Spectrum Patrolling with Crowdsourced Spectrum Sensors

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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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Spectrum Increasingly a Scarce Resource

The cost of spectrum has increased 3x in 7 years.

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Cost of spectrum increased 3x in 7 years
Illegal Spectrum use Becoming More Lucrative

![Chart showing the increase in median $/MHz/Population from 2009 to 2016.](chart.png)
Illegal Spectrum use Becoming More Lucrative

Rising gain from illegal use

- Year
- Median $/MHz/Population
Illegal Spectrum use Becoming More Lucrative

- Rising gain from illegal use
- Low-cost SDRs becoming more available

Bar chart showing the median $/MHz/Population from 2009 to 2016.
Illegal Spectrum use Becoming More Lucrative

Low-cost SDRs becoming more available

Easier to illegally use spectrum

Rising gain from illegal use

Easier to illegally use spectrum
Illegal Spectrum use Becoming More Lucrative

Both opportunity and gain of illegal spectrum use rising.
Anecdotal Evidence Suggests Rising Threat
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Shanghai wants law on radio spectrum

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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Florida man fined $48k for jamming cellphones while driving

Probably one of the few people ever pulled over by the FCC.
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FCC Fines Makers, Users of Phone-Jamming Devices That Can Disrupt Cell, GPS Services

CONSUMERIST

FCC Fines Makers, Users Of Phone-Jamming Devices That Can Disrupt Cell, GPS Services

If you’re thinking of using a phone-jamming device to shut up your binge

netizens and get them off their phones while driving, think again.

the Federal Communications Commission could fine you with fines

that could be the equivalent of what you’d pay if you were caught

using a device that could disrupt the cell.

@MaryBethDove
@commslash.com
Anecdotal Evidence Suggests Rising Threat

Illegal transmitters, such as radio frequency identification tags and signal boosters, which operate outside of approved frequencies, are disrupting communications services and affecting business enterprises.
Regulators are getting worried
How can Regulators Protect Spectrum?

Intruder
(Illegal transmitter)
How can Regulators Protect Spectrum?

Intruder (Illegal transmitter)

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

Illegal transmitters must be detected:
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2) by cheap sensors
3) incurring low cost

Deploys a large number of sensors belonging to different users

How can Regulators Protect Spectrum?
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Crowdsourcing promises to satisfy accuracy and cost requirements.

Intruder (Illegal transmitter)

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

Deploys a large number of sensors belonging to different users.
Challenges of Crowdsourcing
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1) Handle sensor heterogeneity?
Challenges of Crowdsourcing

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Challenges of Crowdsourcing

1) Handle sensor heterogeneity?

2) Select sensors

Cost (Energy)
Challenges of Crowdsourcing

1) Handle sensor heterogeneity?

2) Select sensors

Present
Absent

Local Decisions

Global Decision

Present Absent

Fusion Center

Budget

$
Challenges of Crowdsourcing

1) Handle sensor heterogeneity?

2) Select sensors

3) Fuse sensor decisions to get global decision
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Hypothesis-based Detection

Signal Distribution

Noise Distribution

Sensing Metric

Probability

0.08

0.06

0.04

0.02

0
Hypothesis-based Detection

- Probability of Detection $P_D$
- Probability of False Alarm $P_{FA}$
- Threshold
- Sensing Metric
- Probability of Detection $P_D$
- Signal Distribution
- Noise Distribution
Hypothesis-based Detection

- Probability of Detection \( P_D \)
- Probability of False Alarm \( P_{FA} \)
- Threshold

Sensor

Noise Distribution

Signal Distribution

Sensing Metric

Probability
Hypothesis-based Detection

Spectrum Sensor

Maximizes $P_D - P_{FA}$

Optimal Threshold

Probability of False Alarm $P_{FA}$

Probability of Detection $P_D$

Noise Distribution

Signal Distribution

Sensing Metric
Hypothesis-based Detection

Optimal threshold needed for accurate detection

Spectrum Sensor

Maximizes $P_D - P_{FA}$

Optimal Threshold

Probability of False Alarm $P_{FA}$

Probability of Detection $P_D$

Noise Distribution

Signal Distribution

Sensing Metric
Hypothesis-based Detection

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Probability of Detection $P_D$

Noise Distribution

Signal Distribution

Sensing Metric
Hypothesis-based Detection

Spectrum Sensor

Maximizes $P_D - P_{FA}$

Can be computed by observing distributions

Optimal Threshold

Probability of False Alarm $P_{FA}$

Probability of Detection $P_D$

Noise Distribution

Signal Distribution

Sensing Metric
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

4096 512 256 128 64 32

FFT bin size
Inferring Distributions by Observing is Hard

Many possible locations

Diverse Locations

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FFT bin size

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</table>

Too much diversity makes getting observations expensive
Our Solution

Observed distributions (few configurations)
Our Solution

Observed distributions
(few configurations)

Support Vector Regression
Our Solution

Observed distributions (few configurations)

Support Vector Regression

Estimate of distributions (all configurations)

Optimal thresholds
Validation

Error less than 5% is possible using SVR
Sensor Selection

1) Handle sensor heterogeneity?

2) Select sensors

3) Fuse sensor decisions to get global decision

Budget

Global Decision

Present    Absent

Fusion Center

?
Need to Choose Sensor Parameters
Need to Choose Sensor Parameters

- Number of Samples:
  - 1024
  - 512
  - 256
  - 128
  - 64
  - 32

- FFT Bin Size:
  - 1024
  - 512
  - 256
  - 128
  - 64
  - 32

- $P_D$ improves
- Energy cost rises
Need to Choose Sensor Parameters

P_D improves

Number of Samples
1024  512  256  128  64  32

FFT Bin Size
1024  512  256  128  64  32

Energy cost rises

Tradeoff between P_D and energy cost
Working of Sensor Selection
Working of Sensor Selection

Sensor parameters

Sensor Model

Sensor selection algorithm

Budget
Working of Sensor Selection

Sensor parameters → Sensor Model → Sensor selection algorithm → Budget

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Working of Sensor Selection

Sensor Model

Sensor parameters

Sensor selection algorithm

Budget

32, 32
64, 64
512, 128
256, 128

$
Working of Sensor Selection

Selection must consider available sensors and budget

Sensor parameters

Sensor Model

Sensor selection algorithm

Budget

Sensor parameters:
- 32, 32
- 64, 64
- 256, 128
- 512, 128
Selecting Sensor with Highest $P_D$ does not Work
Selecting Sensor with Highest $P_D$ does not Work

Non-linear optimization: Requires exhaustive search
Selecting Sensor with Highest $P_D$ does not Work

Non-linear optimization: Requires exhaustive search
Our Approach

Decorrelation by clustering
Our Approach

Decorrelation by clustering
Our Approach

Decorrelation

Budget
Our Approach

Decorrelation

Knapsack Problem 1

Knapsack Problem 2
Our Approach

Decorrelation

Knapsack Problem 1

Budget

Knapsack Problem 2
Our Approach

Decorrelation

Budget

Knapsack Problem 1

Dynamic programming

Near-optimal solution

Dynamic programming

Knapsack Problem 2

Dynamic programming
Sensor Fusion

1) Handle sensor heterogeneity?

2) Select sensors

3) Fuse sensor decisions to get global decision
Local Decisions have Randomness

Different decisions from sensors close by

Fusion algorithm

<table>
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<th>Global decision</th>
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<th>Absent</th>
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<td>Fusion algorithm</td>
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Local Decisions have Randomness

Different decisions from sensors close by

Sensor fusion algorithm need to fuse noisy local decisions
Chair Varshney Fusion Rule

Local Decisions

Present
Absent

Sensor Model

P_D, P_FA

Linear combination

Fusion algorithm

Optimal global decision
Chair Varshney Fusion Rule

Optimal global decision by weighing each sensor decision
Evaluation
Selection Algorithm

Better performance

![Graph showing probability of detection vs total cost]

- Our Algo
- Greedy
- Random

Probability of Detection ($P_D$) vs Total Cost
Selection Algorithm

Our selection algorithm performs better than both baselines.

Better performance

Our algorithm performs better than both baselines.
Sensor Fusion Algorithm

Better performance
Our sensor fusion performs better than baseline.
Summary
Spectrum Patrolling with Crowdsourced Spectrum Sensors
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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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