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Cognitive Radio For The TV White Spaces

Monisha Ghosh

Philips Research North America

June 21, 2009

Overview

- Update on latest White Space activities in US and UK
  - Adoption of White Space rules in US
  - Consultation released by Ofcom.
- Cognitive radio for the TV bands: challenges and solutions.
- Wireless Regional Area Networks (WRAN)
  - IEEE 802.22 Standard
- Personal/Portable Applications
  - Cognea and Ecma standardization
- Philips prototypes:
  - Sensing prototype
  - UHF Cognitive Radio prototype
- Conclusions

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History……..

From “The early history of cellular telephony”, Joel Engel, IEEE Communicaions Magazine, Aug. 2008

“The proposed reallocation of spectrum met with considerable political opposition. The television broadcasters did not want any spectrum to be taken away.”

- 1968

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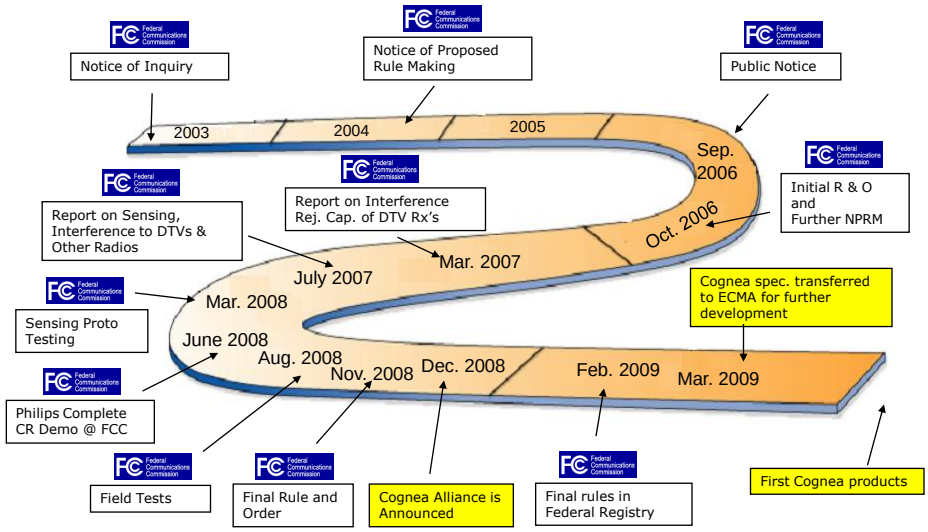
TV White Spaces Regulatory Milestones – US



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TV Band Incumbents

- Digital Television (DTV), Analog television (NTSC)
  - After the transition to DTV on June 12, 2009, some low-power NTSC stations will still remain and will need to be protected.
- Wireless microphones:
  - Currently are treated as secondary users of the TV spectrum.
  - Will be primary as far as unlicensed white space devices are concerned.

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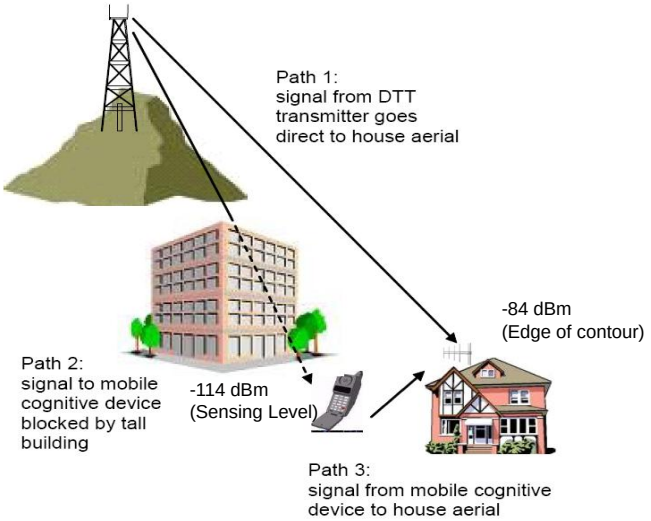
TV Sensing Problem: Hidden nodes



Source: Ofcom Consultation
Feb. 16 2009

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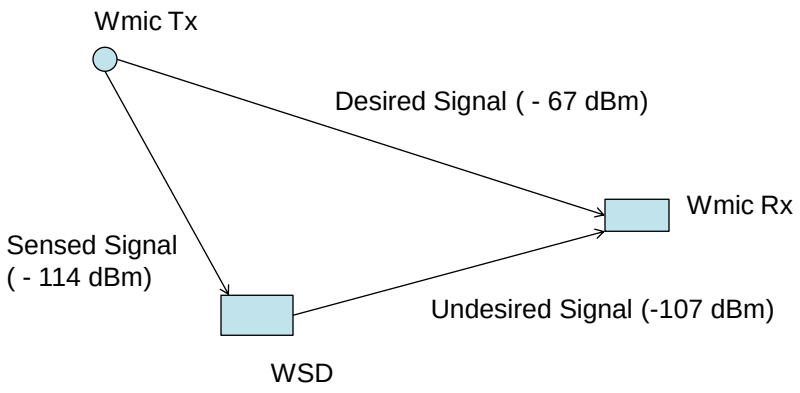
Wireless Microphone Sensing Problem



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FCC 2nd Report and Order (FCC 08-260, 11-14-2008)

- Both fixed and personal/portable devices allowed to operate in the TV white spaces on an unlicensed basis.
- All devices, except personal/portable devices operating in client mode, must include a geolocation capability and provisions to access over the Internet a database, established and administered by a third party.
- All devices must also have a capability to sense TV broadcasting and wireless microphone signals as a further means to minimize potential interference.
- Devices using sensing only as the protection mechanism may be allowed in the future, subject to additional FCC tests.

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FCC 2nd Report and Order cont'

- Fixed Devices (e.g IEEE 802.22)
  - Up to 4 Watts EIRP.
  - Any channel between 2 and 51, except channels 3, 4 and 37.
  - Employ geo-location database and spectrum sensing to determine when TV channels are available.
  - Incorporate a dynamic frequency selection (DFS) mechanism to ensure that TV band devices operate only on vacant TV channels.
  - Shall employ a transmission power control (TPC) mechanism.
  - Not allowed in adjacent channel.

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FCC 2nd Report and Order cont'

- Personal/Portable Devices
  - Up to 100mW; limited to 40mW if operating in adjacent channels.
  - Any channel between 21 and 51, except channel 37.
  - Mode II device (Master device) must employ geo-location database to determine channel availability.
  - Mode I device (Client device) operates under signaling control of Mode II device.
  - Employ sensing mechanism to determine channel availability in addition to geolocation.
  - Incorporate a dynamic frequency selection (DFS) mechanism and transmission power control (TPC) mechanism.
  - Future sensing only device operates <= 50mW.

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FCC proposed rules for spectrum sensing

(FCC 08-260)

Parameter	Value
Channel Availability Check Time	30 sec
In-Service Monitoring Interval	60 sec
Channel Move Time	2 sec
Detection Threshold	ATSC : -114 dBm over 6 MHz NTSC : -114 dBm over 100 kHz WM: -114 dBm over 200 kHz

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Ofcom: UHF Band After Digital Switch Over in UK

Source: Ofcom Consultation
Feb. 16 2009

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Ofcom on TV White Space

- Released consultation on White Spaces on Feb. 16 2009, with comments due by May 01 2009. Awaiting next statement.
- Proposed parameters:

Cognitive parameter	Value
Sensitivity assuming a 0 dBi antenna	-114 dBm in 8 MHz channel (DTT) -126 dBm in 200 kHz channel (wireless microphones)
Transmit power	13 dBm (adjacent channels) to 20 dBm
Transmit-power control	Required
Bandwidth	Unlimited
Out-of-band performance	< -44 dBm
Time between sensing	< 1 second
Maximum continuous transmission	400 milliseconds
Minimum pause after transmission	100 milliseconds

Source: Ofcom Consultation
Feb. 16 2009

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Characteristics of cognitive/agile radios

Cognitive/agile radio =

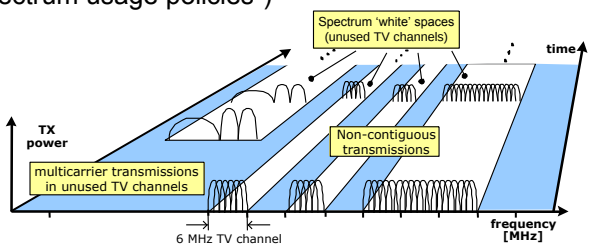
flexible re-configurable radio

("quickly adapts transmission characteristics")

+

smart

("aware of spectrum usage in vicinity,
makes intelligent decisions on that basis, and
reacts to evolving spectrum usage policies")



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Cognitive Radio For the TV Band: Challenges

- Agile radios must detect primaries/incumbents, and at a much lower threshold
  - Primaries in UHF band: Analog and digital TV, Wireless microphones
  - Detection levels: -114 dBm
    - 1000 times lower than the minimum signal strength required to view TV
  - Incumbents like wireless microphones can appear and disappear any time
    - Periodic sensing required
- Long integration times needed for reliable detection at these levels
  - Sensing for this long means poor QoS support
    - Difficult to support VoIP
- **Sensing Requirements**
  - **Fast, robust, coordinated sensing and quite periods, that protect incumbents as well as provide QoS.**

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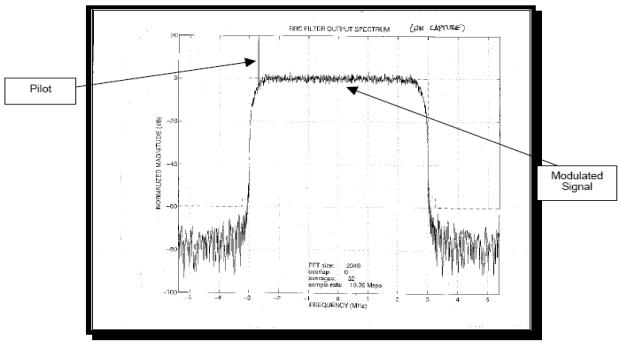
ATSC signal characteristics

- Pilot
  - ATSC signal uses a 8-VSB (Vestigial Side Band) modulation with signal levels (-7,-5,-3,-1,1,3,5,7) + pilot value 1.25.
- Cyclostationarity
  - The ATSC signal is a digital signal with a symbol rate of 10.76 MHz.



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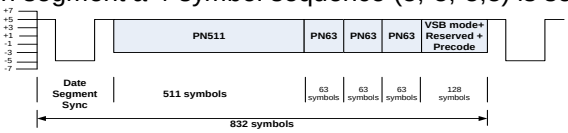
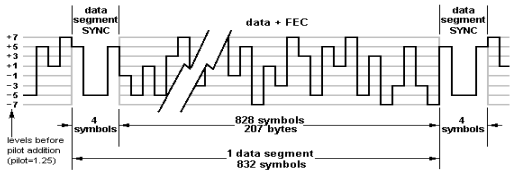
ATSC signal characteristics (cont')

- PN 511 sequence
  - A 511-symbol long PN sequence is inserted in data stream every 24.2 ms.
- Segment-synch
  - The ATSC data is sent in segments of 828 symbols. At the beginning of each segment a 4-symbol sequence (5,-5,-5,5) is sent.
- Duty cycle
  - Last for hours





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Wireless Microphone Signal Characteristics

- Part 74 compliant.
- 200 kHz bandwidth, 250 mW maximum transmit power in UHF.
  - 10 mW is more commonly used as the transmit power level.
- Center frequencies are 25 kHz apart, anywhere in the 6 MHz band including band-edges.
- No standard: most are FM, but newer ones are digital.
- Duty cycle: intermittent.

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Philips sensing approach: Pilot-based sensing

- The ATSC pilot is an unique feature that can be used to sense the presence of the ATSC signal.
- Standard approach:
  - Narrow-band filter (~ 10 kHz) centered around nominal ATSC pilot location.
  - Calculate energy of filtered signal, compare to a threshold.
- Problems:
  - Pilot could be in a deep fade: quite common.
  - Threshold is susceptible to noise uncertainty.
  - Uncertainty in pilot location: could require a 100kHz bandwidth filter. The larger the filter bandwidth, the worse the performance.
- Challenge: Can ATSC pilot detection be made to provide robust sensing at SNR = -20 dB and short sensing times?

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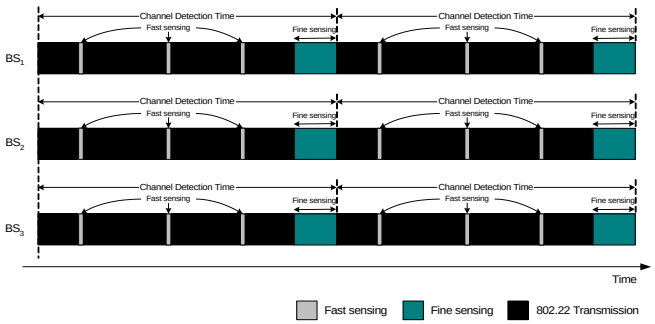
Spectrum Sensing: Solution

- Proposed solution:
  - Use a pilot based DTV sensing algorithm
  - Use a two stage sensing approach: Fast sensing, and, Fine sensing



Carlos Cordeiro, Monisha Ghosh, Dave Cavalcanti and Kiran Challapali, "Spectrum Sensing for Dynamic Spectrum Access of TV Bands," *The Second International Conference on Cognitive Radio Oriented Networks and Communications (CownCom 2007)*

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Cognitive Protocols

- Coordination of quiet periods between otherwise un-coordinated networks
- Channel management
  - Bootstrap, neighbor discovery
  - Channels appear and disappear
    - upon detection of incumbent vacate to pre-agreed backup channel
- QoS support with sensing and channel management
  - Schedule quiet periods for detection of incumbents

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IEEE 802.22 overview

- IEEE 802.22 is the cognitive radio based standard for the following:
  - Fixed point-to-multipoint wireless regional area networks
  - Reuse of TV broadcast bands on a non-interfering basis
  - PHY/MAC air interface specification
- Draft standard is under development
  - Expected to become an official IEEE standard in 2009
- Key design objectives
  - Primary protection (e.g., DTV, wireless microphones)
  - Secondary coexistence

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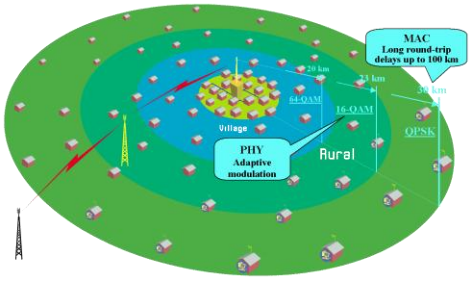
Typical application of the 802.22 WRAN standard

- Wireless Regional Area Networks (WRANs)
  - Wireless broadband access (e.g. Rural areas)
- Topology:
  - Point-to-Multipoint
  - Master/Slave relationship
- Entities:
  - Base Station (BS)
  - Consumer Premise Equipment (CPE)



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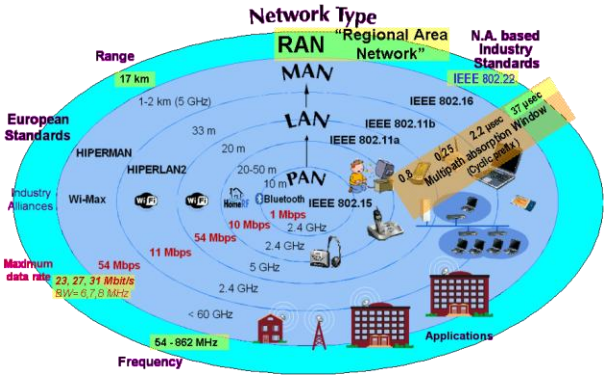
WRAN standard relative to other wireless network standards

- User net-peak-throughput
  - 18.72 Mbit/s
- Service Range:
  - 17-30 km depending on EIRP, up to 100 km



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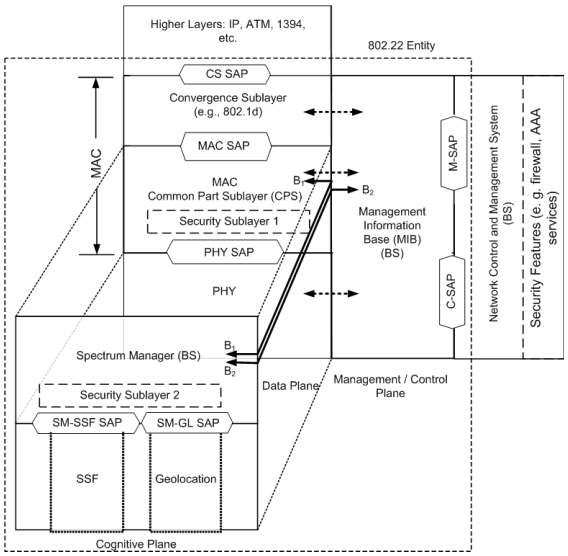
IEEE 802.22 System Architecture



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IEEE 802.22 system parameters (draft specification)

Parameters	Specification
Frequency range	54~862 MHz
Bandwidth	6 and/or 7, and/or 8 MHz
Data rate	1.51~22.69 Mb/s
Spectral Efficiency	0.25~3.78 b/s/Hz
Payload modulation	QPSK, 16-QAM, 64-QAM
Transmit EIRP	Default 4W for CPEs
Multiple Access	OFDMA/TDMA
FFT Mode	2048
Cyclic Prefix Modes	¼, 1/8, 1/16, 1/32
Duplex	TDD

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IEEE 802.22: PHY Overview (draft specification)

- Modulation
  - OFDMA both in uplink and downlink
  - QPSK, 16-QAM, and 64-QAM
- TDD Duplexing
- Enhanced PHY features:
  - Adaptive sub-carrier allocation
  - Adaptive pilot insertion
  - Enhanced channel coding (LDPC, Turbo Code, SBTC)

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IEEE 802.22: MAC overview (draft specification)

- Access mechanism: TDMA
  - Frame structure and QoS model similar to 802.16
- A new superframe structure defined:
  - Better coexistence and self-coexistence, synchronization, Part 74 beacon support, etc.
- Coexistence mechanisms:
  - Two-stage intra- and inter-frame mechanism and opportunistic sensing
  - Incumbent avoidance and Spectrum measurements (incumbents and itself)
  - Channel classification and Management
  - Dynamic resource sharing, Coexistence Beacon Protocol (CBP), Etiquette
  - Synchronization of overlapping BSs and quiet periods
  - Wireless microphone beacon mechanism (TG1)

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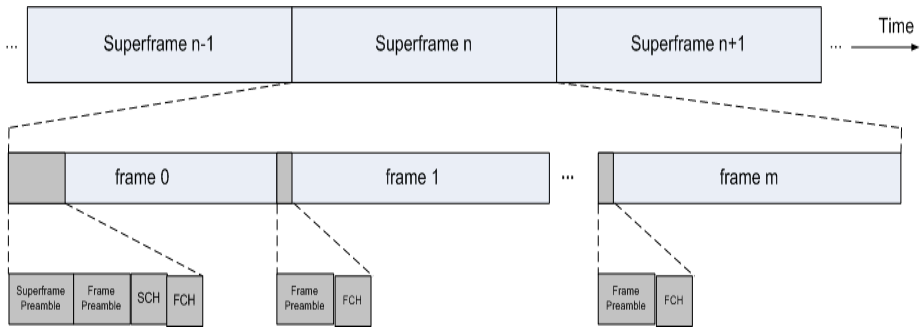
IEEE 802.22 Superframe Structure

Superfarme duration : 160 ms
Frame duration: 10 ms



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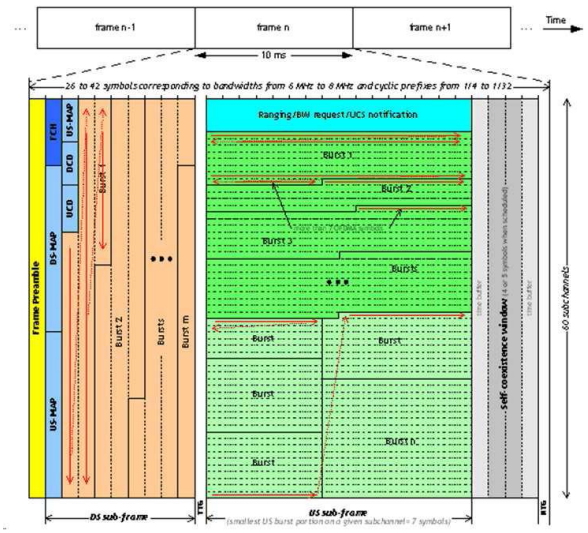
IEEE 802.22 Frame Structure



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Incumbents and Spectrum Sensing in 802.22

- Incumbents in TV bands
  - TV broadcasting services (in the US, use 6 MHz channels in VHF and UHF bands)
  - Wireless microphones (in the US, regulated by Part 74 FCC rules, use 50 mW for a 100 m coverage and 200 KHz channel bandwidth)
- Spectrum sensing requires
  - Sensing algorithms to quickly and robustly detect the presence of incumbent signals
  - Well-designed coordination and communication protocols

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IEEE 802.22 spectrum sensing requirements

- Key incumbent sensing requirements defined within the IEEE 802.22 standard (draft)

Parameter	Value for Wireless Microphones	Value for TV Broadcasting
Channel Detection Time	≤ 2 sec	≤ 2 sec
Channel Move Time	≤ 2 sec	≤ 2 sec
Channel Closing Transmission Time	100 msec	100 msec
Incumbent Detection Threshold	-107 dBm (over 200KHz)	-116 dBm (over 6MHz)
Probability of Detection	90%	90%
Probability of False Alarm	10%	10%

Reference: 802.22 FRD

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Spectrum Sensing: Key Challenges

- Problem context:
  - Incumbents must be reliably detected within the CDT
    - 802.22 Draft Standard specifies IDT of -116 dBm and CDT of 2 sec
  - Reliable sensing requires network wide quiet periods (QP)
  - For typical energy detection approach, integration time is low, however, neighboring WRANs may be detected as incumbent
    - Higher probability of false alarms
  - Feature detection can accomplish more accurate detection of incumbents, however, the integration time required is the main issue
    - Long integration times mean poor QoS support, especially for VoIP
- Problem statement:
  - How to meet incumbent sensing requirements and support QoS?

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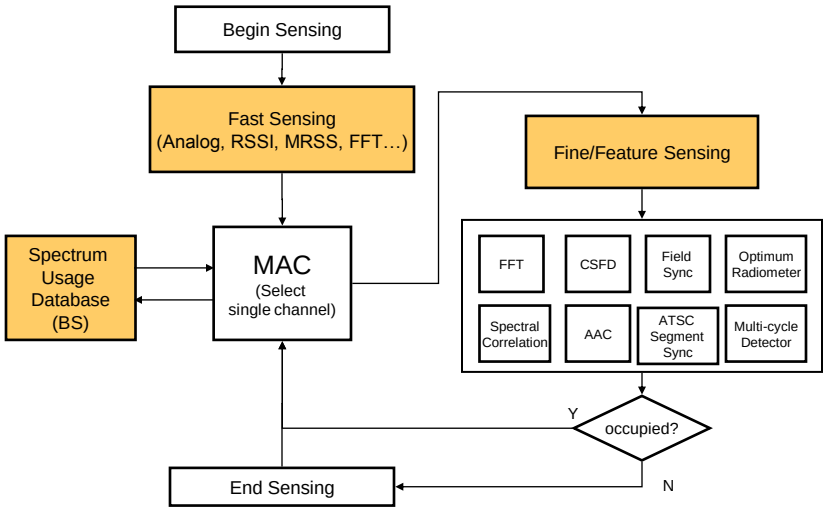
Sensing architecture and strategy



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Fine sensing algorithms*

- FFT-based pilot detection
  - Pilot-energy detection: find maximum of FFT output-squared, and compare to a threshold
  - Pilot-location detection: compare location of maximum of FFT-output between multiple dwells
- Spectrum sensing of the DTV in the vicinity of the pilot using higher order statistics
  - Detect the DTV signals in Gaussian noise using higher order statistics (HOS)
  - Perform non-Gaussianity check in the frequency domain in the vicinity of the pilot of the DTV

*Note: These two sensing algorithms have been approved by IEEE 802.22 for fine sensing as informative purpose. More sensing algorithms have been submitted for discussion and are described in the 802.22 draft.

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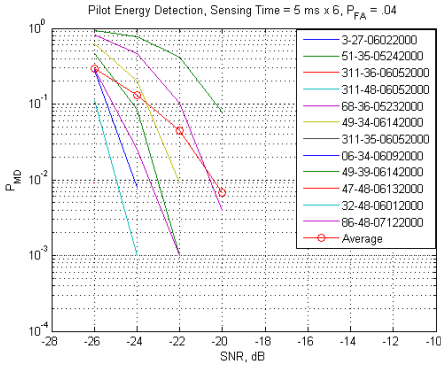
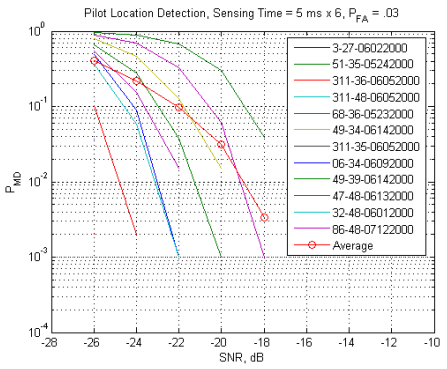
Performance of FFT-based pilot detection





Note: 12 signals supplied by MSTV to IEEE 802.22 for testing different sensing algorithms

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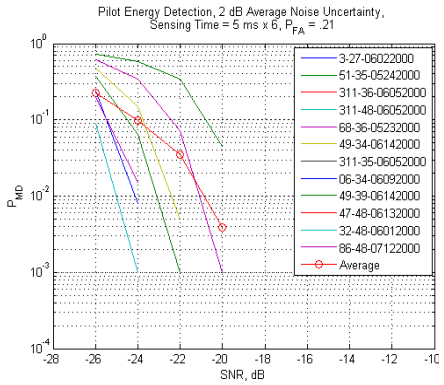
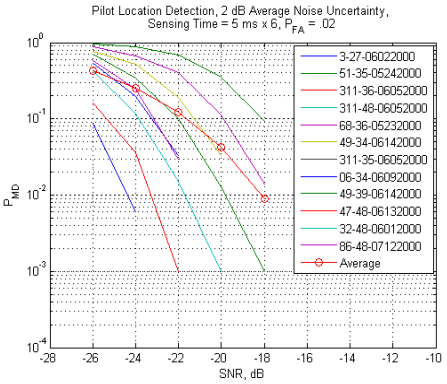
Performance of FFT-based pilot detection w/ 2 dB average noise uncertainty





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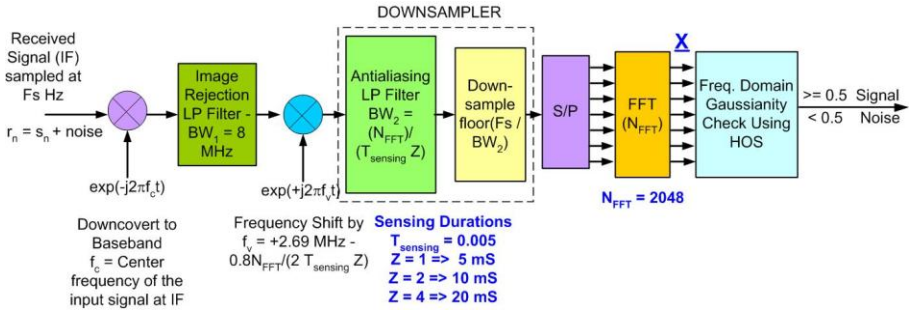
Spectrum sensing of the DTV in the vicinity of the pilot using higher order statistics



Reference: Apurva Mody , BAE Systems, August 2007, doc.: IEEE 802.22-07/0370r2

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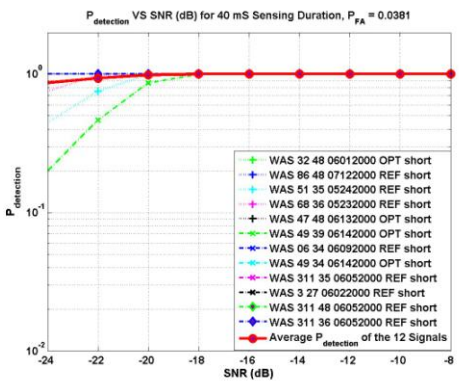
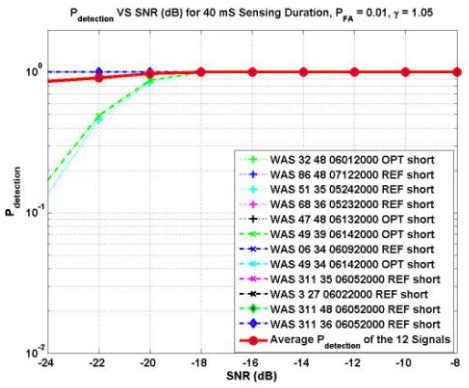


$\gamma = 0.8$, $P_D > 0.9$ and $P_{FA} < 0.05$



$\gamma = 1.05$, $P_D > 0.9$ and $P_{FA} = 0.01$

Reference: Apurva Mody , BAE Systems, August 2007, doc.: IEEE 802.22-07/0359r1

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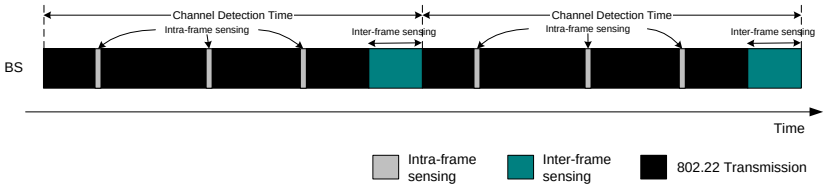
Sensing schedule on the MAC layer

- Spectrum Sensing is performed during network quiet periods (QPs) scheduled by the BS
- Two types of QPs for sensing:
  - Intra-frame (Fast sensing)
  - Inter-frame (Fine sensing)



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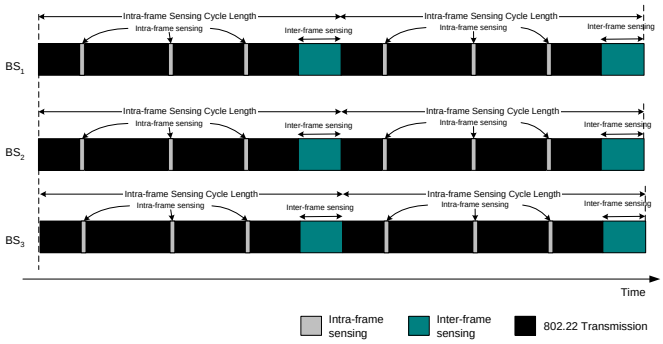
Synchronization of QPs among neighboring WRANs

- QPs of neighboring WRANs should be synchronized for more reliable sensing
  - especially for in-band sensing in the operating channel (N) and adjacent channels (N+/-1)



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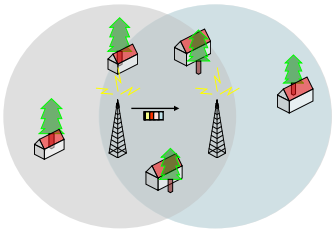
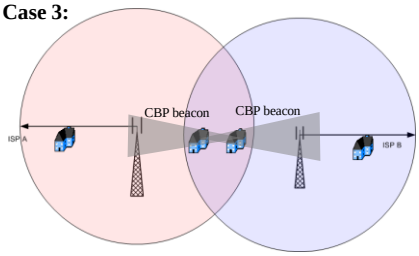
Coexistence Beacon Protocol (CBP)

- CBP packets carry the schedule of the QPs and self-coexistence information
- Three cases

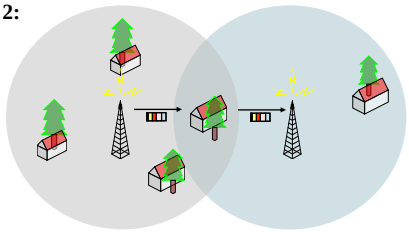
Case 1:



Case 3:



Case 2:



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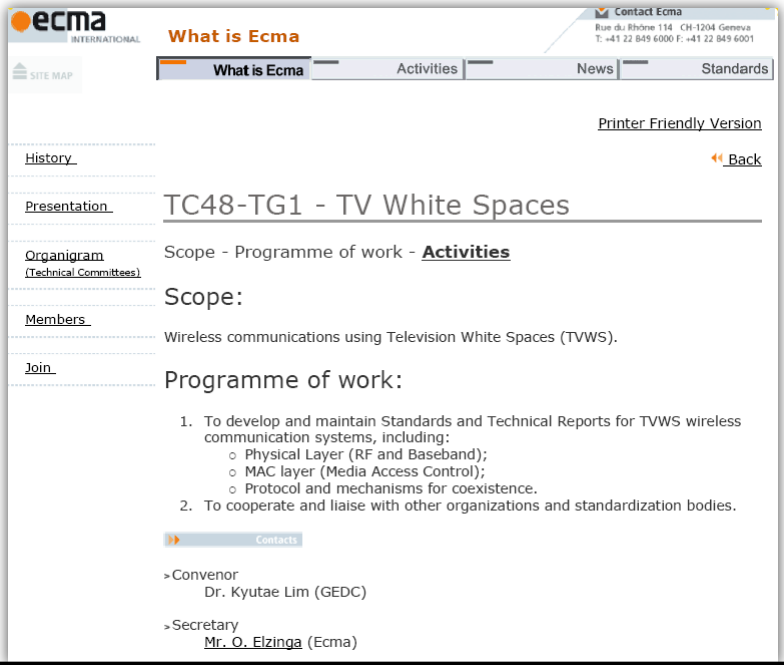

ecma INTERNATIONAL

What is Ecma

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SITE MAP

What is Ecma | Activities | News | Standards

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History

Presentation

Organigram
(Technical Committees)

Members

Join

TC48-TG1 - TV White Spaces

Scope - Programme of work - **Activities**

Scope:

Wireless communications using Television White Spaces (TVWS).

Programme of work:

1. To develop and maintain Standards and Technical Reports for TVWS wireless communication systems, including:
   - Physical Layer (RF and Baseband);
   - MAC layer (Media Access Control);
   - Protocol and mechanisms for coexistence.
2. To cooperate and liaise with other organizations and standardization bodies.

Contacts

>Convenor
Dr. Kyutae Lim (GEDC)

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Mr. O. Elzinga (Ecma)

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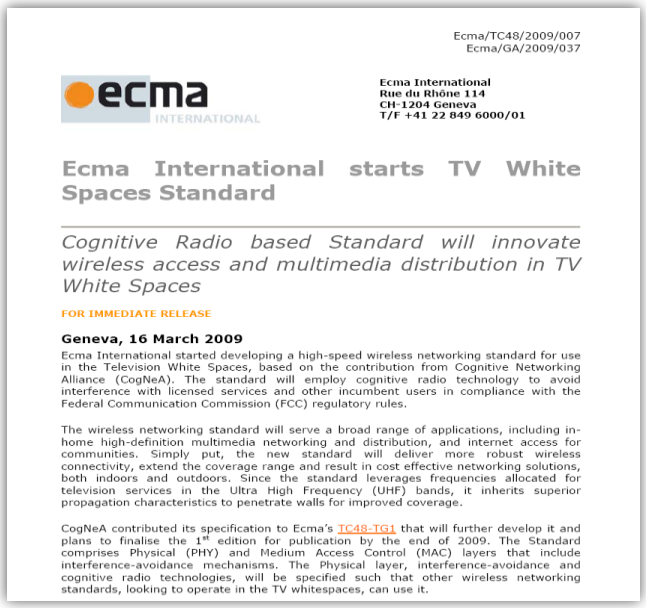

Ecma/TC48/2009/007
Ecma/GA/2009/037

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Ecma International starts TV White Spaces Standard

Cognitive Radio based Standard will innovate wireless access and multimedia distribution in TV White Spaces

FOR IMMEDIATE RELEASE

Geneva, 16 March 2009

Ecma International started developing a high-speed wireless networking standard for use in the Television White Spaces, based on the contribution from Cognitive Networking Alliance (CogNeA). The standard will employ cognitive radio technology to avoid interference with licensed services and other incumbent users in compliance with the Federal Communication Commission (FCC) regulatory rules.

The wireless networking standard will serve a broad range of applications, including in-home high-definition multimedia networking and distribution, and internet access for communities. Simply put, the new standard will deliver more robust wireless connectivity, extend the coverage range and result in cost effective networking solutions, both indoors and outdoors. Since the standard leverages frequencies allocated for television services in the Ultra High Frequency (UHF) bands, it inherits superior propagation characteristics to penetrate walls for improved coverage.

CogNeA contributed its specification to Ecma's TC48-TG1 that will further develop it and plans to finalise the 1st edition for publication by the end of 2009. The Standard comprises Physical (PHY) and Medium Access Control (MAC) layers that include interference-avoidance mechanisms. The Physical layer, interference-avoidance and cognitive radio technologies, will be specified such that other wireless networking standards, looking to operate in the TV whitespaces, can use it.

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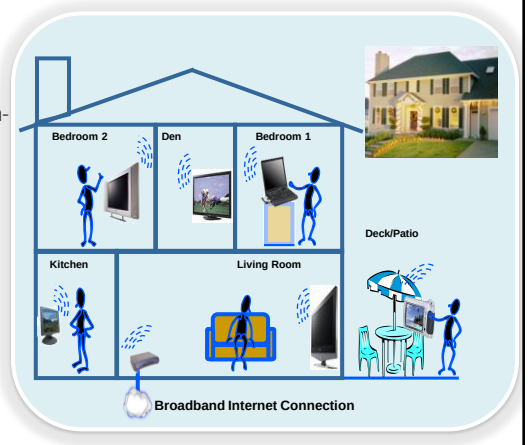
Cognea: Whole home application

- Television white spaces will enable wireless distribution of high-quality high-definition television for whole home, vastly improving the DTV experience.
- The new standard will provide reliable and robust coverage anywhere in a home, while consuming much lower power.



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Cognea: Community internet access application

- Television white spaces will provide more widely available and cost effective access to the internet in underserved markets.
- The superior propagation characteristics provide much greater coverage range than existing unlicensed technologies.

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Ecma TC48-TG1Standardization: General technical spec. and functions

Parameter	Value	Remark
Operating frequency	• CH21~51 (512~698MHz) except CH37(608~614MHz)	FCC 08-260
Channel bandwidth	• 6, 7, 8MHz	
Channel bonding and aggregation	• Optional	Not in 1st edition
Data rate	• Upto 20 Mbps at 55 m • Upto 3 Mbps at x100 m	
Multiple antenna	• Optional	
Mesh architecture	• Optional	
Medium access	• Reservation-based access • Contention-based access (yielding to reservation) • Multiple streams on a channel	
Link layer protection	• Supported	
Network security	• Supported	
QoS	• Support delay-bounded packet and bandwidth reservation	

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Ecma TC48-TG1Standardization cont'

- PHY features
  - OFDM based system
    - 128 FFT
  - Multiple PHY data rates to support different applications and QoS requirements
    - Supports full HD streaming using one TV channel
  - Inner and outer coding
    - Convolutional code and RS code
    - Puncturing of a base inner code to provide multiple code rates
  - Normal and burst modes to support different application types
  - Low preamble overhead
  - Hopping pilot pattern
    - Repeats every six symbols
  - Enhanced retransmission scheme

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Ecma TC48-TG1Standardization cont'

- MAC features
  - MAC architecture
    - Infrastructure mode: master-slave
    - Ad hoc mode: peer-peer
  - Channel access and frame processing
    - Support both reservation based access and contention based access
    - Highly optimized QoS and efficient support for HDTV
  - Incumbent protection
    - DFS and TPC based on geo-location/database and sensing
  - Self-coexistence between networks
    - Use beacon exchange for coordination
  - Security
    - Supported

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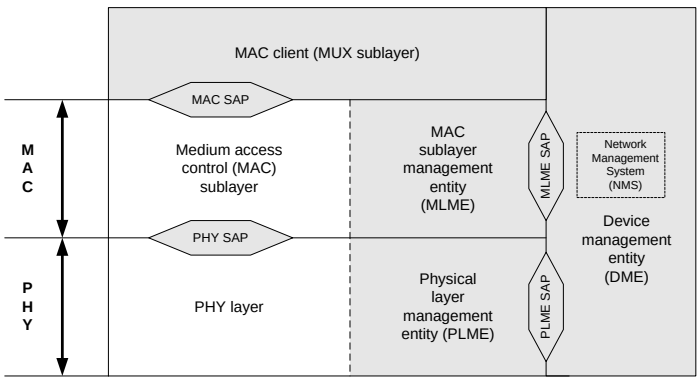
Ecma TC48-TG1Standardization cont'

- Protocol reference model



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Overview

- Update on latest White Space activities in US and UK
  - Adoption of White Space rules in US
  - Consultation released by Ofcom.
- Cognitive radio for the TV bands: challenges and solutions.
- Wireless Regional Area Networks (WRAN)
  - IEEE 802.22 Standard
- Personal/Portable Applications
  - Cognea and Ecma standardization
- Philips prototypes:
  - Sensing prototype
  - UHF Cognitive Radio prototype
- Conclusions

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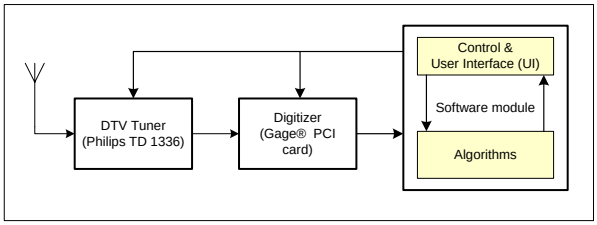
Philips Sensing Prototype



- The prototype consists of
  - a Philips TV tuner
    - for tuning to a specified 6 MHz TV channel and translating to IF frequency of 44 MHz
  - a digital processing board
    - for A/D and processing, and,
  - a computer
    - for user-interface, control and processing.

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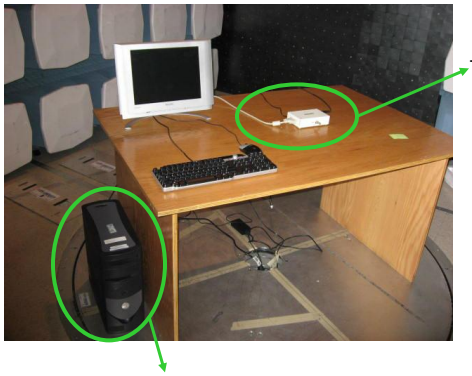
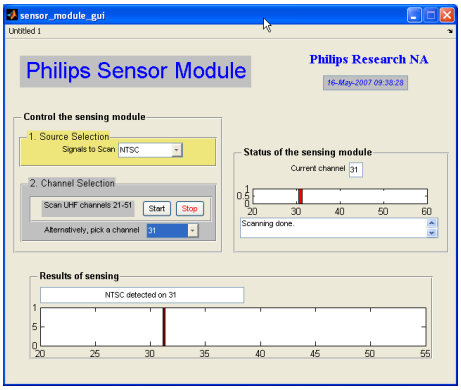
Philips Sensing Prototype at FCC OET



Prototype User Interface (UI)



OET – Office of Engineering and Technology

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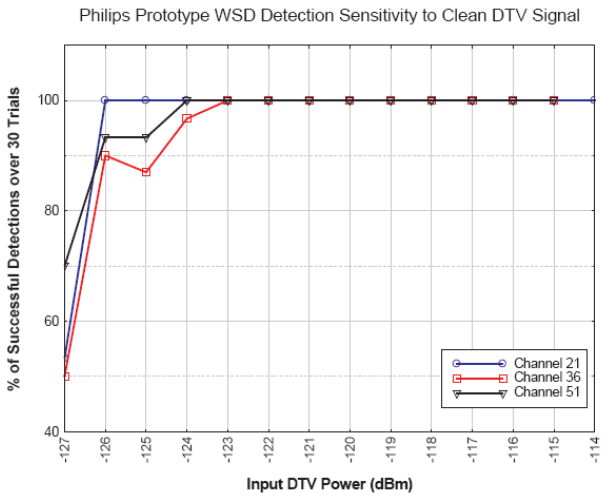
FCC Report, October 2008: Clean Signal



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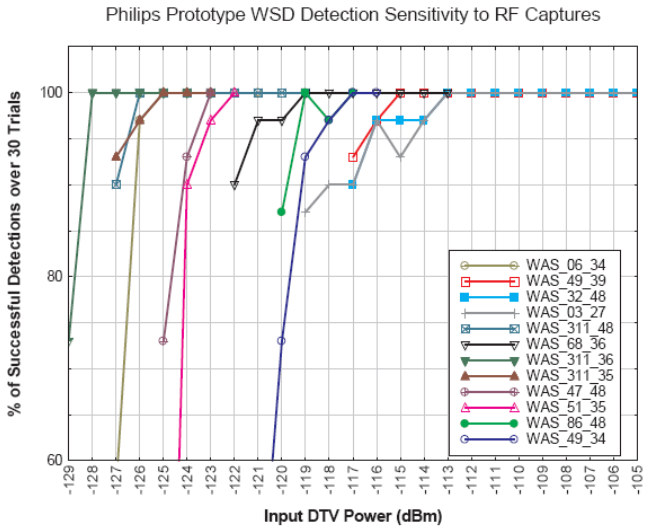
FCC Report, October 2008: Captured Signals



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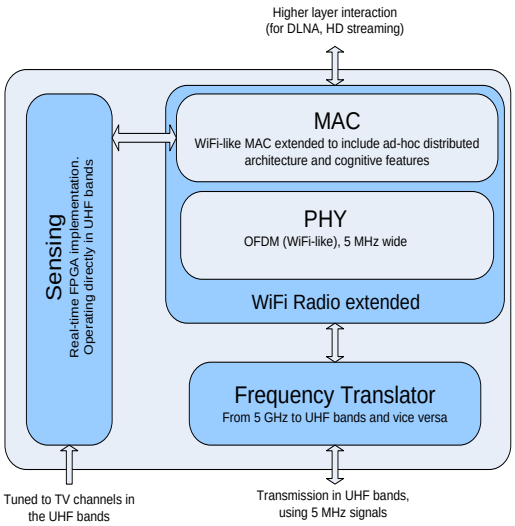
Philips WS Protoype: UHF Cognitive Radio Architecture

- A CR network for UHF bands
  - with real-time sensing operating in TV bands,
  - WiFi-like MAC extended to show distributed and cognitive features, and,
  - OFDM PHY (5 MHz wide)
  - Frequency translator



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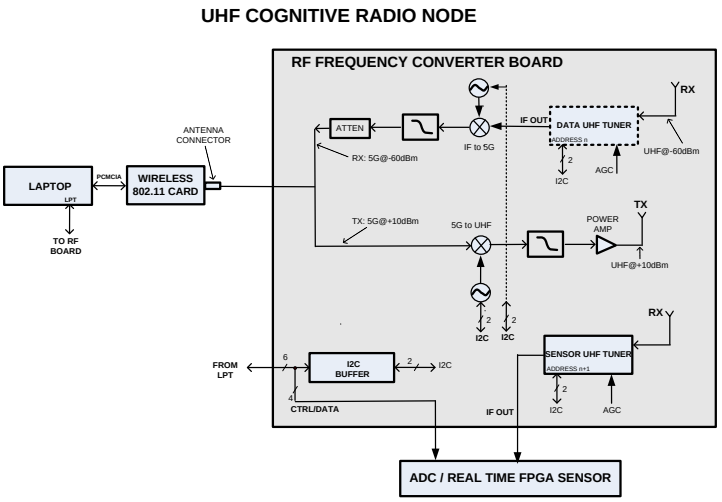
Block Diagram of UHF Cognitive Radio Node



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Philips UHF Prototype

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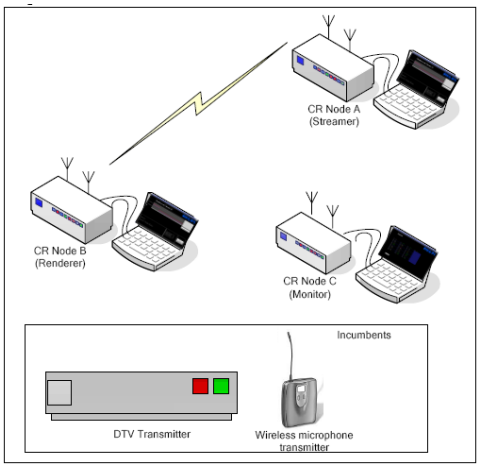
Philips UHF Demo Set Up



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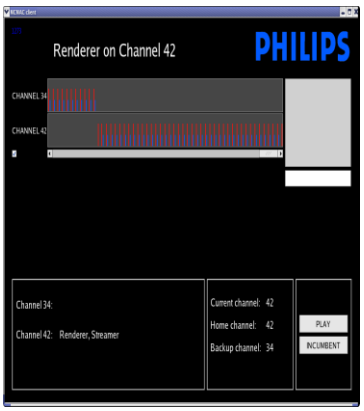
Demo: Video Streaming in a Vacant UHF TV Channel

- Demonstrates all aspects of CR
  - Incumbent sensing on boot-up and during quiet periods
  - Cognitive MAC protocols to detect incumbents and handle channel switching
- The CR nodes identify home channel and backup channel and exchange this information with each other
- The video is transmitted on a vacant UHF TV channel
  - Switches to a backup channel when an incumbent is detected on home channel



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Demo: Monitoring of UHF TV bands

- Continuously scans the UHF channels 21-51 for
  - ATSC and NTSC
  - Wireless microphone
  - Secondary transmissions
- Very short sensing time enables faster detection of incumbents
  - Minimizes interference to incumbents
  - QoS is mantained.

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Conclusions

- With the recent FCC ruling, the stage is set for cognitive devices in the TV white spaces.
- The technology for the various parts: sensing, geolocation/database, dynamic frequency selection, have been demonstrated by various companies.
- Industry standards need to be developed quickly to maximize the use of this spectrum.

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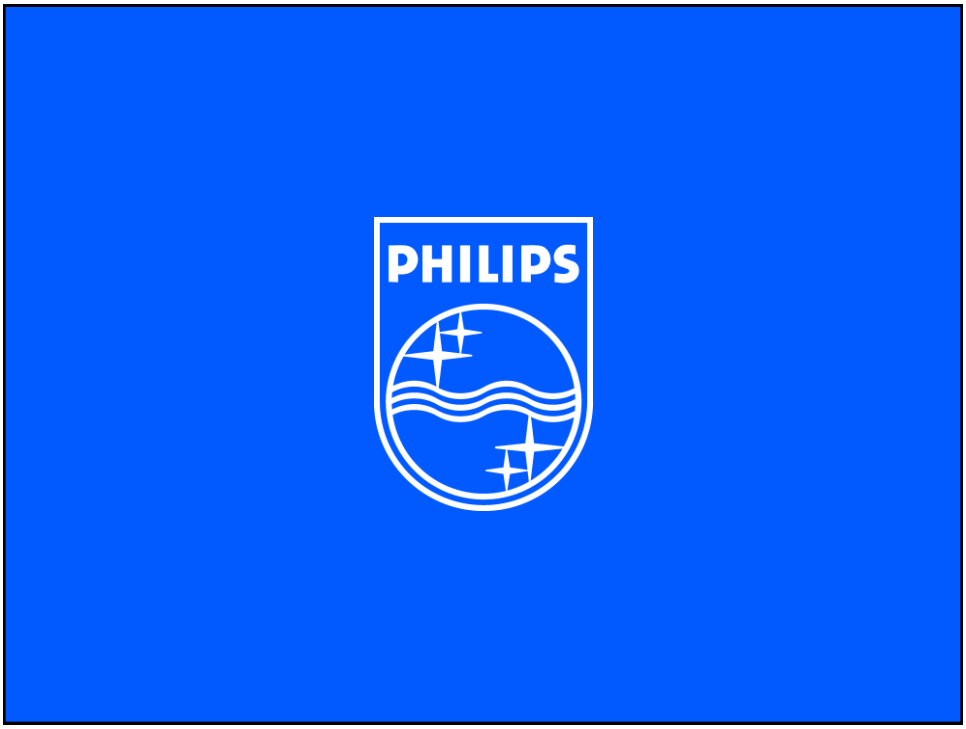
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