CHAPTER 12.
Cognitive Radio Standards
IEEE 802.22, IEEE 1900, IEEE 802.19

OUTLINES

- FCC Spectrum Regulations
- Cognitive Wireless Standards IEEE and IETF
- Future Cognitive Radio Standard Challenges

FCC Spectrum Regulation Models

- **Command and Control**
  - National Regulatory Authority (NRA) determines the usage details of the spectrum
- **Market Mechanism**
  - E.g. Spectrum Auction
  - Licensees choose the deployed technology
- **Commons Model**
  - No exclusive usage rights (shared)
  - Access is regulated by
    - A general license
    - Type of services and technologies permitted
    - "Good neighborhood" rules (such as output power restrictions, protocol rules for collision avoidance, etc.)

FCC Spectrum Regulation Models Based on Cognitive Radio

Opportunistic Spectrum Access

- Gain access to a spectrum band that is currently used by some licensed incumbent systems on a condition that the new systems would not interfere with the incumbent systems
- E.g. White Spaces in TV bands

Spectrum Pooling

- Licensed (PUs) put their unused spectrum into a pool from which SUs can lease spectrum

FCC Regulation on TV Spectrum

FCC, "Second Report and Order and Memorandum Opinion and Order,"
ET Docket No. 08-260, Nov. 14, 2008.

- FCC opened a portion of TV spectrum for unlicensed access
- Two types of unlicensed devices are allowed
  - Fixed: Maximum Transmission Power 4 W
  - Mobile: Maximum Transmission Power
    100 mW (non-adjacent channels) /
    40 mV (adjacent channels)

FCC Decision on TVWS

FCC, "Second Memorandum Opinion and Order,"
ET Docket No. 10-174, Sept. 23, 2010.

- On September 23, 2010, the FCC released a Memorandum Opinion and Order (MO&O) that determined the final rules for using the white space for unlicensed wireless devices
- New rules removed mandatory sensing requirements →
  PU protection by geolocation-based database
- Final rules adopt a proposal from the White Spaces Coalition for very strict emission rules that prevent the direct use of other TV band device (TVBD)

FCC Regulations

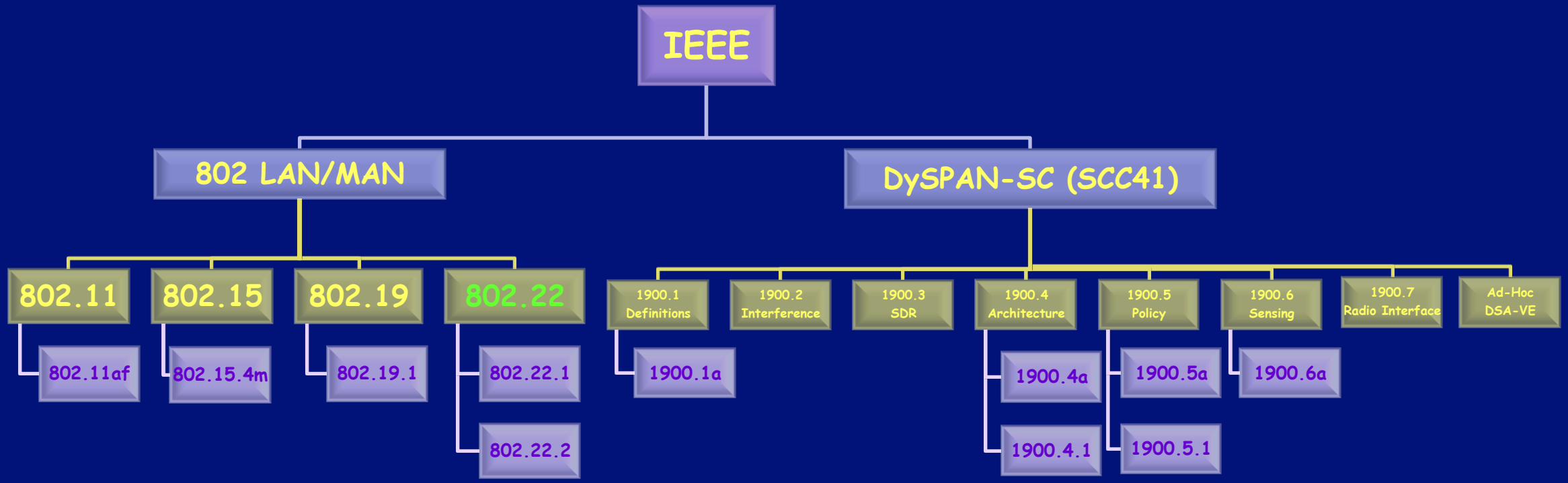
- **Protection criteria for incumbent services**
  - Fixed and Mode II personal/portable devices operating with power levels greater than 40 mW
  - must operate outside the protected contours of both co-channel and adjacent channel TV stations at a sufficient separation distance
    - At least three continuous TVWS bands should be available
  - Personal/portable device operating with power levels of 40mW or less

    are permitted to operate within the protected contours of adjacent channel TV stations due to lower risk of causing harmful interference at that power level

IEEE and IETF Spectrum Sharing Standardization Activities

Title	Contributor
IEEE 802.11 (Wireless Local Area NWs)	Rich Kennedy (WG)
IEEE 802.15.4m (Wireless Personal Area NWs)	Clint Powell (WG)
IEEE 802.19.1 (Coexistence)	Stanislav Filin (WG)
IEEE 802.22 (Wireless Regional Area NWs and Enabling Technologies)	Apurva N. Mody (WG)
IETF Protocol to Access White Spaces	John Malyar, Gabor Bajko (IETF PAWS)
P1900 Stand. Activity (Dynamic Spectrum Access NWs)	H. Harada, M. Sherman (IEEE DySPAN - SC)

IEEE Cognitive Radio Standards: The Big Picture



IEEE 802.22 Standard
Overview

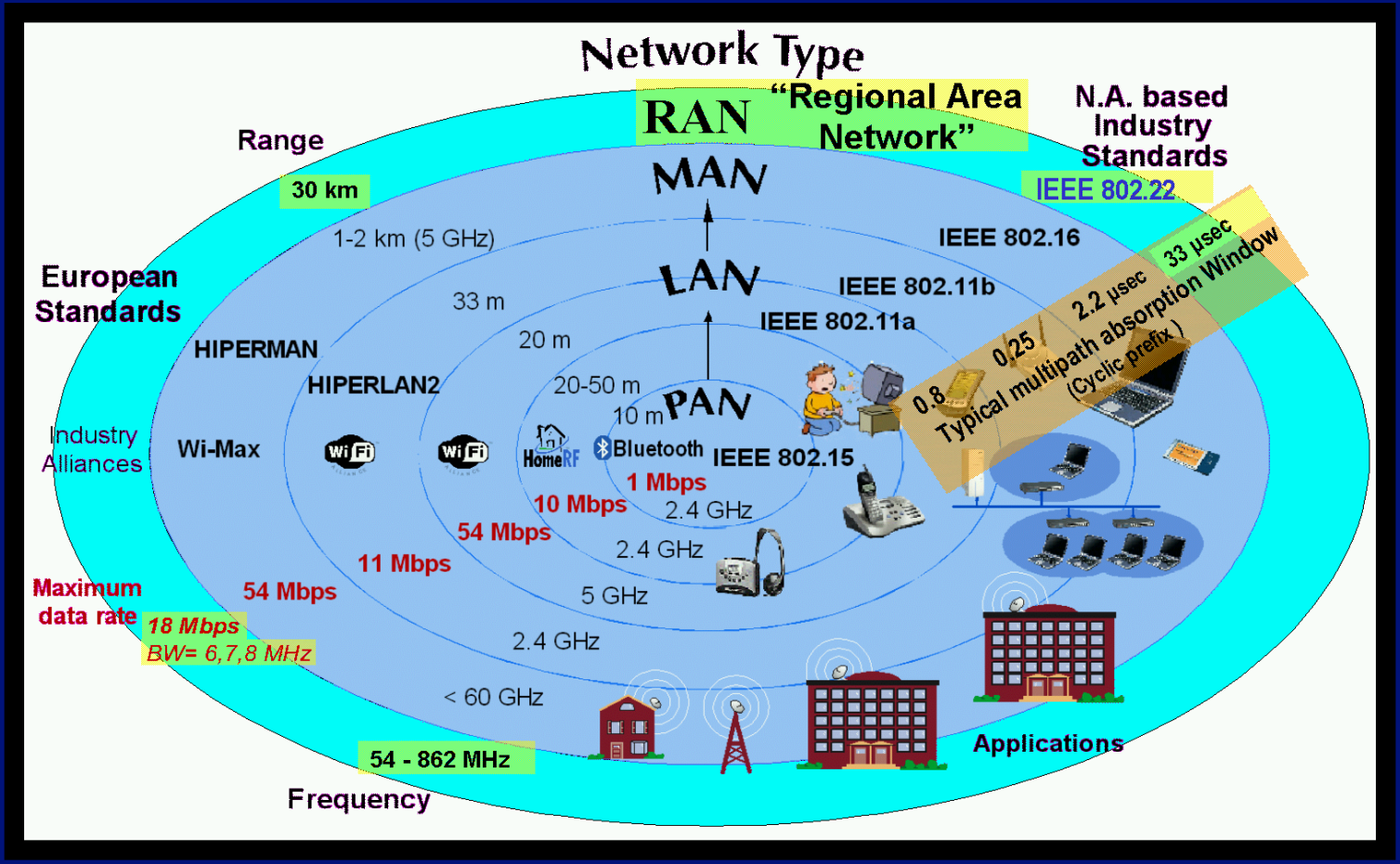
- Established in 2004, approved on June 16, 2011

- Standards for Wireless Regional Area Networks (WRAN)
  - Part 22: Cognitive Wireless RAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications: Policies and Procedures for Operation in the TV Bands
  - Part 22.1: Standard to Enhance Harmful Interference Protection for Low-Power Licensed Devices Operating in TV Broadcast Bands
  - Part 22.2: Recommended Practice for the Installation and Deployment of IEEE 802.22 Systems (D1.0)

IEEE 802.22 Standard

Overview

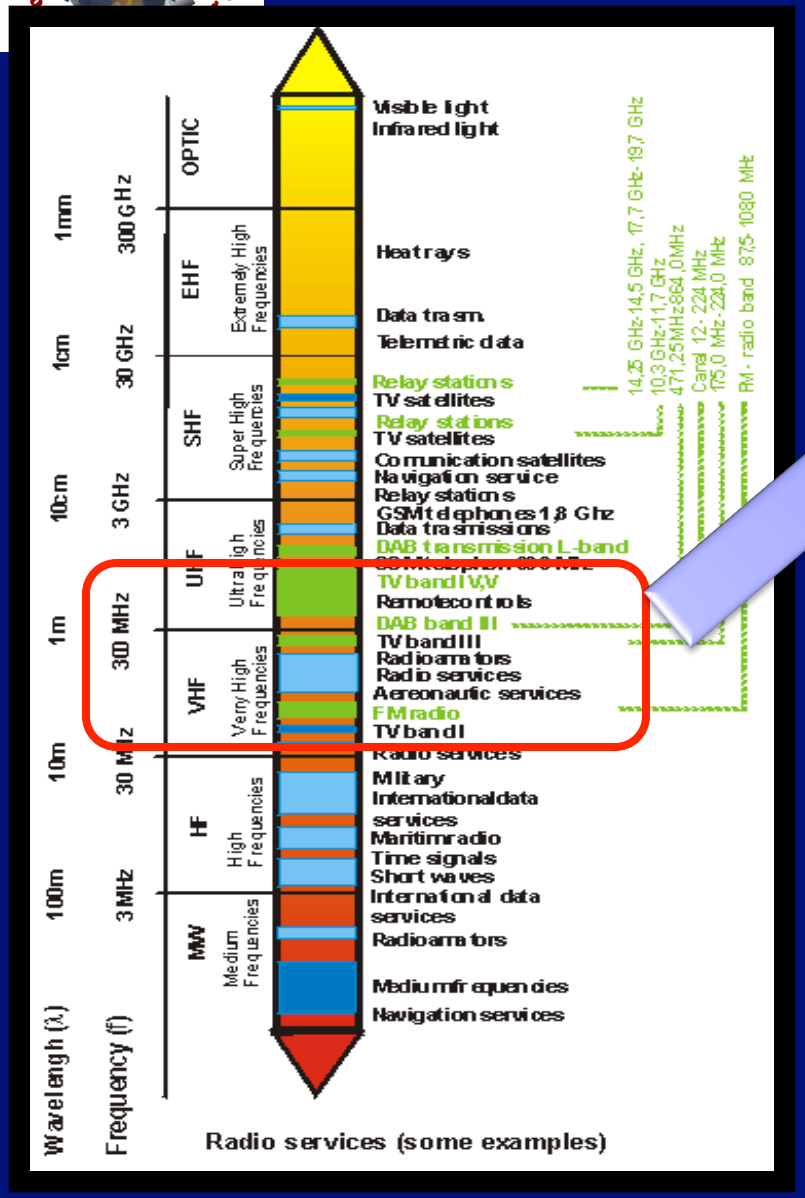
Where does RAN stand compared to other wireless networks ?



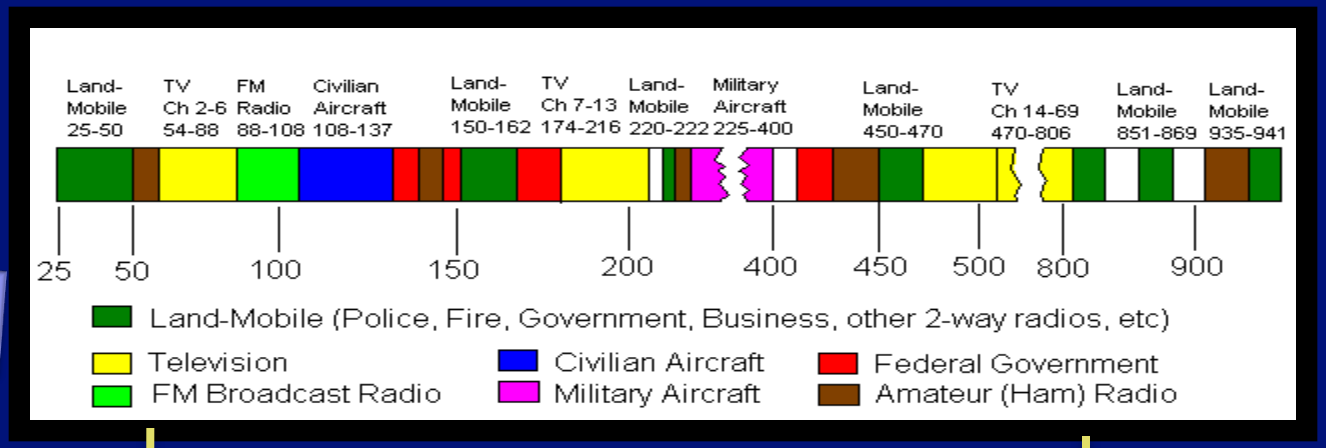
Purpose of IEEE 802.22

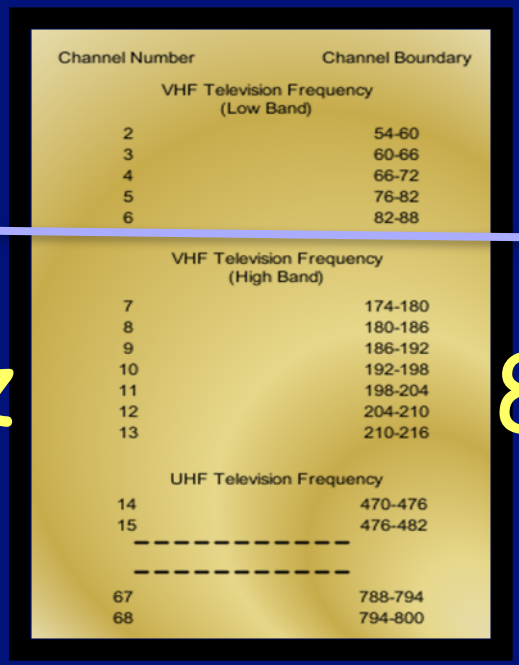
- To facilitate competition in broadband access
- To provide alternatives to wire-line broadband access
- To extend the deploy-ability of these broadband systems into diverse geographic areas, including sparsely populated rural areas

Spectrum Targeted



VHF/UHF TV broadcast bands





54 MHz

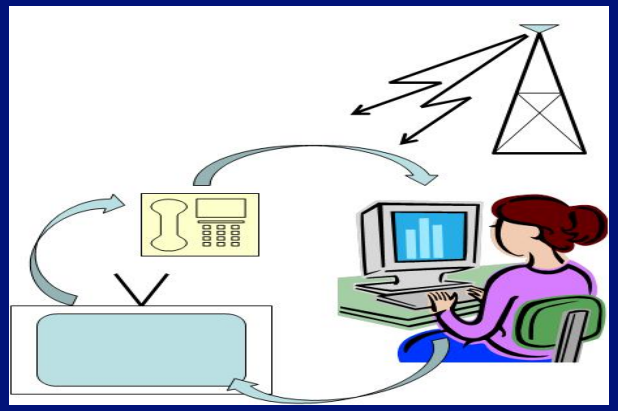
826 MHz

Properties of IEEE 802.22

- Wireless Regional Area Network
- Low Population Density
- Point to Multi-point Communication
- TV channels as well as the guard bands of these channels are planned to be used
- Prevent harmful interference to incumbent licensed services by:
  - Geolocation database in a fixed location
  - Spectrum sensing (optional)

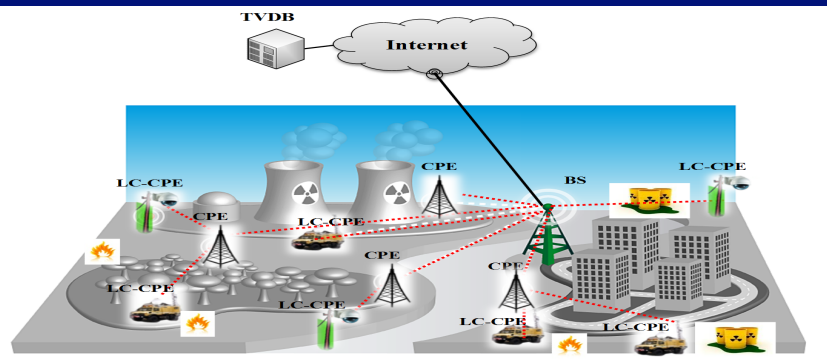
IEEE 802.22 Applications

Triple play

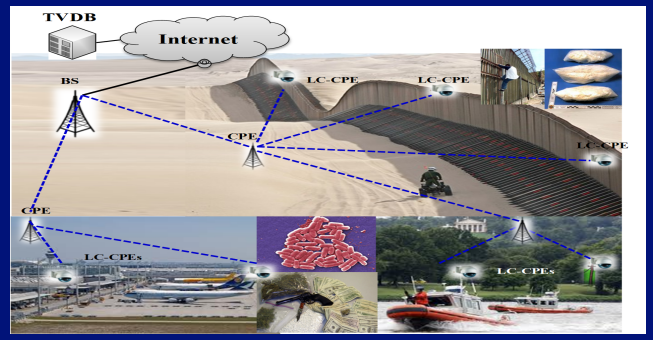


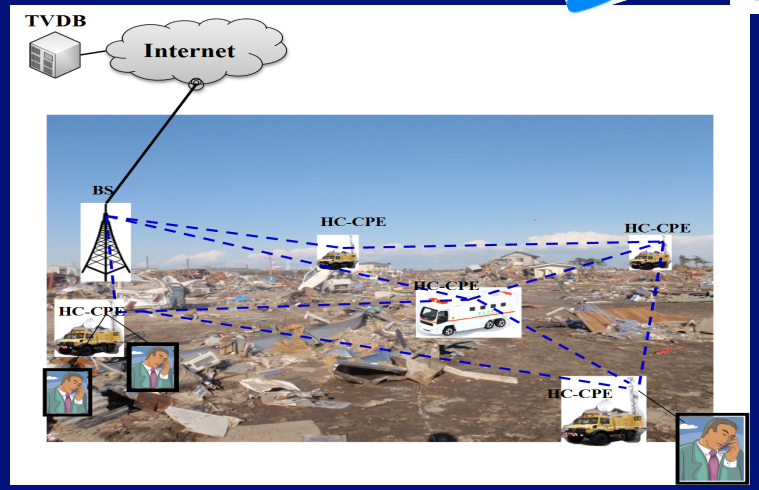
Cellular offload

Critical Infrastructure Monitoring

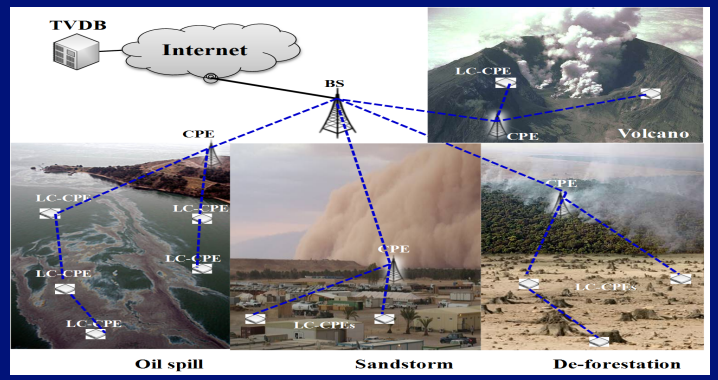


Border Protection



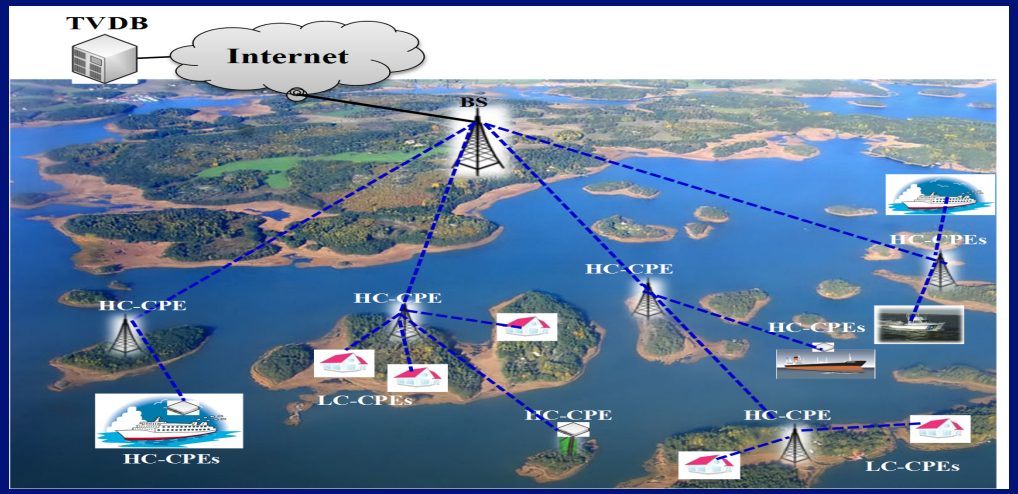


Emergency Broadband Infrastructure



Environmental monitoring

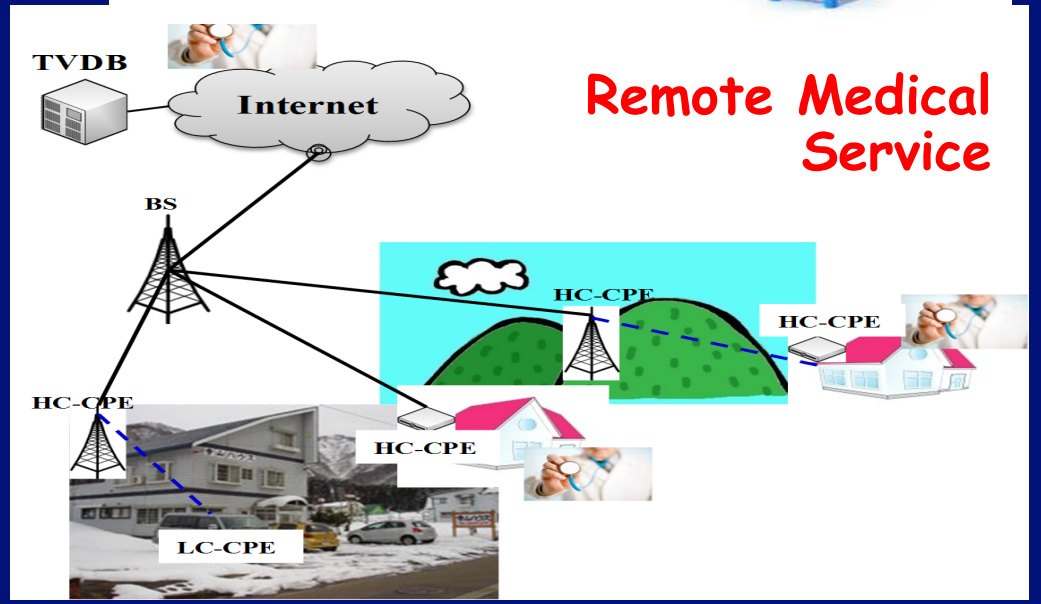
IEEE 802.22 Applications



Archipelago and marine broadband service

Servicing oil rigs

- TVDB = (TV Database)
- LC- CPE = Low Capability CPE



Remote Medical Service

IEEE 802.22 WG on Cognitive Radio Based Spectrum Sharing and Wireless Regional Area Networks

IEEE 802.22 WG is the recipient of the IEEE SA Emerging Technology Award

IEEE 802.22 Standard – Wireless Regional Area Networks: Cognitive Radio based Access in TVWS

802.22.1 – Std for Enhanced Interference Protection using beaconing

802.22.2 – Std for Recommended Practice for Deployment of 802.22 Systems

802.22a – Enhanced Management Information Base and Management Plane Procedures

802.22b Enhancement for Broadband Services and Monitoring Applications

802.22.1a – Advanced Beaconing

NEW!! Spectrum Occupancy Sensing (SOS) Study Group

IEEE 802.22 (Wi-FAR™) Summary

- *First* IEEE Standard for operation in TV Whitespaces
- *First* IEEE Standard that is specifically designed for rural and regional area broadband access aimed at removing the digital divide
- *First* IEEE Standard that has all the CR features
- IEEE 802.22 (Wi-FAR™) provides BWA to Regional, Rural and Remote Areas under LoS and NLOS conditions using CR Technology (*without causing harmful interference to the incumbents*).
- CR technology added to a simple and optimized OFDMA waveform
- Meets all the regulatory requirements such as protection of incumbents, access to the database, accurate geolocation, spectrum mask, etc.
- Large regional area footprint can allow placement of the BS closer to the area with cheaper Internet backhaul / backbone.

IEEE 802.22 (Wi-FAR™) Summary

Core Technology – CR technology used to co-exist with and protect the PUs (incumbents).

Representation – Commercial industry, Broadcasters, DoD, Regulators, and Academia

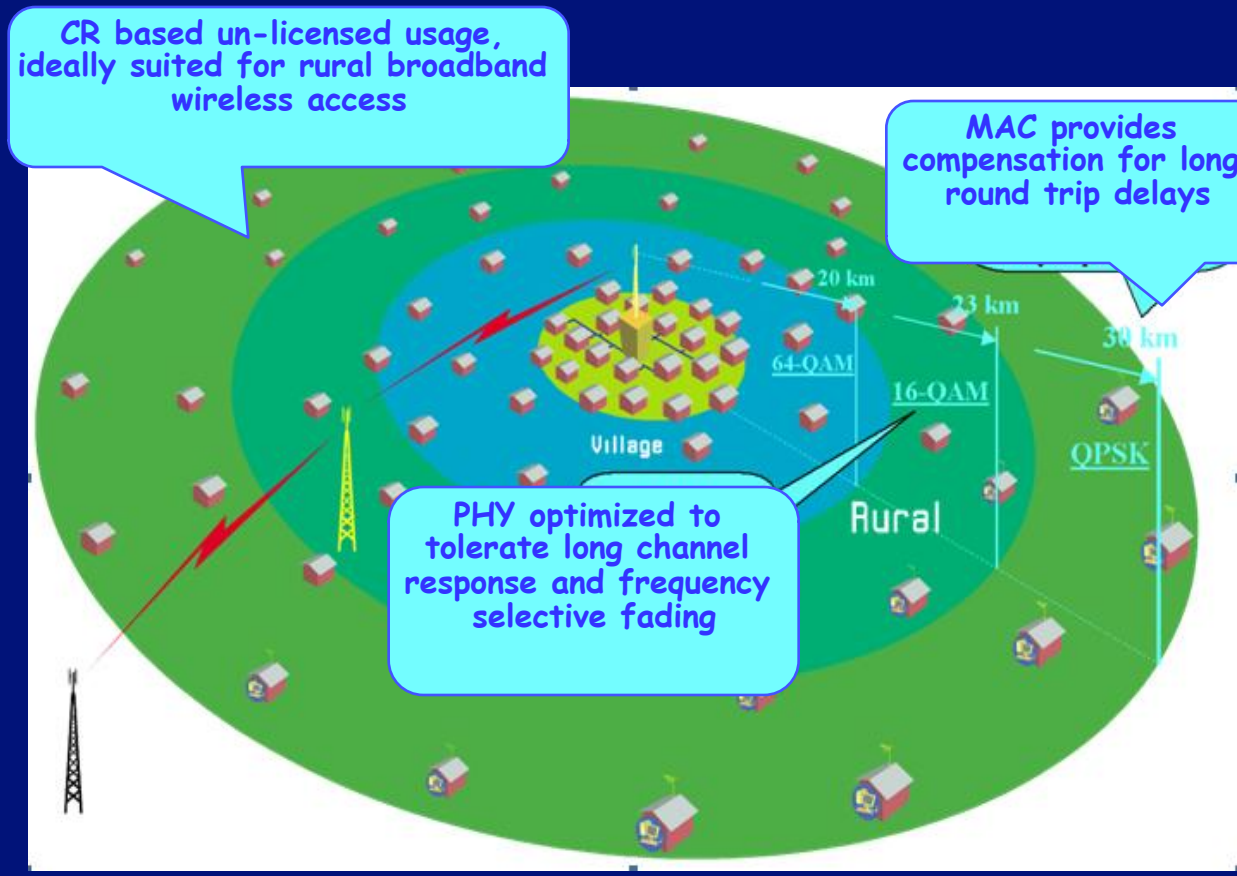
Membership – 30 on an average (over 5 years)

CONOPS – VHF/UHF band operation allows long range propagation and cell radius of 10–30 km, exceptionally extensible to 100km in favorable conditions.

PHY - Optimized for long signal propagation distances and highly frequency selective fading channels (multipath with large excess delays).

MAC – Provides compensation for long round trip delays to provide service to up to 100 km.

Unique Features introduced for CR based operation: database access, spectrum sensing, spectrum management, incumbent protection, coexistence, geo-location and security



Portability – IEEE 802.22 (Wi-FAR(TM)) allows portability (nomadic use). In case the rules do change, IEEE 802.22 (Wi-FAR(TM)) PHY is designed to support mobility of up to 114 km/h (no hand-off is included in the current version).

IEEE 802.22 (Wi-FAR™) Summary

- PHY Transport - 802.22 uses OFDM as transport mechanism. OFDMA is used in the Upstream.
- Modulation - QPSK, 16-QAM and 64-QAM supported
- Coding – Convolutional Code is mandatory. Either Turbo, LDPC or Shortened Block Turbo Code can be used for advanced coding.
- Pilot Pattern - Each OFDM/OFDMA symbol is divided into sub-channels of 28 subcarriers of which 4 are pilots. Pilot carriers are inserted once every 7 sub-carriers. Pilots cycle through all 7 sub-carriers over 7 symbol duration. No frequency domain interpolation is required because of low Doppler spread in TV bands.
- Net Spectral Efficiency - 0.624 bits/s/Hz – 3.12 bits/s/Hz

TV channel bandwidth (MHz)	6	7	8
Total number of subcarriers, N_{FFT}	2048		
Number of guard subcarriers, N_G (L, DC, R)	368 (184, 1, 183)		
Number of used subcarriers, $N_T = N_D + N_P$	1680		
Number of data subcarriers, N_D	1440		
Number of pilot subcarriers, N_P	240		
Signal bandwidth (MHz)	5.6240625	6.5625	7.494375

Data Rates in NLOS Conditions

PHY capacity		Mbit/s	bit/(s*Hz)
Mod.	Rate	CP= 1/8	
QPSK	1/2	3.74	0.624
	2/3	4.99	0.832
	3/4	5.62	0.936
	5/6	6.24	1.04
16QAM	1/2	7.49	1.248
	2/3	9.98	1.664
	3/4	11.23	1.872
	5/6	12.48	2.08
64QAM	1/2	11.23	1.872
	2/3	14.98	2.496
	3/4	16.85	2.808
	5/6	18.72	3.12

PHY performance: SNR (dB)		
Mod.	Rate	SNR
QPSK	1/2	4.3
	2/3	6.1
	3/4	7.1
	5/6	8.1
16QAM	1/2	10.2
	2/3	12.4
	3/4	13.5
	5/6	14.8
64QAM	1/2	15.6
	2/3	18.3
	3/4	19.7
	5/6	20.9

Note: includes phase noise: -80dBc/Hz at 1 kHz and 10 kHz and -105 dBc/Hz at 100 kHz

IEEE Dynamic Spectrum Access Networks Standards Committee (DySPAN-SC)

http://grouper.ieee.org/groups/dyspan/

- Established in 2005, formerly known as Standards Coordinating Committee 41 (SCC41) and IEEE P1900 Standards Committee

- Purpose

  "To develop supporting standards dealing with new technologies and techniques being developed for next generation radio and advanced spectrum management"

- IEEE 1900 defines higher-layer standards for DSA networks in the layers higher than MAC and PHY

IEEE Dynamic Spectrum Access NWs –Standards Committee (DySPAN-SC) Organization

- IEEE Dynamic Spectrum Access Networks (DySPAN) Standards Committee (DySPAN-SC)
  - Originated as IEEE P1900 -> IEEE SCC 41 -> DySPAN-SC
  - http://grouper.ieee.org/groups/dyspan/
  - Home to the IEEE 1900 working groups
  - "Owns" the P1900 series of standards…

- Scope (from http://grouper.ieee.org/groups/dyspan/)

  - Dynamic spectrum access radio systems and networks with the focus on improved use of spectrum
  - New techniques and methods of dynamic spectrum access including the management of radio transmission interference, and
  - Coordination of wireless technologies including network management and information sharing amongst networks deploying different wireless technologies

IEEE Dynamic Spectrum Access Networks -Standards Committee (DySPAN-SC) Organization

IEEE 1900.1: Standard Definitions and Concepts for Spectrum Management and Advanced Radio System Technologies

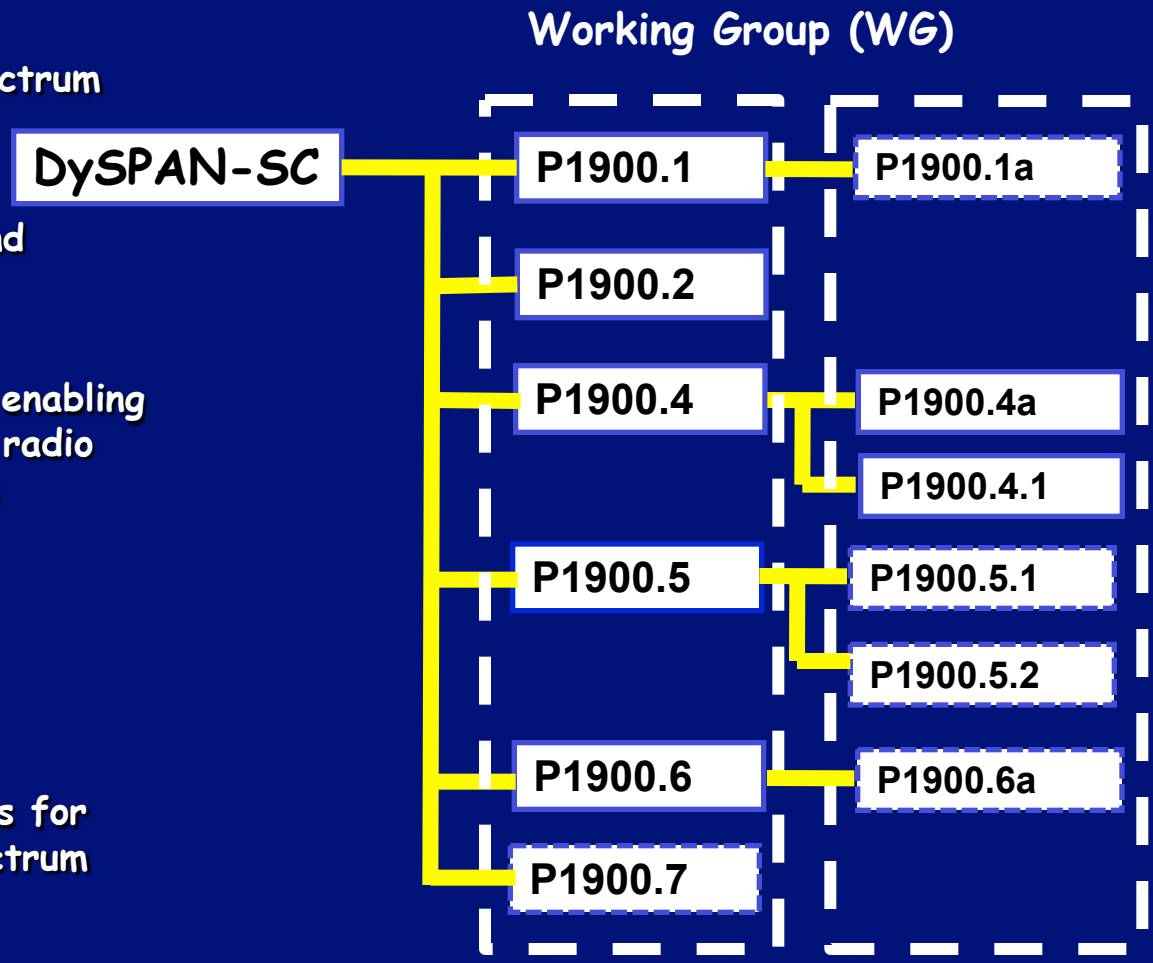
IEEE 1900.2: Recommended Practice for Interference and Coexistence Analysis

IEEE 1900.4: Standard for Architectural building blocks enabling network-device distributed decision making for optimized radio resource usage in heterogeneous wireless access networks

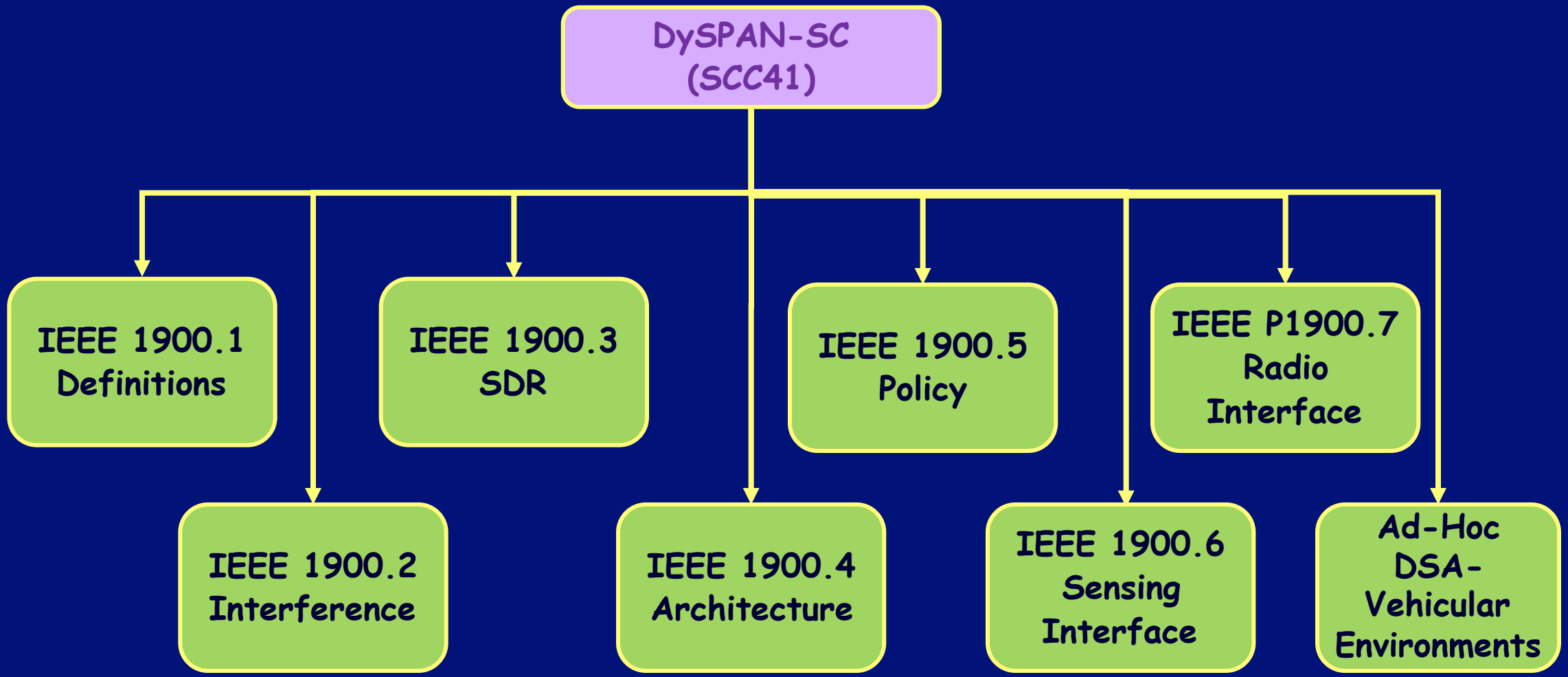
IEEE 1900.5: Standard on Policy Language and Policy Architectures for Managing Cognitive Radio for Dynamic Spectrum Access Applications

IEEE 1900.6: Standard on interfaces and data structures for exchanging spectrum sensing information for dynamic spectrum access systems

IEEE 1900.7: Standard on radio interface for white space dynamic spectrum access radio systems supporting fixed and mobile operation



IEEE 1900 Working Groups



IEEE 1900.1:
Definitions and Concepts for Dynamic Spectrum Access
IEEE Std 1900.1-2008

- **Need ?**
  - Different cognitive groups defined CR and other terms differently
- **Responsibilities**
  - Create glossary of important CR terms and concepts
  - Give a coherent view of various efforts taking place in the field of CR

IEEE P802.19.1 Wireless Coexistence

T. Baykas, M. Kasslin, and S. Shellhammer,
"System Design Document,"
IEEE 802.19-10/0055r3, March 2010.

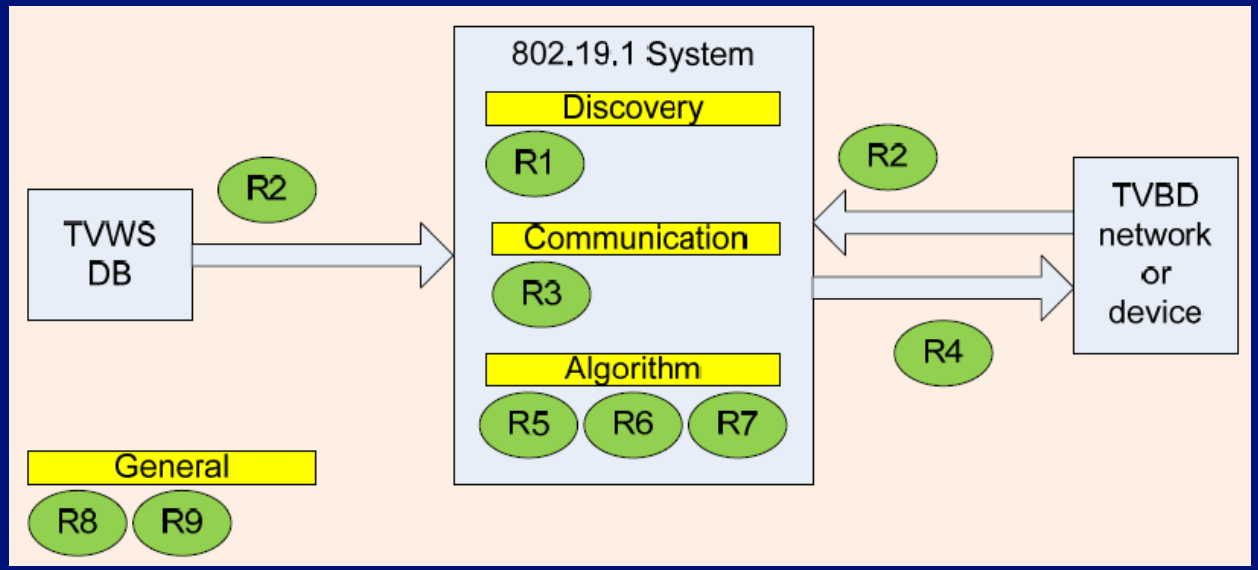
- **Need ?**
  - Massive standardization activities and high market demand will result in heterogeneous TVBDs operating in possibly crowded TVWS
  - TVBDs need to coexist in TVWS for most effectively use of TVWS

- **Purpose**
  - Specify radio technology independent methods for coexistence among dissimilar or independently operated TVBD networks and dissimilar TVBDs
  - Provide standard coexistence methods among dissimilar or independently operated TVBD networks and dissimilar TVBDs
  - Address coexistence for IEEE 802 networks and TVBDs

IEEE P802.19.1 Wireless Coexistence

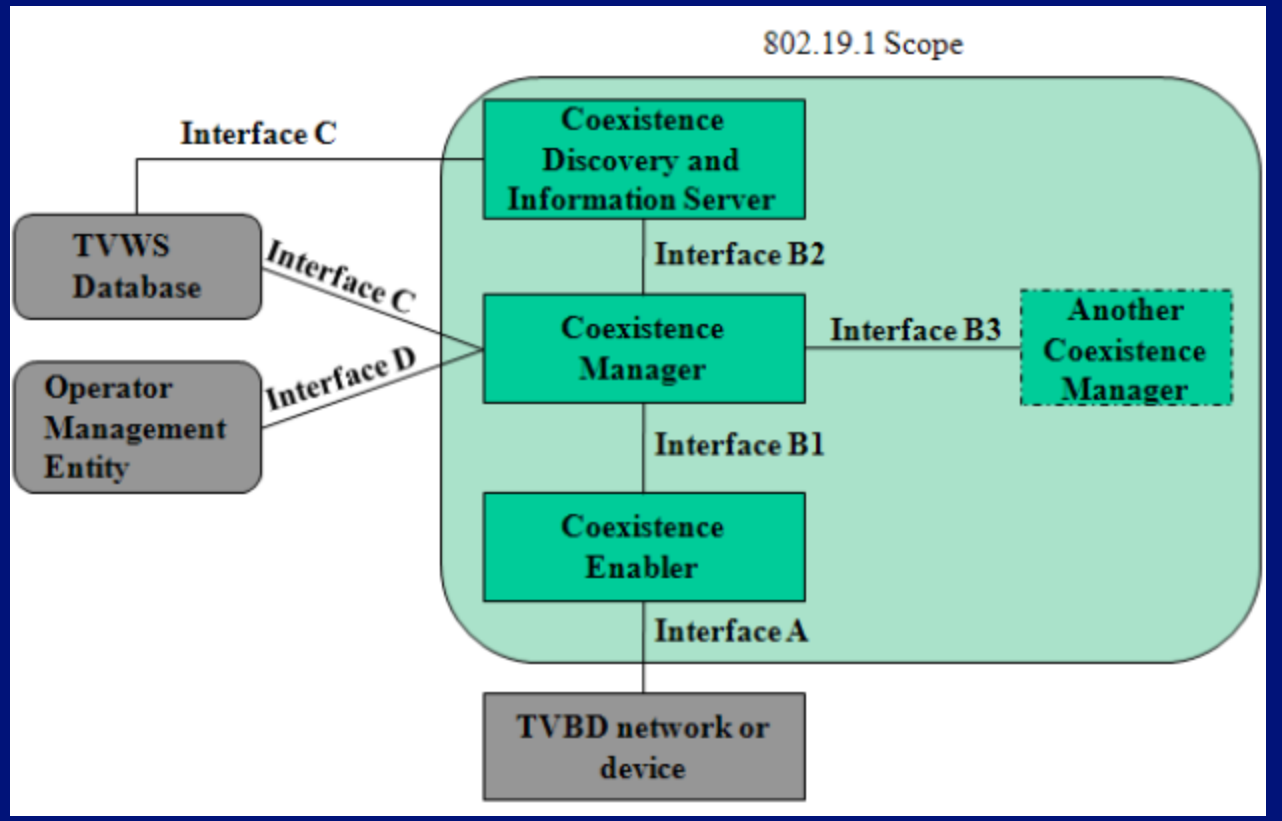
System Requirements

R1: enable discovery for TVBDs
R2: obtain and update information
R3: means to exchange information
R4: provide reconfiguration/controls
R5: analyze obtained information
R6: make TVWS coexistence decisions
R7: support different topologies
R8: support security mechanisms
R9: achieve coexistence



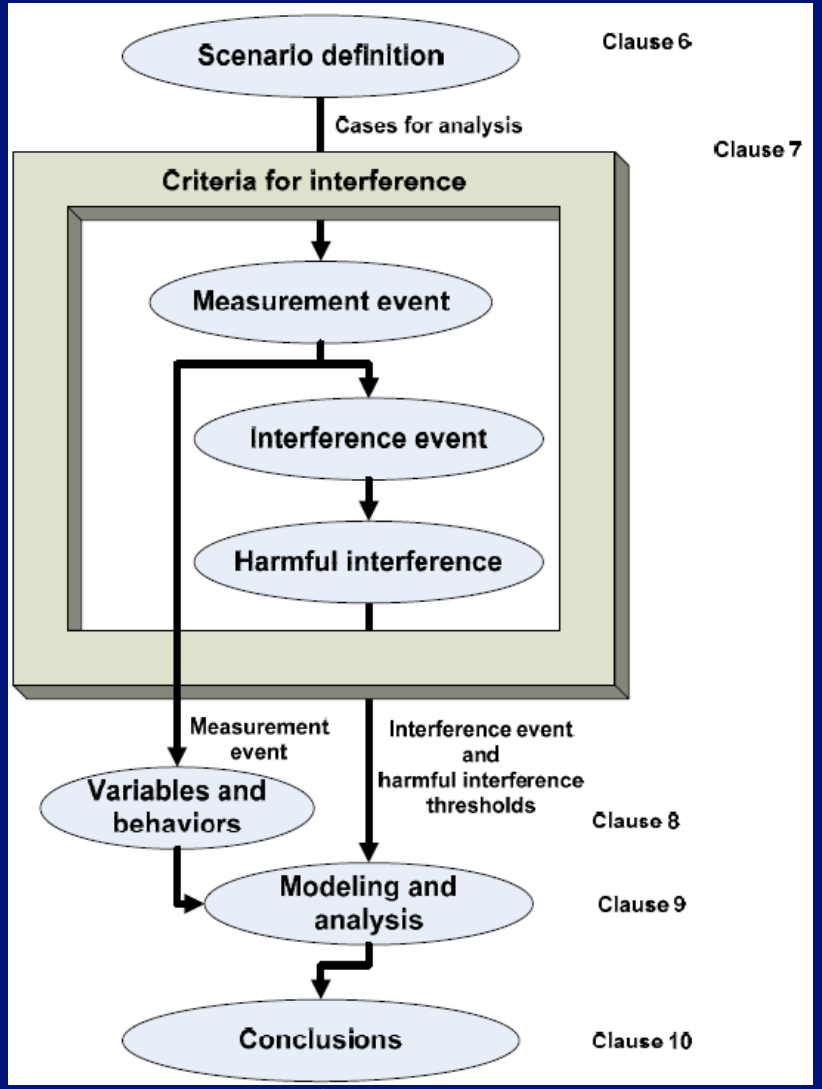
IEEE P802.19.1 Wireless Coexistence

- Three logical entities
  - Coexistence Manager (CM)
  - Coexistence Enabler (CE)
  - Coexistence Discovery and Information Server (CDIS)
- Interact with 3 external elements
  - TVWS database
  - TVBD network or device
  - Operator Management Entity (OME)
- Six logical interfaces defined



IEEE 1900.2:
Recommended Practice for the Analysis of Interference and Coexistence

- **Need?**
  - Accurate measurement of interference and impact of factors on aggregate interference
  - Analyze potential for interference and coexistence between systems
  - Support for decision making
- **Responsibilities**
  - Establish framework for measuring/analyzing interference between radio systems



IEEE Std 1900.2-2008

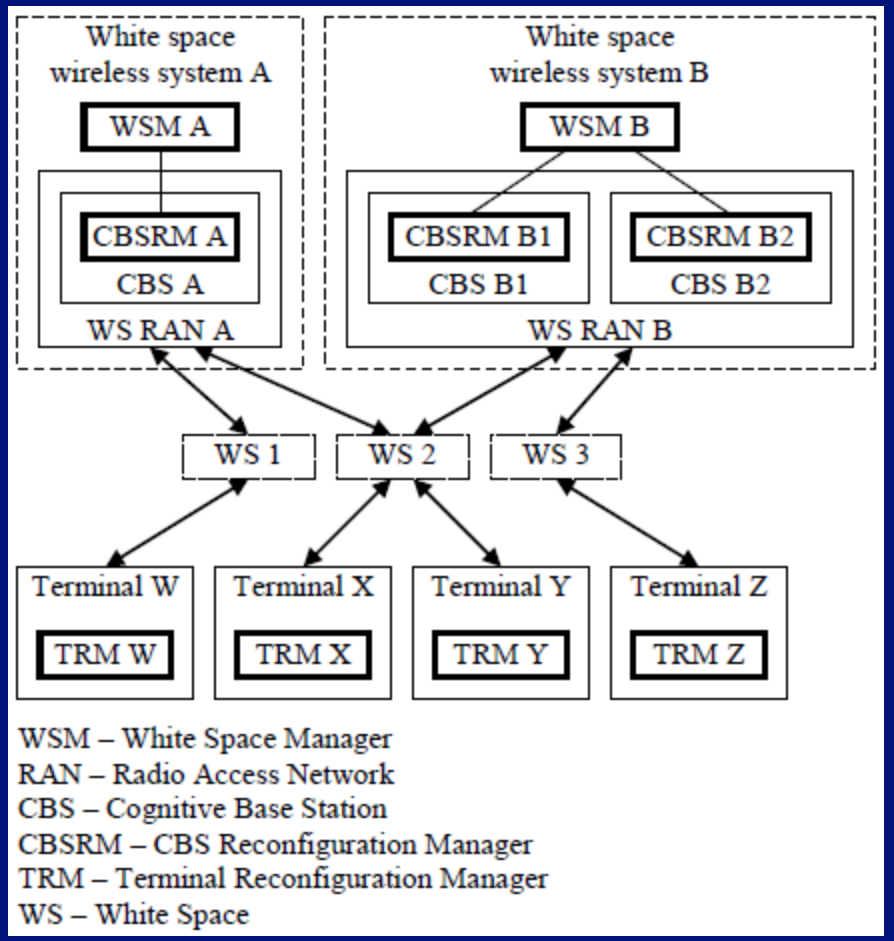
IEEE 1900.3: Recommended Practice for Conformance Evaluation of Software Defined Radio Software Modules

- **Need ?**
  - SDR important component of future CR networks
  - Create high confidence in deployed SDR devices
- **Responsibility**
  - Define a set of recommendations that help in assuring the coexistence and compliance of the software modules of CR devices before proceeding towards validation and certification of the final devices
- **IEEE 1900.3 WG has been disbanded**

IEEE 1900.4:
Architectural Building Blocks Enabling Network-Device Distributed Decision Making for Optimized Radio Resource Usage in Heterogeneous Wireless Access Networks

- **Amendment 1 (1900.4a):**
  Architecture and Interfaces for Dynamic Spectrum Access Networks in White Space Frequency Bands

- **Need ?**
  - -Operation of mobile devices on multiple wireless networks
  - -Distributed decision making
- **Responsibilities**
  - -Increase overall system utilization of reconfigurable terminals while increasing the perceived QoS
    - Define overall system architecture
    - Split functionality between terminals and networks
    - Information exchange between coordinating entities



IEEE Std 1900.4a-2011

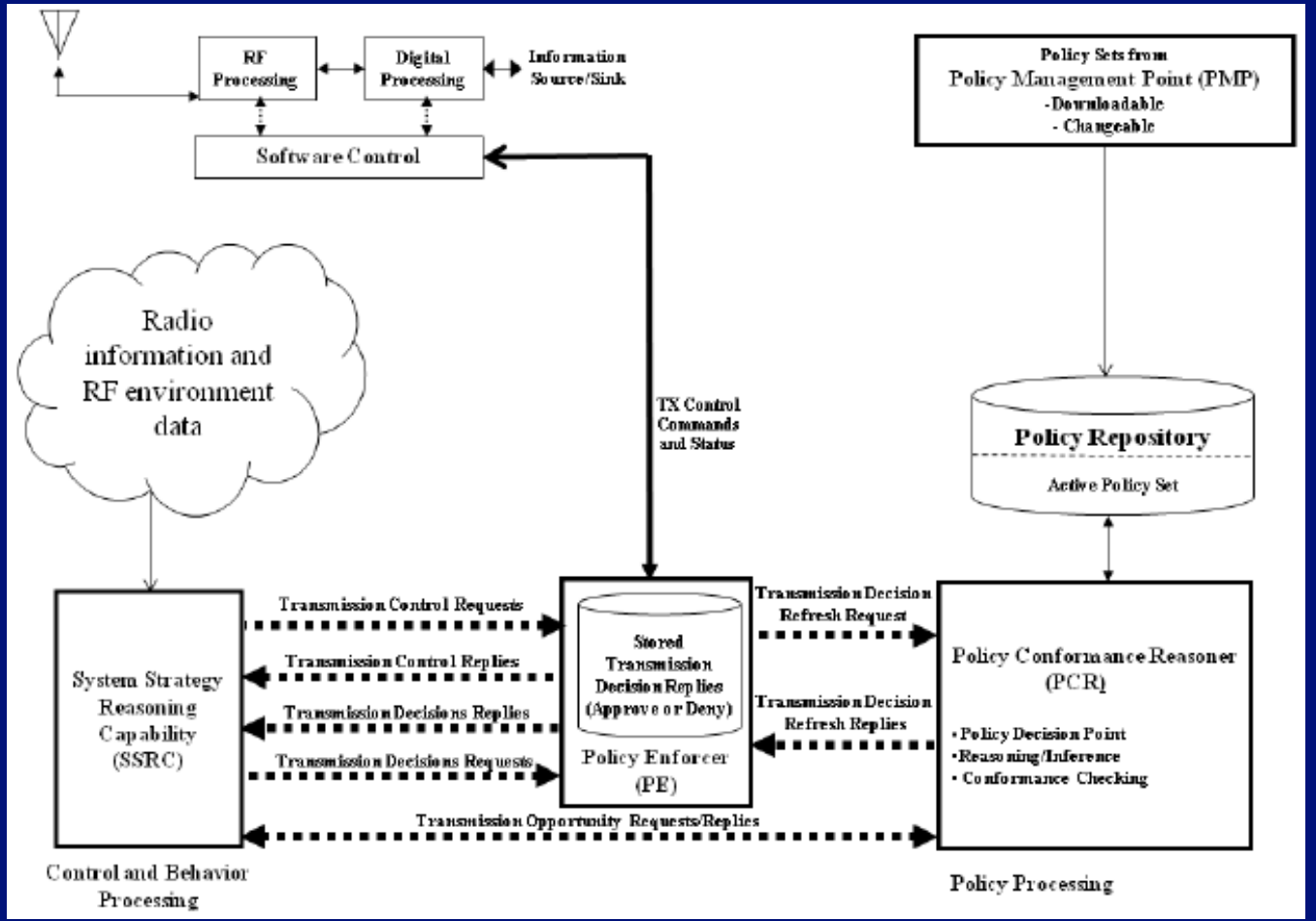
IEEE 1900.5:
Policy Language Requirements and System Architectures for Dynamic Spectrum Access Systems

- **Need ?**

  Manage the functionality and behavior of dynamic spectrum access networks

- **Purpose**

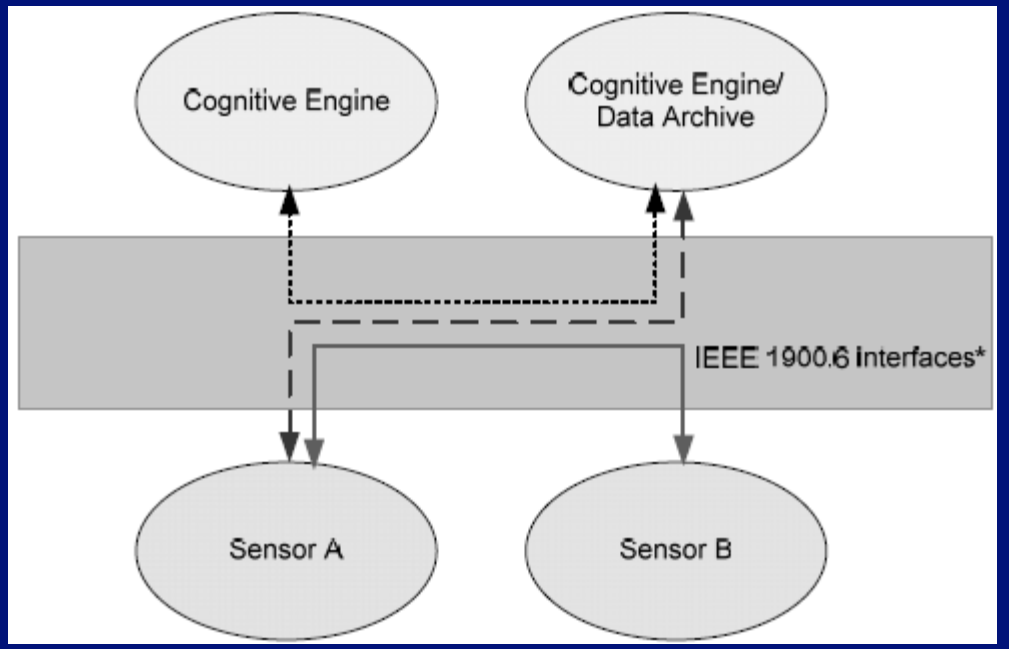
  Defines a vendor-independent set of policy-based control architectures and corresponding policy language requirements



IEEE Std 1900.5-2011

IEEE 1900.6:
Spectrum Sensing Interfaces and Data Structures for Dynamic Spectrum Access and Other Advanced Radio Communication Systems

- **Need ?**
  - Efficient and portable dynamic spectrum access operation
- **Responsibilities**
  - Define the logical interface and data structures used for the information exchange between spectrum sensors and their clients in radio communication systems



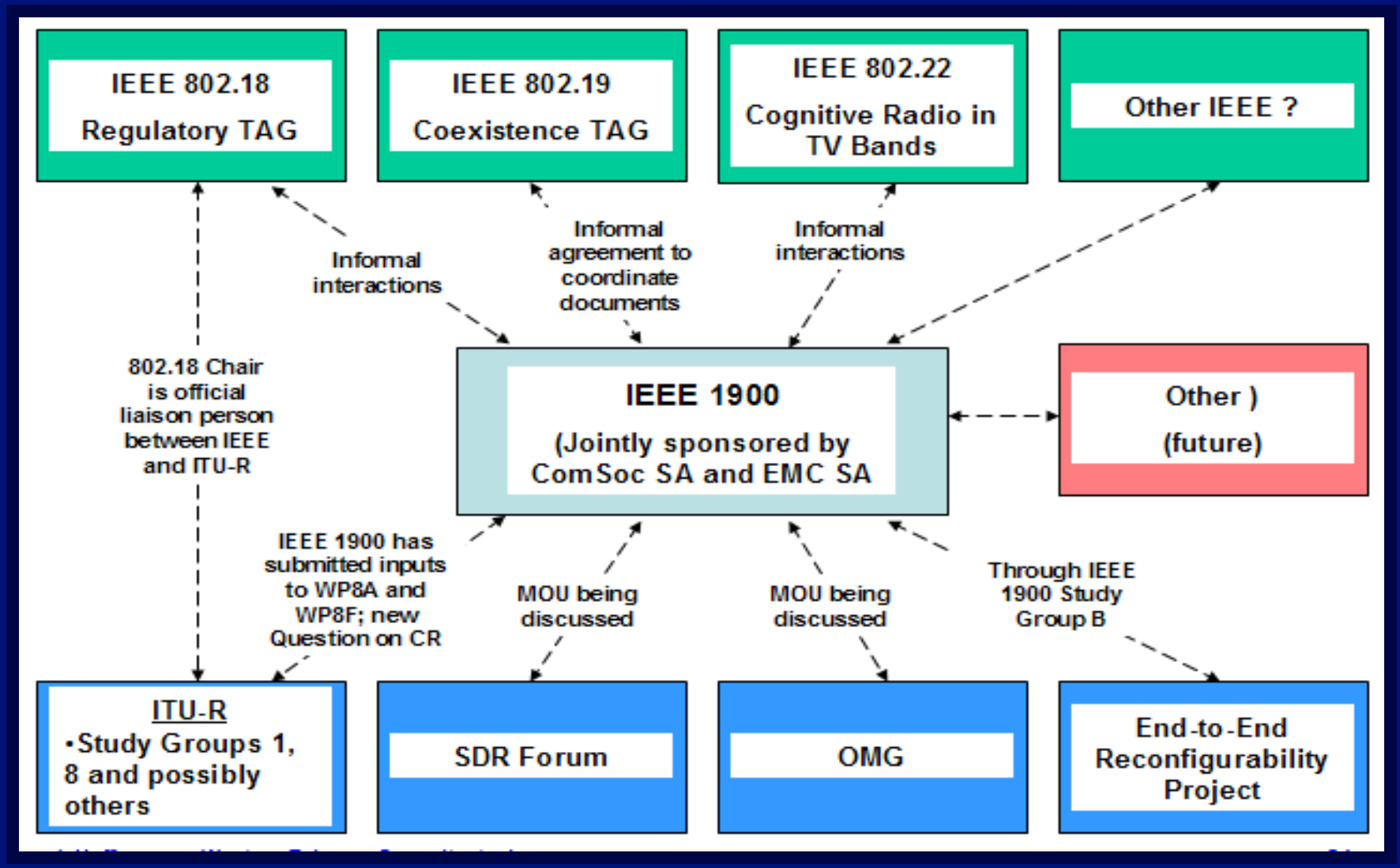
IEEE Std 1900.6-2011

IEEE P1900.7:
Radio Interface for White Space Dynamic Spectrum Access Radio Systems Supporting Fixed and Mobile Operation

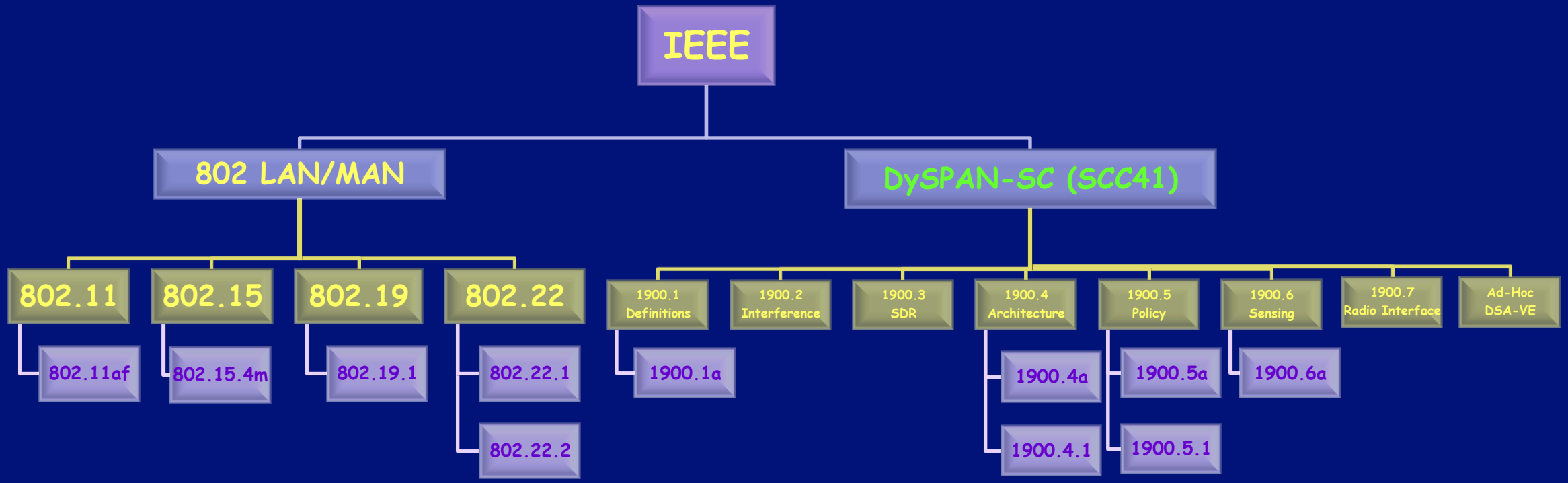
- **Draft standards under development**

- **Scope**
  - Specify a radio interface including MAC sublayers and PHY layers of WS DSA radio systems supporting fixed and mobile operation in WS frequency bands, while avoiding causing harmful interference to incumbent users in these frequency bands
  - Provide means to support P1900.4a for white space management and P1900.6 to obtain and exchange sensing related information (spectrum sensing and geolocation information)

IEEE 1900 Committee – Possible Relations with External Organizations



IEEE Cognitive Radio Standards: The Big Picture

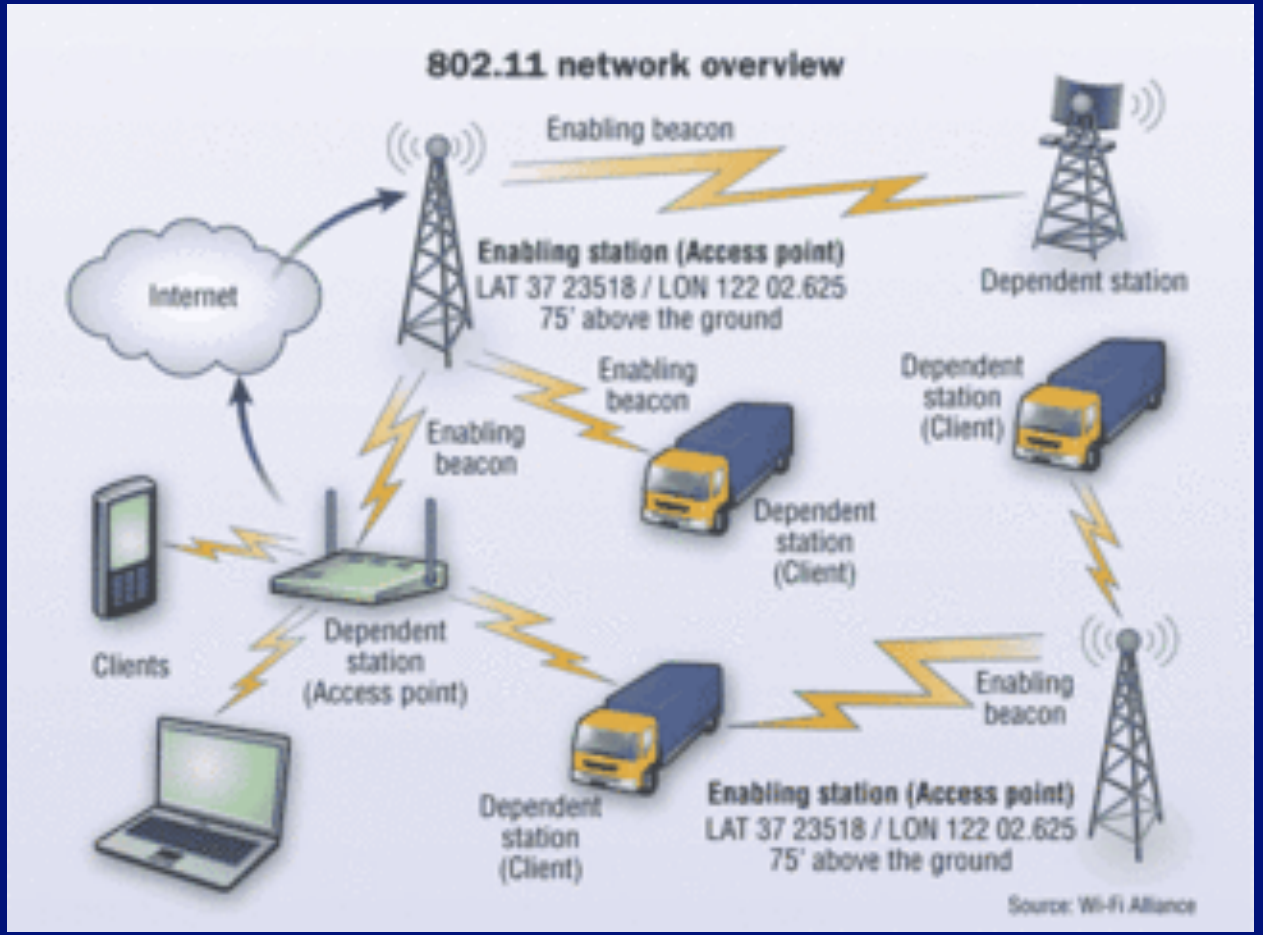


OTHER STANDARDS

- IEEE 802.11af
- IEEE 802.15m
- ECMA 392
- LTE-Advanced
- IETF PAWS

IEEE 802.11af: 802.11y History

- IEEE 802.11y
  - Amendment for 3650–3700 MHz operation in USA
  - Based on contention based protocols (CBPs) adopted by FCC for use in sharing the TV bands
  - Developed an enablement scheme adopted by 802.11af that requires devices to hear and decode an enabling beacon in order to transmit
  - Key features
    - Database of existing devices
    - "Light licensing"
    - Automatic policy recognition



IEEE 802.11af

R. Kennedy and P. Ecclesine,
"IEEE P802.11af Tutorial,"IEEE 802.11-10/0742r0, July 2010.
https://mentor.ieee.org/802.11/dcn/10/11-10-0742-00-0000-p802-11af-tutorial.ppt

- **Regulatory Driven Amendment**
  - Second Report & Order and Memorandum Opinion and Order (FCC 08-260 Nov. 2008)
  - Second Memorandum Opinion and Order (FCC 10-174 Sept. 2010)
  - "FCC frees up vacant TV airwaves for "Super WI-FI" technologies" (FCC NEWS Sept. 23, 2010)
- **Scope**
  - Define modifications to both the 802.11 PHY and MAC to meet the legal requirements for channel access and coexistence in the TVWS
- **Purpose**
  - Allow 802.11 wireless networks to be used in the TV white space

IEEE 802.11af

R. Kennedy and P. Ecclesine,
"IEEE P802.11af Tutorial,"IEEE 802.11-10/0742r0, July 2010.
https://mentor.ieee.org/802.11/dcn/10/11-10-0742-00-0000-p802-11af-tutorial.ppt

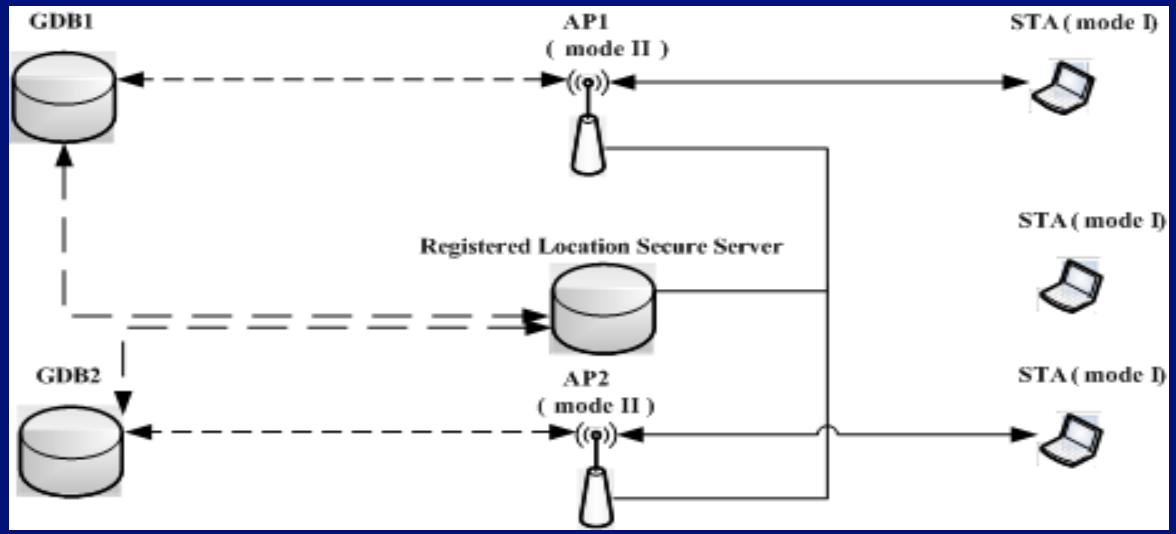
- For much higher speed and wider coverage than current Wi-Fi
  - Better propagation characteristics of the VHF/UHF bands
- Support QoS guarantees and resource-intensive multimedia services more easily than the current Wi-Fi
- Interference Mitigation
  - Enablement is the key to effective interference mitigation
    - Devices in a white space network cannot transmit without being enabled
    - Beacons contain location information for enabling STA (station)
    - Incumbents interfered with can easily establish the source and react without regulatory intervention

IEEE 802.11AF Wireless Local Area Networks

- Based on the IEEE 802.11ac PHY layer, supports multiple concurrent downlink transmissions utilizing MU MIMO
- More efficient spectrum use with smart antenna technology, enables
  - More efficient spectrum use
  - Higher system capacity
  - Reduced latency by supporting up to four simultaneous user transmissions
- Provides support for operation in unused TV channels in the VHF and UHF bands
- Multiple operating modes in 6, 7 and 8 MHz channels
  - W (1x channel width)
  - 2W (2x channel width)
  - W + W (non-contiguous)
  - 2W + 2W (non-contiguous)
  - 4W (4x channel width)

IEEE 802.11AF Operation in the TV Bands

- Access to spectrum via geolocation database(s)
- Master device (AP) connection to database; client (STA) dependent on master
- Allows for Registered Location Secure Server (RLSS) to cache the relevant portion of the database(s); allows for central control for campus TVWS network (not in all regulatory domains)



IEEE 802.15.4m

http://www.ieee802.org/15/pub/TG4m.html

- Part 15.4:
  Low Rate Wireless Personal Area Networks (LR-WPANs)
  Amendment:
  TV White Space Between 54 MHz and 862 MHz Physical Layer

- Purpose
  - Specify a PHY layer for 802.15.4 and to enhance and add functionality to the existing standard MAC meeting TVWS regulatory requirements
  - Enable operation in the available TVWS, supporting typical data rates in the 40 kbps to 2000 kbps range
  - Realize optimal and power efficient device command and control applications

IEEE 802.15.4m – Wireless Personal Area Networks

* Project Title

- IEEE Standard for Local and Metropolitan Area Networks Part 15.4: Low Rate Wireless Personal Area Networks (LR-WPANs) Amendment 6: TV White Space Between 54 MHz and 862 MHz Physical Layer

* Intro of Draft

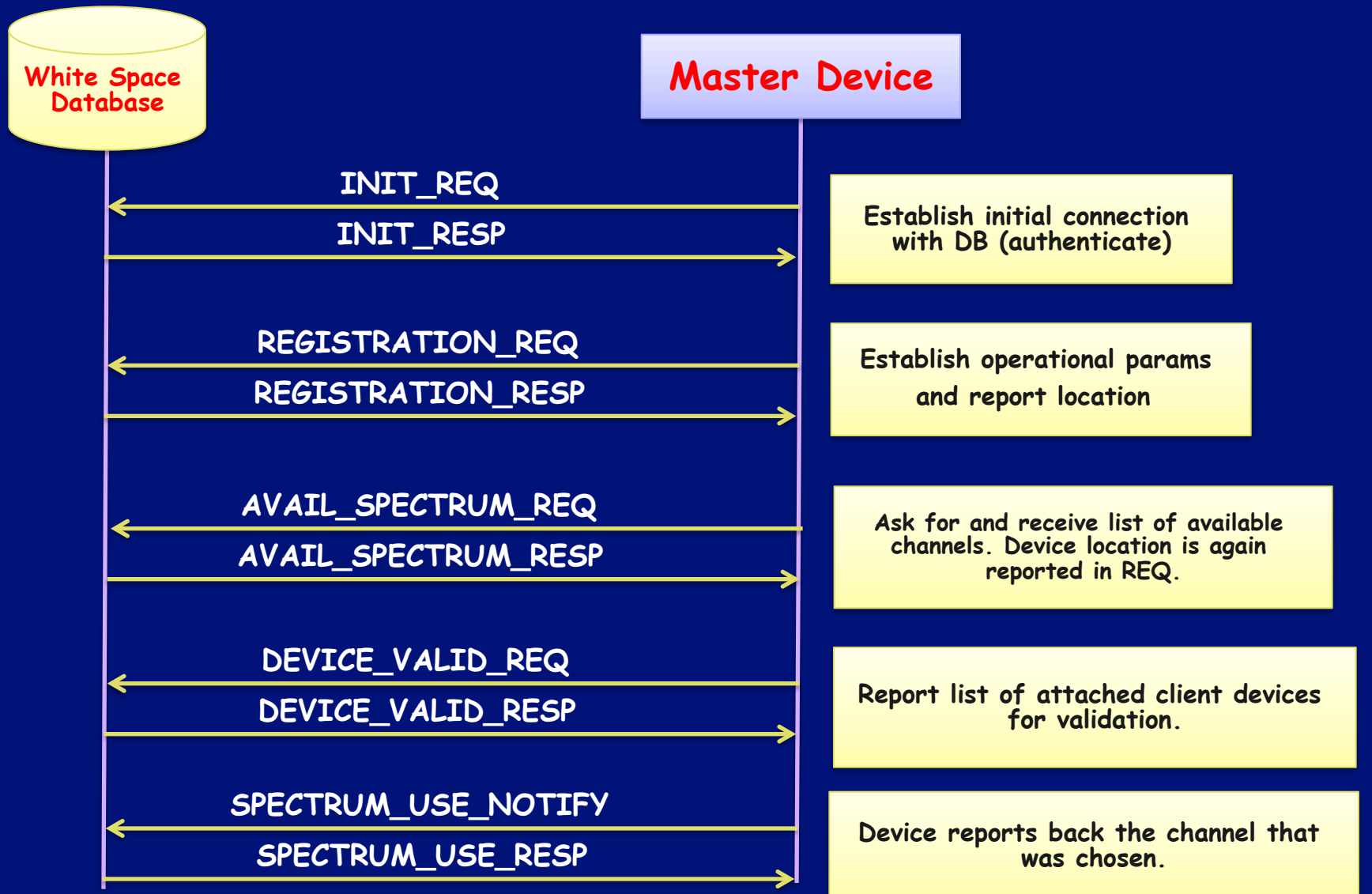
- This amendment specifies alternate PHYs in addition to those of IEEE Std 802.15.4-2011.
- In addition to the new PHYs, the amendment also defines those MAC modifications needed to support their implementation.

- The alternate PHYs support principally outdoor, low-data-rate, wireless, TV White Space network (TVWS) applications under multiple regulatory domains. The TVWS PHYs are as follows:
  - — Frequency shift keying (TVWS-FSK) PHY
  - — Orthogonal frequency division multiplexing (TVWS-OFDM) PHY
  - — Narrow Band Orthogonal frequency division multiplexing (TVWS-NB-OFDM) PHY
- TVWS PHYs support multiple data rates in bands ranging from 54 MHz to 862 MH

IETF PAWS

- IETF is defining a Protocol to Access Spectrum Database in PAWS (Protocol to Access White Space) WG
  - http://tools.ietf.org/wg/paws/
- Use Cases and Requirements: RFC6593
  - http://www.rfc-editor.org/rfc/pdfrfc/rfc6953.txt.pdf
- Latest Version of the Draft Protocol
  - http://www.ietf.org/id/draft-ietf-paws-protocol-07.txt

IETF PAWS Protocol



Future Cognitive Radio Standard Challenges

- SU-SU coexistence
  - Creation of different CR standards will result in coexistence problems among CR networks
  - IEEE 802.19 deals with coexistence between unlicensed wireless networks such as 802.11, 802.15, 802.16, and 802.22
  - Spectrum sharing and fairness

    E.g. distinct MAC strategies: 802.22 (TDM-based), 802.11af (CSMA-based), ECMA 392 (reservation and contention-based)

Future Cognitive Radio Standard Challenges

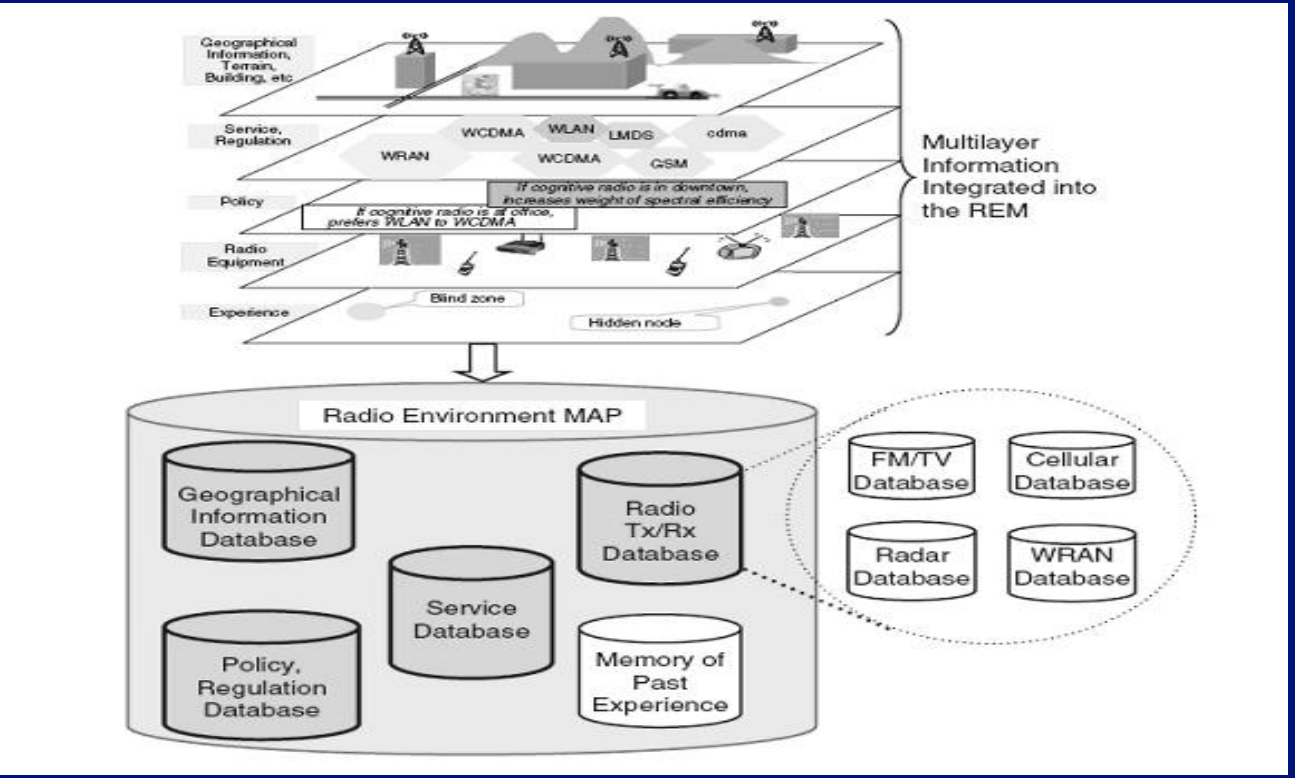
- PU-SU cooperation
  - Legacy services may want to actively coexist with SUs by providing some means of cooperation
  - The legacy network operators may provide some fraction of their spectrum on a payment basis for DSA
  - Legacy network may want to provide a method of cooperation with the secondary network to ease the SUs' burden for PU protection (e.g., spectrum sensing)

New Spectrum Occupancy Sensing (SOS) Task Group

Spectrum Occupancy Sensing (SOS)

- Administrations all over the world are looking to improve the utilization of the spectrum. White Space Database access is one of the techniques to enable spectrum sharing and the use of unused frequency bands also known as the White Spaces.
- However, in many administrations, locations and characteristics of the radiators are not well documented.
- Individual and collaborative spectrum sensing is one of the tools to complement the information contained in databases to create an accurate spectrum occupancy survey.
- Such a Spectrum Occupancy Sensing (SOS) system will combine information from multiple sensors along with local terrain information to predict the spectrum occupancy patterns.
- This could lead to more efficient use of spectrum especially in places where the information about the primary users is difficult to find.
- The SOS Study Group will explore on-going research, challenges and aspects that require standardization.

Spectrum Occupancy Sensing (SOS) System



- SOS will create use cloud and crowd collaborative opportunistic sensing (e.g. cell phones acting as sensors)
- SOS will combine sensing information with digital terrain data
- It will provide this information to the databases for more realistic spectrum occupancy

Spectrum Sharing in 3.5 GHz Band

Radar, Commercial Comms Spectrum Sharing Using IEEE 802.22.1 Advanced Beaconing

Objective To Create NATIONAWIDE availability of the 3550-3650 MHz Band using IEEE 802.22.1 advanced beaconing approach

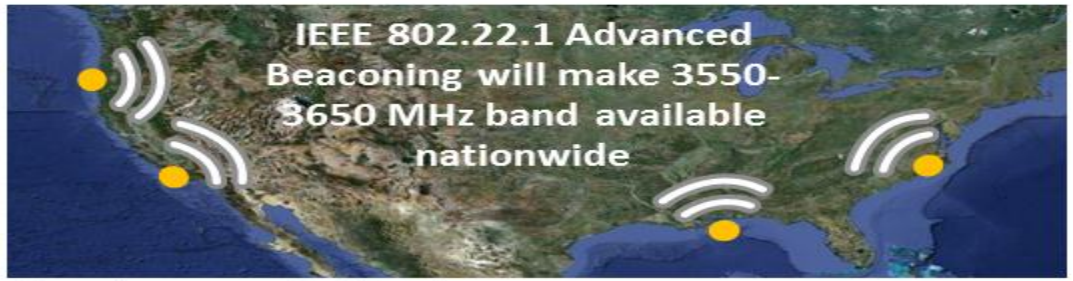
Current Plan: The current plan is the use of exclusion zones to protect U.S. Navy coastal operations and other Department of Defense test and training areas. This means that major part of the US population will not be able to use these bands.

Alternatives: However, there may be some other approaches which will make 100 MHz of spectrum available nation-wide, and especially in the coastal areas where significant US population resides.

Background

3550 – 3650 MHz Band: One of the portions of the spectrum identified to achieve the goal of freeing up 500MHz of spectrum, is the 3550-3650 MHz where maritime radars have been deployed.

Use of Advanced Beaconing Approach: Advanced beaconing approaches, such as the one developed in the IEEE Standard 802.22.1 for spectrum sharing between the primary signals and incumbent signals is suitable for the 3550-3650 band.

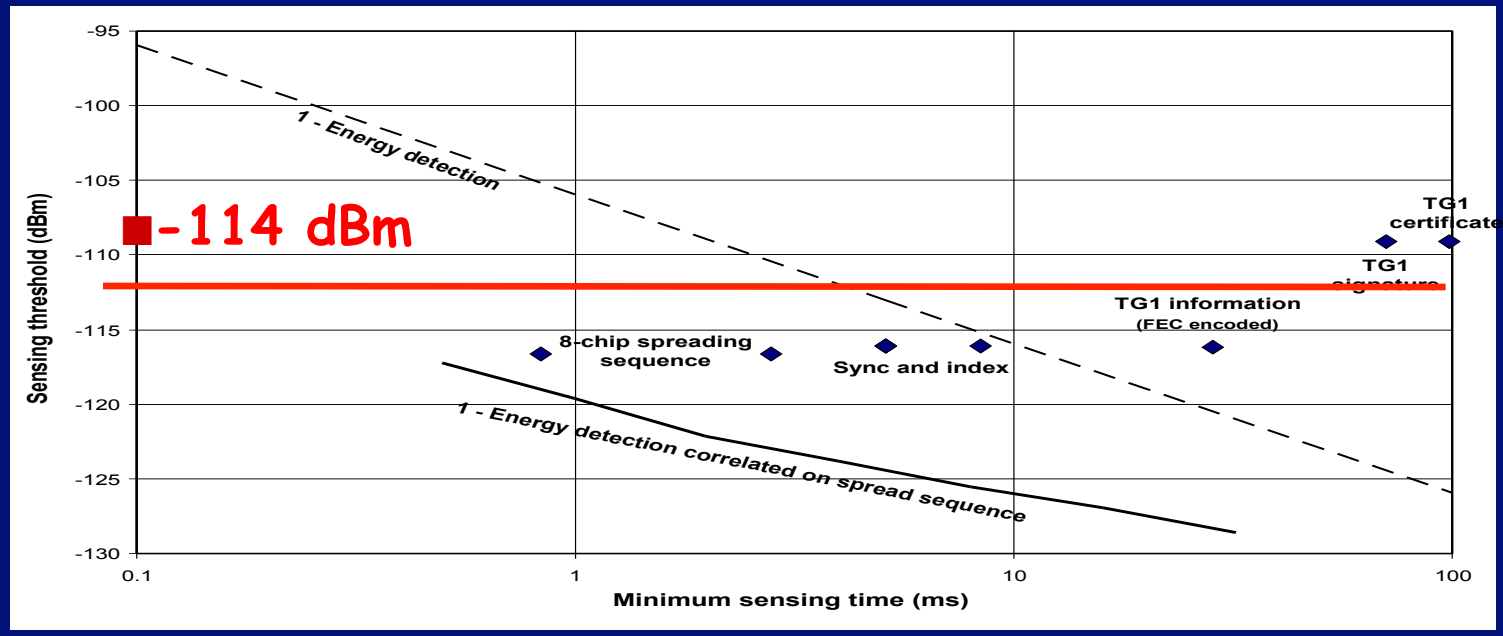


Deployment Strategy

Regulators have realized that beaconing is a viable option for spectrum sharing. *The IEEE 802.22.1-2010™ standard has been completed and is currently being revised for protection of radars and satellite earth stations*

IEEE 802.22.1 Advanced Wireless Beaconing – Applies to Other Bands to Enable Spectrum Sharing with Radars

- IEEE 802.22.1 defines a beacon signal for primary user protection
- Security features are provided for beacon authentication
- Such beacons can be used for spectrum sharing with primary users when fast response times are desired or hidden node detection is an issue
- IEEE 802.22.1 Revision Project will explore radar and comms spectrum sharing in 3.5 GHz Band



Conclusions

- Spectrum sharing can benefit *developed and developing countries*
- Cognitive Radio technology and use of White Spaces will provide ubiquitous wireless connectivity and support many other M2M applications
- Spectrum sharing can create *tomorrow's spectrum super-highways*
- It supports licensed, license-exempt and hierarchical access business models
- Technologies and Standards for Cognitive Radios, and Database enabled Spectrum Access exist
- *Regulations* to support spectrum sharing need to be developed