SpecNet: Spectrum Sensing Sans Frontières

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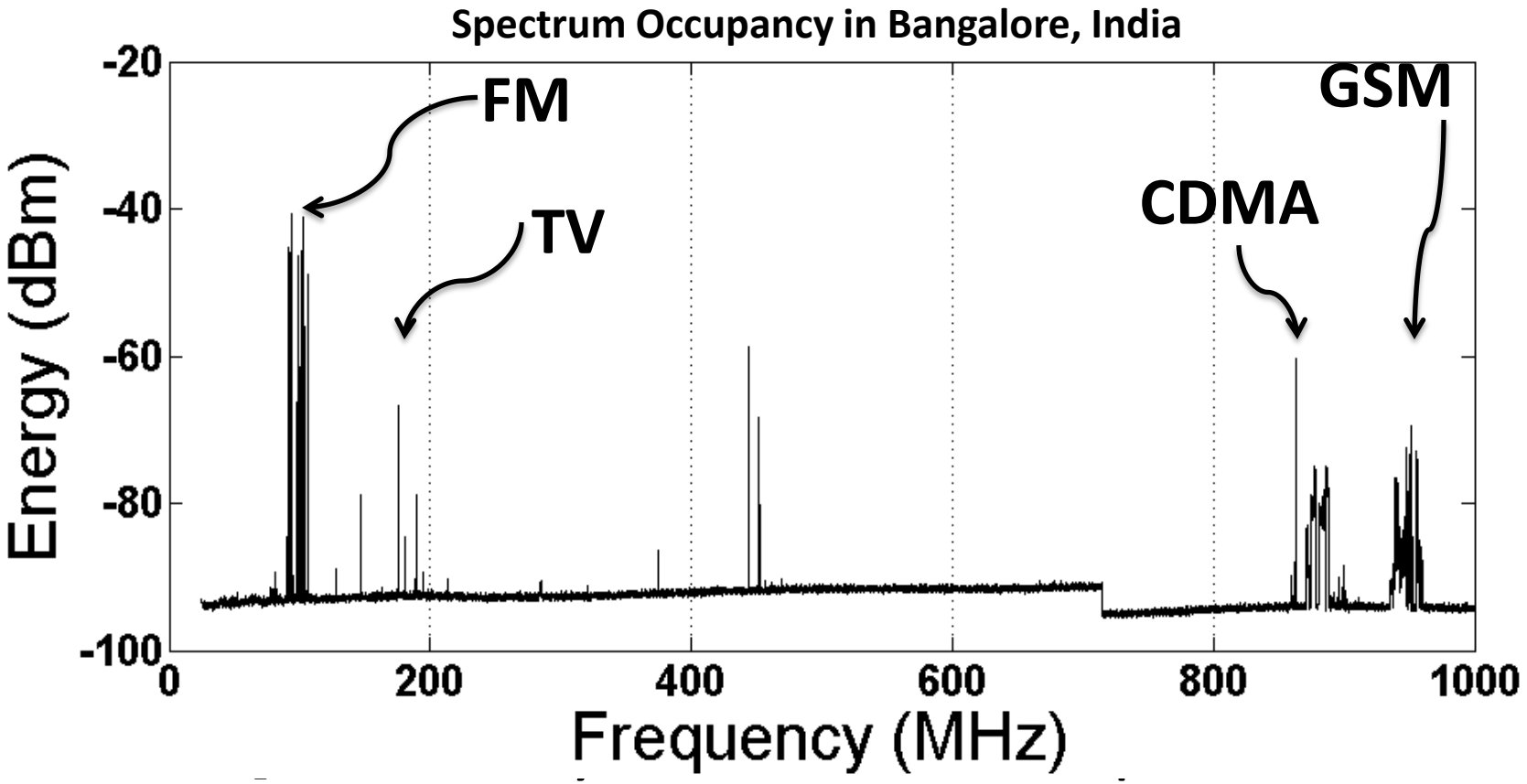
Spectrum Measurement Studies

- *McHenry* "NSF Spectrum Occupancy Measurement Project Summary"
  - Average occupancy ~5.2% in 30MHz – 3GHz
- *McHenry et.al.* "Chicago Spectrum Occupancy Measurements & Analysis" [TAPAS 2006]
  - 17% occupancy in Chicago, 13% in New York
- China [MobiCom 2009], Singapore [CrownCom 2008], Germany, New Zealand, Spain…

Spectrum Measurement Studies



Spectrum heavily underutilized

Impact

Nov 4, 2008: FCC voted 5-0 to approve Opportunistic Spectrum Access (OSA) in licensed bands

FCC Approves White Space "Wi-Fi on Steroids"

FCC's Whitespace Ruling: The Real Wi-Fi Revolution Is About to Happen

BY KIT EATON Mon Sep 13, 2010

Sep 23, 2010: FCC determines final rules for the use of whitespaces. Removes mandatory sensing requirement

Get Ready to Innovate! FCC Approves White Spaces Rules

By Ryan Kim | Sep. 23, 2010, 9:19am PT | 12 Comments

FCC White Spaces Ruling Enables Super Wi-Fi

Networking | News | Wayne Rash, Friday, September 24, 2010
Tags: government agencies, Telecommunications Services, Wi-Fi, Wireless Networking

However…

- Studies conducted only at a handful of locations

  - Till date, only the US has allowed OSA

- Represent static spectrum occupancy

  - Future OSA devices may require dynamic spatio-temporal occupancy information

- Through evaluation of OSA proposals from the research community is hard

  - Little or no access to real-world data from cross-geographic locations

However…

- Studies conducted only at a handful of locations

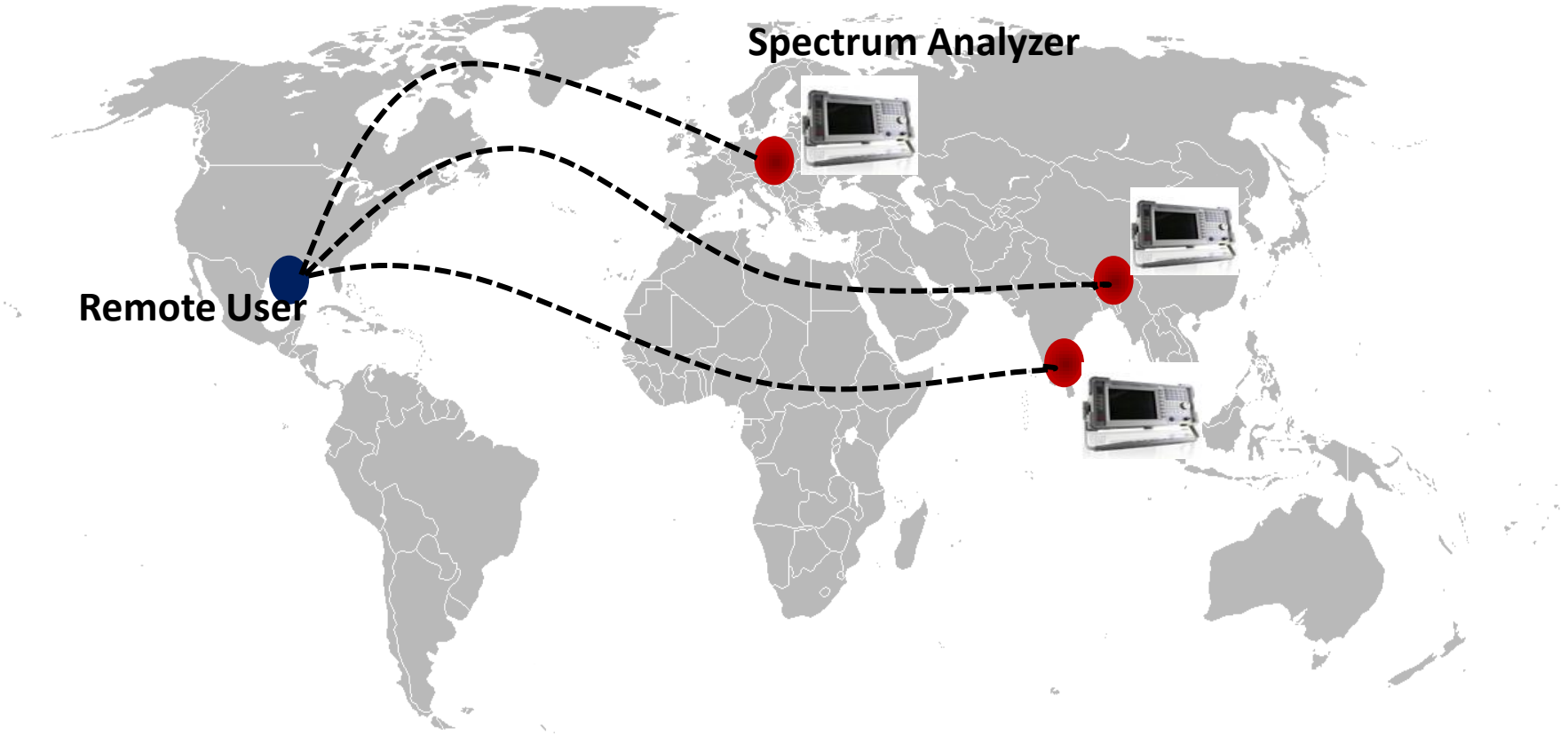
  - Till date, only the US has allowed OSA

No infrastructure for measuring real-time spectrum occupancy across vast regions

- Through evaluation of OSA proposals from the research community is hard

  - Little or no access to real-world data from cross-geographic locations

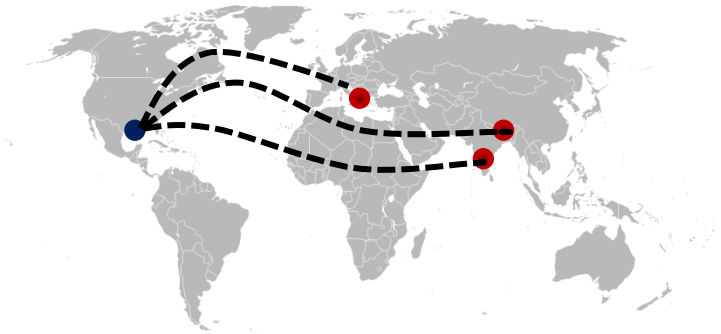
SpecNet

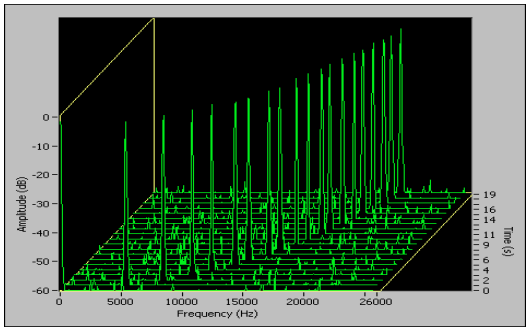


"A first-of-its-kind *platform that allows spectrum analyzers around the world to be networked and efficiently used in a coordinated manner* for spectrum measurement as well as implementation and evaluation of distributed sensing applications"

SpecNet

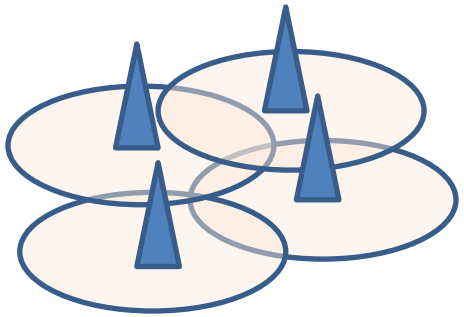
Conduct remote spectrum measurements





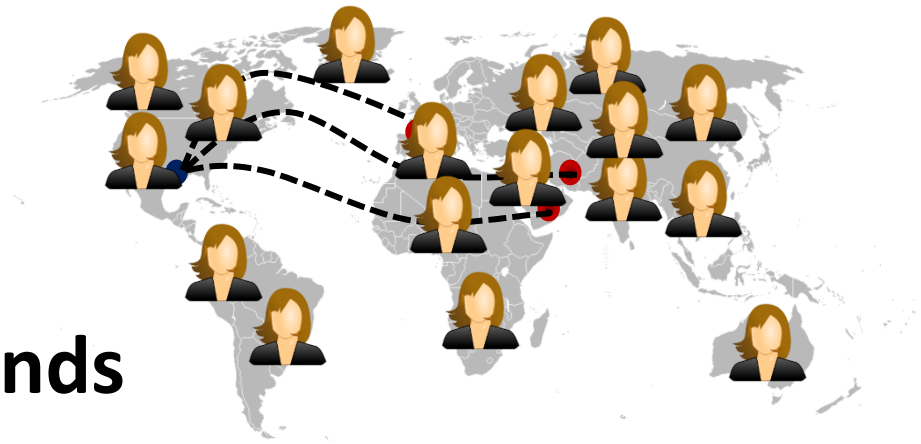
Construction & maintenance of spatio-temporal usage maps

Deploy & evaluate real-time distributed sensing applications



Challenges

- **Expensive ($10K - $40K)**
- **Limited availability**
- **Support user demands**



- **Applications require quick detection**

Complete tasks in minimal time

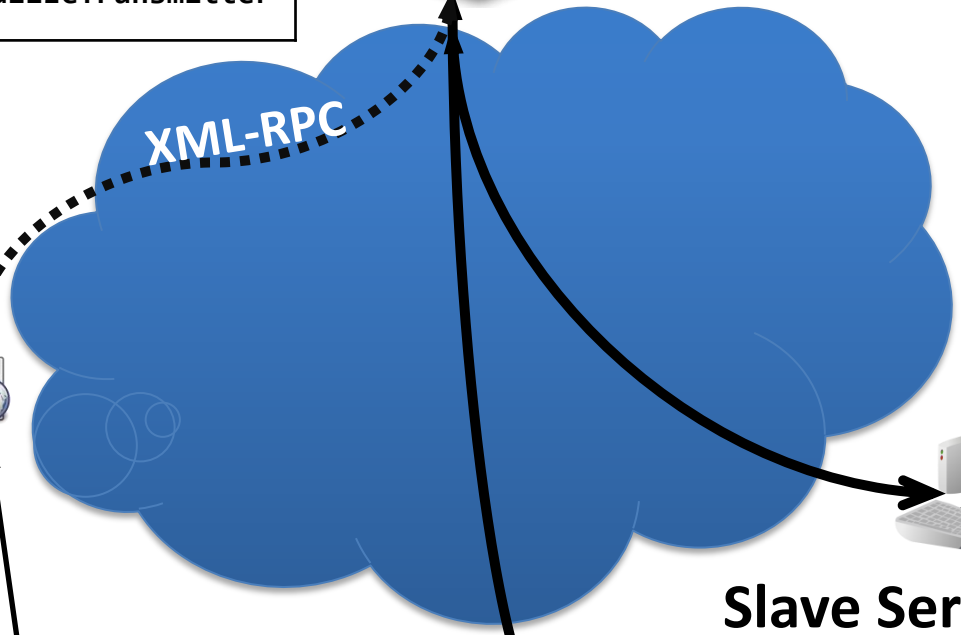
Overview

- Motivation
- SpecNet
  - Architecture
  - Components
  - Programmability
- Spectrum Analyzer Primer
- Key Challenge – Resource Management
- Applications

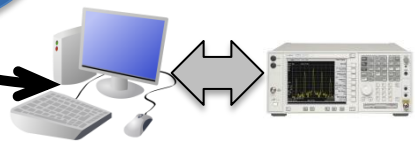
SpecNet Operation

Low-level	High-level
GetDevices	GetOccupancy
ReserveDevices	GetPowerSpectrum
RunCommandOnDevice	FindPowerAtLocation
	LocalizeTransmitter

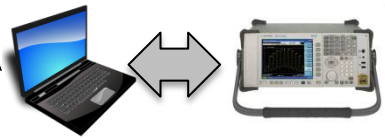
Master Server



Users

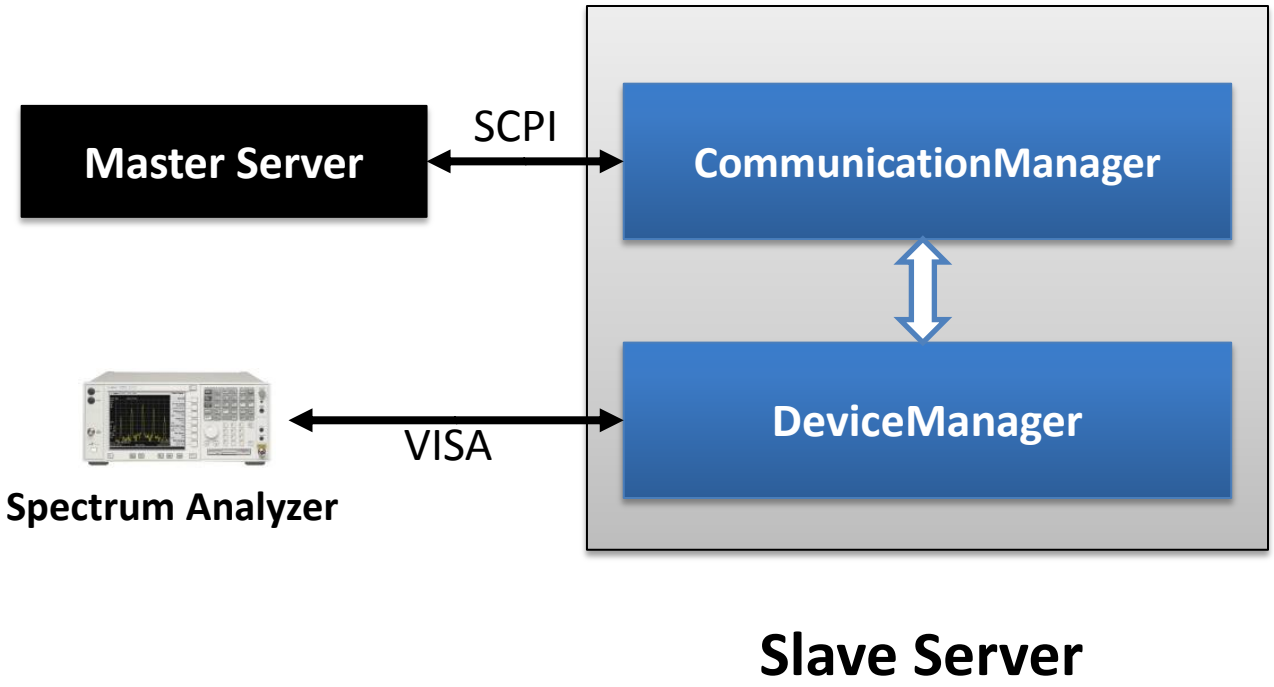


Slave Servers

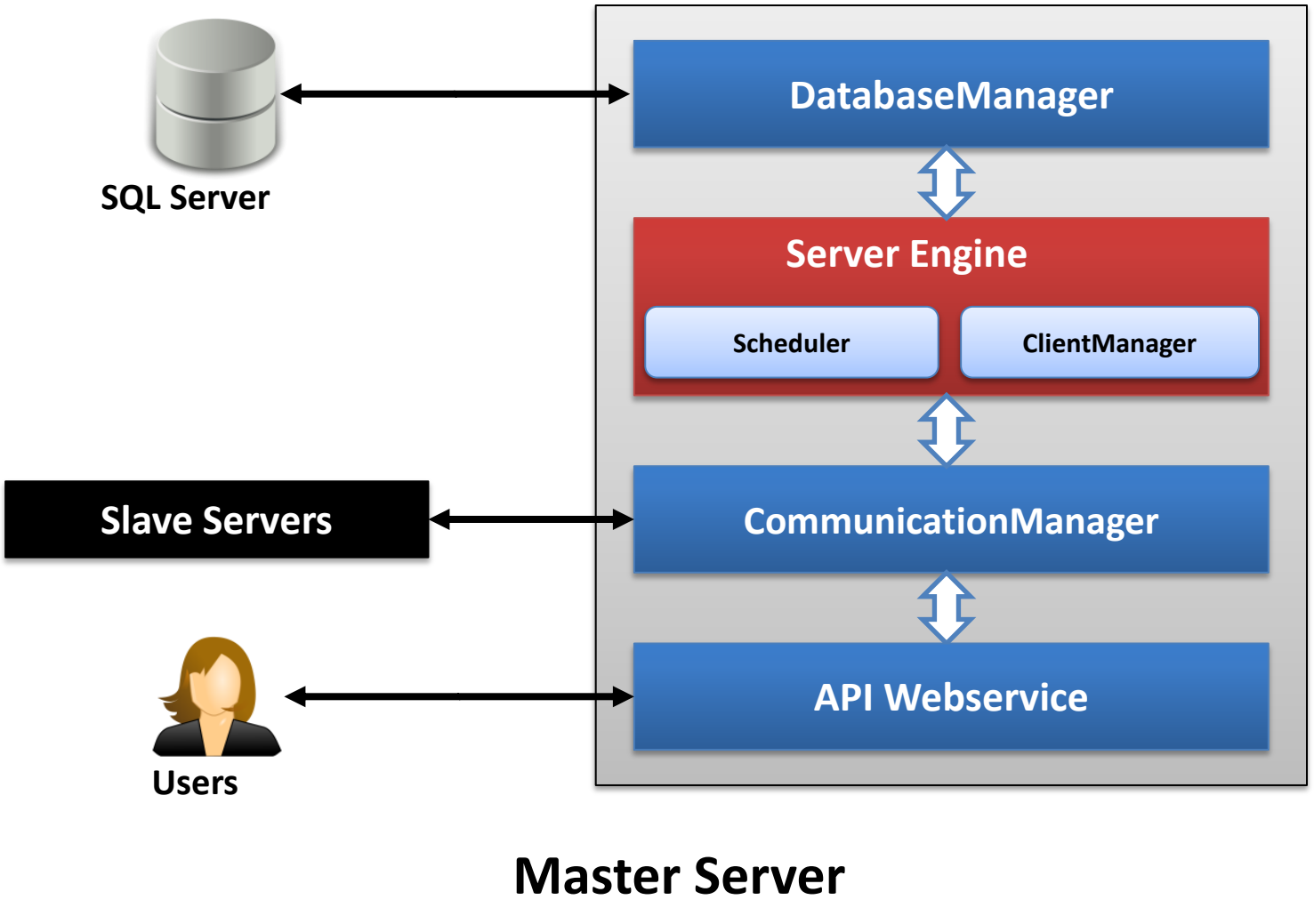


```
import xmlrpclib;
APIServer =
xmlrpclib.ServerProxy(http://bit.ly/Sp
ecNetAPI, allow_none=True);
devices = APIServer.GetDevices(None,
None);
```

Components


Master Server
SCPI
CommunicationManager
DeviceManager
VISA
Spectrum Analyzer
Slave Server

Components

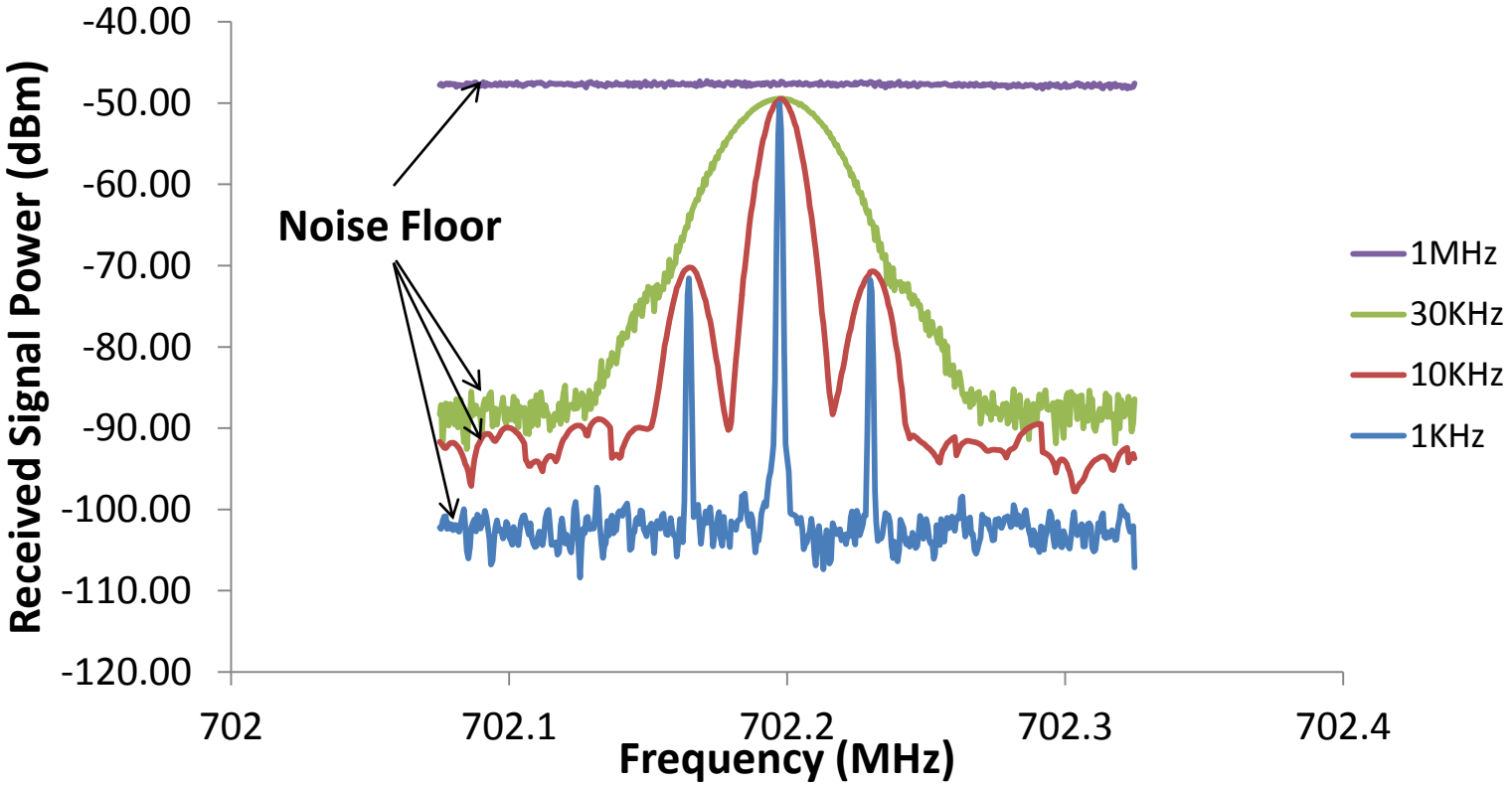

SQL Server
DatabaseManager
Server Engine
Scheduler
ClientManager
Slave Servers
CommunicationManager
API Webservice
Users
Master Server

Programmability

- Sophisticated Users
  - **ReserveDevices**
  - **RunCommandOnDevice**
- Policy Users
  - **GetPowerSpectrumHistory**
  - **GetOccupancyHistory**
- Others (E.g. network operators)
  - **LocalizeTransmitter**
  - **FindPowerAtLocation**
  - **GetPowerSpectrum**
  - **GetOccupancy**

Spectrum Analyzer Primer

- Used to measure the spectral composition of waveforms
- Frequency span (Q) and Resolution Bandwidth (RBW, ρ)



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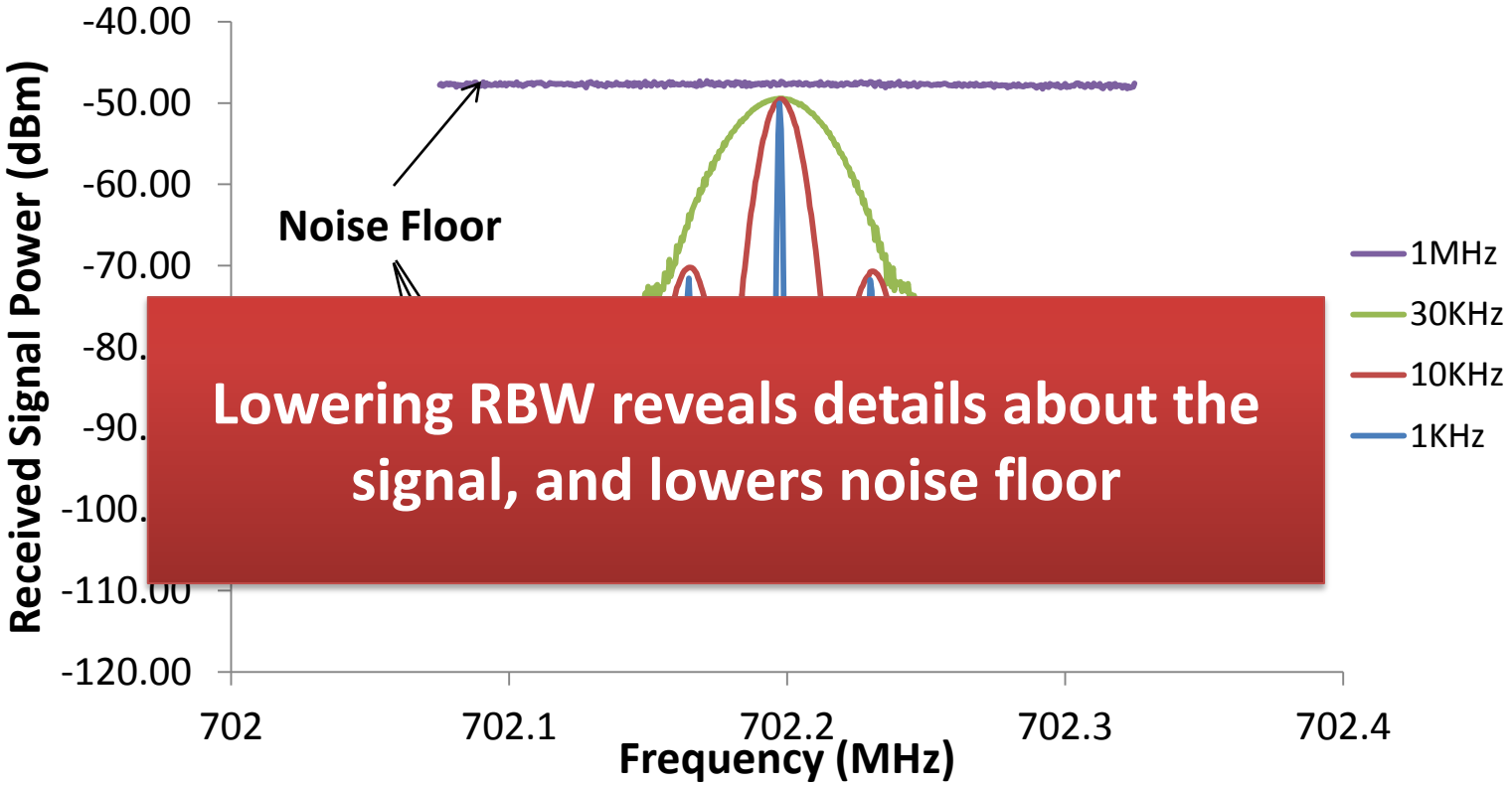
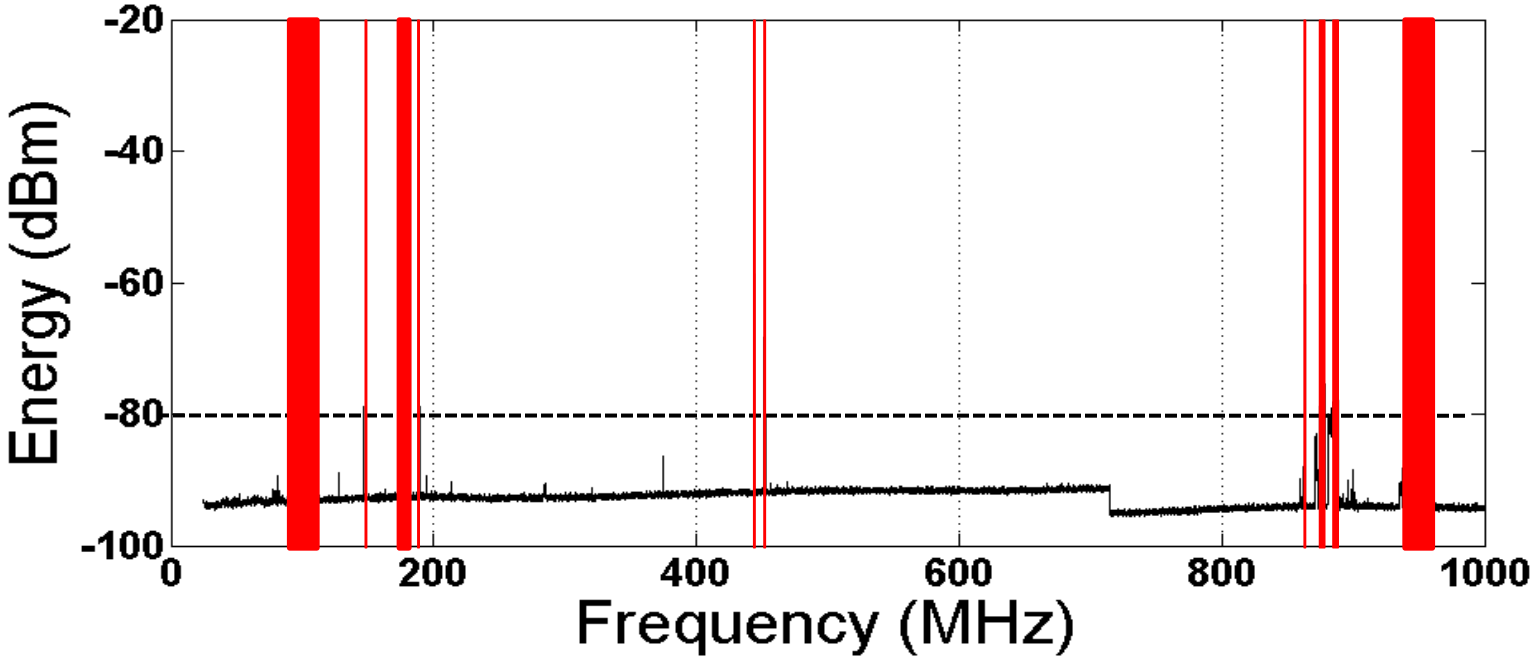


Spectrum Analyzer Primer

- Often users are interested in determining which parts of the spectrum are in use.
  - Distinguish between signal and noise



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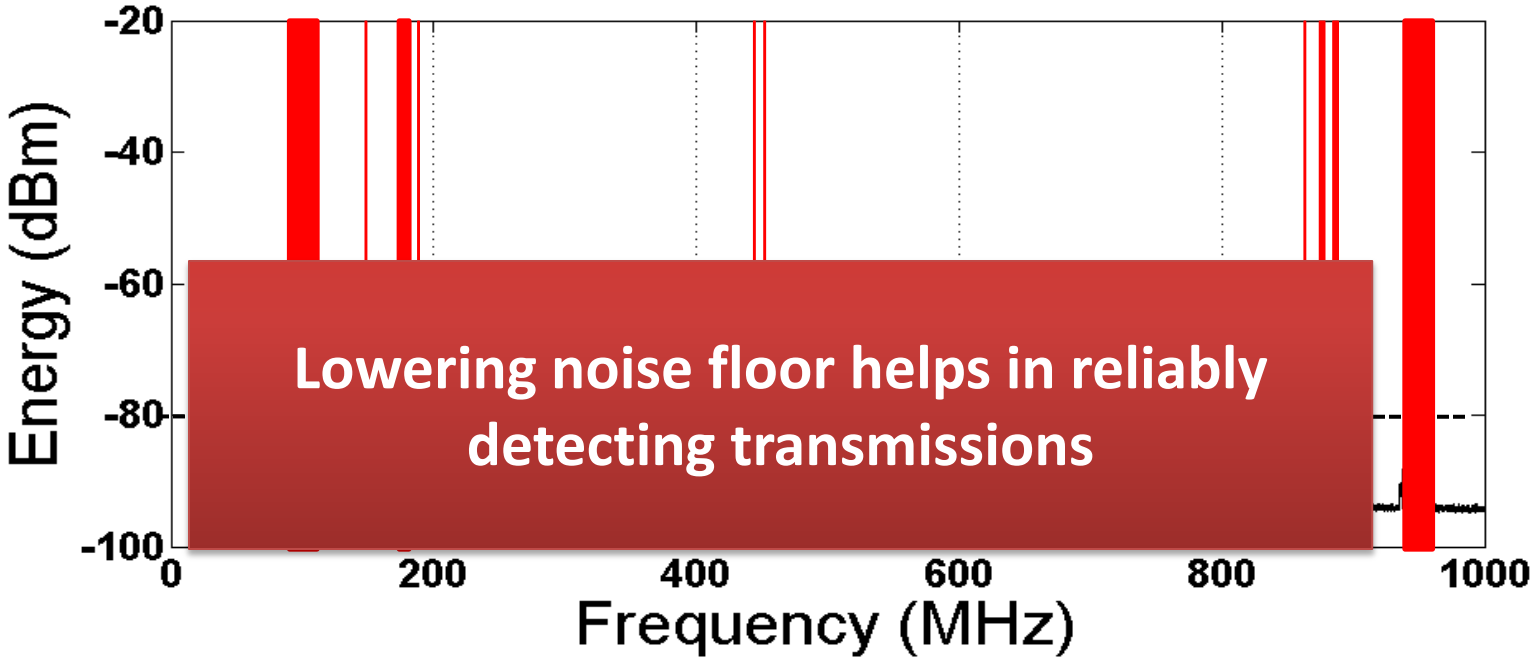
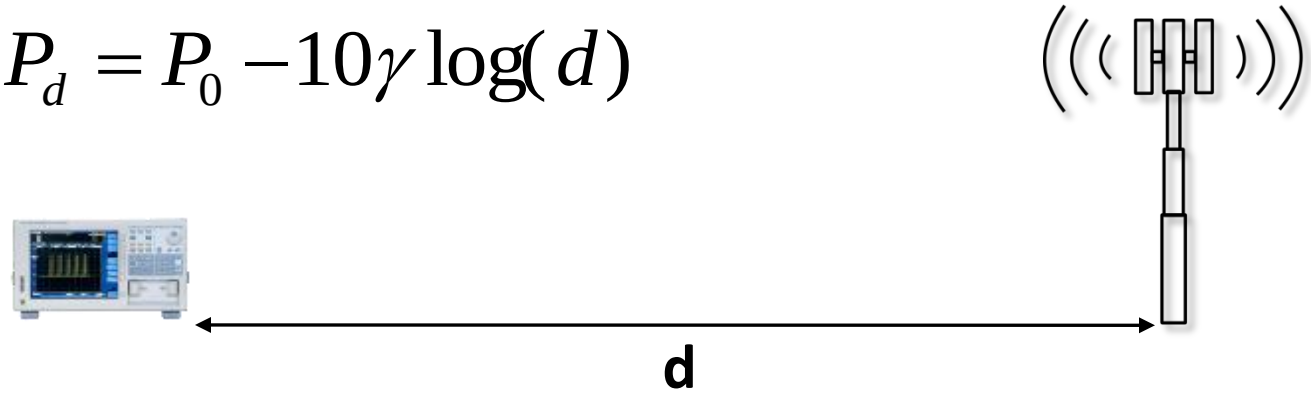


Spectrum Analyzer Primer

- Noise floor determines the detection range of a spectrum analyzer

$$P_d = P_0 - 10\gamma \log(d)$$



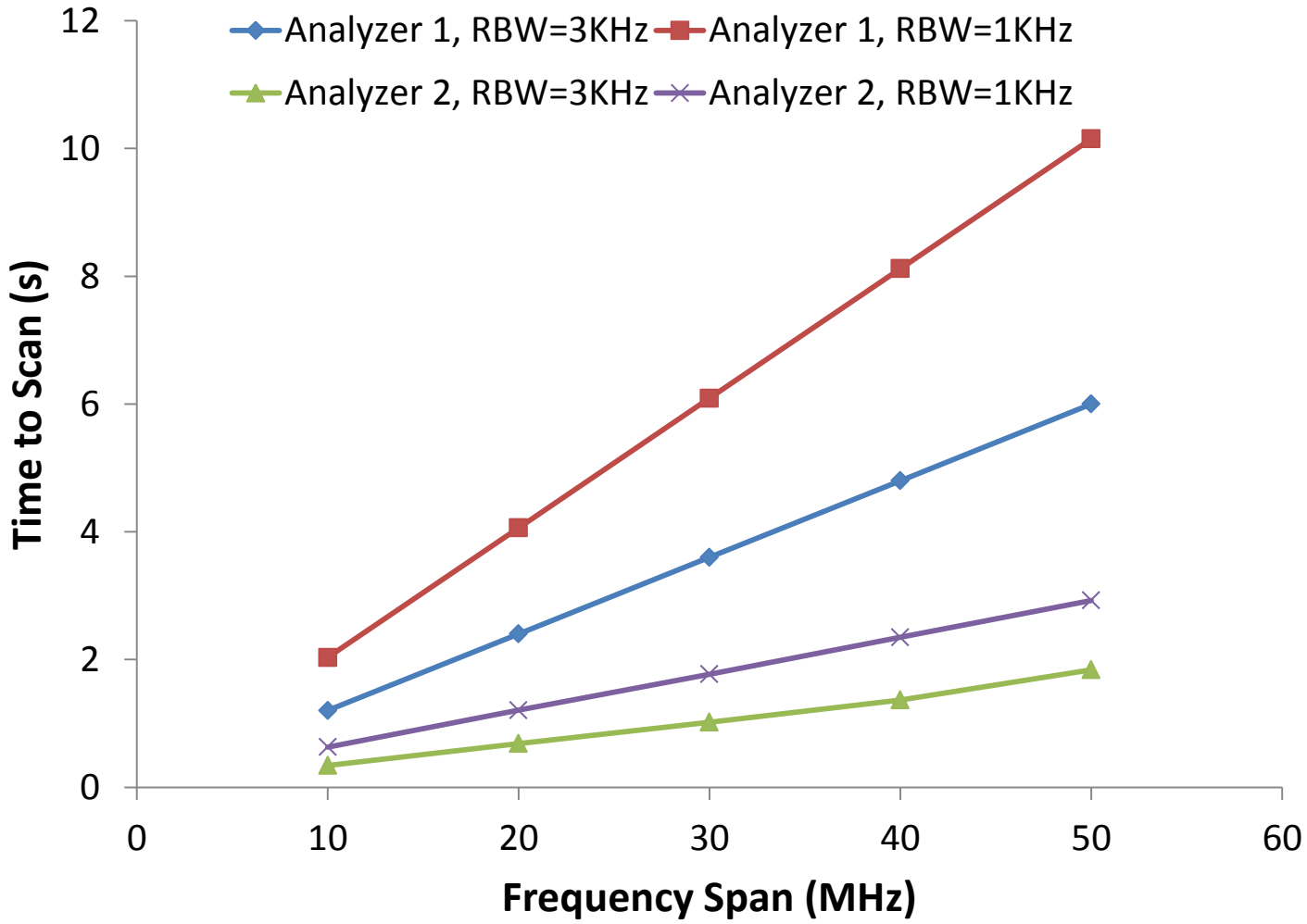
Lowering noise floor helps in detecting transmitters farther away

Overview

- Motivation
- SpecNet
  - Architecture
  - Components
  - Programmability
- Spectrum Analyzer Primer
- **Key Challenge – Resource Management**
  - **When multiple devices are available, how should the scanning task be scheduled?**
- **Applications**

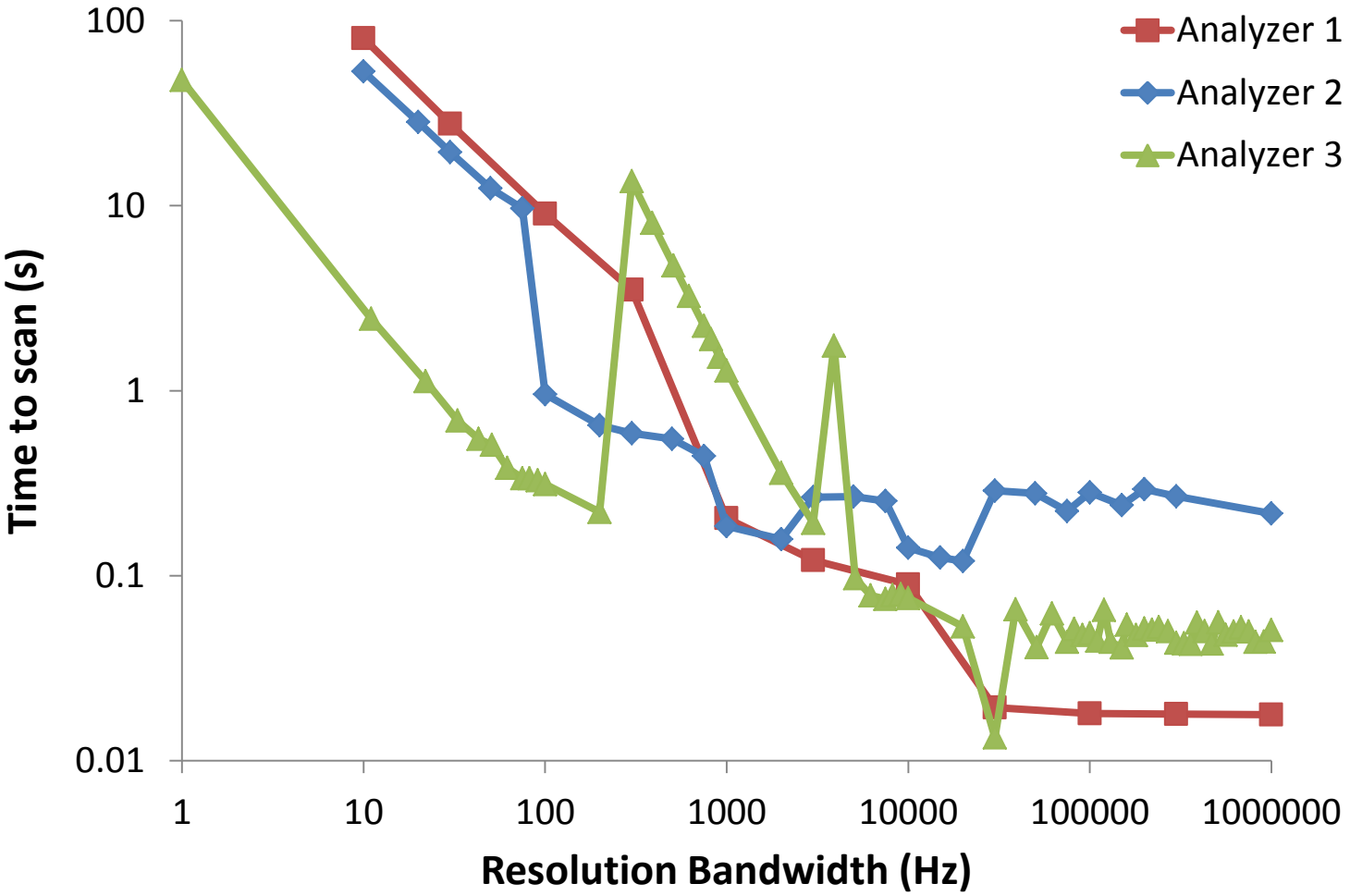
Scan Time

- Depends on Frequency Span (Q) and RBW (ρ)
- Linear dependency on span, $T \propto Q$



Scan Time

- In theory inversely proportional to RBW, $T \propto \frac{1}{\rho}$
  In practice… piece-wise linear!



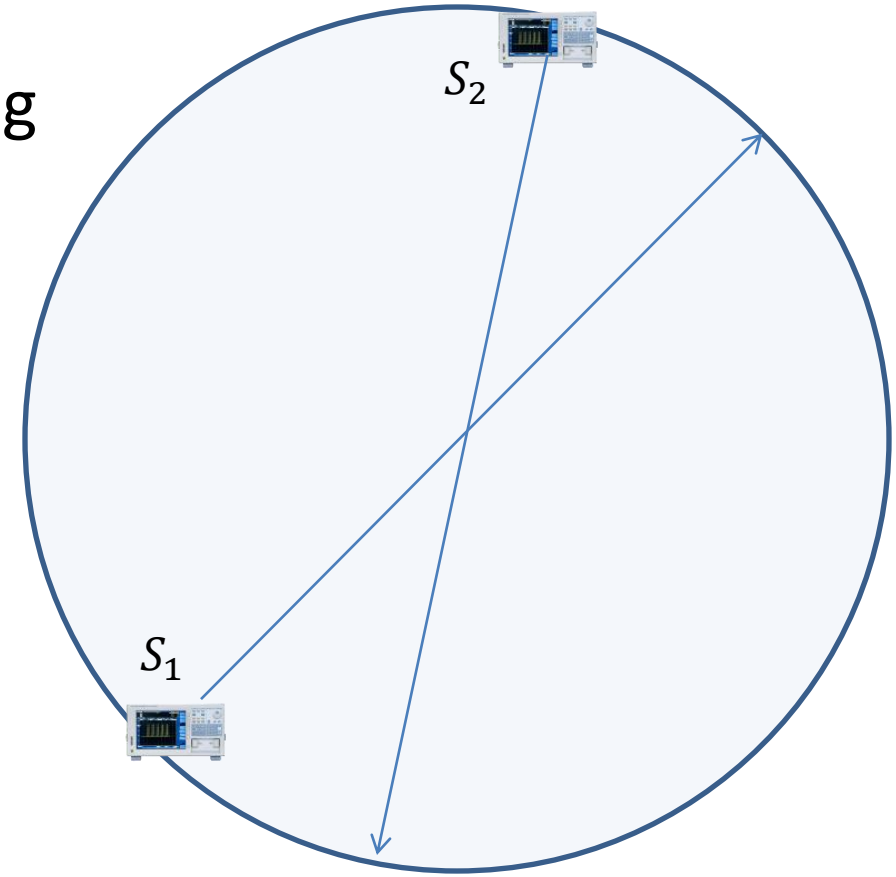
a. Spectral Load Sharing

S_1 and S_2 split the frequency span among themselves

If τ_i is the minimum scanning time per MHz for S_i

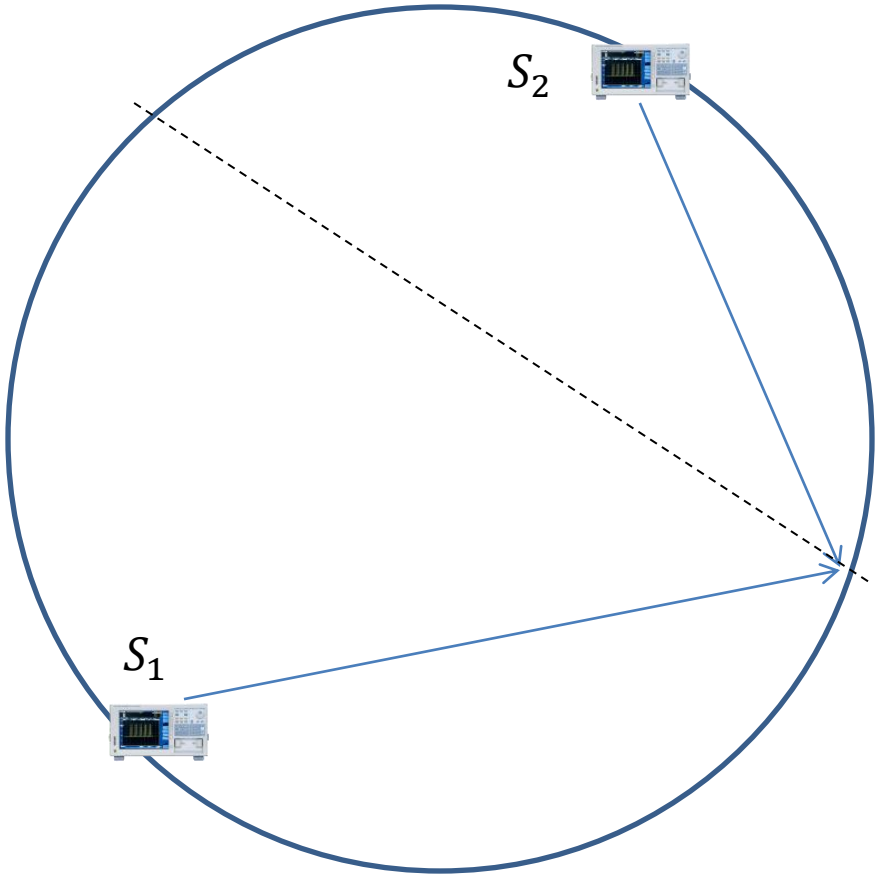
$$T = \max(\tau_1 Q_1, \tau_2 Q_2)$$

$$Q_1 : Q_2 = \frac{1}{\tau_1} : \frac{1}{\tau_2}$$



b. Geographical Load Sharing

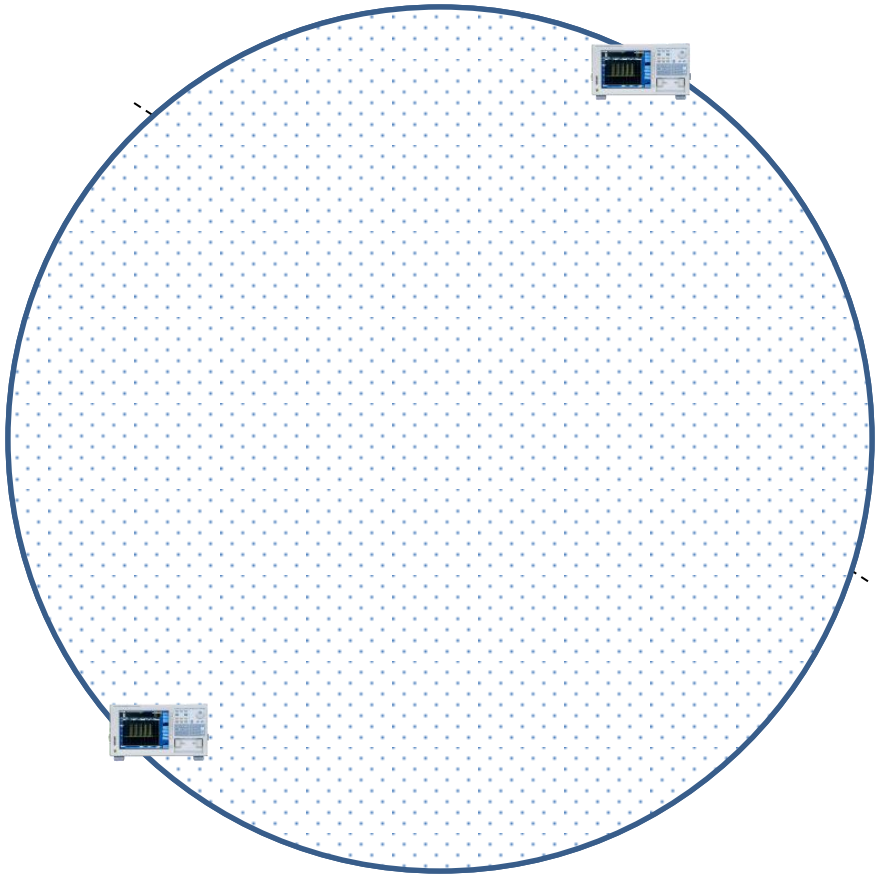
S_1 and S_2 partition the region of interest



b. Geographical Load Sharing

S_1 and S_2 partition the region of interest

SpecNet uses a numerical approximation to Voronoi partitioning



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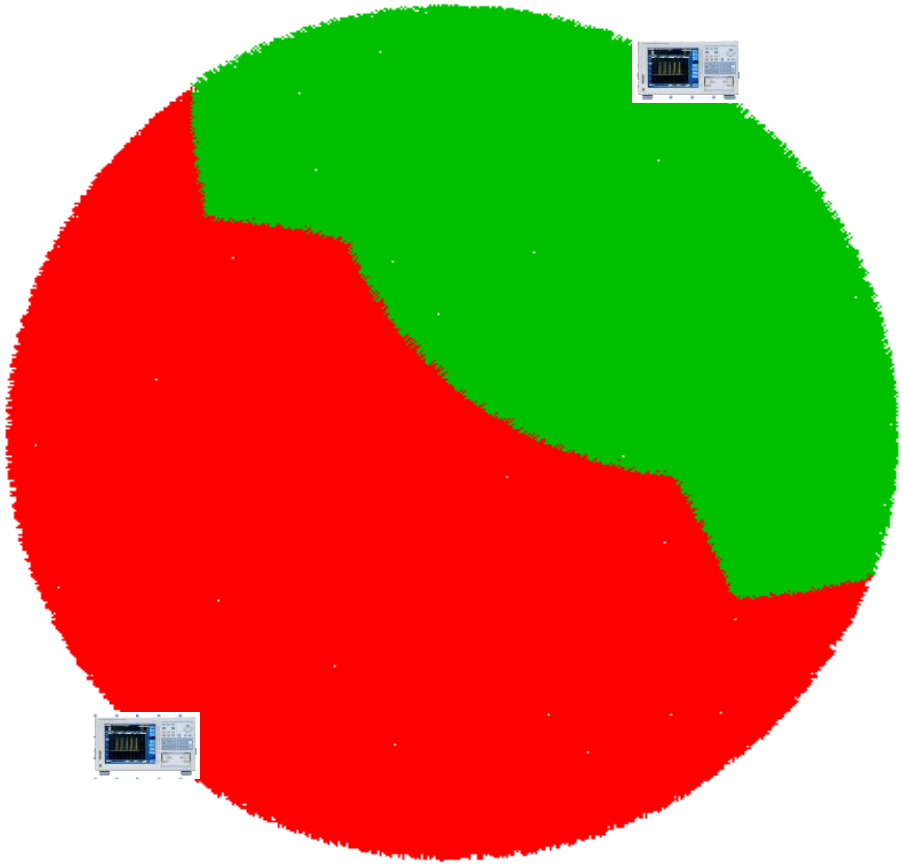
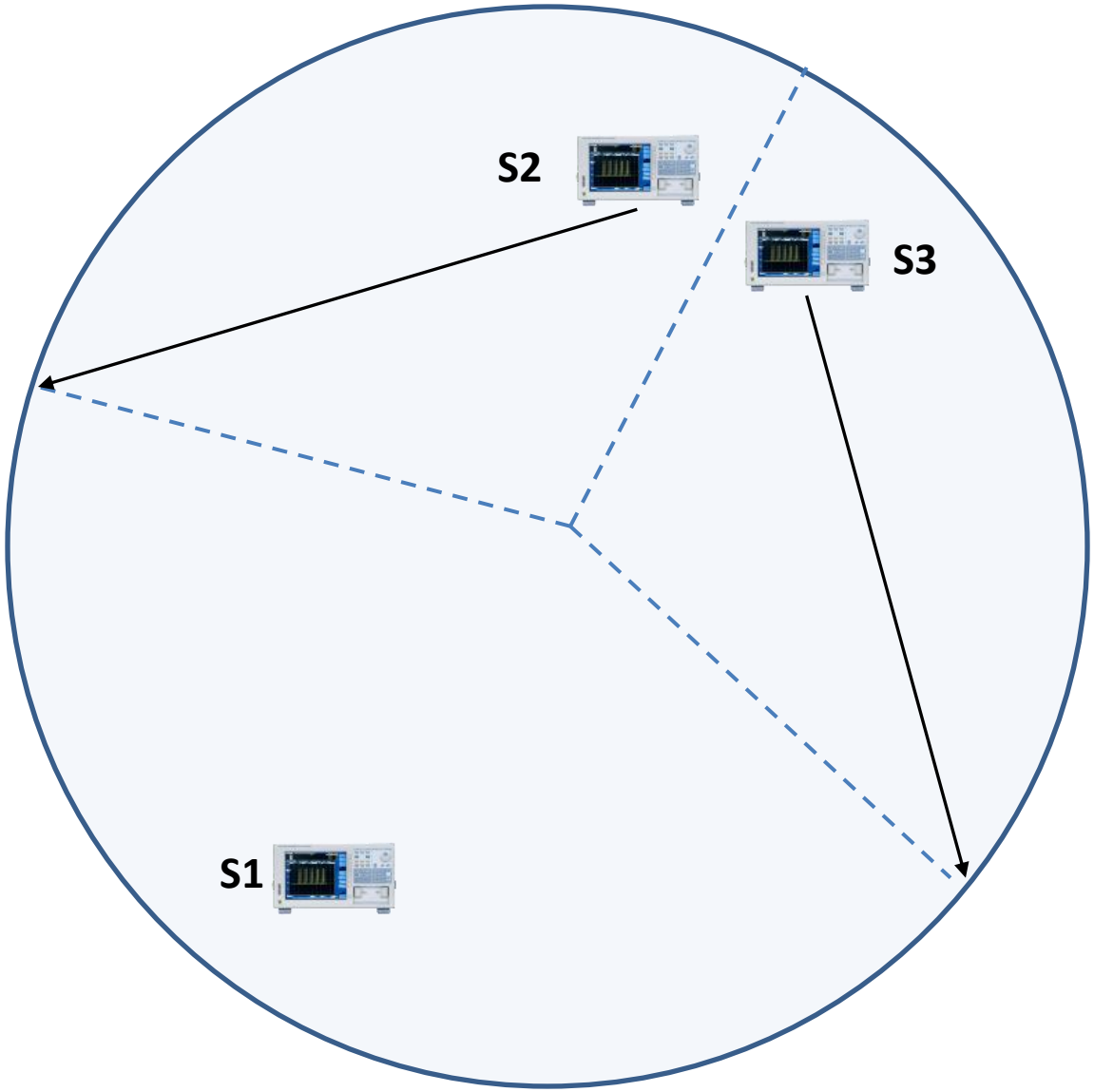


Scan time depends on detection range as:

$$T \propto d^{\gamma}$$

T decreases super-linearly

c. Geo-Spectral Load Sharing



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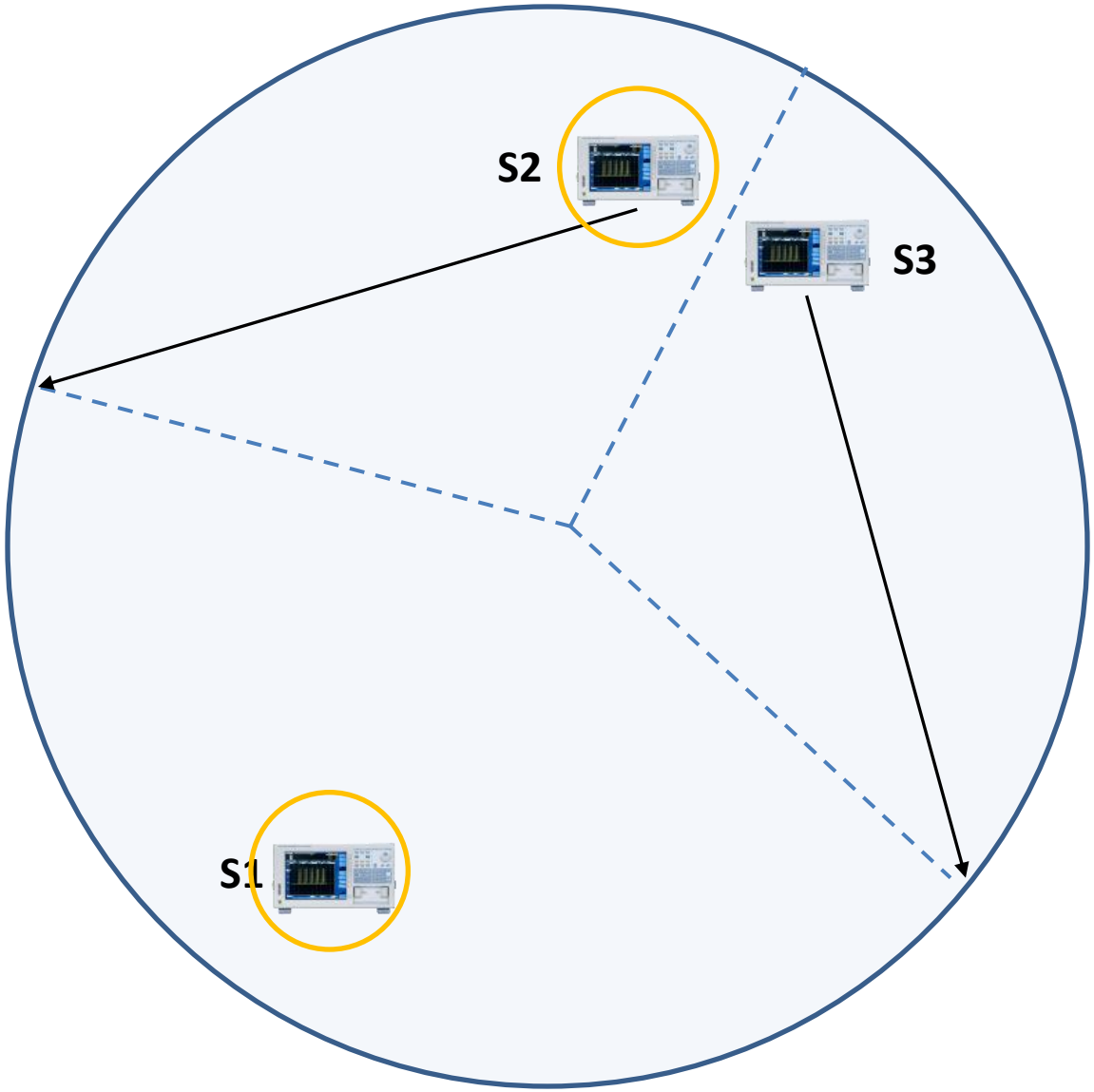

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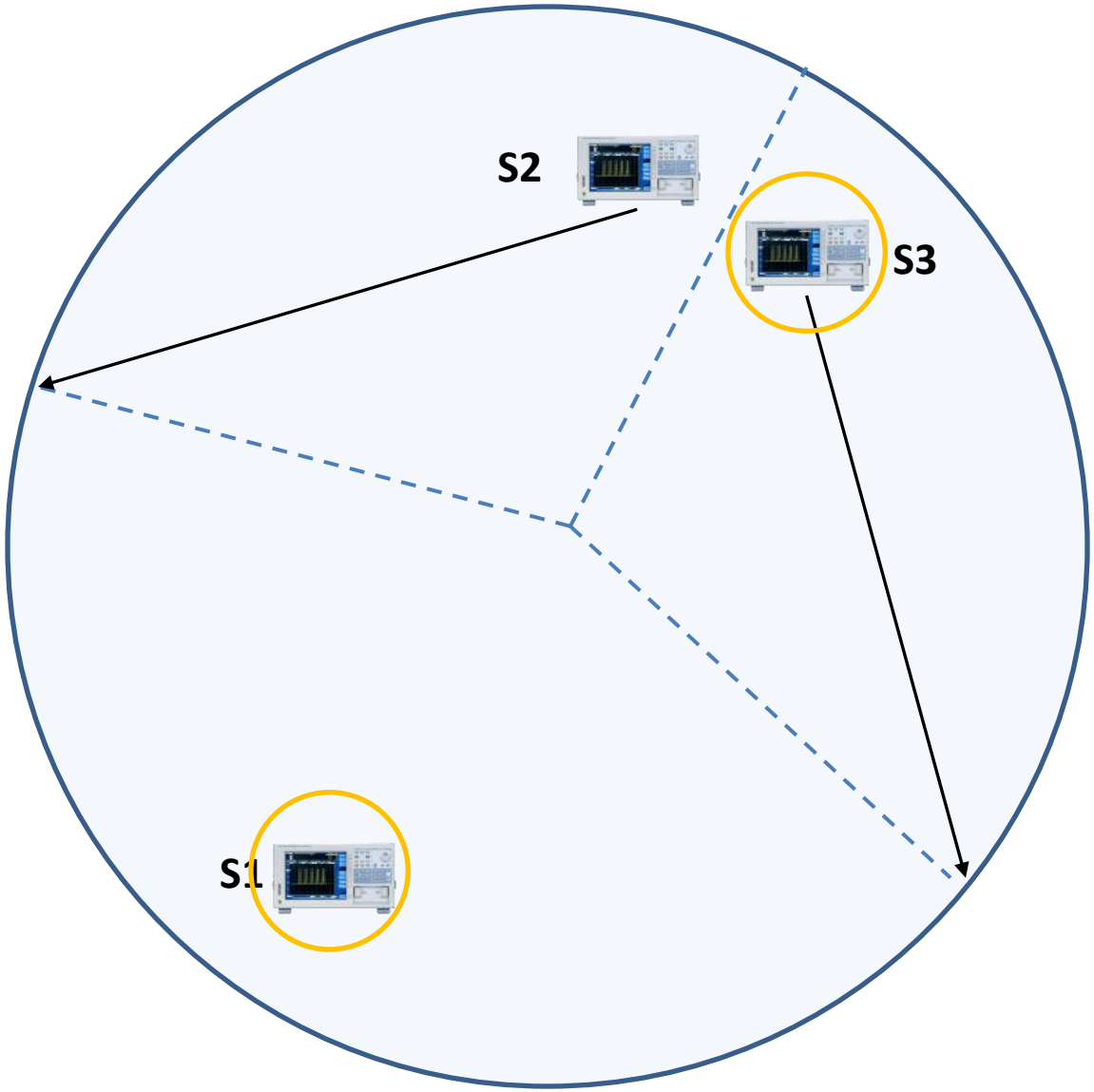

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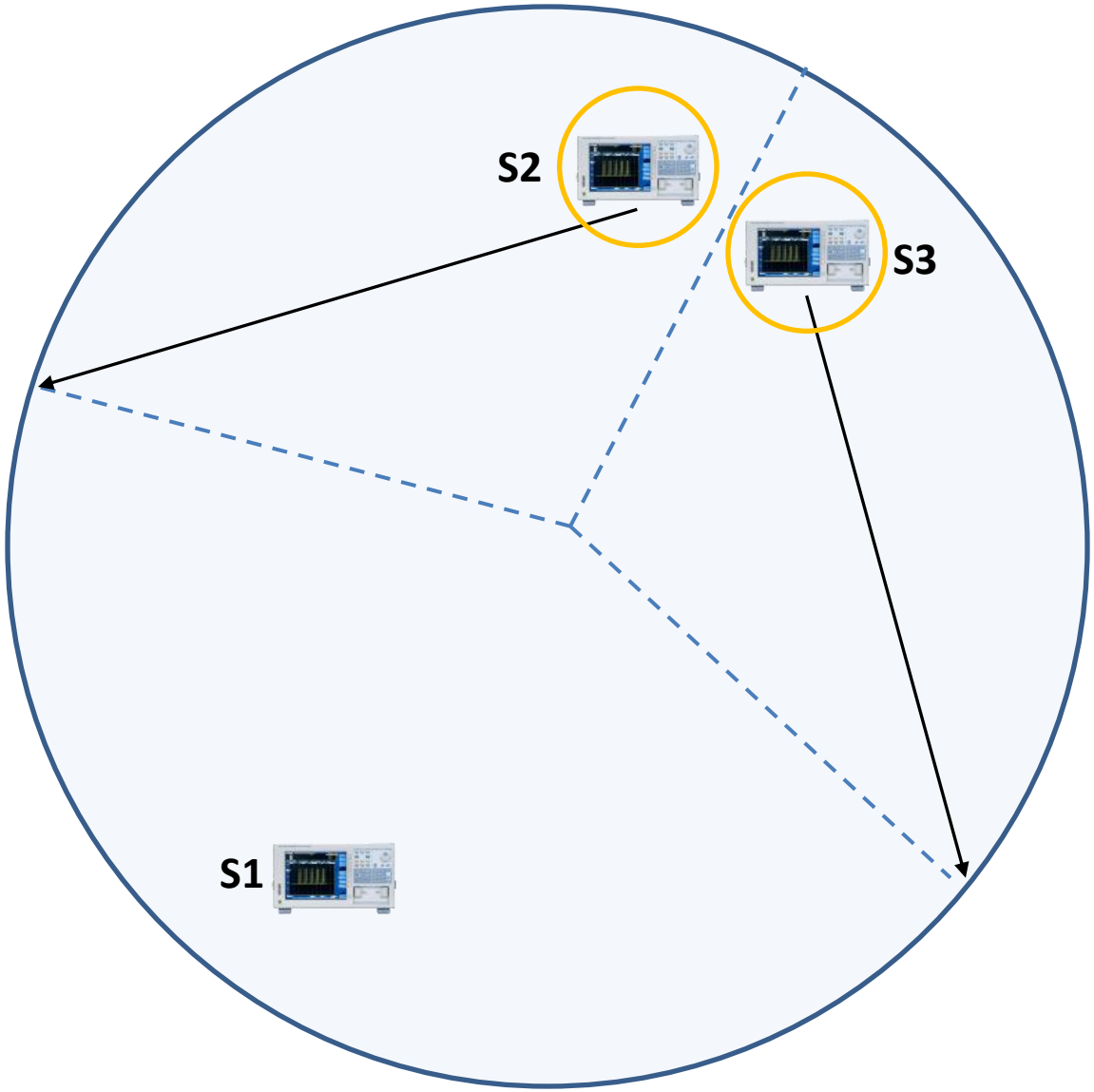

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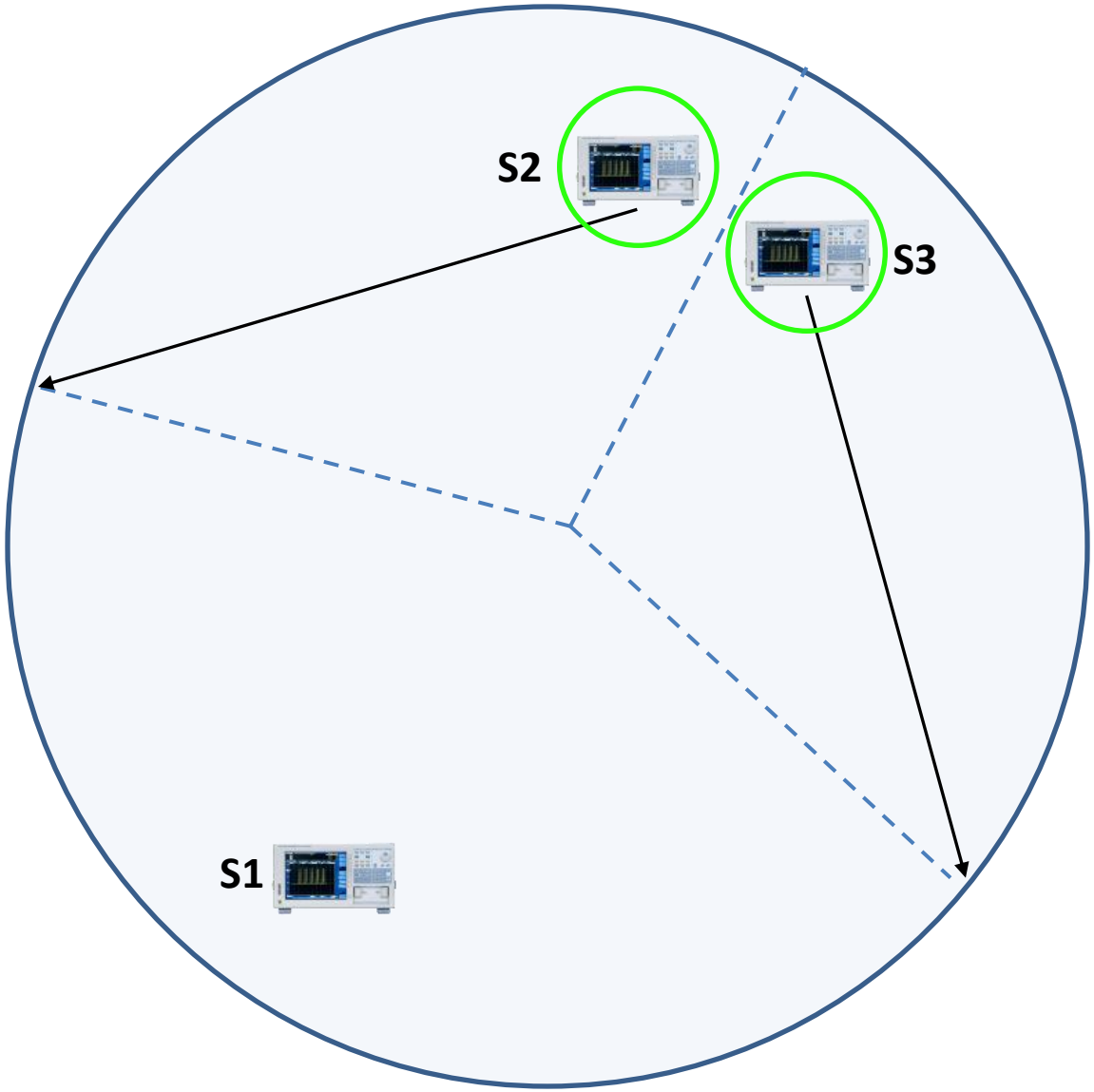

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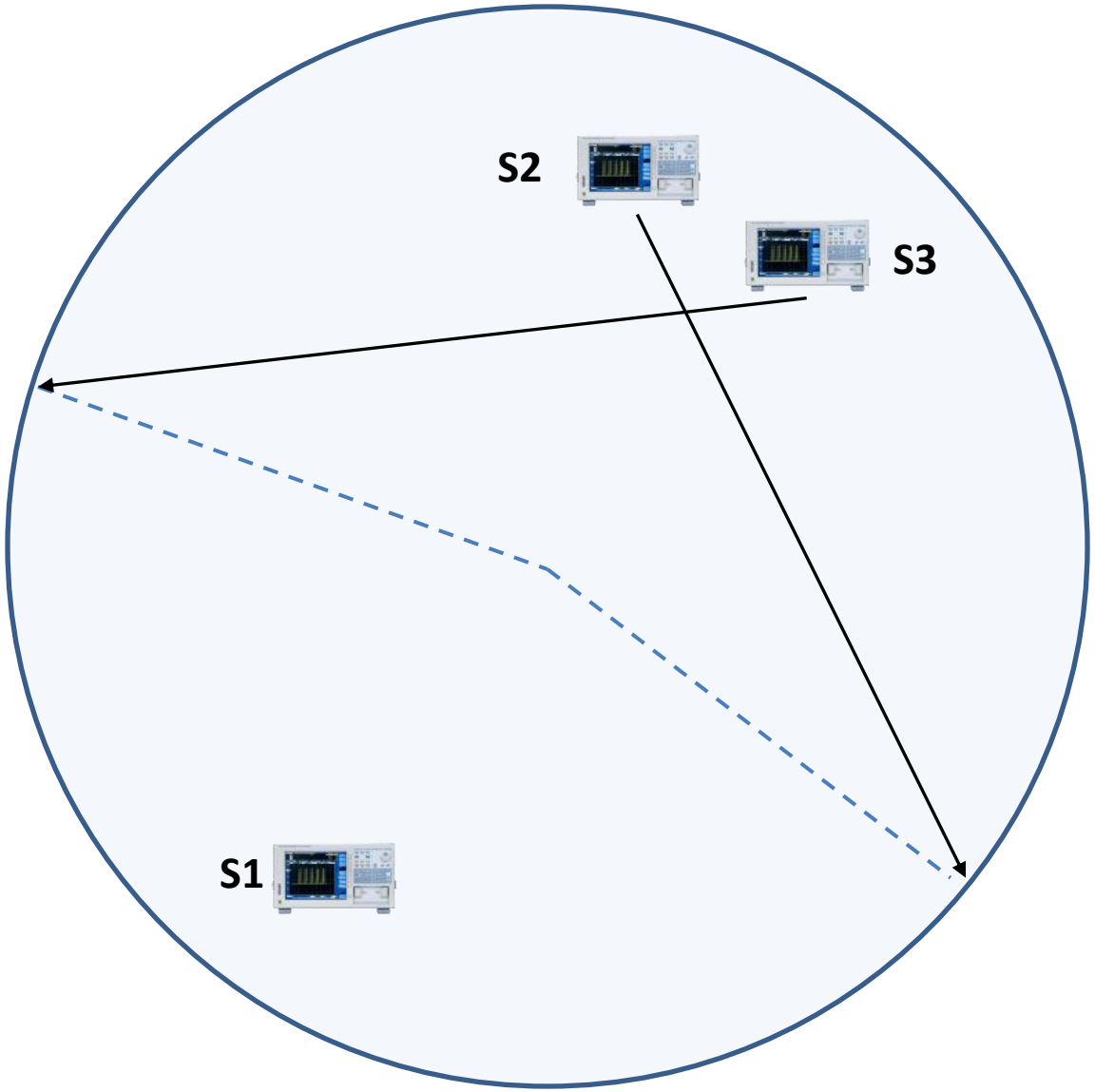
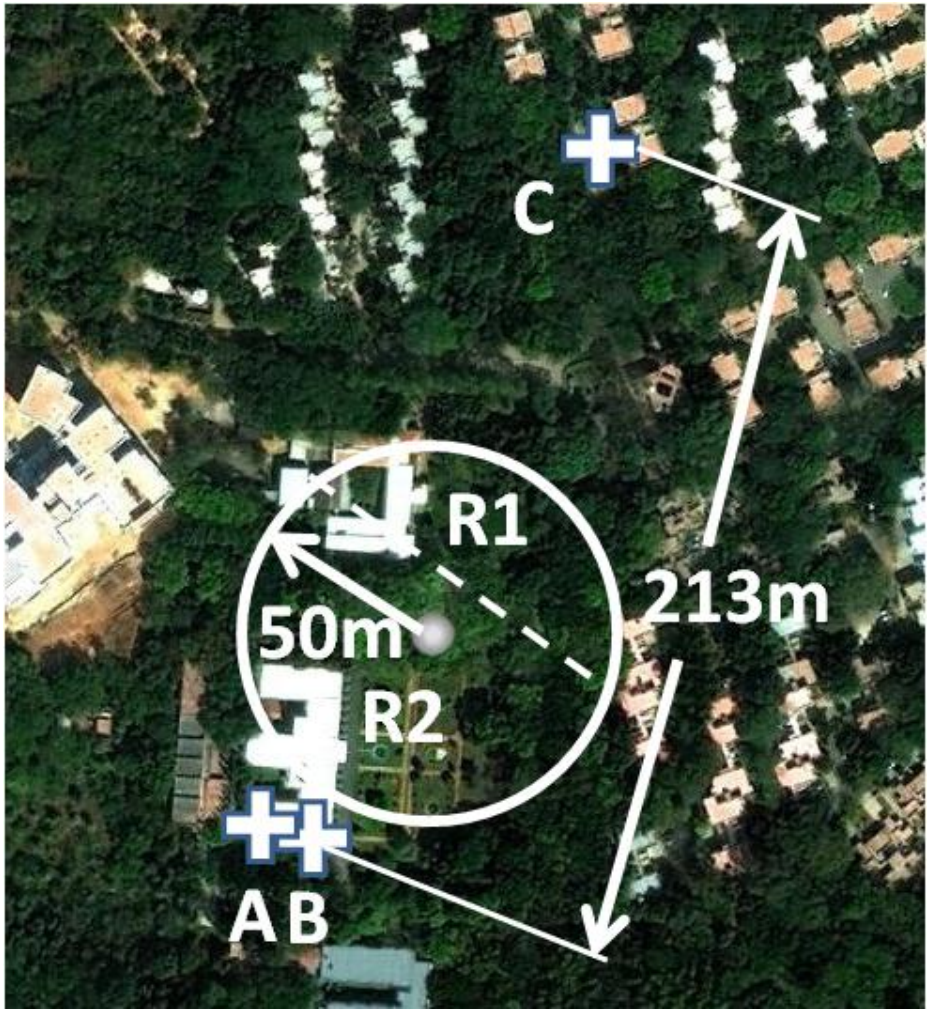


Geo-Spectral Performance



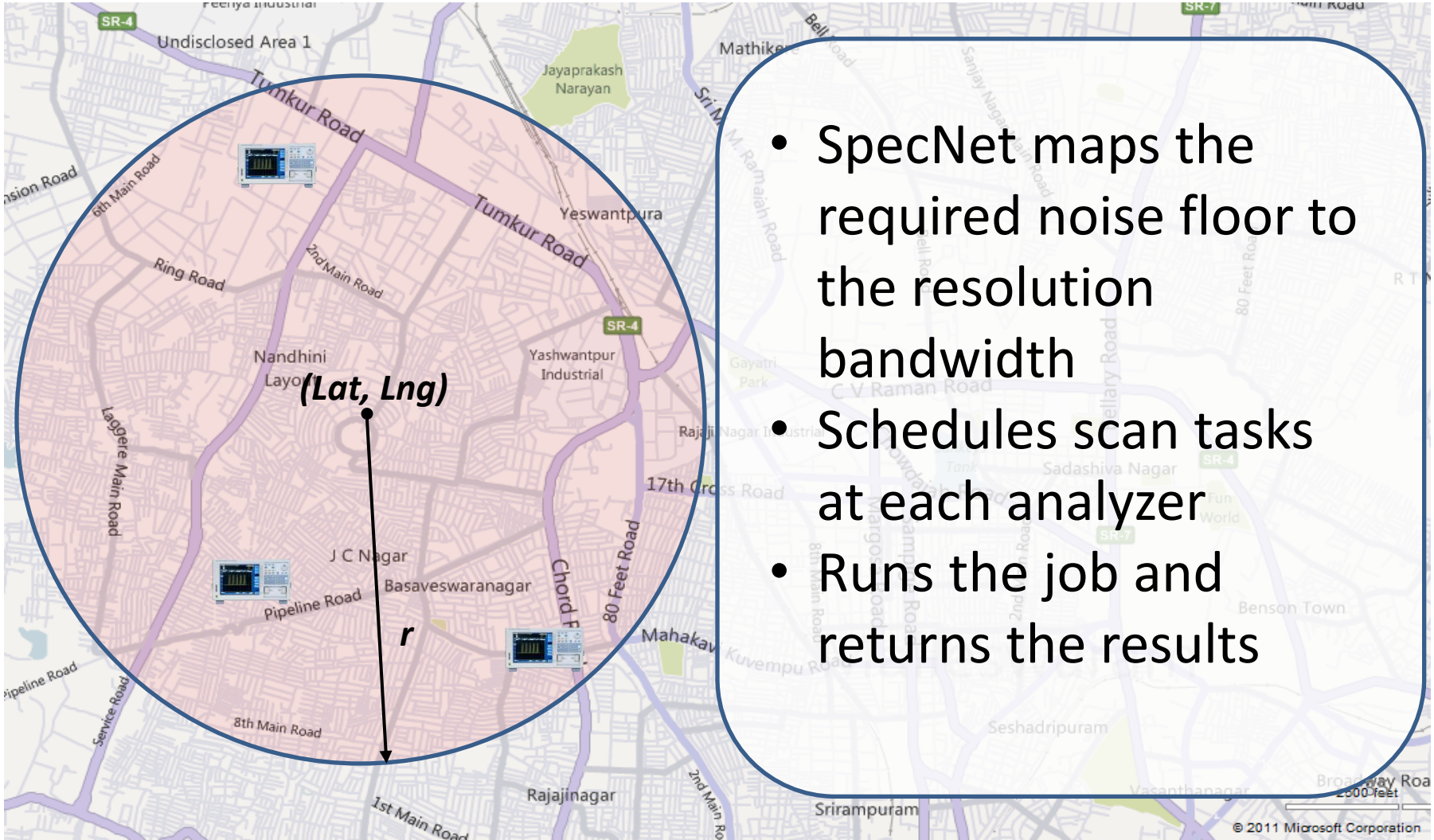
	Spectral	Geographical	Geo-Spectral
Time to detect (s)	1118	1205	526

Overview

- Motivation
- SpecNet
  - Architecture
  - Components
  - Programmability
- Spectrum Analyzer Primer
- Key Challenge – Resource Management
- **Applications**
  - **Remote Measurements**
  - Primary Coverage Estimation
  - **Spectrum Cop**

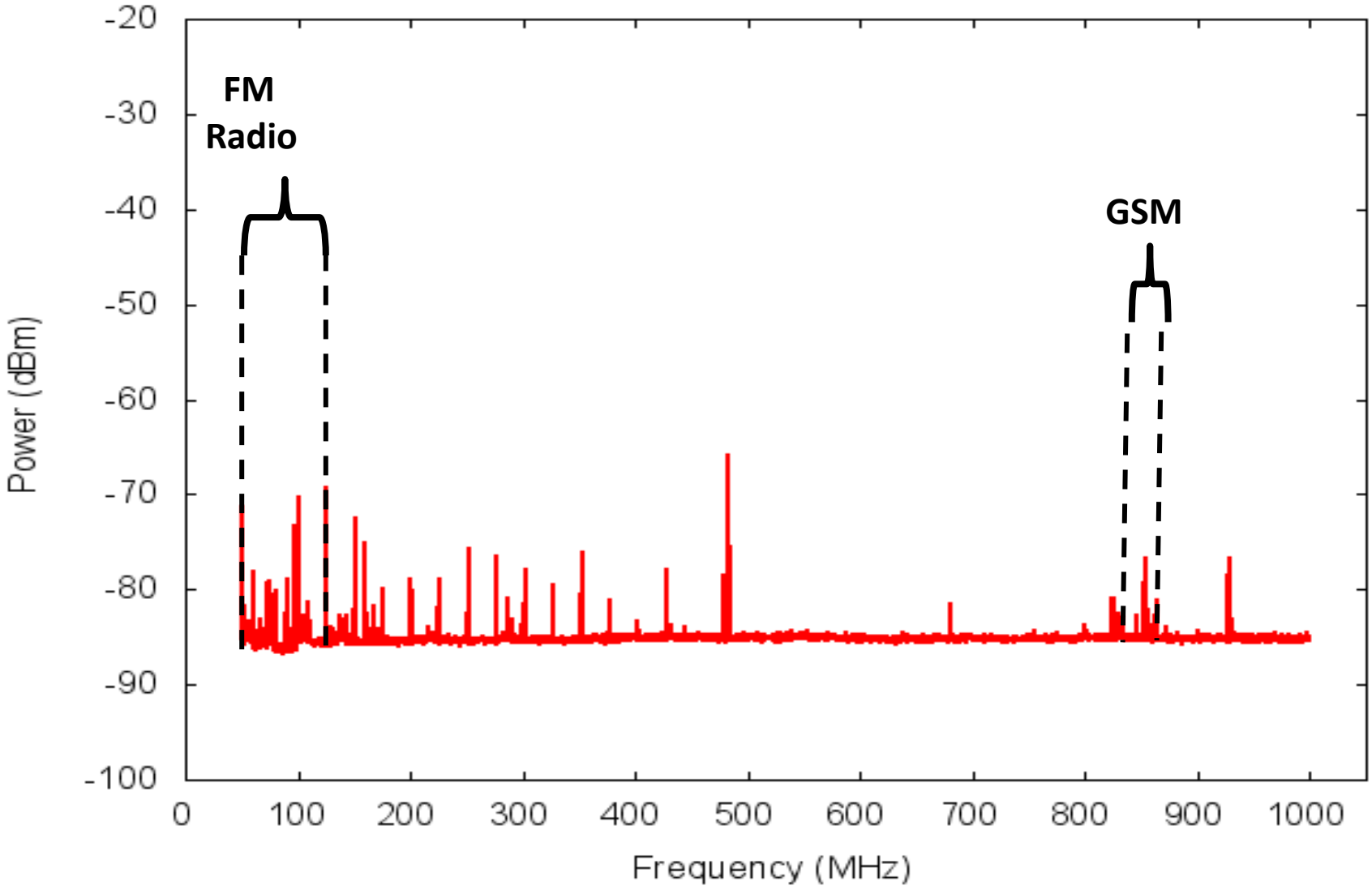
#1. Doing Simple Scans

```
GetDevices([lat,lng,r])
GetPowerSpectrum(device_id,Fs,Fe,Nf)
```



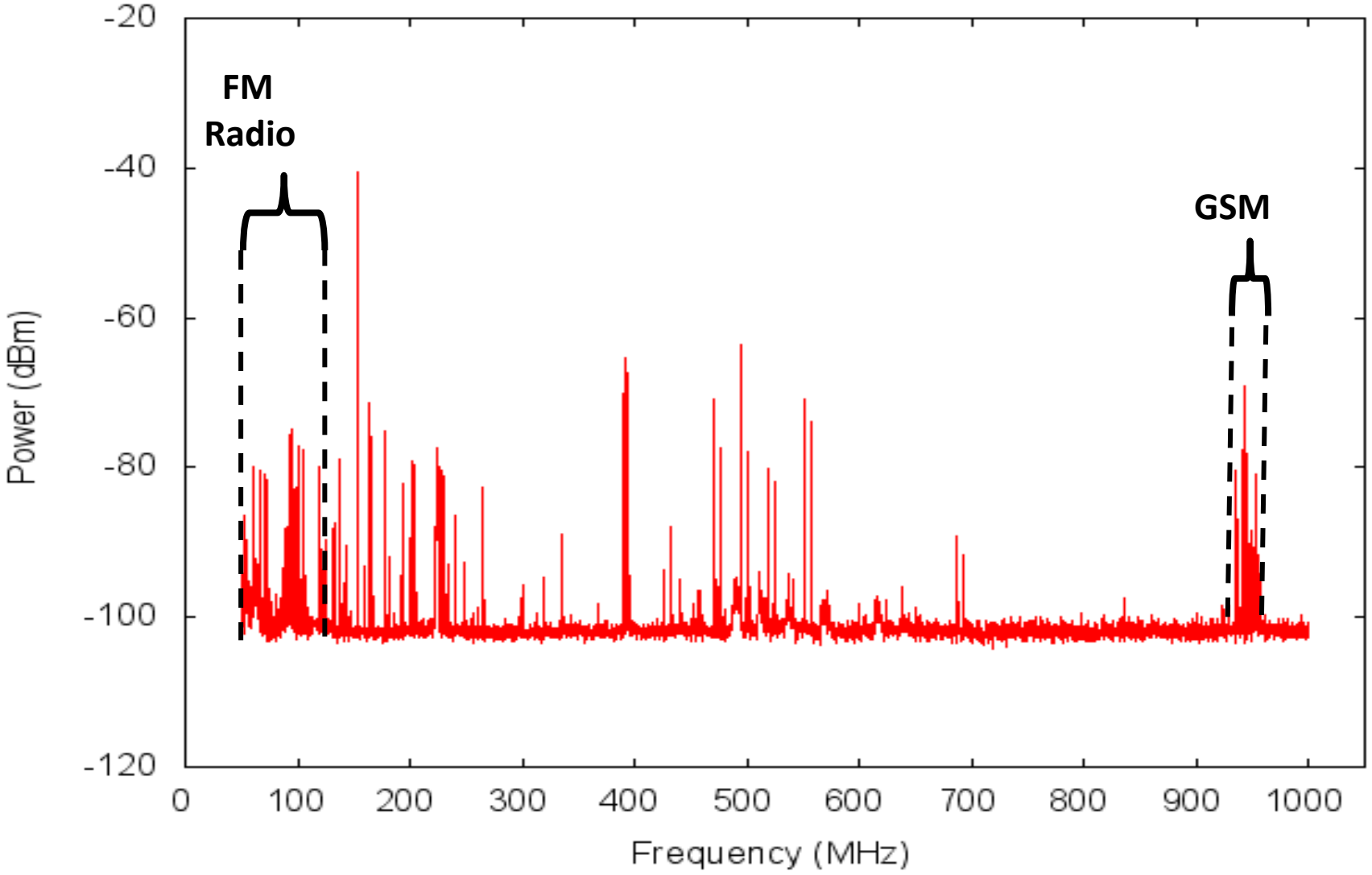
- SpecNet maps the required noise floor to the resolution bandwidth
- Schedules scan tasks at each analyzer
- Runs the job and returns the results

Remote Measurement Studies



Stony Brook, USA

Remote Measurement Studies



Edinburgh, UK

Remote Measurement Studies

How does the FM band look like in Bangalore, India **NOW**?

#2. Spectrum Cop

- Quickly detect violators

  - Simplicity in writing complex real-time sensing applications requiring coordination

- Use `GetOccupancy` to get an occupancy list in the desired frequency span
- For each occupied frequency band, do finer scans using `GetPowerSpectrum` by setting a lower RBW,
- Feed the results to `LocalizeTransmitter` to locate the transmitter.

#2. Spectrum Cop

- Quickly detect violators
  - Simplicity in writing complex real-time sensing applications requiring coordination

```
# Find occupancy in desired region
bound = [lat, lng, radius];
options = [lat, lng, radius, min_power_to_detect];
occupancy_list = APIServer.GetOccupancy(bound,
 start_frequency, end_frequency, min_power_detect);

# Get power spectrum for transmitter frequency
for occupancy in occupancy_list:
    if (occupancy['Occupied'] == 1):
        new_f_start = occupancy['Frequency'] - 250e3;
        new_f_end = occupancy['Frequency'] + 250e3;
        devices = APIServer.GetDevices(bound, None);
        for device in devices:
            locs.append([device['Latitude'],
                         device['Longitude']]);
            results[device['ID']] = APIServer.
             GetPowerSpectrum(device['ID'],
             new_f_start, new_f_end,
             options); # Actual call in new thread.
        break;

# Localize transmitter based on power measurements
for r in results:
        powers.append(max(r));
print APIServer.LocalizeTransmitter(bounds, locs,
 powers, 'LDPL', [P, 3.0]);
```

Limitations

- Benefit to owners
  - Expensive devices
- Attenuation
  - 5-20 dB attenuation due to buildings
- Privacy/Security concerns
  - Fine-grained traffic monitoring/user-tracking not possible

Conclusion

- FCC ruling has spurred tremendous interest, both in academia and industry
- Key requirement is a measurement infrastructure that provides real data
- SpecNet fulfills this need by enabling a geographically distributed spectrum analyzer network

SpecNet requests your participation!
Please contact Anand Iyer (v-anandi@microsoft.com) or Krishna Chintalapudi (krchinta@microsoft.com)

http://bit.ly/SpecNet