V-Scope: An Opportunistic Wardriving Approach to Augmenting TV Whitespace Databases

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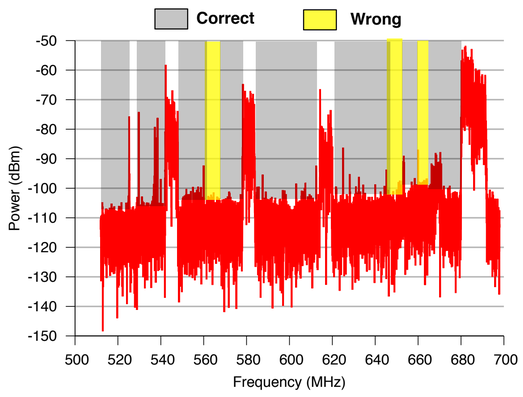
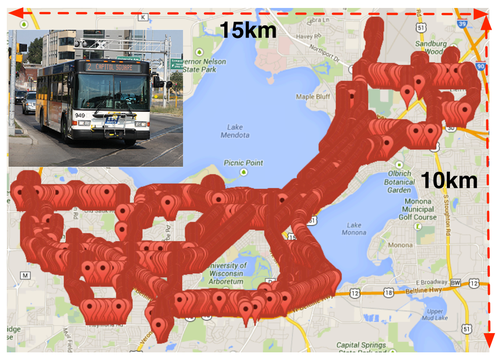
Motivation

BACKGROUND:
- TV whitespaces are vacant TV channels that can be used for unlicensed communications
- It has large spectrum resource and good propagation range
- Whitespace devices query spectrum occupancy databases to determine which channel is free to use



Commercial spectrum databases have errors in predicting whitespaces

GOALS:
- How much spectrum is generally wasted by commercial databases?
- How can we reduce spectrum waste with local measurements?

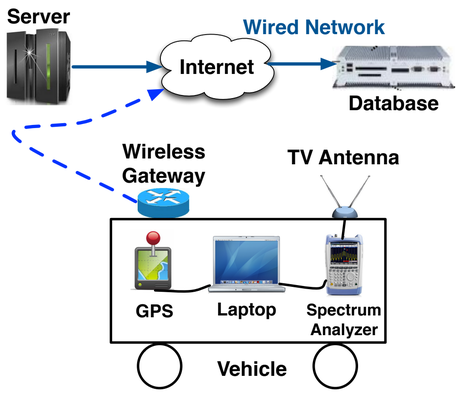


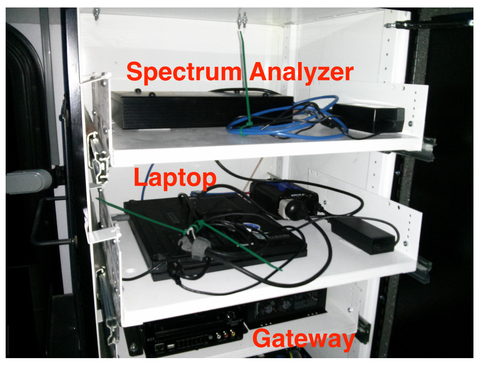
Public vehicles travel over wide area

V-Scope:
- Put spectrum sensors on public transmit to collect wide-area measurements
- Use measurements to augment propagation models in databases

CHALLENGES AND SOLUTIONS:
- Zoom-in detection to detect weak primary signals in real-time
- Weighted model fitting to deal with measurement density variation

V-scope Architecture





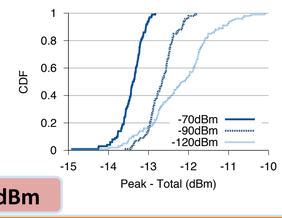
PROCEDURE:
- Mount spectrum sensors on public vehicles
- Detect primary signals in real-time
- Upload detection results through a wireless gateway
- Server queries a commercial database (SpectrumBridge)

Primary Detection Accuracy

Classification Accuracy

Detected / Ground truth	Digital	Analog	MIC
Digital	94.9%	0.7%	4.4%
Analog	0.5%	97.4%	2.1%
MIC	1.2%	0.7%	98.1%

Power Estimation Accuracy



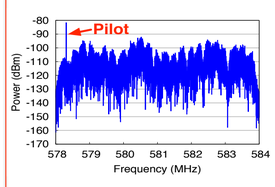
Test signals from -40dBm to -114dBm

- Detect different primary devices with > 95% accuracy
- TV pilot can be used to accurately estimate TV power

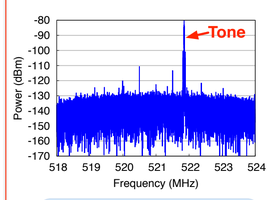
Primary Detection Algorithm

How to detect and measure the power of primary signals up to -114dBm?

Example of Strong Primary Signals



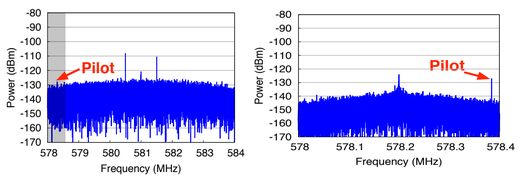
TV at -60dBm



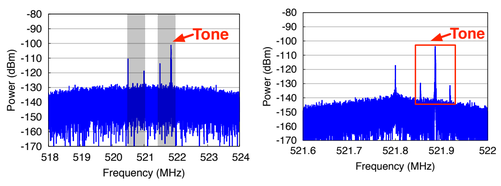
Microphone at -60dBm

Challenge and Solution for Detecting Weak Primary Signals

Capture FFT Samples → Zoom-in Peak Spectrum → Feature Extraction → Classification → Power Estimation

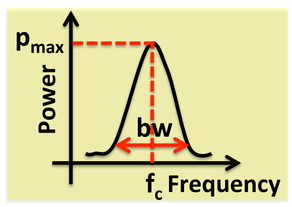


TV at -114dBm



MIC at -114dBm

Zoom-in spectrum with 12dB lower noise floor



Extracted peak features

$$power = \sum_{f_i \in bw} p_i + \delta$$

Detection results

$$power = \sum_{f_i \in bw} p_i$$

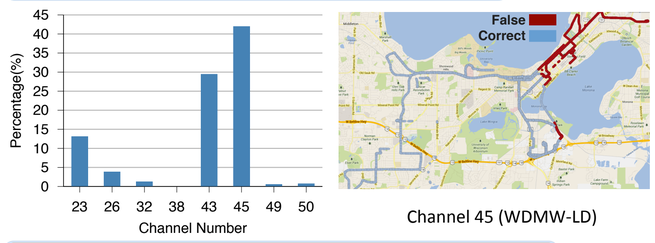
Add power offset to wide band TV signal

Accuracy of Spectrum Databases

DEPLOYMENT
- Deploy on a metro bus for two months
- Measure 1000,000 locations over 150 square km

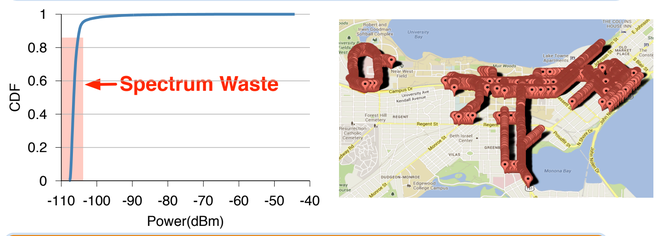
- Negligible under-protection is found

Spectrum Waste in TV Protection



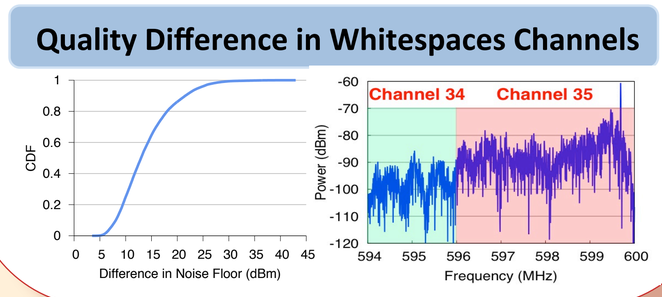
- Up to 42% area is wasted by over-protection

Spectrum Waste in Microphone Protection



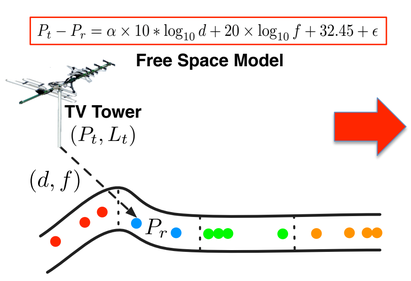
- Microphone is inactive at 80% reserved locations

Quality Difference in Whitespaces Channels

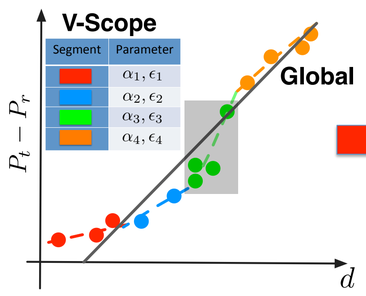


Model Refinement Procedure

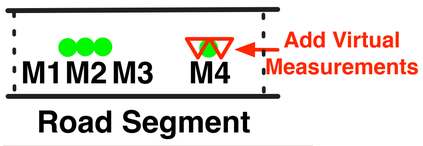
How to improve databases?
Use measurements to fit parameters of propagation models



Divide measurements based on road segments



Fit model parameters for each segment

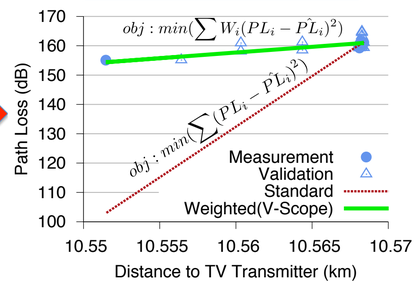


Measurement	Weight
M_1	1
M_2	1
M_3	1
M_4	3

$$W_i = \sum_j dist(i,j)$$

Sparse measurements carry higher weights in local fitting

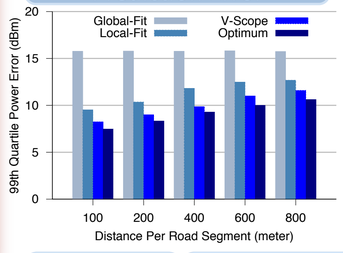
Real World Example



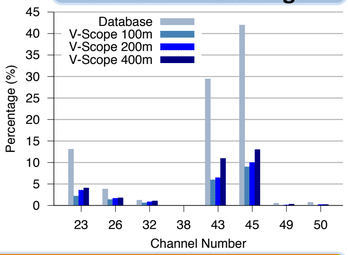
Weighted regression in V-Scope outperforms linear regression

Database Improvement

99th Quartile in Power Prediction Error



Reduction in Spectrum Waste for Protecting TV



5 Fold Cross Validation

Fitting a local model for each 100m road segment can reduce spectrum waste up to 4x