Qualcomm Cognitive Radio Contest

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QUALCOMM

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New Spectrum

- The use of TV white space offers significant new spectrum
- Additional spectrum is an excellent way to provide additional wireless capacity
- For portable TV white space devices there are a multiple 6 MHz TV white space channels, in the UHF frequency band
- Over the 50 largest US metropolitan area
  - The median number of TV white space channels is around 16
  - The 95% number of TV white space channels is around 6
- The UHF TV white space is in the range of 512 MHz to 698 MHz. This frequency band offers excellent RF propagation
- Provides better range than Wi-Fi but less than macro cellular
- In order to utilize the spectrum one must meet the FCC rules

Spectrum Sensing Rules

- In the TV white space the FCC requires protection of licensed services
  - ATSC and NTSC TV broadcasts
  - Wireless microphones
- The FCC specifies two methods of protecting these services
  - Geo-location/Database
  - Spectrum Sensing
- Must be able to sense signals as low as -114 dBm
- If the minimum antenna gain (G) is less than 0 dBi then the sensitivity must be reduced to $(-114 + G)$ dBm
- This corresponds to an SNR often below -20 dB
- There has been significant research on ATSC & NTSC sensing
- Research on wireless microphone sensing has been limited

Challenges for Wireless Microphone Sensing

Negative SNR	A 6 dB receiver noise figure results in noise power of -100 dBm. If we have a -4 dBi antenna gain, sensing must be performed at around -22 dB SNR
Multipath	Narrow-band wireless microphone signals subject to multipath fading
Manmade Noise	There is significant manmade noise in the UHF band, at a power level of -95 dBm or higher. Manmade noise is not AWGN
Adjacent Channel Blockers	Sensing needs to be performed in channels adjacent to broadcast TV signals

Signal Database

- Qualcomm captured signals in the TV UHF band
- Signals were collected in a small suburban city to avoid channels with other wireless microphones
- Six different wireless microphones used
- RF attenuation performed using a small Faraday cage, physical distance and finally a programmable attenuator
- Target RX power between -100 and -114 dBm. Fading leads to variation around target power
- Signals collected with three different audio signals
  - Silent
  - Speech
  - Music
- Signals were also captured on empty channels without TV or wireless microphone signals

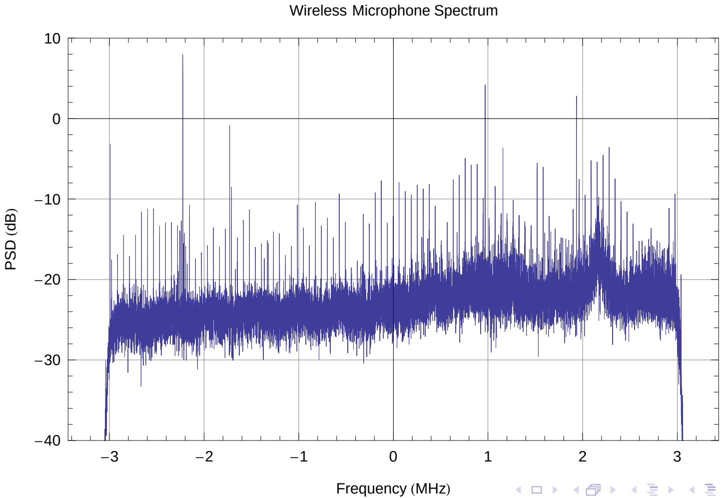
Signal Database – Wireless Microphones

Manufacturer	Model	Freq. Range	TX Power
Shure	SM58	578-638	50 (mw)
Shure	SM86	470-530	50 (mw)
Sennheiser	SKM100	518-554	30 (mw)
AudioTechnica	AEW-T5400	655.5 - 680.375	35 (mw)
AudioTechnica	ATW-T341	541.5 - 566.375	30 (mw)
AKG	AKG-HT450C	650.1 - 680	50 (mw)

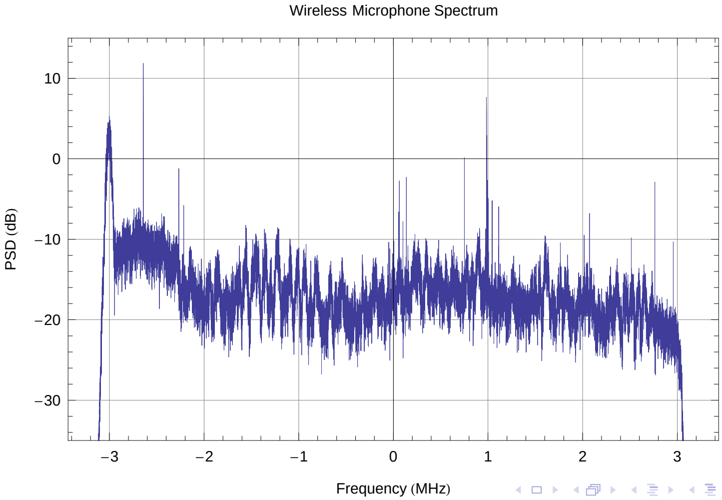
Signal Database – Manmade Noise

- The signals were captured over-the-air in typical suburban neighborhood
- The "empty channels" contain manmade noise due to out-of-band emissions from TV broadcast signals, and other unknown sources
- The manmade noise is NOT additive white Gaussian noise (AWGN) but often consists of narrow-band signals
- These narrow-band manmade signals can be difficult to distinguish from weak wireless microphone signals
- By averaging over multiple observations the thermal noise (which is AWGN) can be reduced, leaving the manmade noise
- Example of manmade noise in "empty channels" are provided on subsequent slides

"Empty Channel" Examples



"Empty Channel" Examples



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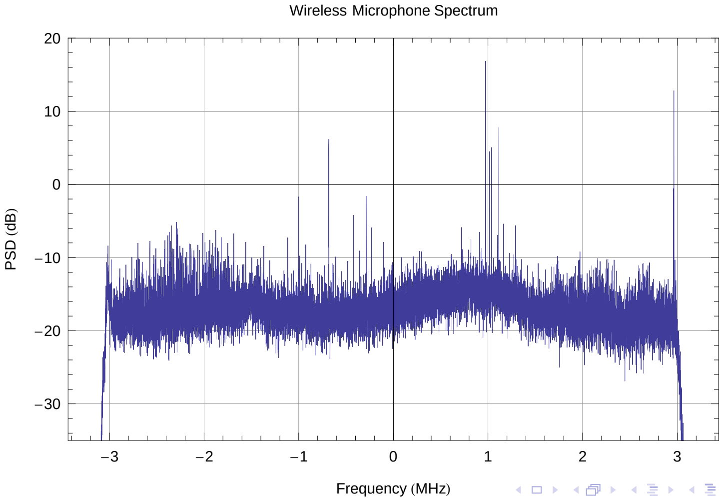

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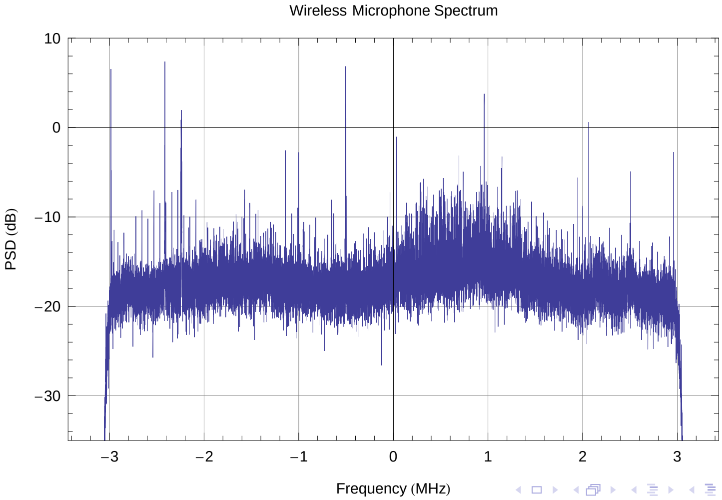
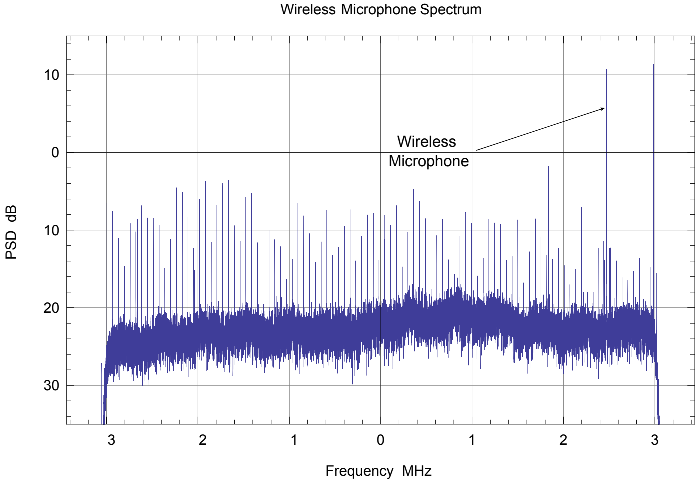
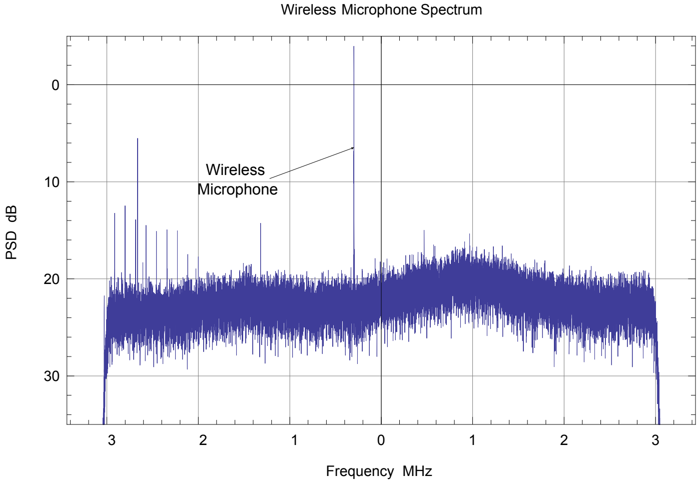


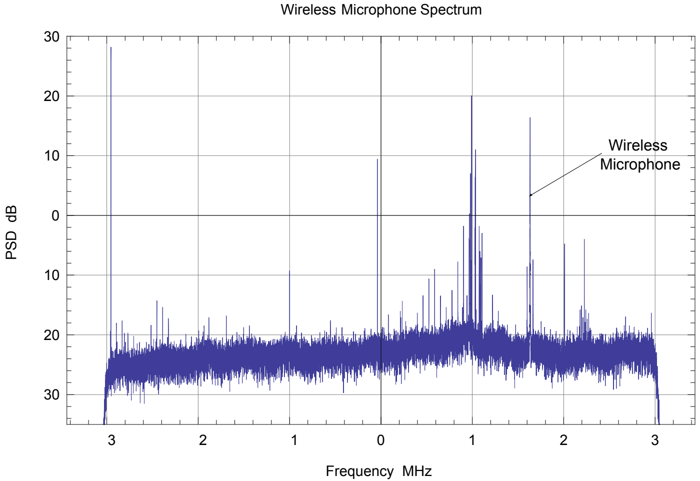
Wireless Microphone Examples



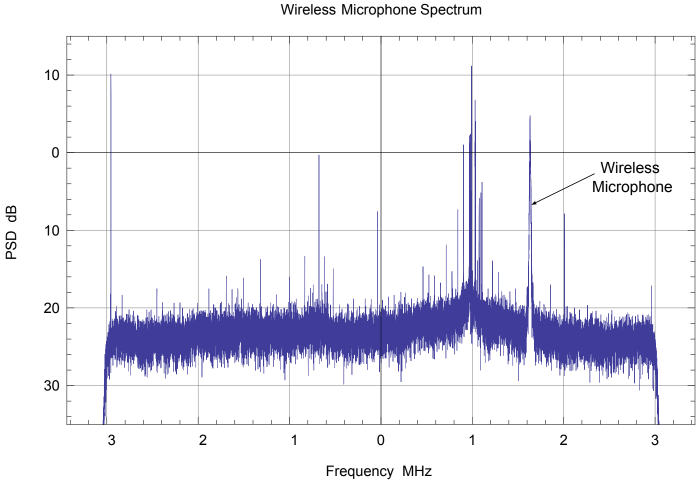
Wireless Microphone Examples



Wireless Microphone Examples



Wireless Microphone Examples



Invited Universities

Professor	University
Anant Sahai	UC Berkeley
Danijela Cabric	UCLA
Bhaskar Rao	UC San Diego
Simon Haykin	McMaster University
Michael Buehrer	Virginia Tech
Dipankar Raychaudhuri	Rutgers WINLAB
Lang Tong	Cornell University
Vincent Poor	Princeton University
Venugopal V. Veeravalli	University of Illinois
Geoffrey Li	Georgia Tech
Tim Brown	University of Colorado
David J. Thomson	Queens University
Xin Liu	UC Davis
Lizhong Zheng	MIT

Contest Rules

- Qualcomm provided two sets of signals
  - Training Set - Empty and wireless microphone channels with power and frequency information (15 files)
  - Testing Set - Mixture of files from Empty Channels and Wireless Microphone channels (36 files)
- Students were permitted to work in teams
- Students should include in their submission
  - Description of sensing technique
  - Code (Matlab or C) implementing the sensing technique
  - The results of the sensing technique on the test set
- Winner will be judged on sensing performance, complexity, novelty, description of the sensing technique
- Winner receives $25,000 and preferred consideration as a Qualcomm Intern

Submissions

Contestants	University
Shafi Bashar, Neil Jacklin, Fabio Lapiccirella, Keqin Liu, Wei Ren, Pouya Tehrani and Jia Ye,	UC Davis
Xiao Li and Lin Li	UC Davis
Michael P. Daly and Erica L. Daly	University of Illinois
V. Sreekanth Annapureddy, Sreeram Kannan, Adnan Raja and Jayakrishnan Unnikrishnan	University of Illinois
Mina Karzand	MIT
Wesley Burr	Queen's University
Jared Dulmage, Oussama Sekkat, Jihoon Park, Alican Gk, Paulo Isagani Urriza and Jun Wang	UCLA
Harpreet Dhillon, Jeong-O Jeong, Dinesh Datla and Mike Benonis	Virginia Tech
Dan Zhang and Lijun Dong	WINLAB, Rutgers University
Goran Ivkovic and Dusan Borota	WINLAB, Rutgers University
Ashwin Revo and Samson Sequeira	WINLAB, Rutgers University

Performance Metrics

- The code for all the sensing techniques was run at Qualcomm
- Ran code on original test set and an additional test set
- Several metrics were used to measure performance
  - Probability of detection - Number of files with wireless microphones detected at the proper frequency (within a tolerance), out of the total number of files containing a wireless microphone
  - Probability of false alarm - Number of files with wireless microphones detected, out of the files that do not contain a wireless microphone
  - Probability of a double error - Number of files with a wireless microphone detected in the wrong frequency, and not detected at the correct frequency, out of the number of filed containing a wireless microphone

Top Three Submissions

The top three submissions, in alphabetical order by University name

Contestants	**University**
Wesley Burr	Queen's University
Jared Dulmage, Oussama Sekkat, Jihoon Park, Alican Gk, Paulo Isagani Urriza and Jun Wang	UCLA
V. Sreekanth Annapureddy, Sreeram Kannan, Adnan Raja and Jayakrishnan Unnikrishnan	University of Illinois

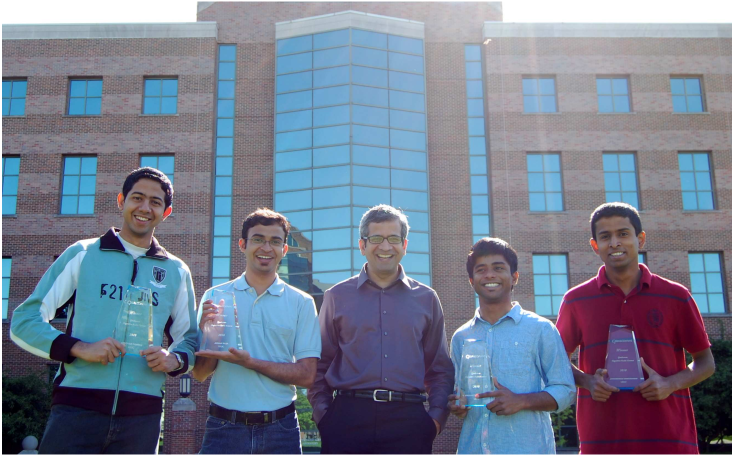
Brief Summary of Approaches – Top Three Submissions

- Used some form of Spectral Analysis (several approaches)
- Some used a two step approach
  - Low resolution PSD to find candidate frequencies
  - High resolution PSD for further processing
- Others used a single set approach with a higher resolution PSD
- Several methods were used for identification of wireless microphones
  - Correlation with PSD templates based on training data
  - Power and bandwidth tests
  - Frequency tests
- Other statistical tests
- Some teams will consider submitting methods to publication

Contest Winner

Winning Team	University
V. Sreekanth Annapureddy Sreeram Kannan Adnan Raja Jayakrishnan Unnikrishnan	University of Illinois

Contest Winner



Future Research

- There are several open areas of applied research for wireless microphone spectrum sensing
  - Modeling of the narrow-band manmade noise in the TV white space
  - Modeling and characterization of weak wireless microphone signals
  - Such models would be useful in developing and testing methods to distinguish between weak wireless microphone signals and manmade noise

Questions