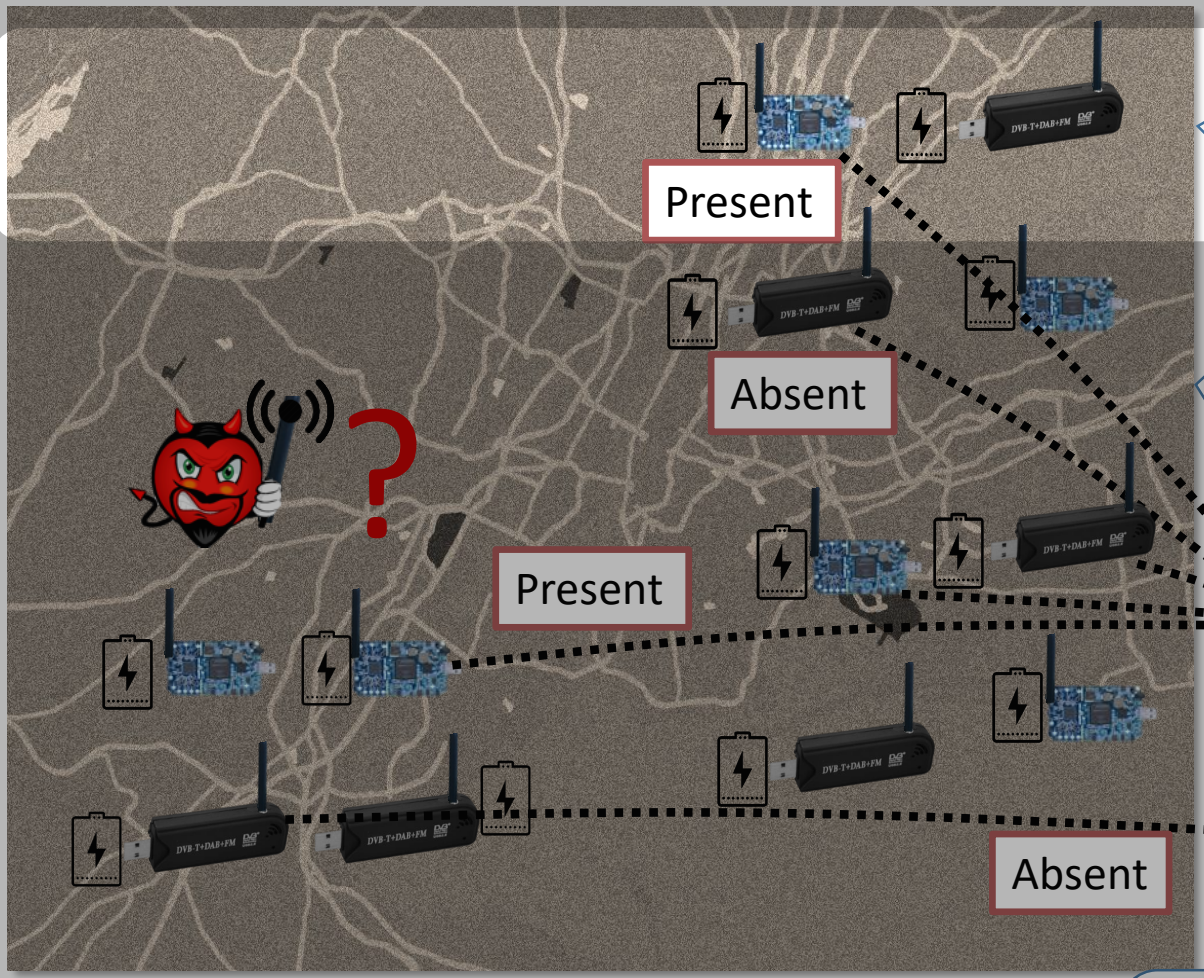
Fusion Center

Global Decision

Present	Absent

3) Fuse sensor decisions to get global decision

Challenges of Crowdsourcing



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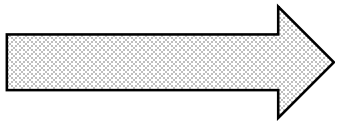
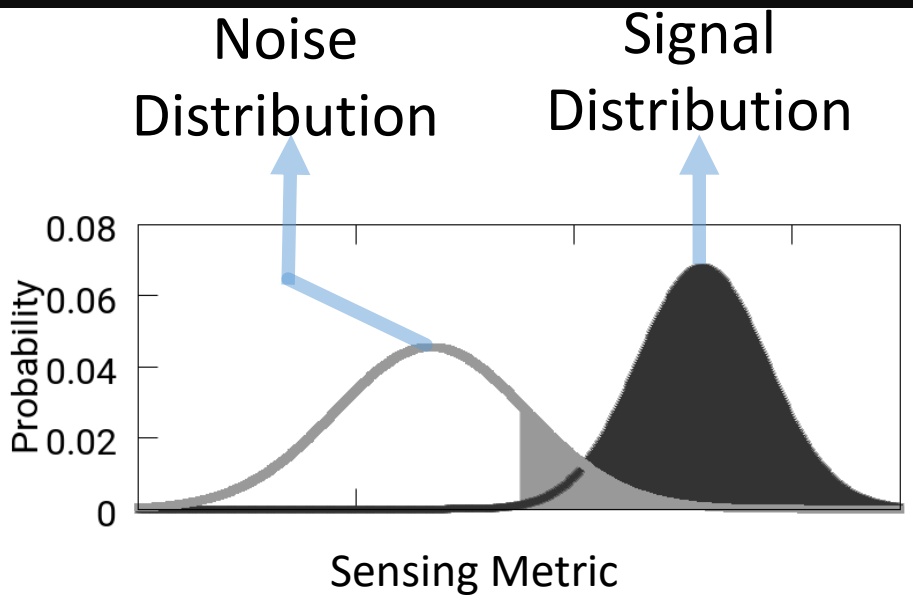
Hypothesis-based Detection

Spectrum Sensor





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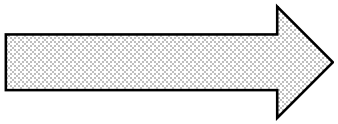

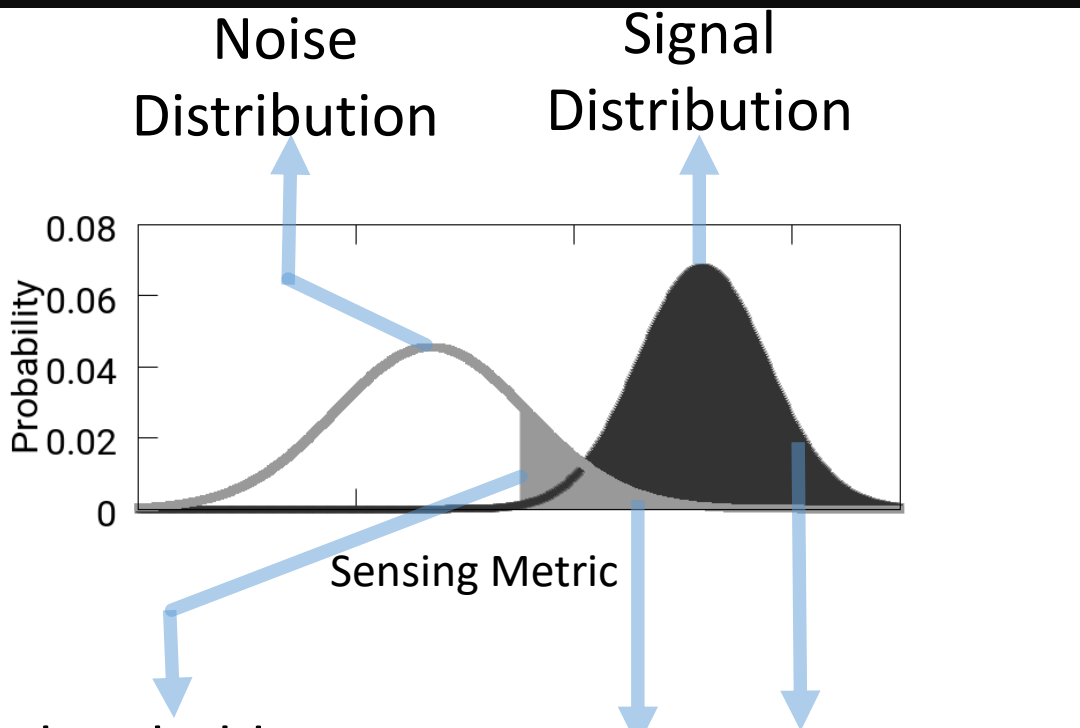

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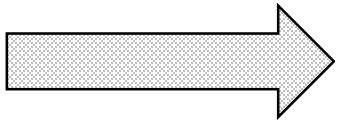
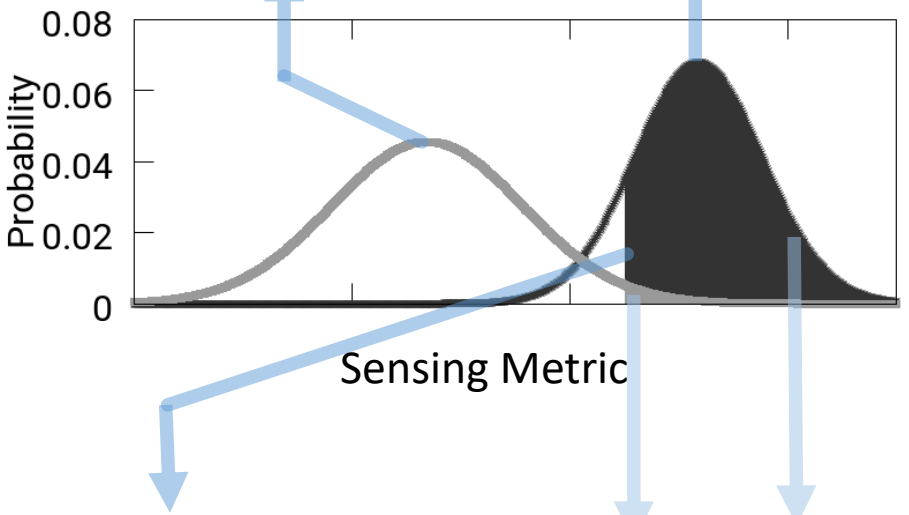


Noise Distribution

Signal Distribution



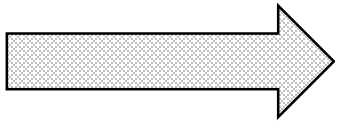
Threshold

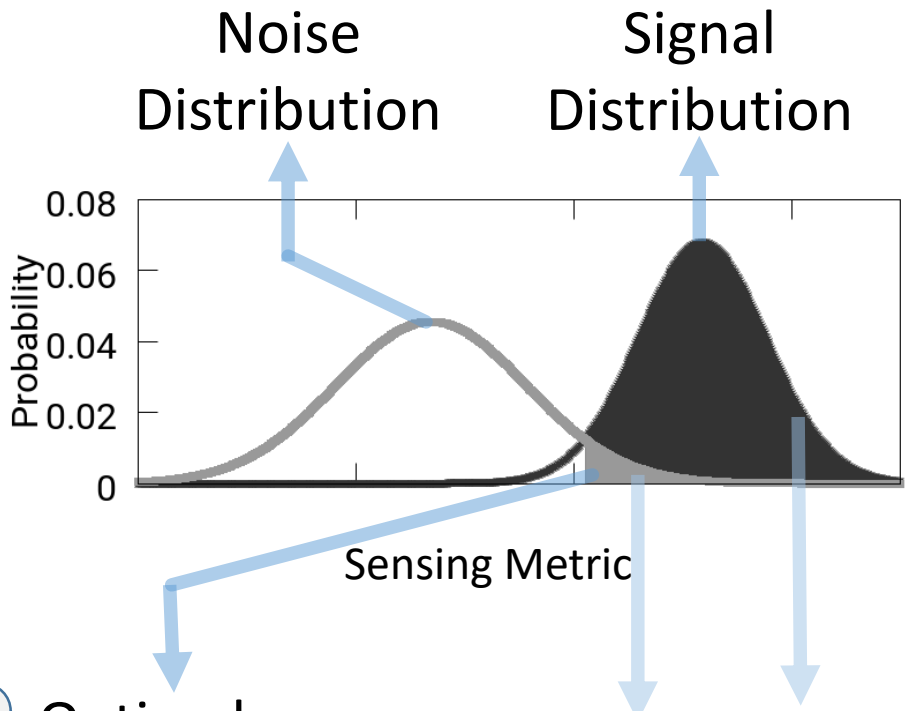
Probability of False Alarm P_{FA}

Probability of Detection P_D

Hypothesis-based Detection

Spectrum Sensor





Maximizes $P_D - P_{FA}$

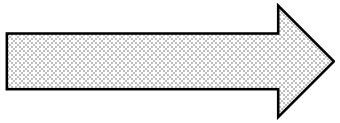
Optimal Threshold

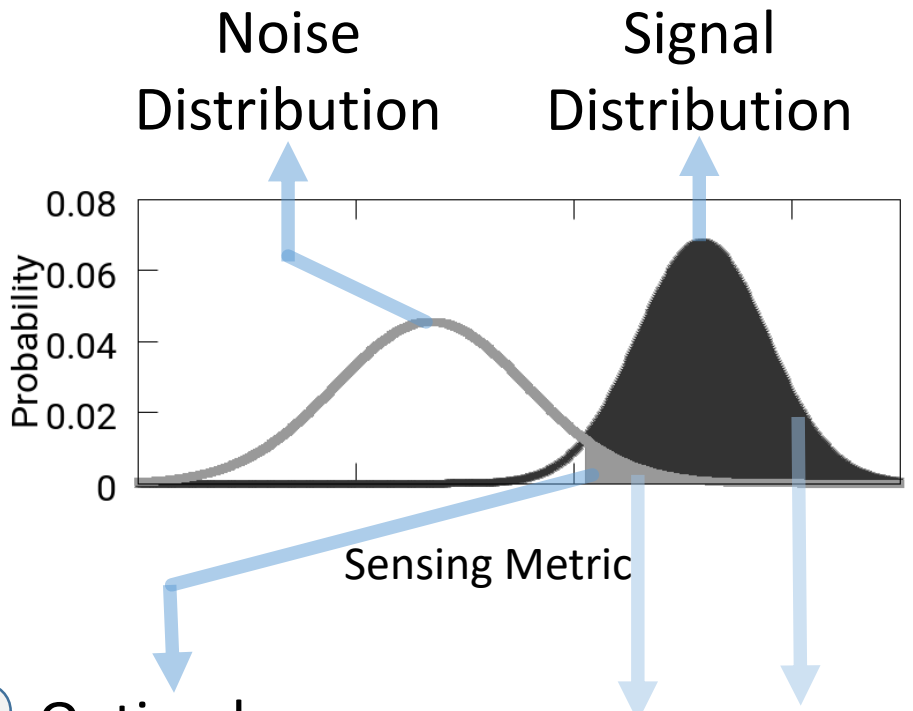
Probability of False Alarm P_{FA}

Probability of Detection P_D

Hypothesis-based Detection

Spectrum Sensor





Maximizes $P_D - P_{FA}$

Optimal Threshold

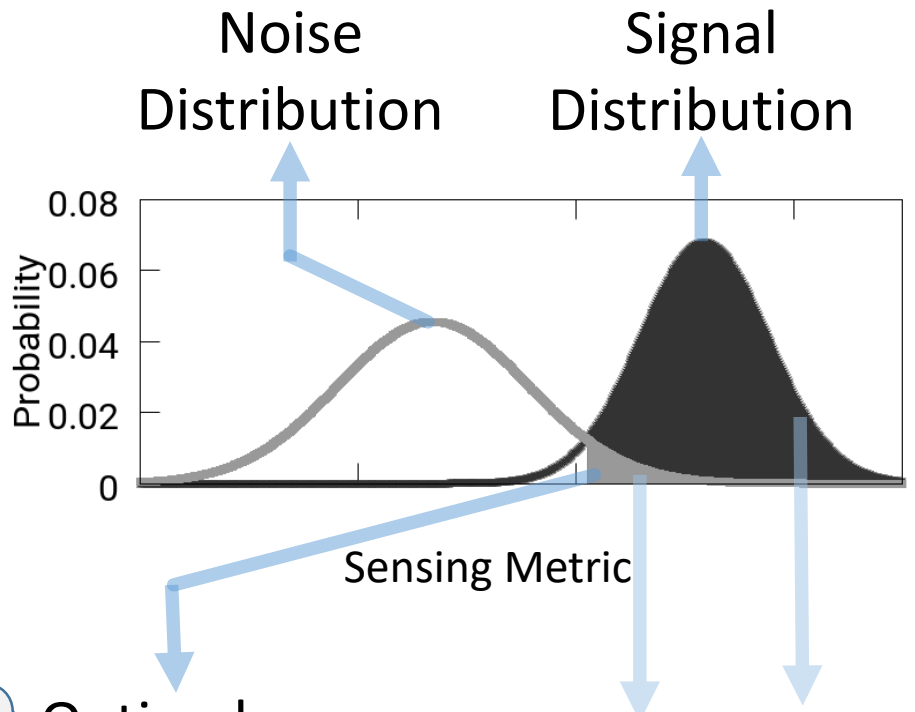
Probability of False Alarm P_{FA}

Probability of Detection P_D

Optimal threshold needed for accurate detection

Hypothesis-based Detection

Spectrum Sensor



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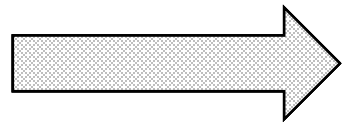

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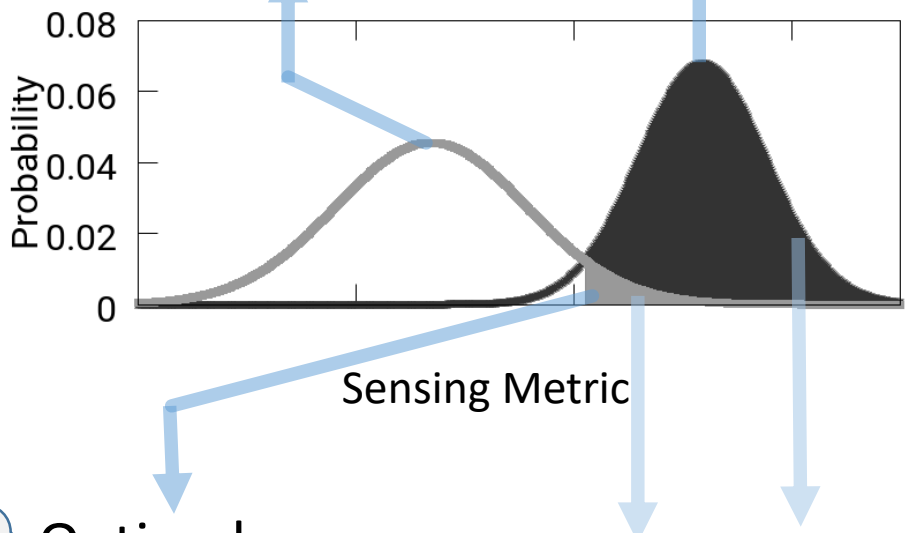
Signal Distribution



Optimal Threshold

Probability of False Alarm P_{FA}

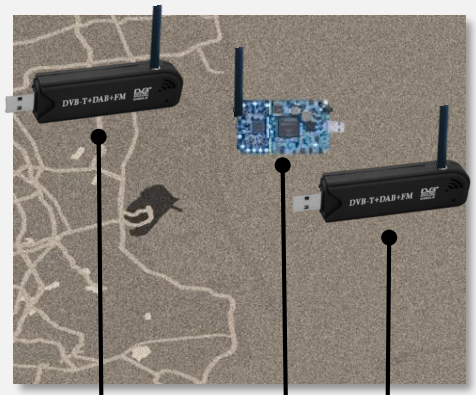
Probability of Detection P_D

Maximizes $P_D - P_{FA}$

Can be computed by observing distributions

Inferring Distributions by Observing is Hard

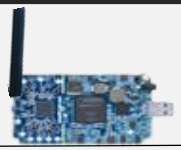
Many possible locations



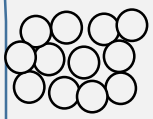
Diverse Locations

Number of configurations = 128

Different hardware

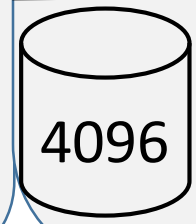


Number of samples



4096 ... 512 256 128 64 32

FFT bin size



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Inferring Distributions by Observing is Hard

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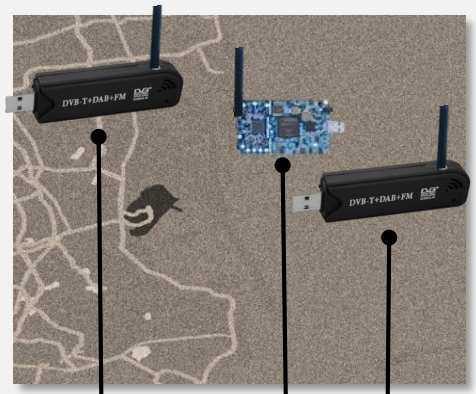

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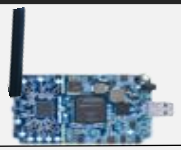

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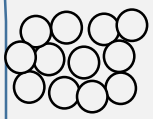

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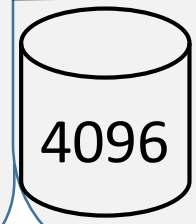

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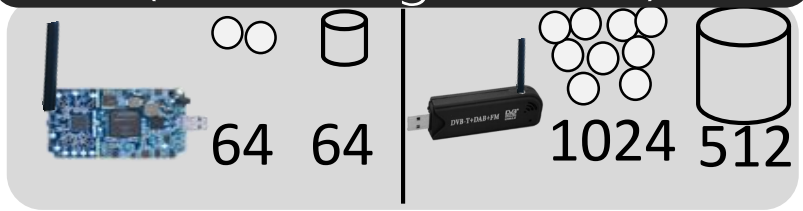
Too much diversity makes getting observations expensive

Our Solution

Observed distributions
(few configurations)



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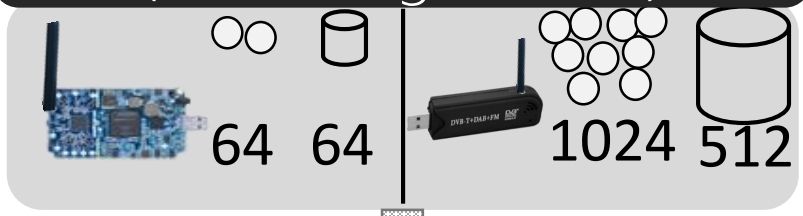
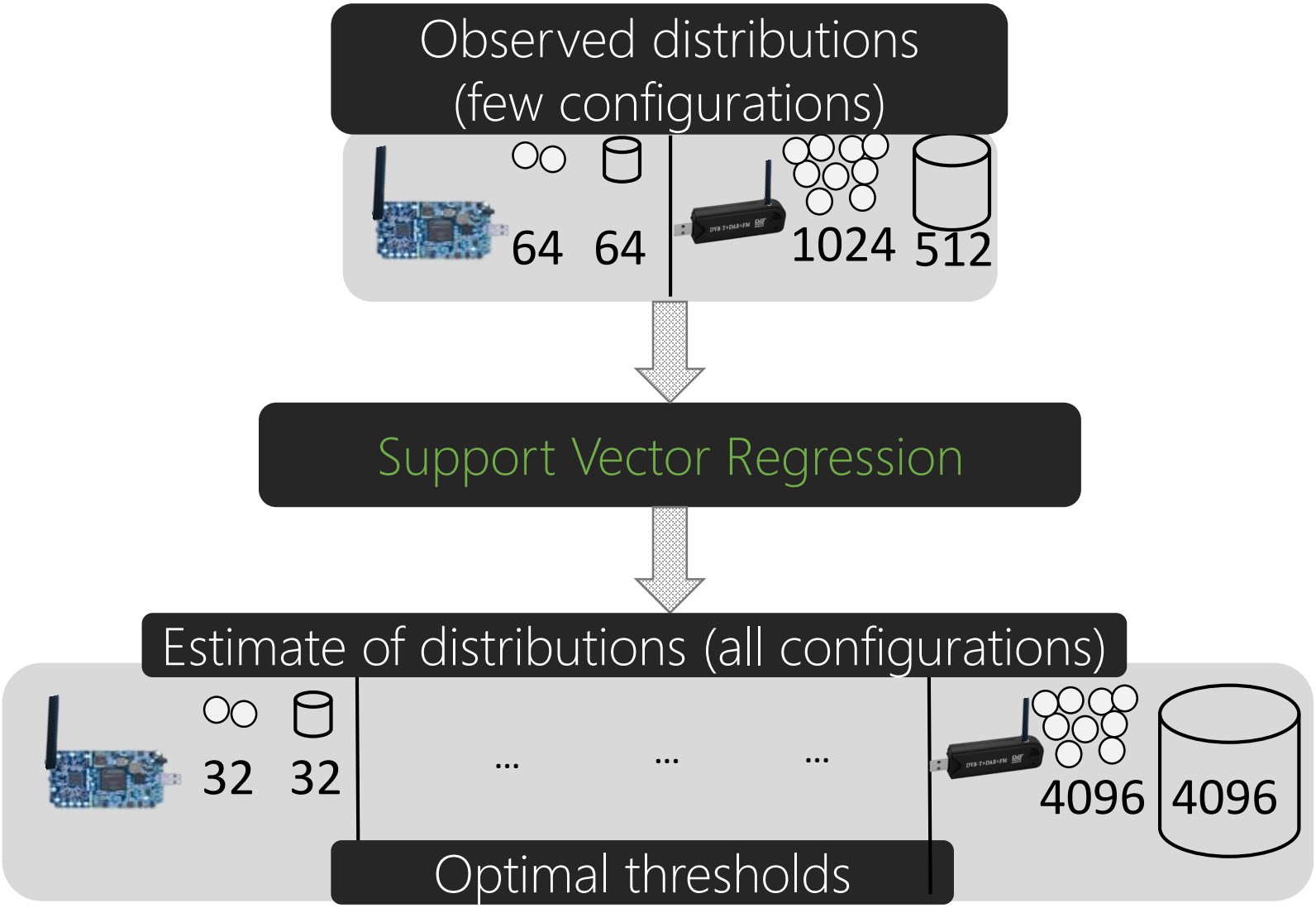
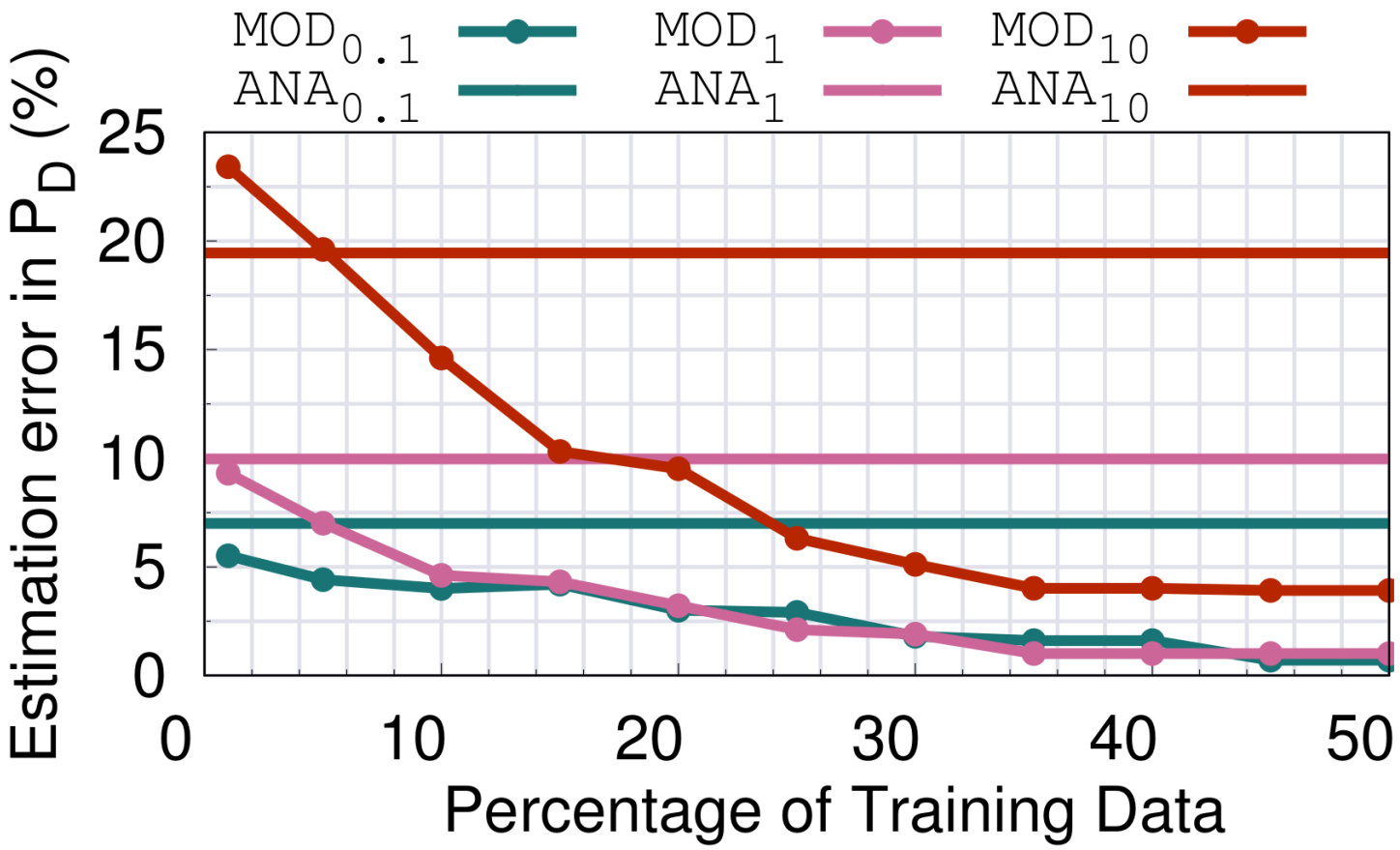


Support Vector Regression

Our Solution

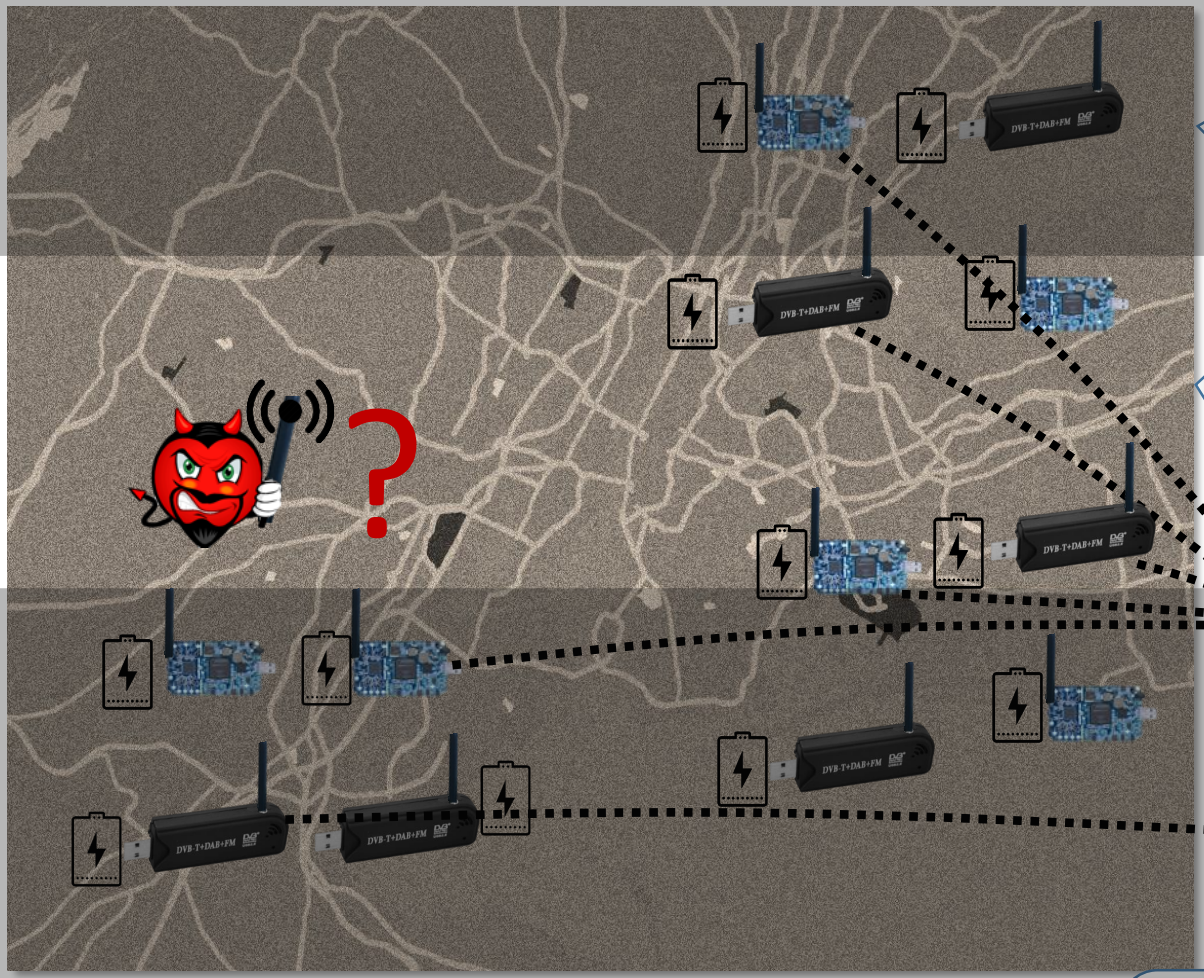


Validation



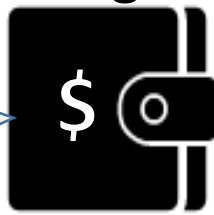
Error less than 5% is possible using SVR

Sensor Selection



1) Handle sensor heterogeneity?

Budget



2) Select sensors

Fusion Center

Global Decision

Present	Absent

3) Fuse sensor decisions to get global decision

Need to Choose Sensor Parameters

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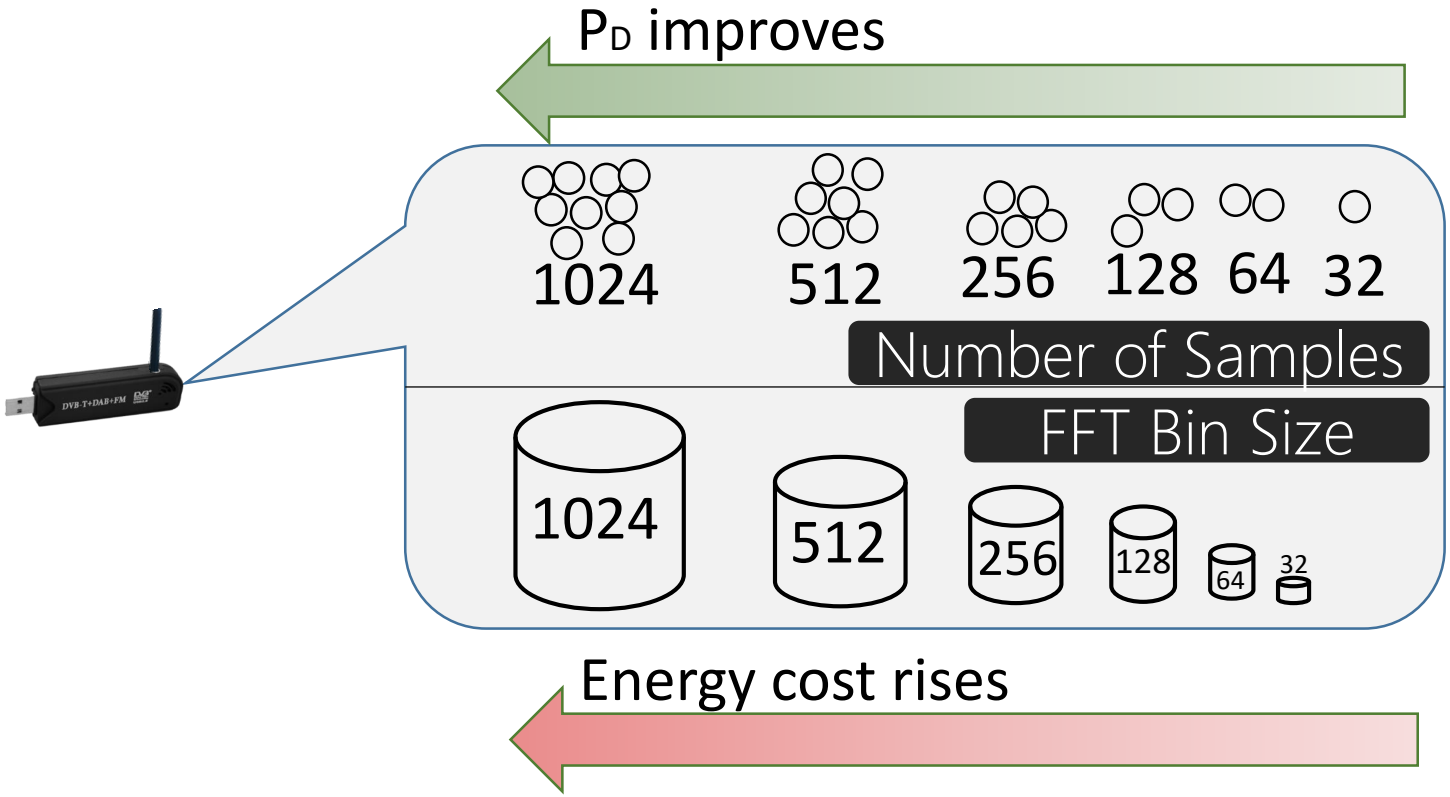

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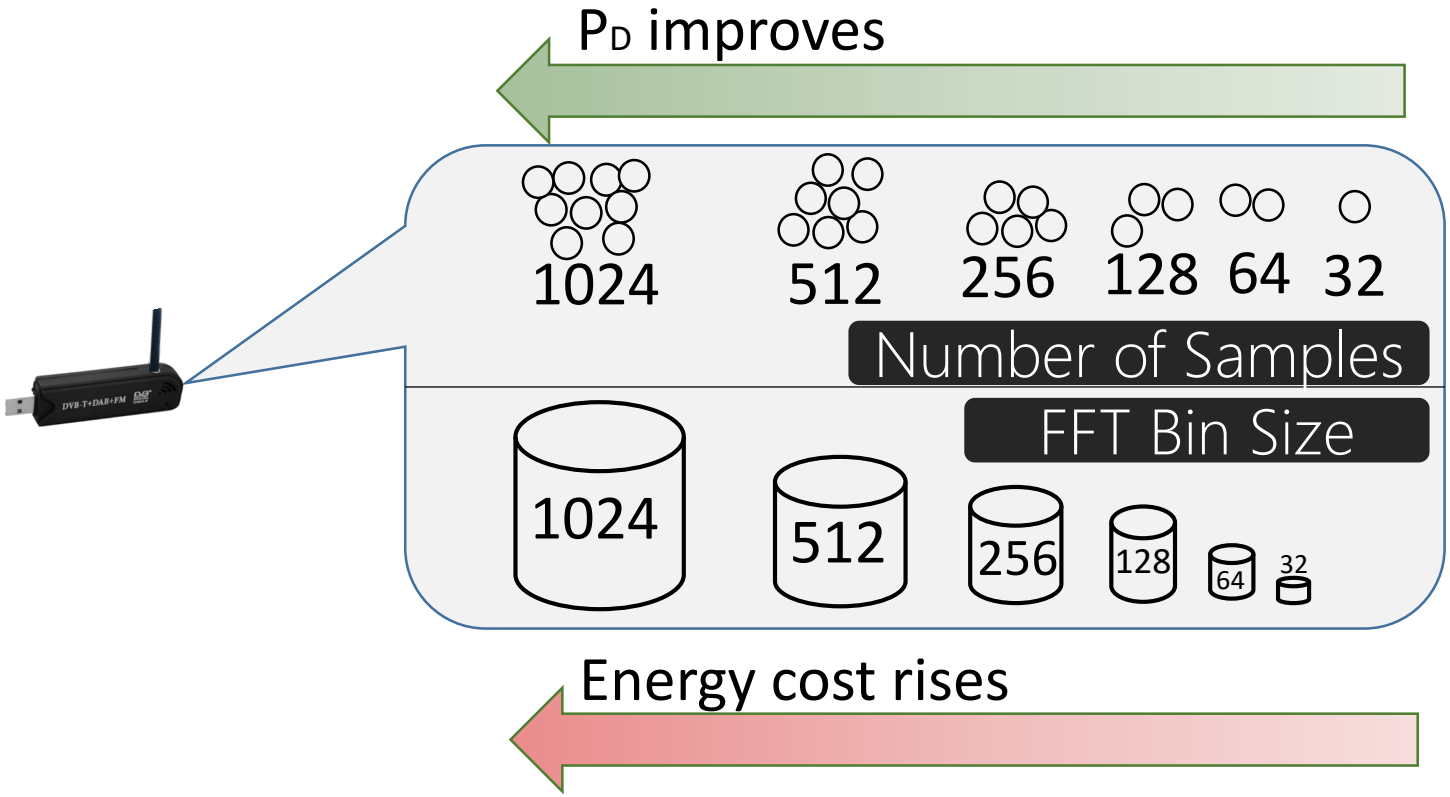
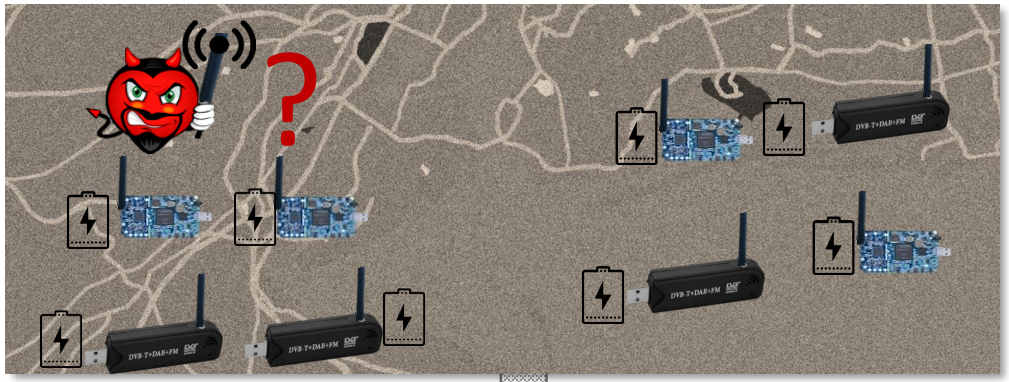


Tradeoff between **P_D** and energy cost

Working of Sensor Selection

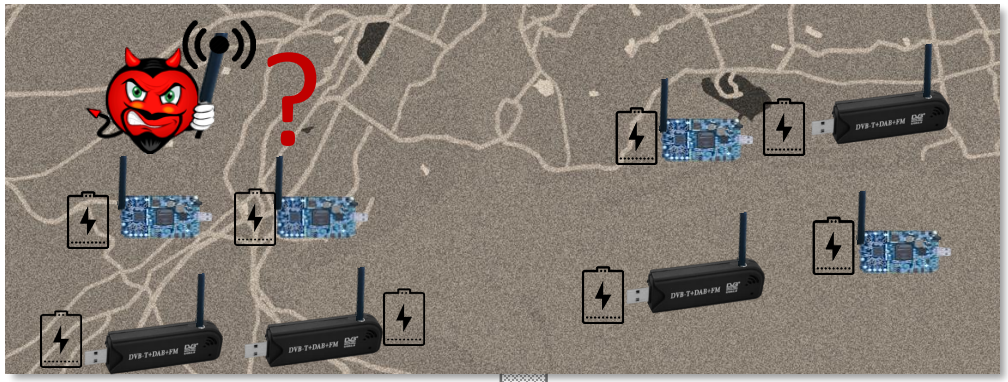


Budget

Sensor Model

Sensor selection algorithm

Working of Sensor Selection



Sensor parameters

Budget

Sensor Model

Sensor selection algorithm

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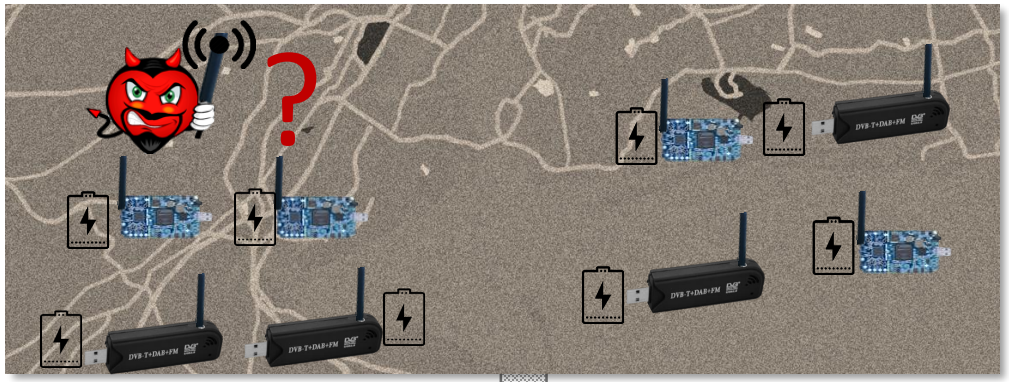
Working of Sensor Selection



Sensor parameters

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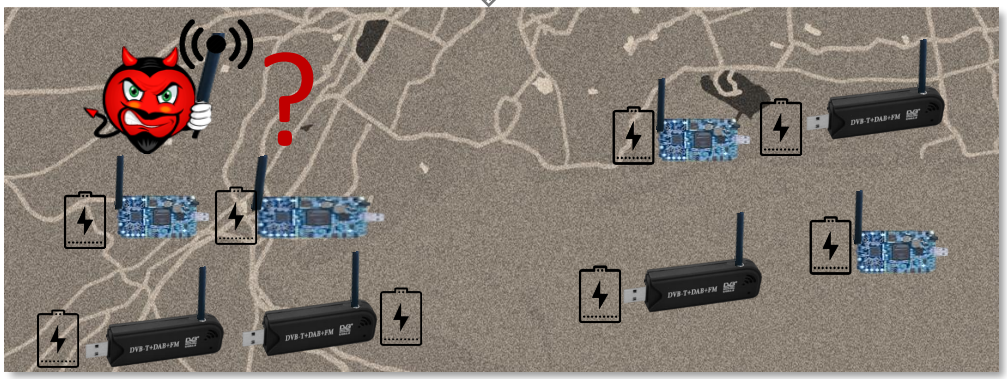

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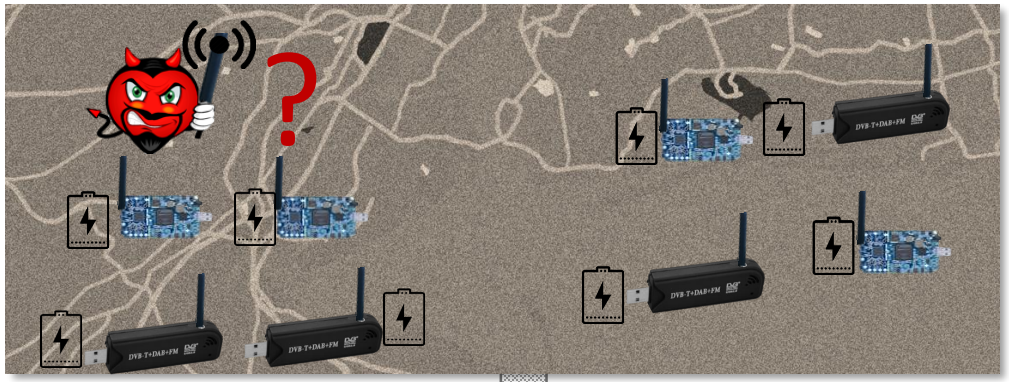

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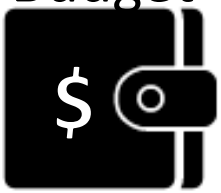

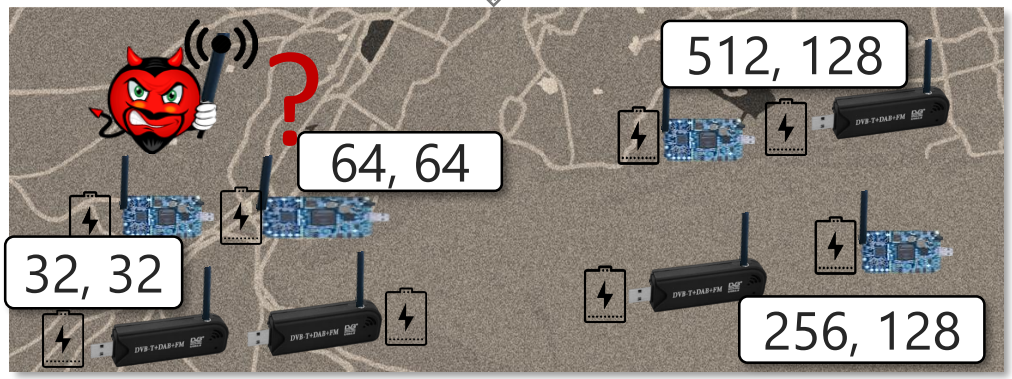

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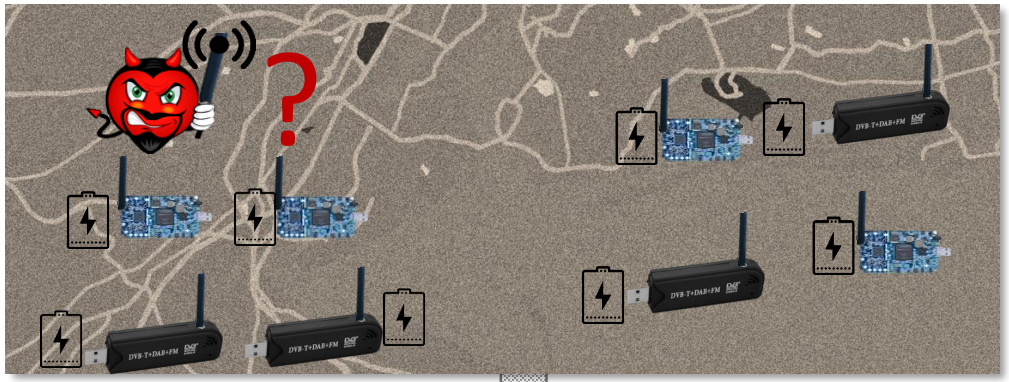

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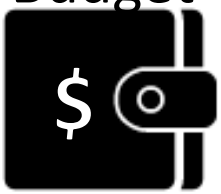
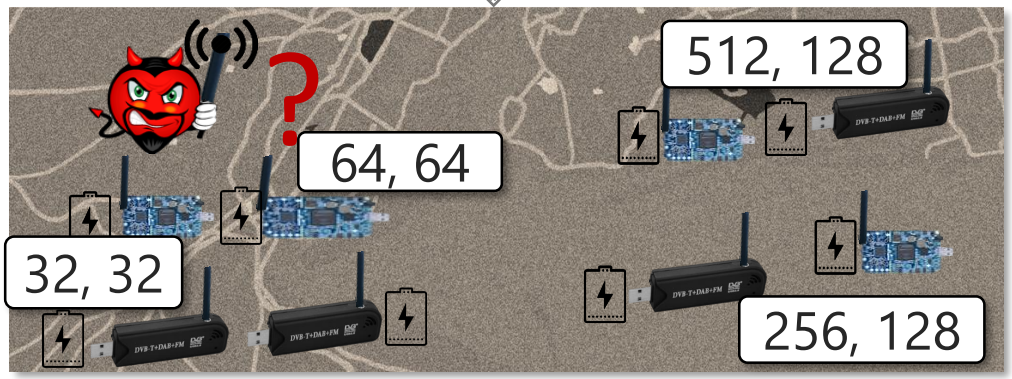
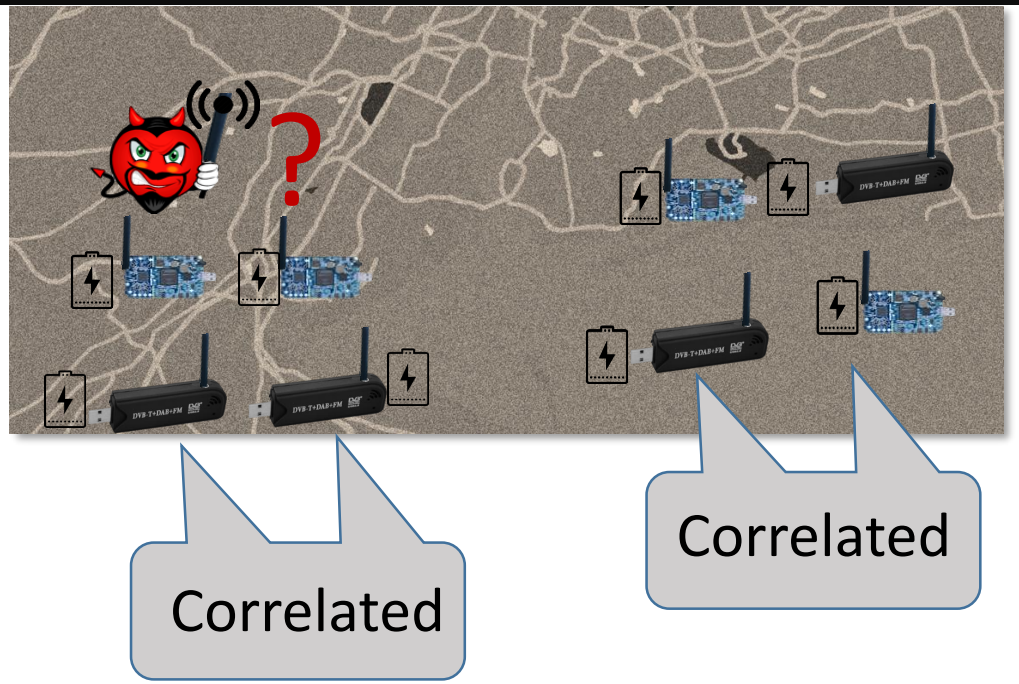




Selection must consider available sensors and budget

Selecting Sensor with Highest P_D does not Work



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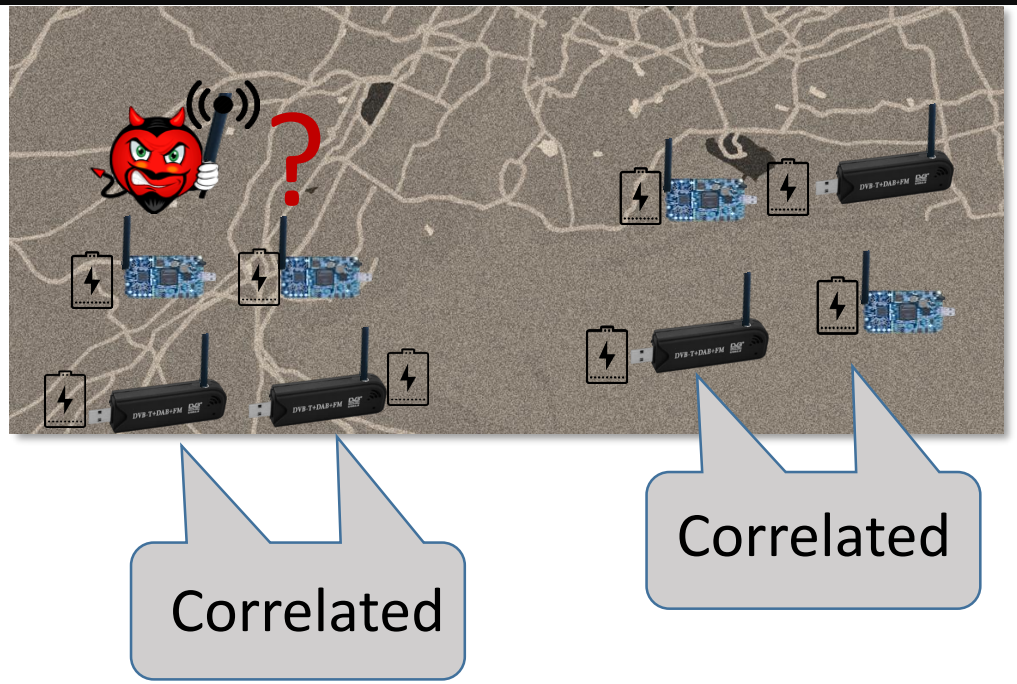

Non-linear optimization: Requires exhaustive search

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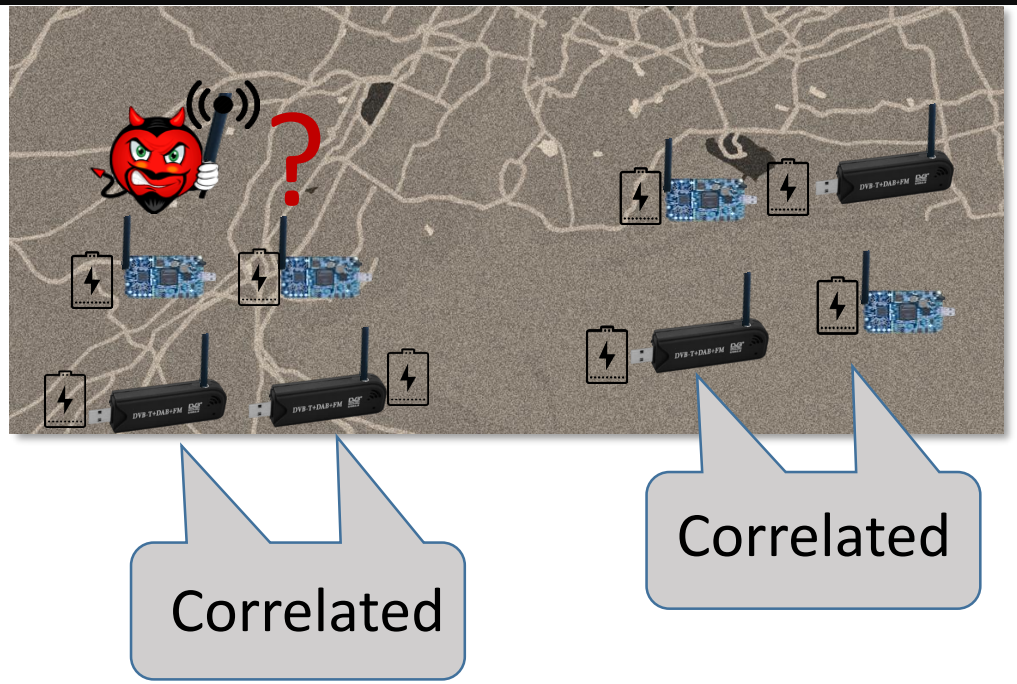
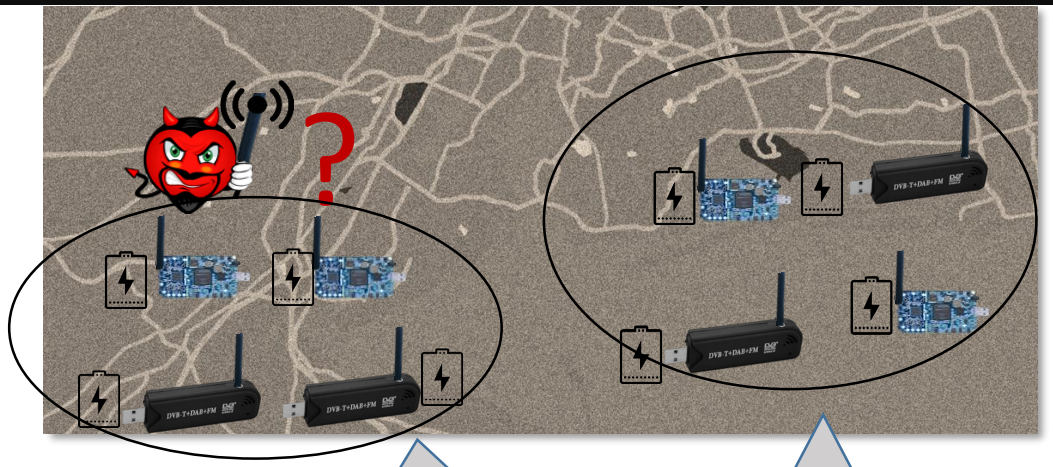


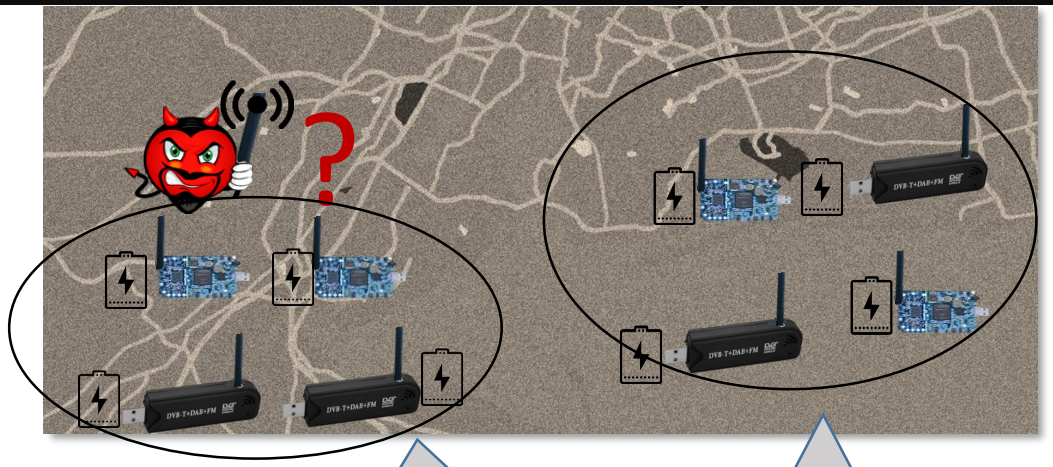
Non-linear optimization: Requires exhaustive search

Our Approach



Decorrelation by clustering

Our Approach



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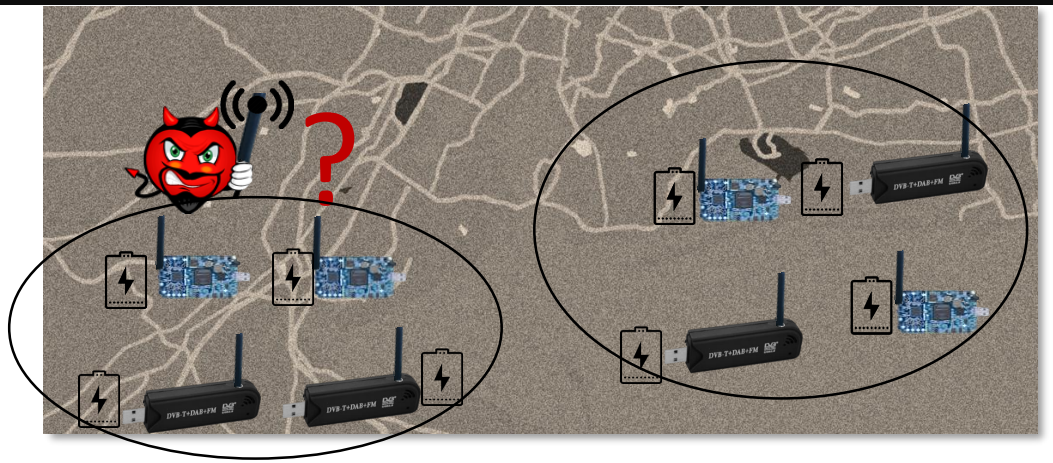
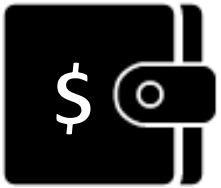


Decorrelation



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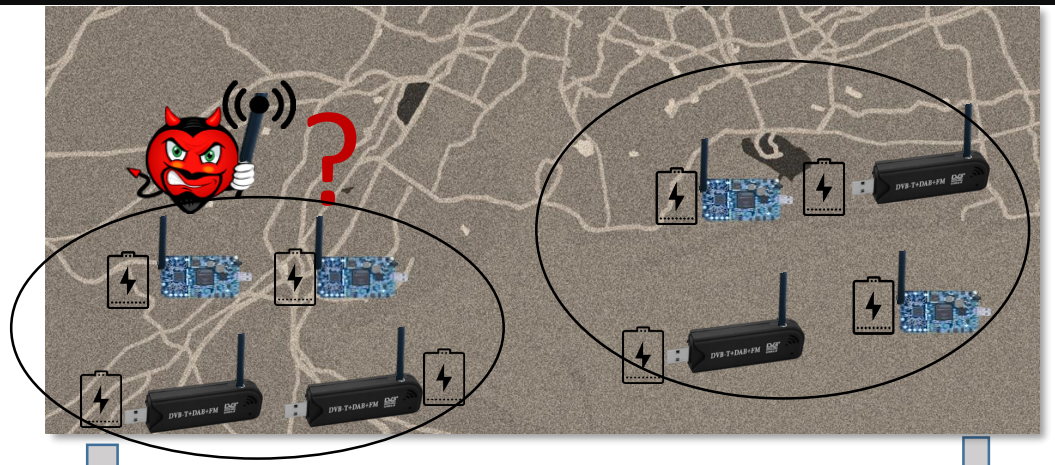

Decorrelation

Knapsack Problem 1

Knapsack Problem 2

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Budget

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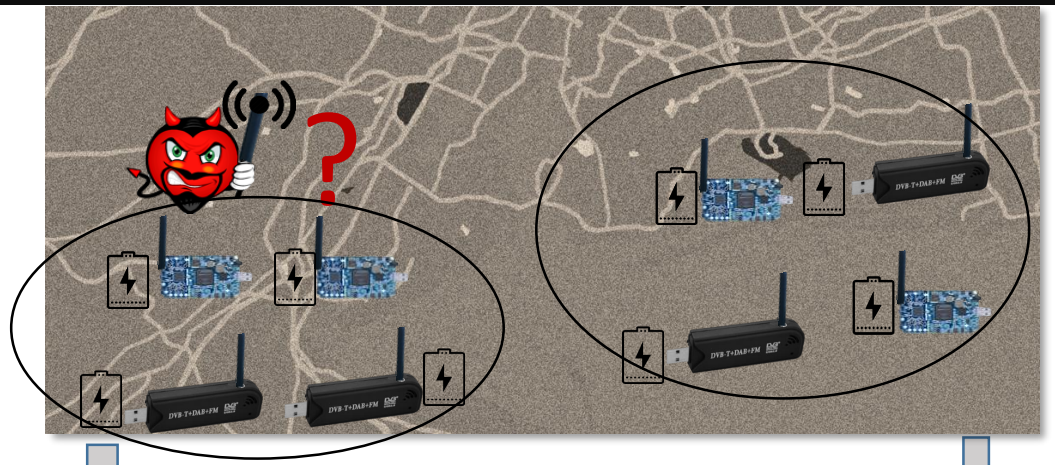

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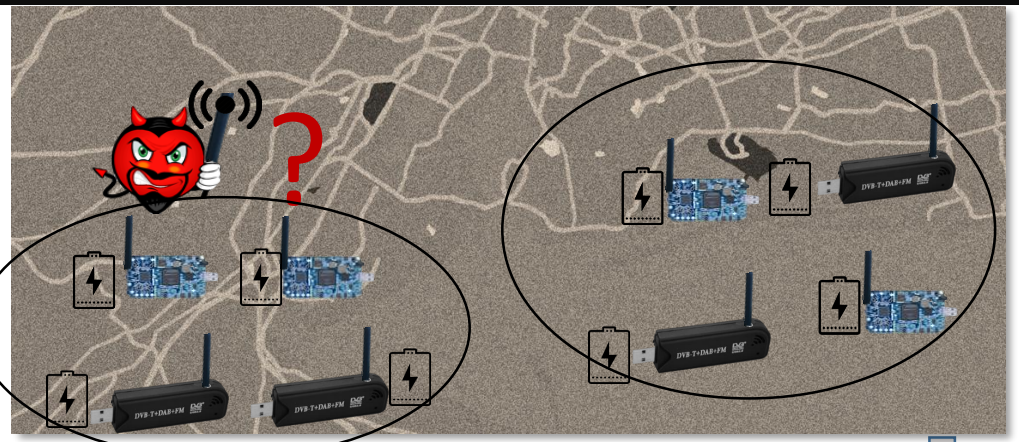

Decorrelation

Knapsack Problem 1

Knapsack Problem 2

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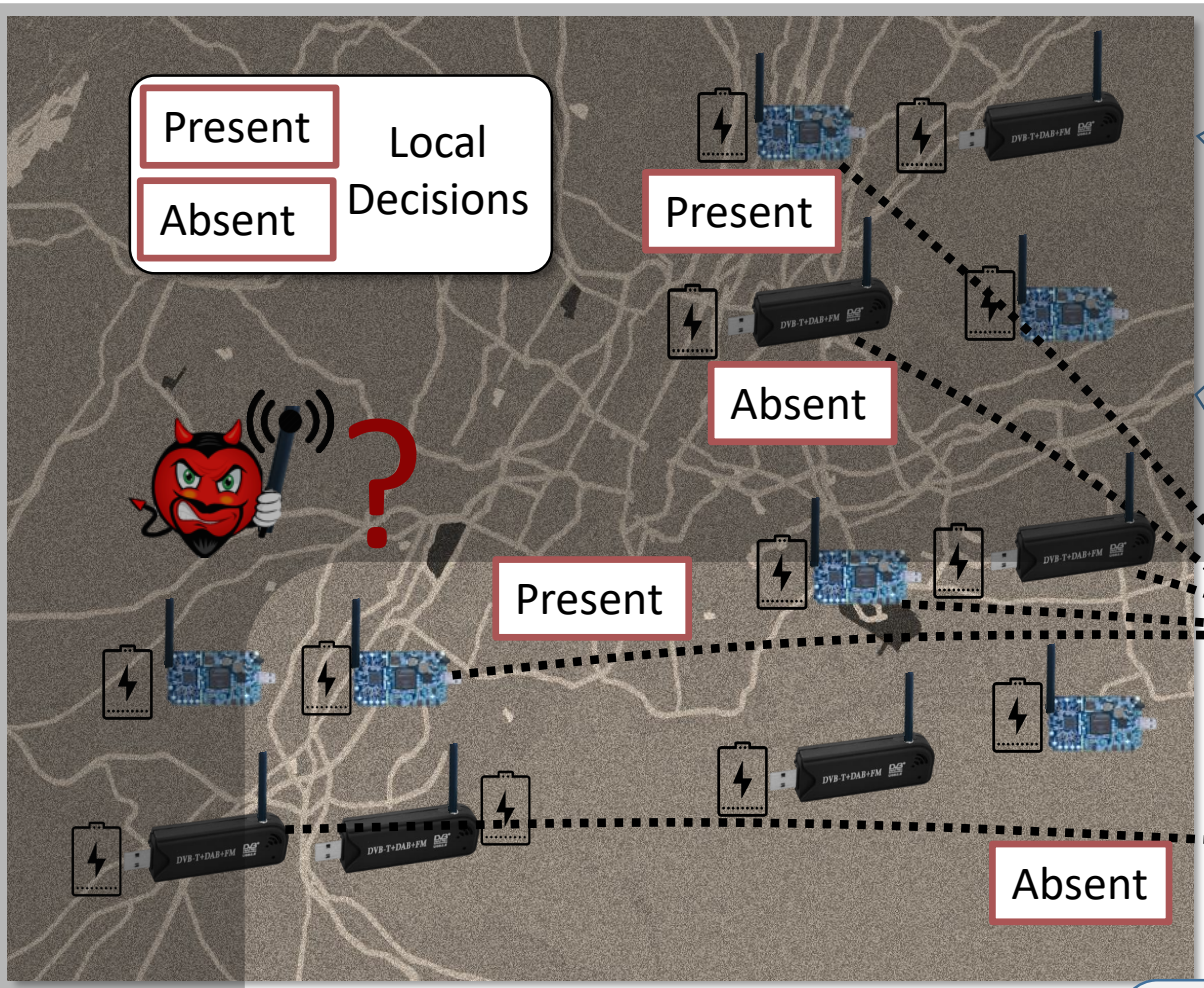
Budget

Dynamic programming

Dynamic programming

Near-optimal solution

Sensor Fusion



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Budget

2) Select sensors

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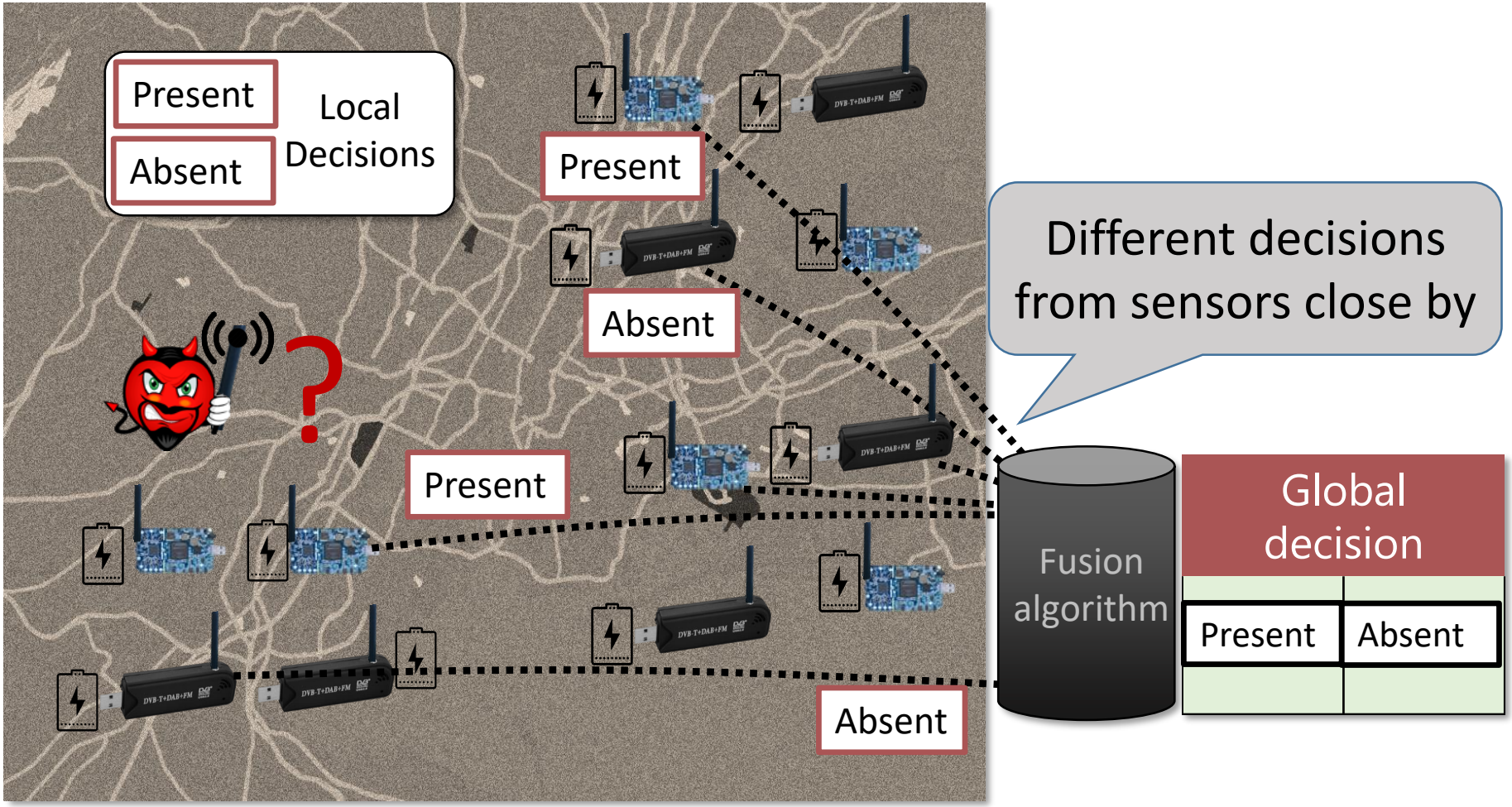
Fusion Center

Global Decision

Present	Absent

3) Fuse sensor decisions to get global decision

Local Decisions have Randomness



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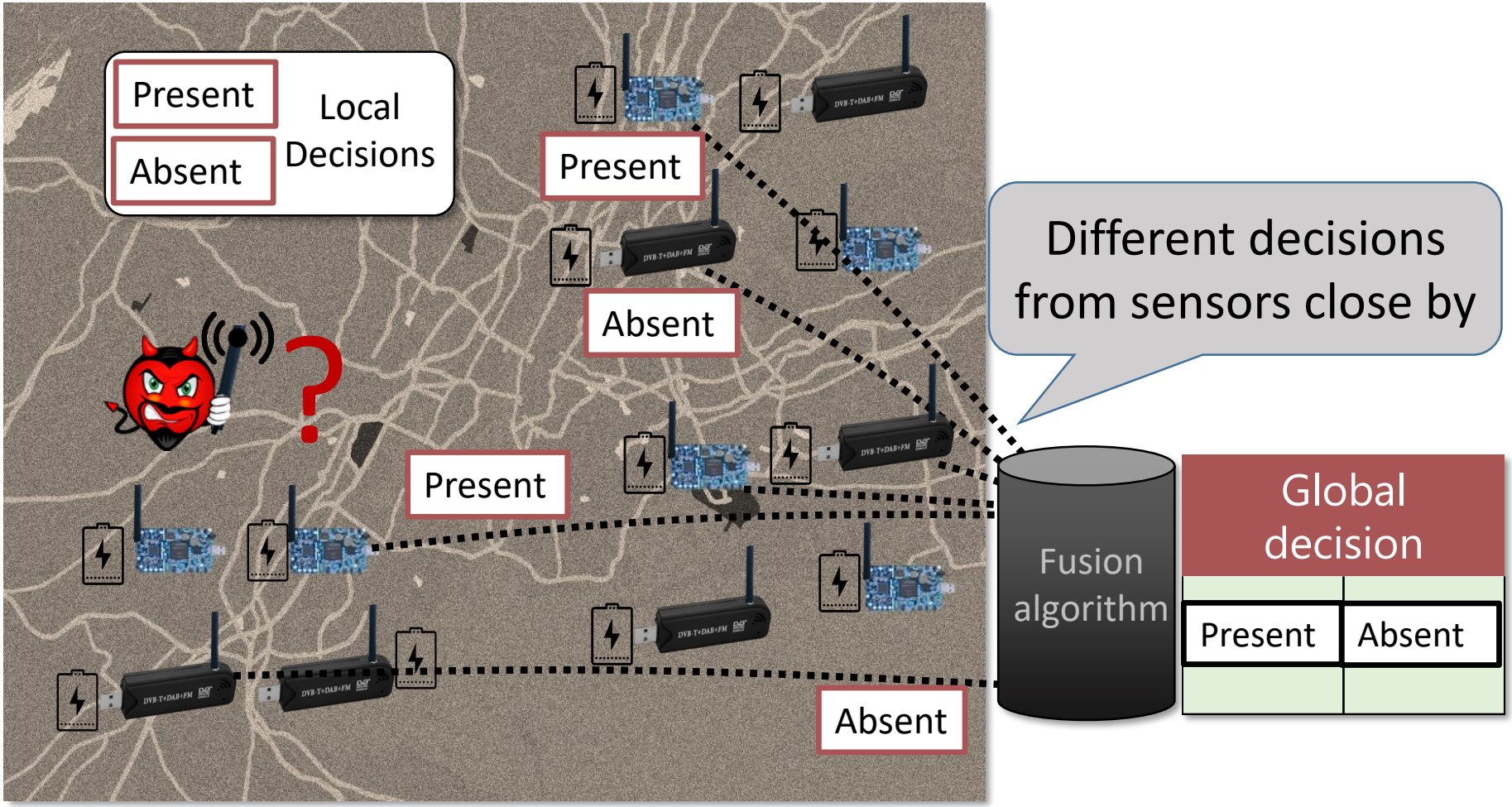
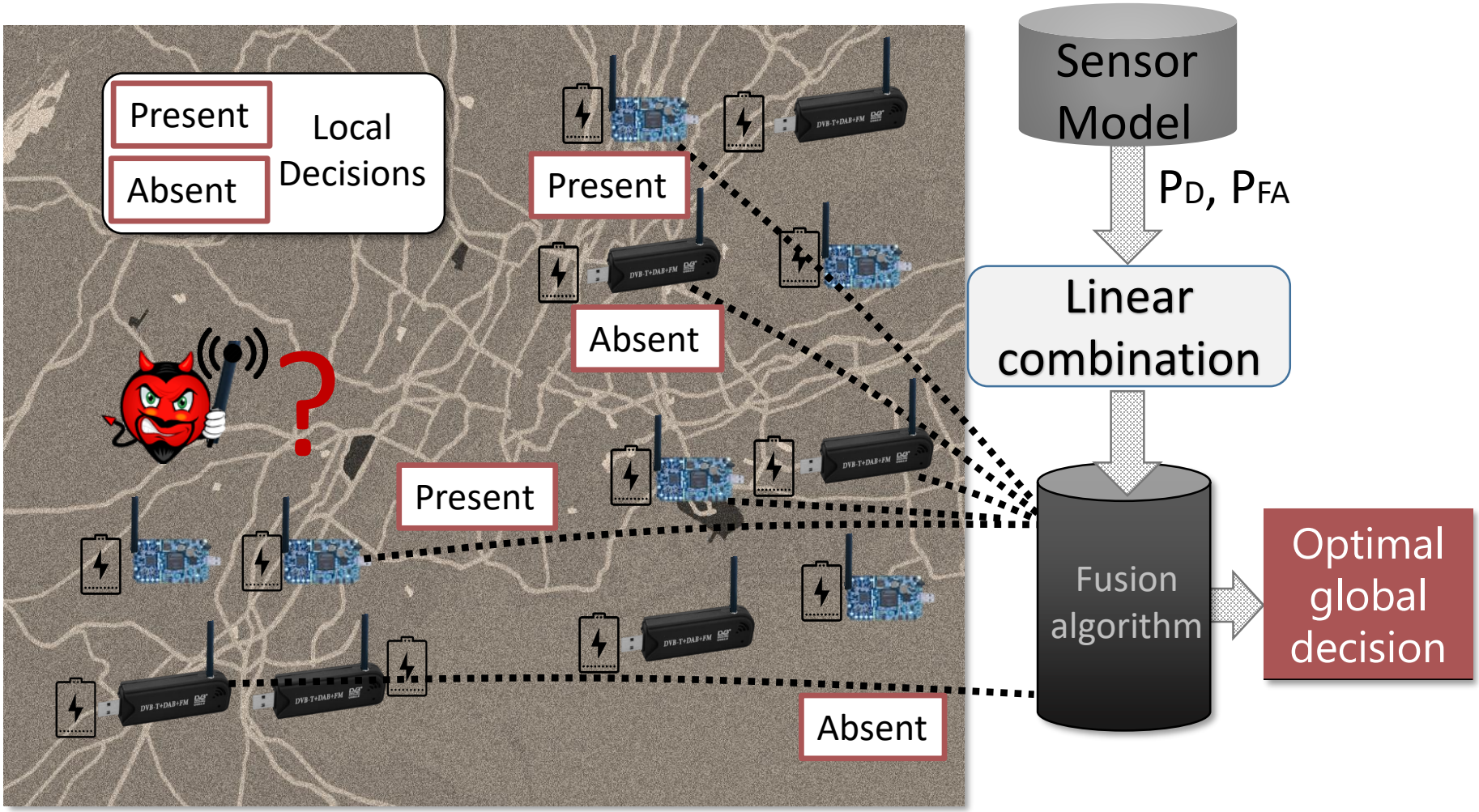


Sensor fusion algorithm need to fuse noisy local decisions

Chair Varshney Fusion Rule



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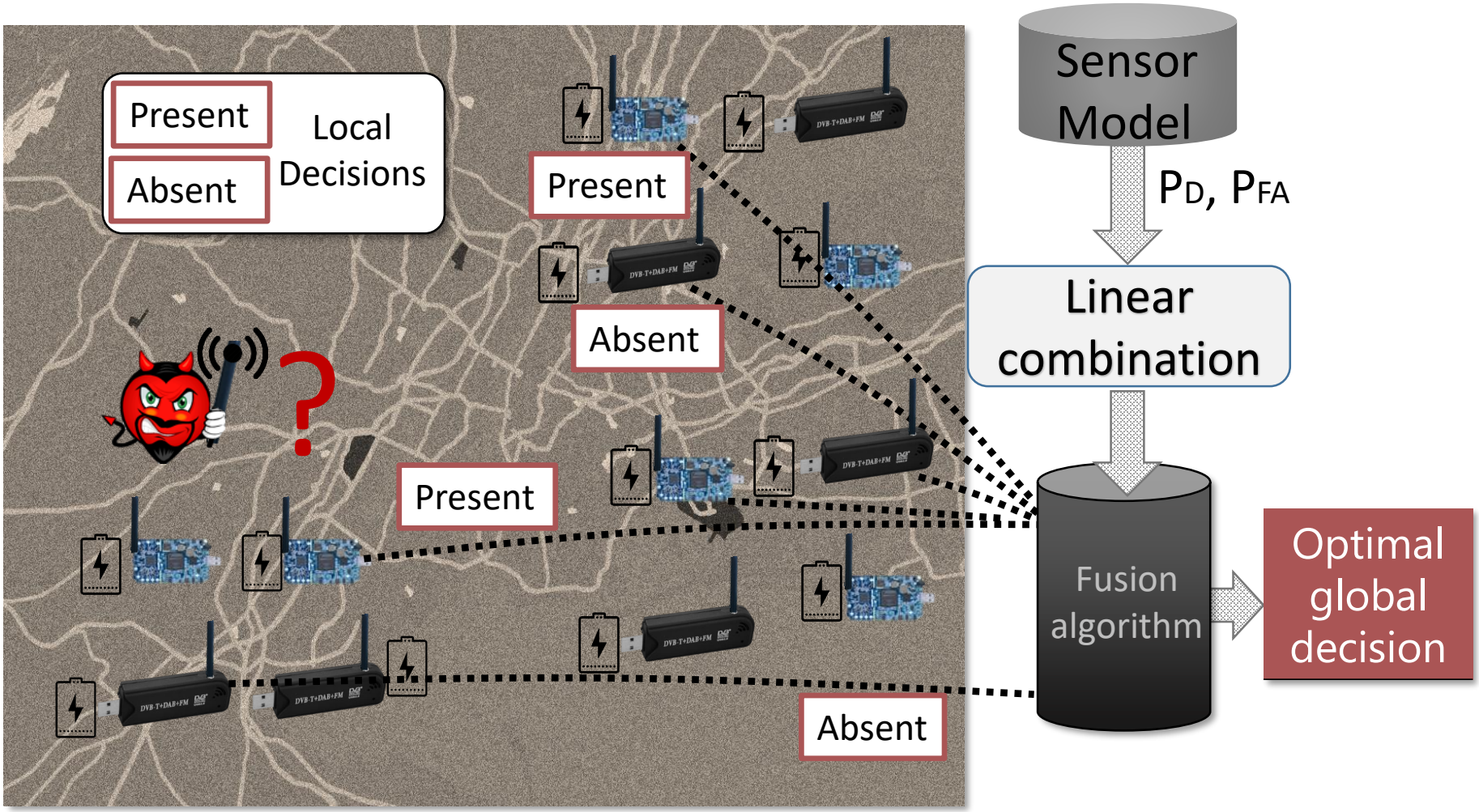
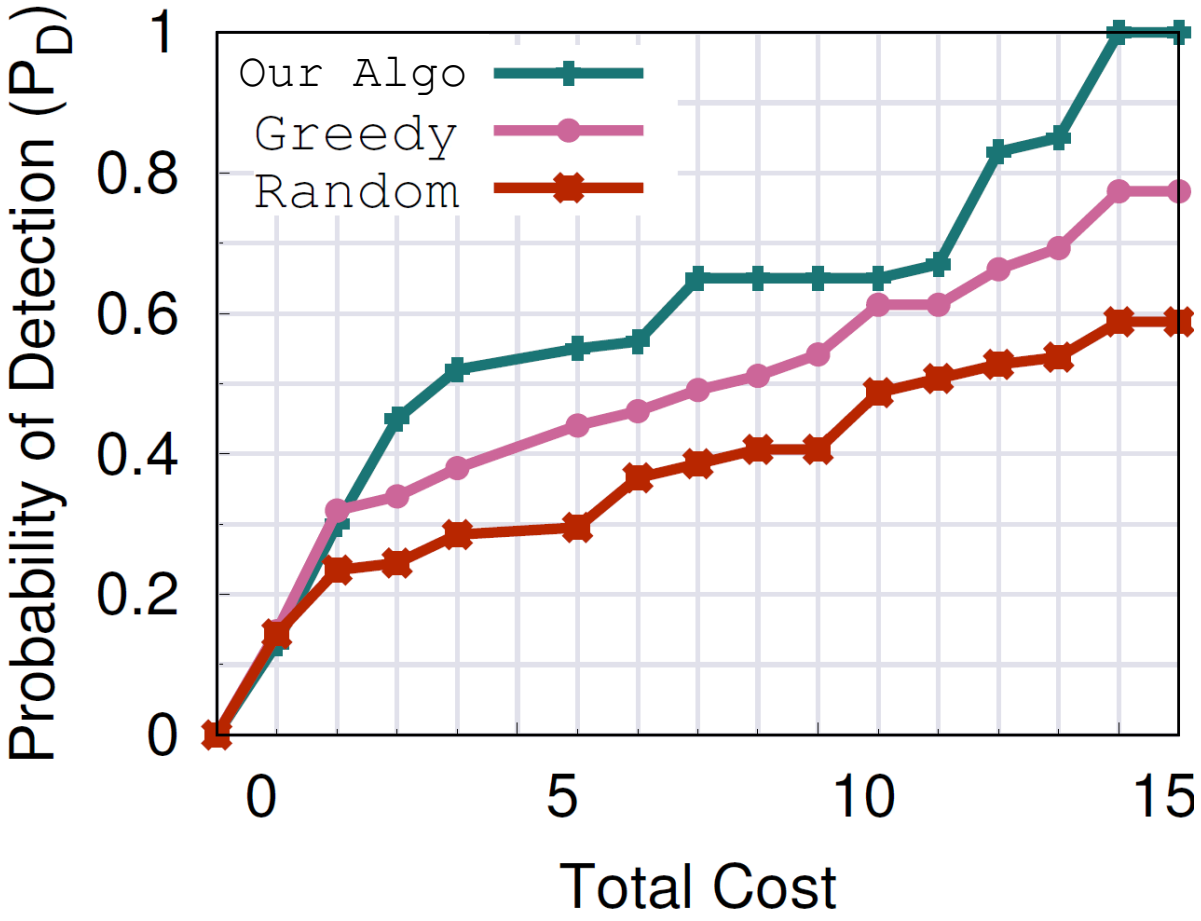


Optimal global decision by weighing each sensor decision

Evaluation

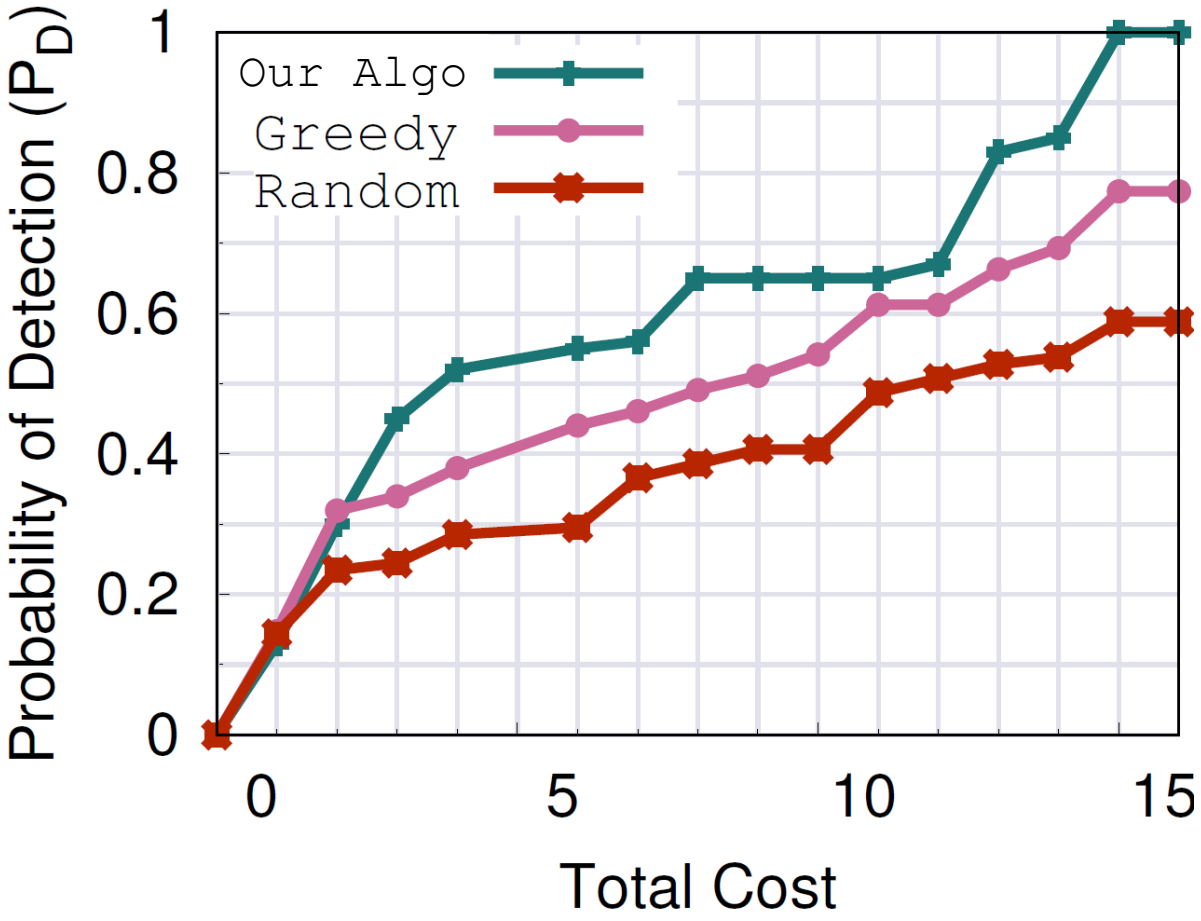
Selection Algorithm

Better performance



Selection Algorithm

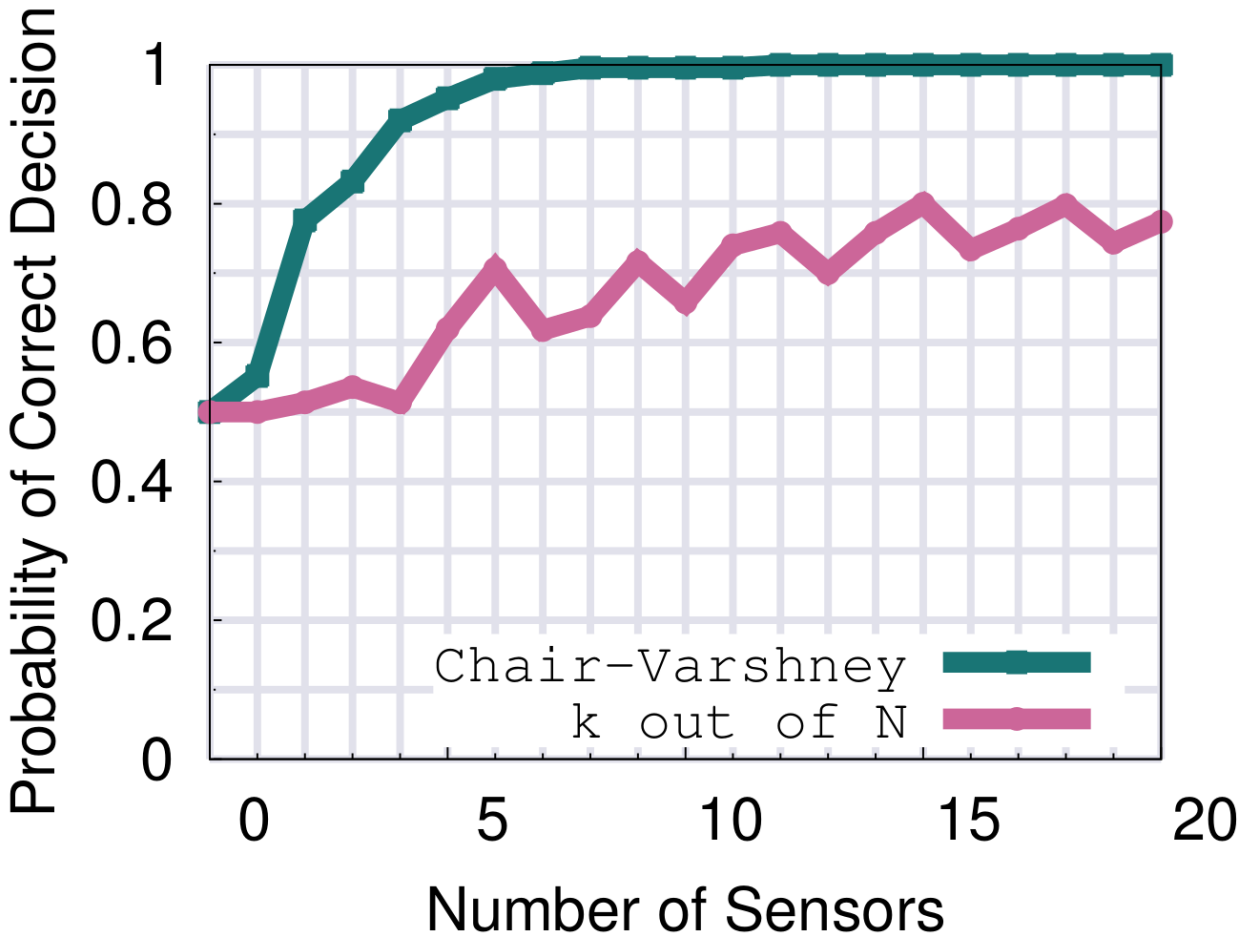
Better performance



Our algorithm performs better than both baselines

Sensor Fusion Algorithm

Better performance



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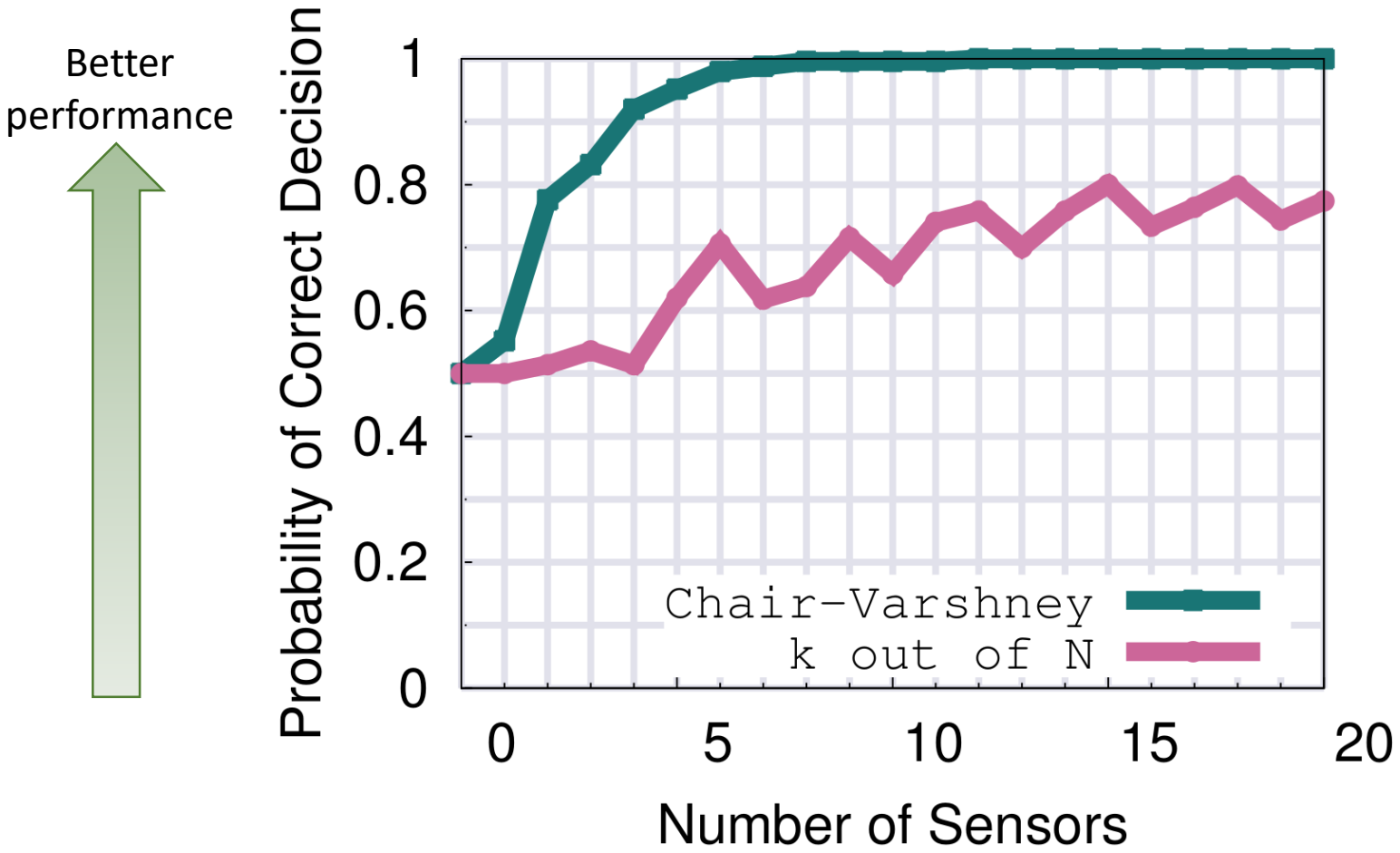

Our sensor fusion performs better than baseline

Summary
Spectrum Patrolling with Crowdsourced Spectrum Sensors

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Spectrum Patrolling with Crowdsourced Spectrum Sensors

Three challenges of crowdsourced-based spectrum patrolling

Deal with heterogeneous sensors

- Use black-box data-driven approach to accurately model sensors

Select sensors

- Decorrelation by clustering
- Knapsack-based solution that satisfy energy cost budget

Get global decision from local noisy sensor decisions

- Weigh local decisions from sensor model to get global decision

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