Cognitive Radio in the TV White Space: Challenges and Some Solutions

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Presentation Outline

- Introduction
- White Space Availability
- Technical Challenges
- Qualcomm Spectrum Sensing Prototype
- References

Introduction

- **The FCC has been working for years on developing regulations to permit unlicensed use of TV white space [1] [2]**
- **Other regulatory organizations are now starting to consider TVWS regulations**
  - Ofcomm (UK)
  - CEPT/ECC (Europe)
  - Singapore
  - Etc.
- **Regulations similar but not identical to FCC**

Summary of FCC Rules

- **Two classes of devices – Fixed and Personal/Portable**

- **Permissible TV channels**

TV Channel	Frequency Band	Frequency (MHz)	Allowed Devices
2	VHF	54 – 60	Fixed
5 – 6	VHF	76 – 88	Fixed
7 – 13	VHF	174 – 216	Fixed
14 – 20	UHF	470 – 512	Fixed
21 – 35	UHF	512 – 602	Fixed & Portable
36	UHF	602 – 608	Portable
38	UHF	614 – 620	Portable
39 – 51	UHF	620 – 698	Fixed & Portable

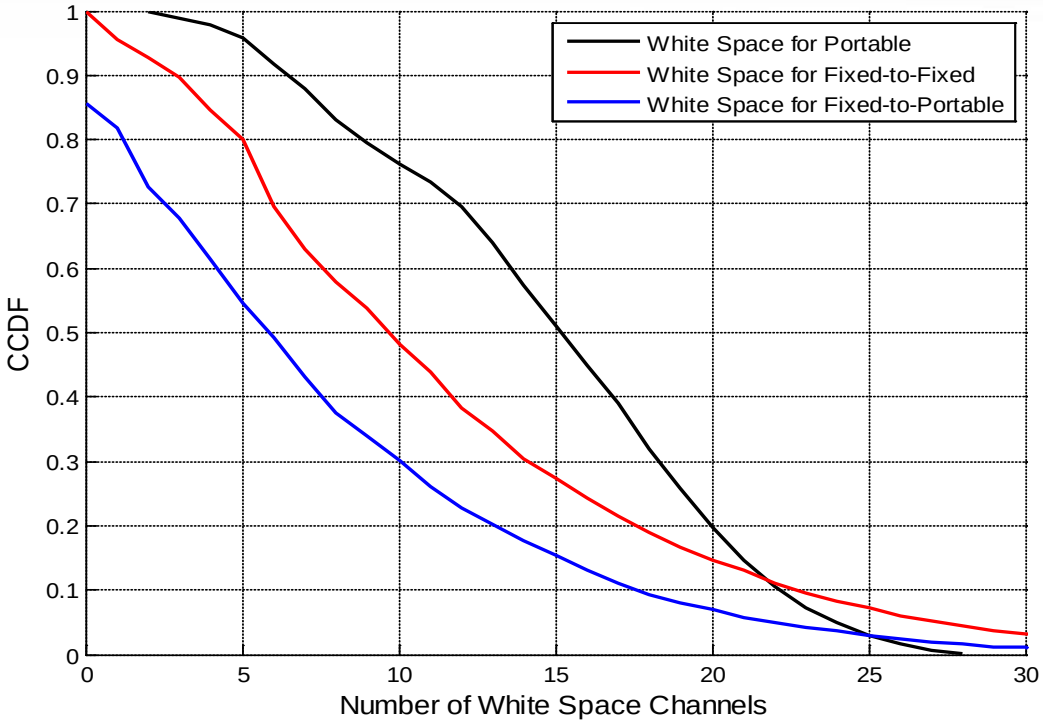
Summary of FCC Rules

- **Fixed devices use outdoor antennas**
- **Classes of portable devices**
  - Mode I – Client
  - Mode II – Access Point
- **Permitted TX power**
  - Fixed – 30 dBm with up to 6 dBi antenna gain
  - Portable – 20 dBm with no antenna gain
- **Channels adjacent to TV broadcasts**
  - Fixed – Not permitted
  - Portable – Reduce power to 16 dBm
- **Strict out-of-band emissions**
- **Interference avoidance mechanisms (either/or)**
  - Geo-location with Database Access
  - Spectrum Sensing

White Space Availability

- **Evaluated the FCC database for both standard and low-power TV broadcast stations**
- **For standard TV stations the exact location and coverage area is provided**
- **For low-power TV stations they only provide the zip codes that are covered**
- **Two channels are reserved for unscheduled wireless microphone use [2]**
- **Evaluated the number of TVWS channels for every zip code in the US**
  - Fixed Network
  - Portable Network
  - Fixed/Portable Network

White Space Availability



Scenario	Set of Channels Considered
Fixed to Fixed	2, 5-13, 14-51 (VHF & UHF)
Fixed to Portable	14-51 (UHF)
Portable	21-51 (UHF)

Complementary Cumulative Distribution of the number of TVWS channels

Technical Challenges

- Originally [1] the FCC required both geo-location/database and spectrum sensing
- Due to limited performance of sensing prototypes the FCC recently [2] made sensing optional
- Discussion of challenges reviewed earlier [3]
- Second part of this talk will discuss a spectrum sensing solution

Technical Challenges

- **Geo-location**
  - Mode II devices must provide 50 meter accuracy and verify location every 60 seconds
- **Challenge**
  - Low cost consumer devices (e.g. Wi-Fi AP) needs to support for GPS indoors
  - Indoors GPS often losses satellite lock due to building penetration
  - High-sensitivity GPS relies of assisted GPS that obtains assistance from cellular network
  - Challenge – Develop low-cost geo-location mechanism for indoor locationing with 50 meter accuracy

Technical Challenges

- **Spectrum sensing – (optional)**

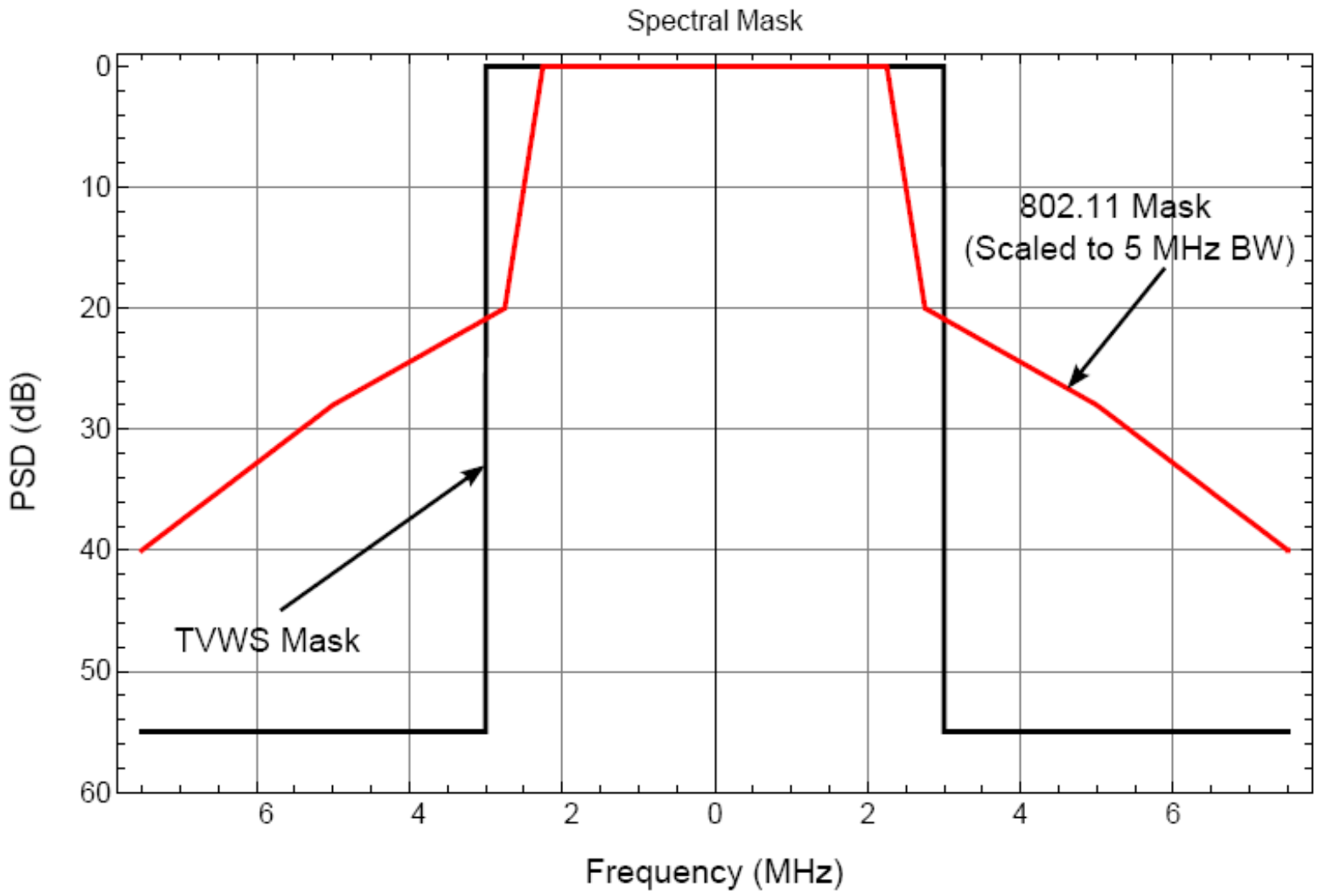
Signal	Sensing Threshold
ATSC	-114 dBm
NTSC	-114 dBm
Wireless Microphone	-107 dBm

Challenge	Comments
Short Quiet Times	Need to be able to quiet the network for a short time to enable sensing
Negative SNR	SNR level around -20 dB
Multipath	Sensing channel subject to multipath and Doppler
Manmade Noise	Weak non-AWGN manmade noise present in the TV bands (out-of-band TV emissions)
Wireless Mics	No wireless microphone standard. Operate anywhere within a channel. Narrowband like manmade noise

Technical Challenges

- **Spectral Mask**
  - FCC is requiring a very stringent spectral mask (illustrated in next slide)
- **Challenges**
  - Meet spectral mask
  - Low-cost implementation
  - Minimize power amplifier (PA) back-off to avoid high power consumption

Technical Challenges



Technical Challenges

- **UHF Antenna**
  - Portable devices need to be able to operate over the majority of the UHF TV band (512 – 698 MHz). Could be wideband or tunable antenna
  - One of the primary benefits of the TVWS is the improved propagation compared to 2.4 and 5 GHz
  - Wavelengths in this band is quite large
    - 43 cm < λ < 59 cm
  - Portable devices are limited in size (laptops & handhelds)
- **Challenge**
  - Small form factor antenna, operating over 512-698 MHz, antenna gain near 0 dBi over entire band

Technical Challenges

- **Coexistence in the TVWS**
  - The TVWS spectrum is unlicensed, like the 2.4 and 5 GHz bands
  - There may be a wide variety of technologies deployed in the TVWS
    - IEEE 802.11af – Wi-Fi
    - IEEE 802.22 – Wireless Regional Area Networks
    - Cognia – In-home video distribution
    - Smart Grid ?
  - The IEEE started a standards project earlier this year for coexistence between TVWS networks
    - IEEE 802.19.1

Technical Challenges

- **Wi-Fi is likely to be deployed in the TVWS**
- **One possible deployment will be with high-power Fixed APs and low-power STAs**
- **Potential large power disparity between APs and STAs**
- **CSMA is based on symmetry in the carrier sense regions of the different stations**
- **TX power asymmetry will increase hidden/exposed nodes resulting in MAC layer inefficiency**

Challenge

- **Develop improved methods of minimizing hidden and exposed nodes**

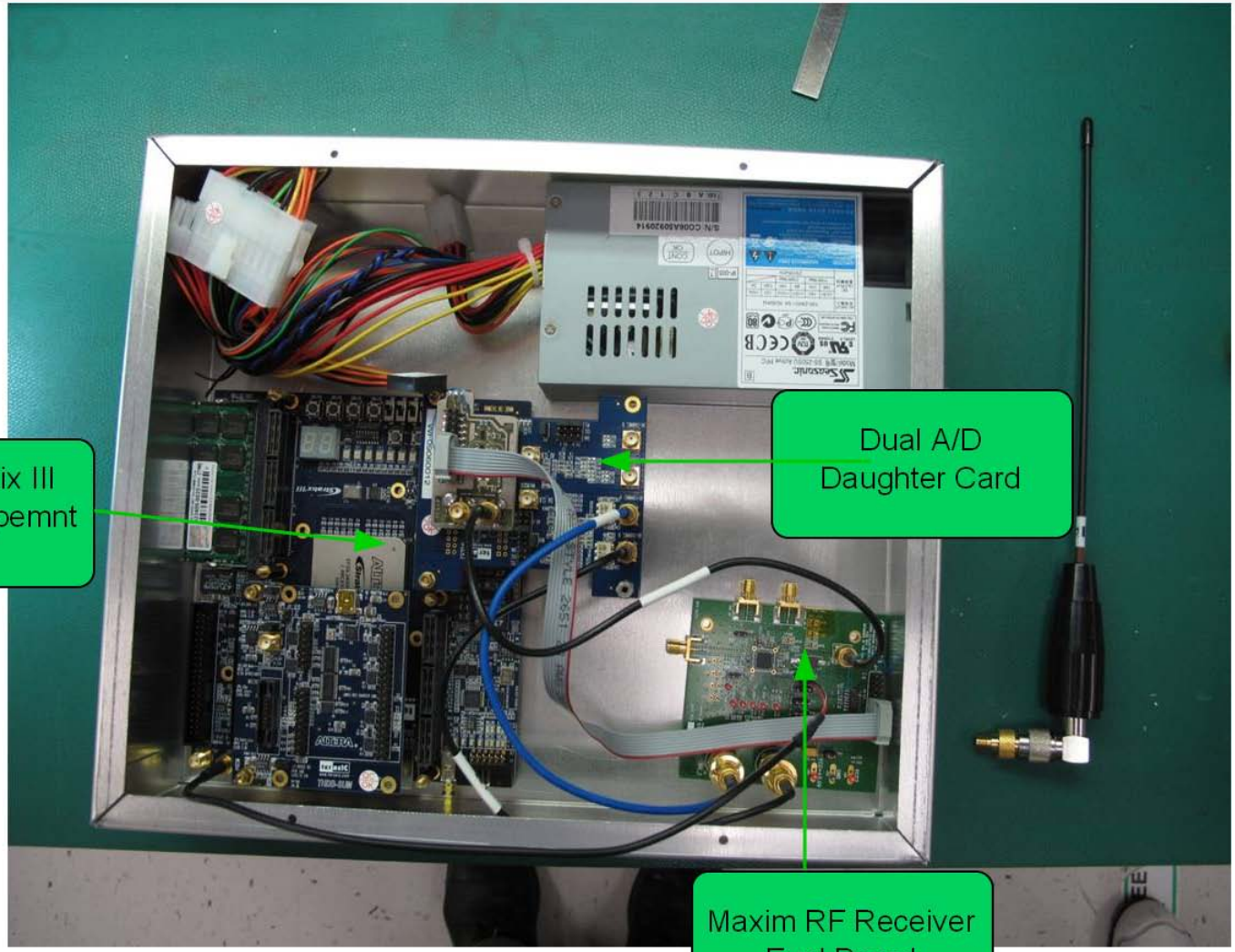
Qualcomm Spectrum Sensing Prototype

- **Developed sensing techniques for ATSC, NTSC and Wireless Microphones**
- **Hosted a Contest for the best wireless microphone sensing technique [4]**
- **Summary of the prototype will be provided at DySPAN 2011 [5]**
- **Also developed theoretical performance for ATSC sensing [6]**

Qualcomm Spectrum Sensing Prototype

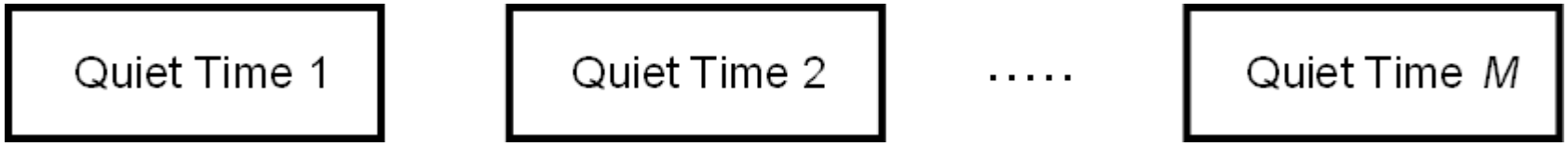
- **Hardware**
  - Dual Antennas
  - Off-the shelf TV tuner
  - Dual ADC
  - FPGA (High-order PSD calculation)
  - USB Interface to personal computer
- **Software**
  - Control software
  - ATSC, NTSC and Wireless Microphone decision engine
  - GUI
  - Perl Interface for statistical testing

Qualcomm Spectrum Sensing Prototype

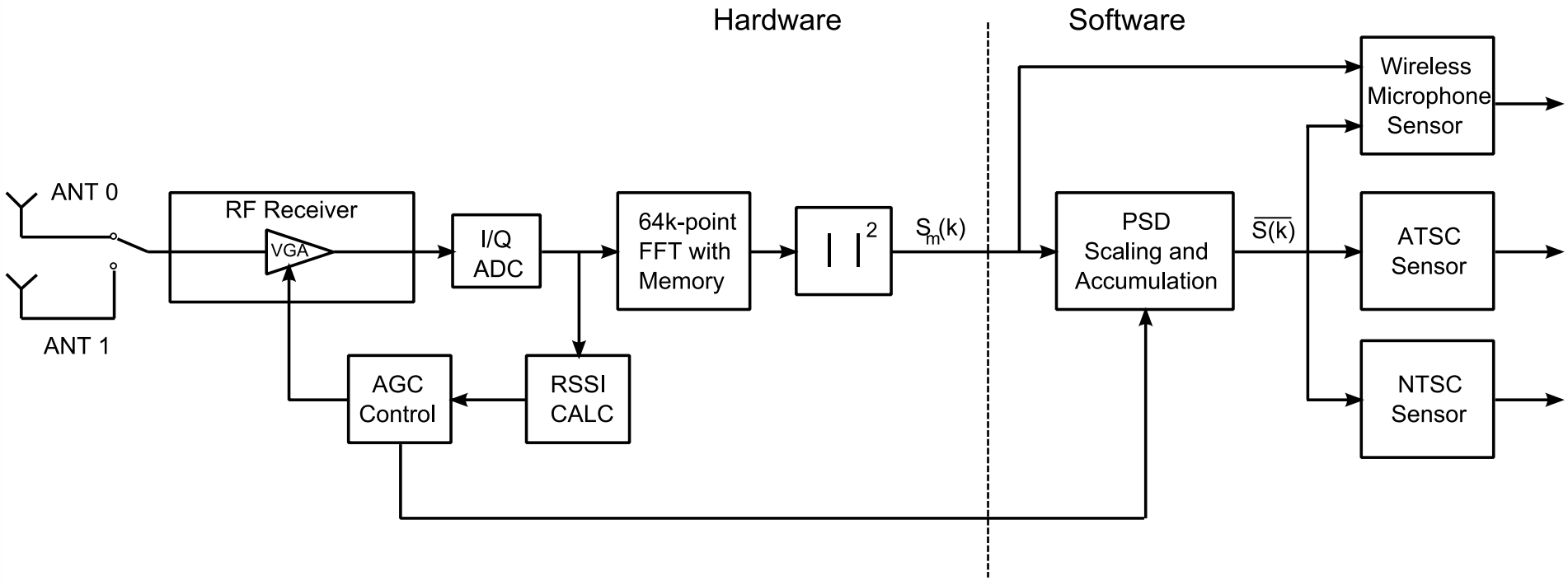


Qualcomm Spectrum Sensing Prototype

- **In order to sense the spectrum a network must quiet (cease transmission)**
- **Quiet times incur overhead and latency**
- **Must sense once a minute during operation**
- **Two quiet time options**
  - One single quiet time
  - Multiple smaller quiet times
- **We use multiple quiet times to minimize latency impact**
- **Quiet Time duration 7 ms**



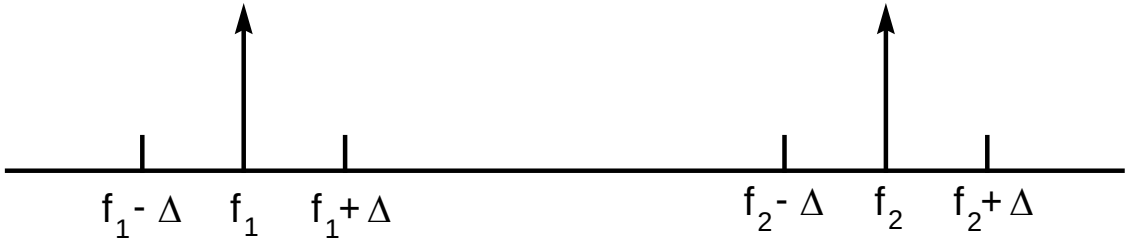
Qualcomm Spectrum Sensing Prototype



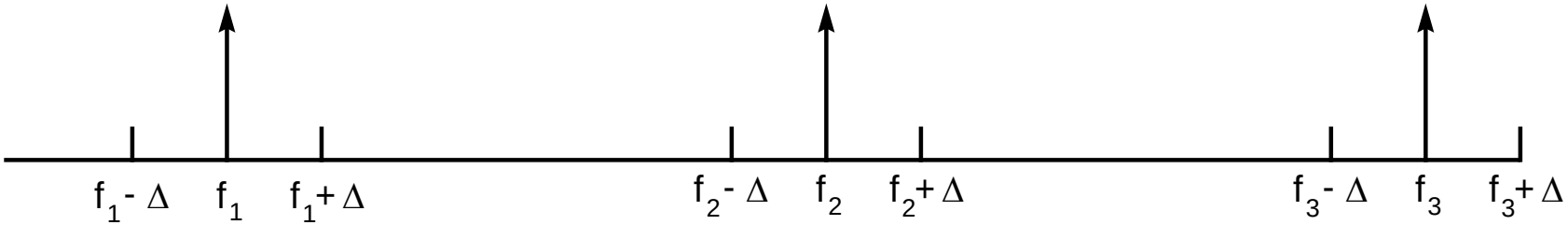
Sensing Architecture

Qualcomm Spectrum Sensing Prototype

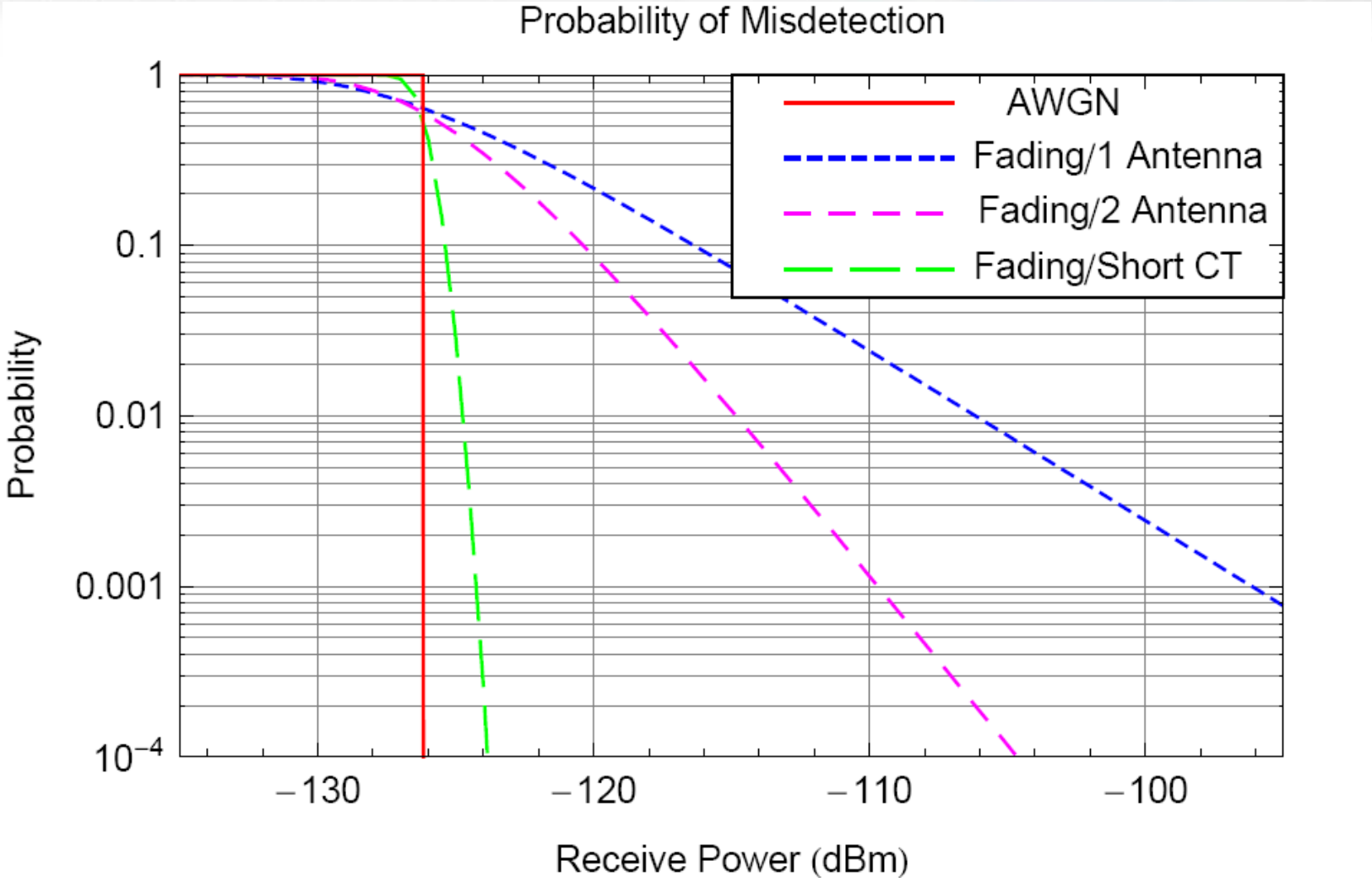
- **ATSC Sensing**
  - Sense for ATSC Pilot Tone and compare to Noise Floor
  - Two possible tone frequencies with RX LO inaccuracy



- **NTSC Sensing**
  - Sense for NTSC Luminance carrier and compare to Noise Floor
  - Three possible frequencies with RX LO inaccuracy



Qualcomm Spectrum Sensing Prototype



Theoretical ATSC Sensing Performance

Qualcomm Spectrum Sensing Prototype

- **Wireless Microphone Sensing**
- **Captured wireless microphone signals**

Category	Conditions
Locations	Outdoors (Park and Residential Area) Indoors (Qualcomm Offices and Labs)
Wireless Mics	8 different microphones 5 different manufacturers
Audio Input	Speech Music Silent
Power Levels	In the range of -100 to -114 dBm

Qualcomm Spectrum Sensing Prototype

- **Wireless Microphone Sensing**
  - Searched the PSD for candidate wireless microphone frequencies
  - Calculated a set of test statistics involving power, bandwidth and bandwidth variation for each candidate wireless microphone frequency
  - Compared the set of test statistics to a set of thresholds
  - Decision on presence or absence of wireless microphone in the channel

Qualcomm Spectrum Sensing Prototype

- **Wireless Microphone Sensing Results**
  - Thresholds set to obtain 100% probability of detection for both voiced (speech and music) wireless microphones (-107 dBm) and silent wireless microphone (-100 dBm)
  - Measured the number of lost empty channels due to false alarms

Location	Number of Lost White Space Channels
Park	1/15
Residential Area	2/15
Qualcomm Lab	3/15
Qualcomm Office	3/15

- **Sensing Silent Wireless Microphones**
  - Silent wireless microphones could only be sensed down to -100 dBm
  - If sensing of silent mics is not required then the false alarms can be eliminated

Video

- **Show Video**

Questions?

References

1. Federal Communication Commission, “Second Report and Order and Memorandum Opinion and Order In the Matter of Unlicensed Operation in the TV Broadcast Bands, Additional Spectrum for Unlicensed Devices Below 900 MHz and in the 3 GHz Band,” November 14, 2008, Document 08-260
2. Federal Communication Commission, “Second Memorandum Opinion and Order In the Matter of Unlicensed Operation in the TV Broadcast Bands, Additional Spectrum for Unlicensed Devices Below 900 MHz and in the 3 GHz Band,” September 23, 2010, Document 10-174
3. S. J. Shellhammer, A. K. Sadek and W. Zhang, “Technical challenges for cognitive radio is TV white space spectrum,” UCSD Information Theory and Applications Workshop, January 2009
4. S. J. Shellhammer, “Qualcomm Cognitive Radio Contest,” IEEE Communication Theory Workshop, May 2010

References

5. R. Balamurthi, H. Joshi, C. Nguyen, A. K. Sadek, S. J. Shellhammer and C. Shen, “A TV White Space Spectrum Sensing Prototype,” DySPAN, May 2011 (Submitted)
6. S. J. Shellhammer, “The Theoretical Performance of ATSC Spectrum Sensing,” DySPAN, May 2011 (Submitted)