IEEE 802.22 Wireless Regional Area Networks

Enabling Rural Broadband Wireless Access Using Cognitive Radio Technology

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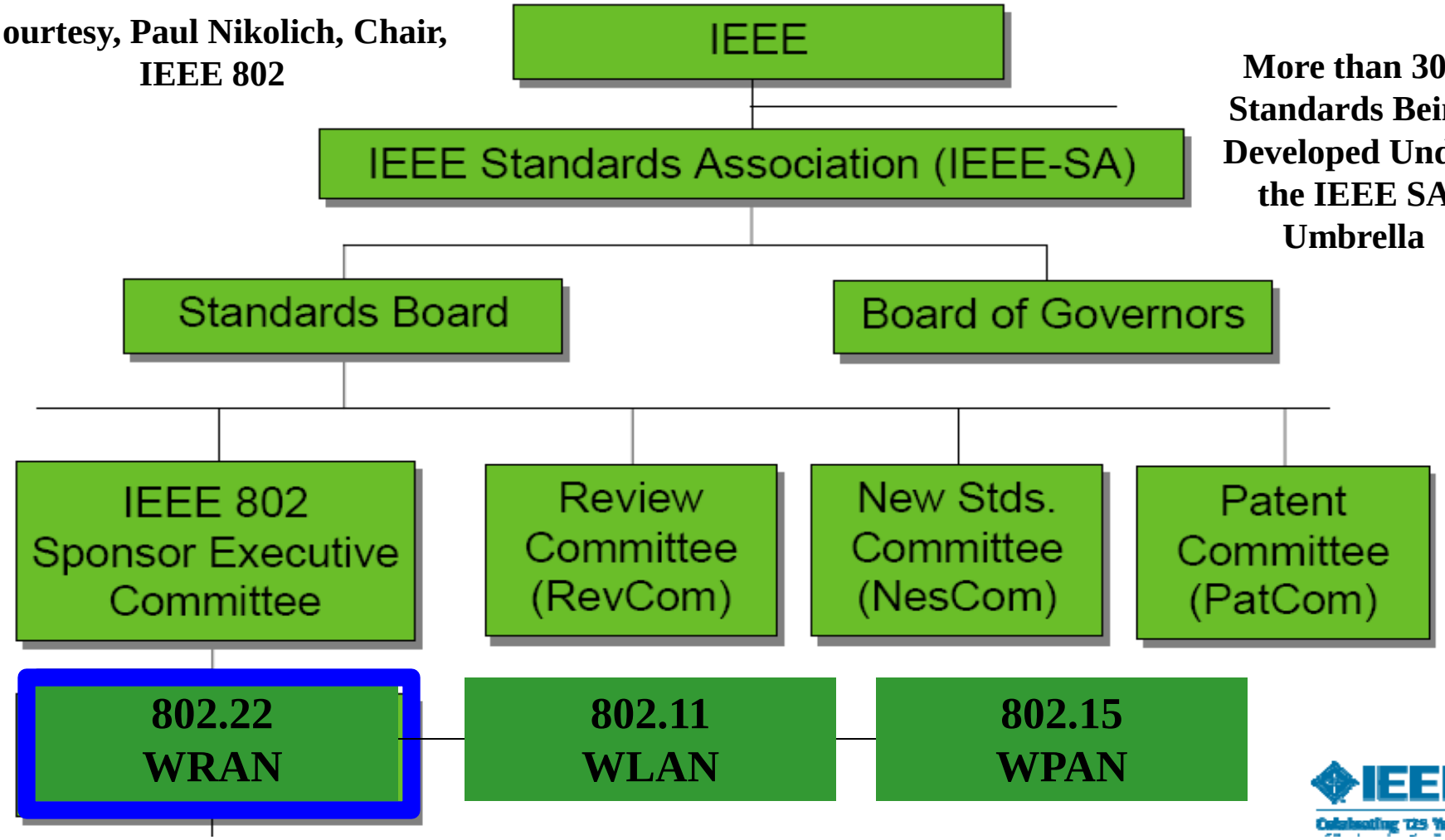
  - Spectrum Sensing
  - Geo-location
  - Interface to Incumbent Database Service
  - Security

IEEE Standards Association Hierarchy

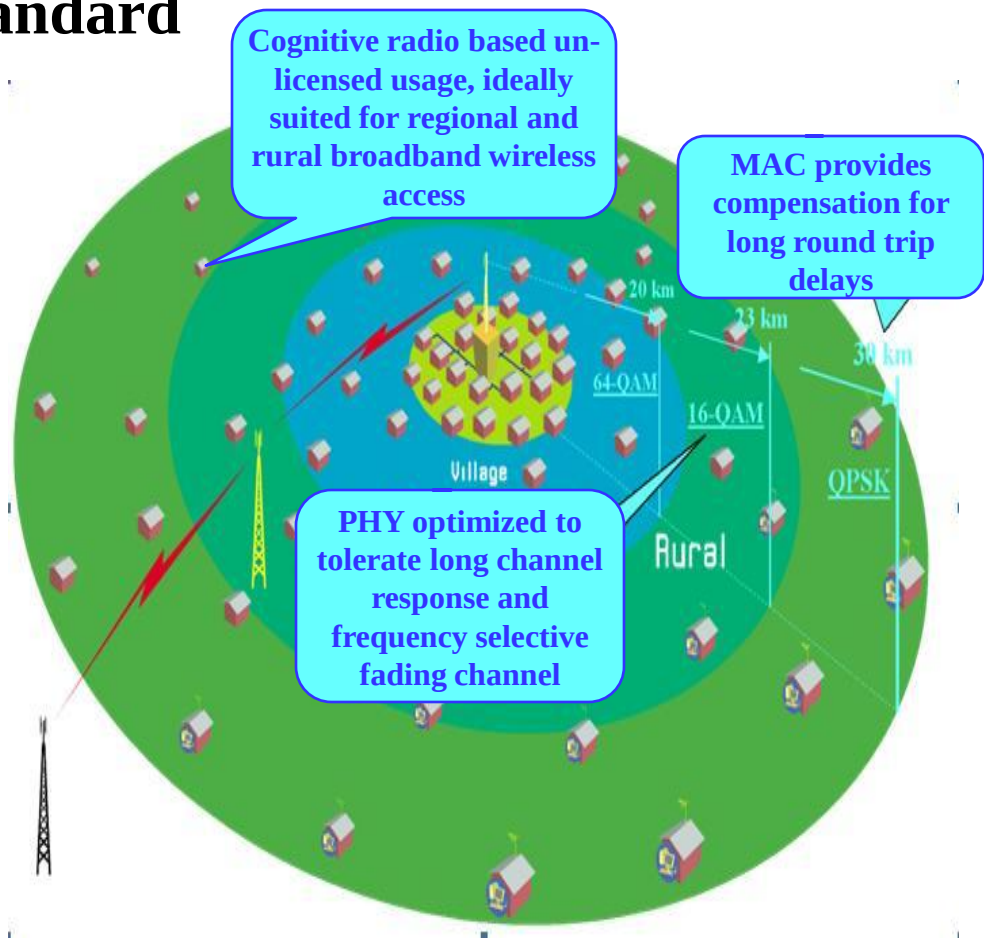
Courtesy, Paul Nikolich, Chair, IEEE 802



More than 300 Standards Being Developed Under the IEEE SA Umbrella

Overview of the IEEE 802.22 Standard

- **Focus - Rural Broadband Wireless Access**
- Core Technology - Cognitive radio technology based un-licensed use, primarily designed to operate in the TV Whitespaces from 54-862 MHz, on a non-interfering basis with the primary users (incumbents).
- Representation – Commercial industry, Broadcasters, Govt., regulators, and Academia
- Membership – 40 on an average
- Projects – IEEE 802.22, IEEE 802.22.1, IEEE 802.22.1
- CONOPS - VHF and UHF band operation allows long range propagation and cell radius of 17 – 33 km. Approx 280 MHz of Bandwidth with 47 TV channels.
- PHY - Optimized for long channel response times and highly frequency selective fading channels.
- MAC – Provides compensation for long round trip delays
- Unique features introduced for Cognitive Radio based operation: spectrum sensing, spectrum management, intra-system co-existence, geo-location and security

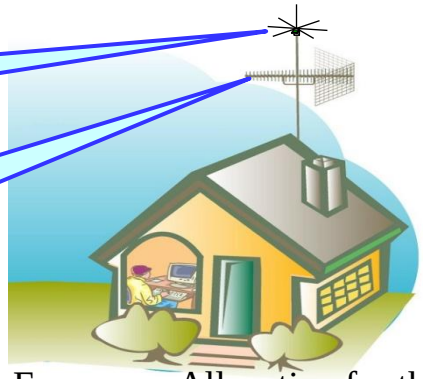


- Mobility and Portability - Portability – IEEE 802.22 allows portability (nomadic use). In case the rules do change, IEEE 802.22 PHY is designed to support mobility of up to 114 km/hr (no hand-off is included in the current version).

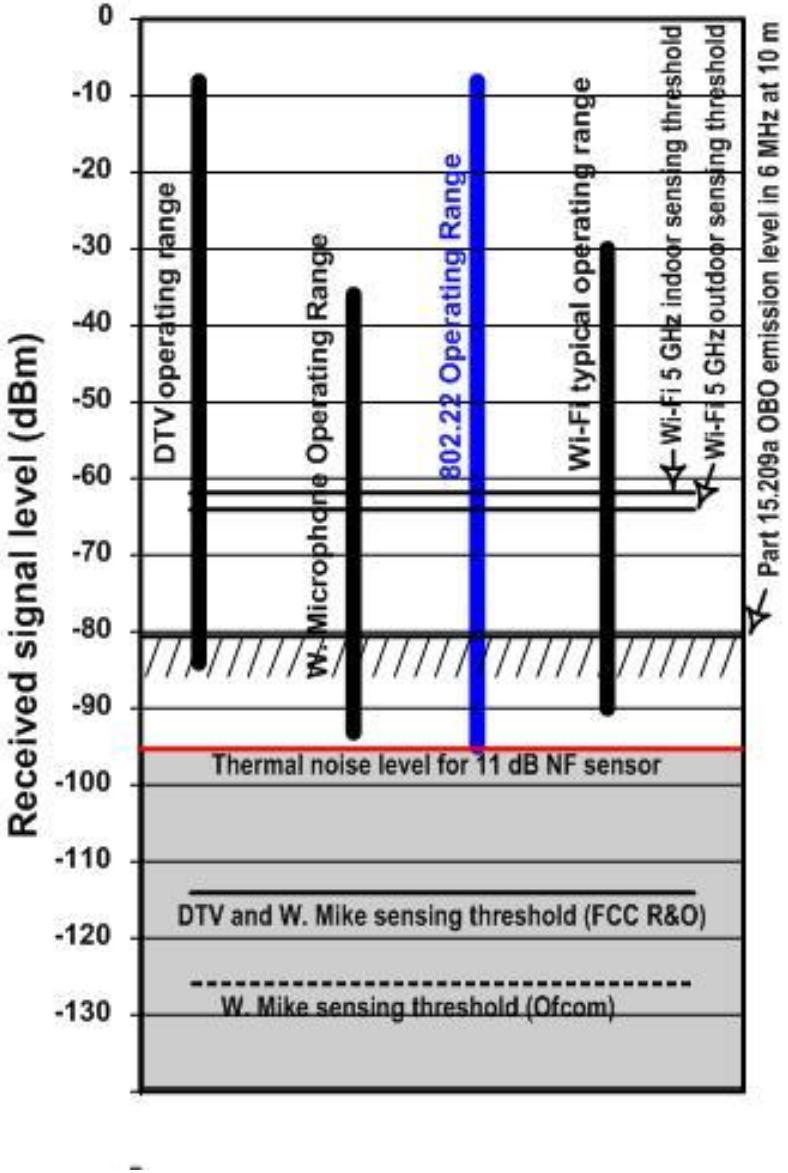
IEEE 802.22 CONOPS

Sensing and GPS Antennas

Directional Tx / Rx Antenna at the Subscriber



- Operation in the VHF / UHF Bands. Frequency Allocation for the United States – 54 – 60, 76 – 88, 174 – 216, 470 - 608 and 614 – 698 MHz => Total of 282 MHz or 47 Channels
- Network Topology – Point-to-Multipoint (PMP)
- Max EIRP and Cell Radius – Fixed BS and Fixed Subscribers using 4W EIRP, Cell Radius 10 – 100 km. Portable Subscribers Station Supported. (Higher power BS allowed in other countries)
- Tx / Rx antenna – BS uses sectorized or omni-directional antenna. At the subscriber Tx /Rx antenna is directional with 14 dB of front-to-back lobe suppression,
- Sensing antenna - Requires horizontal and vertical polarization sensitivities to sense TV and microphone signals respectively, with omni-directional pattern.
- Geo-location - GPS based geo-location is mandatory, but terrestrial geo-location (triangulation) is supported.



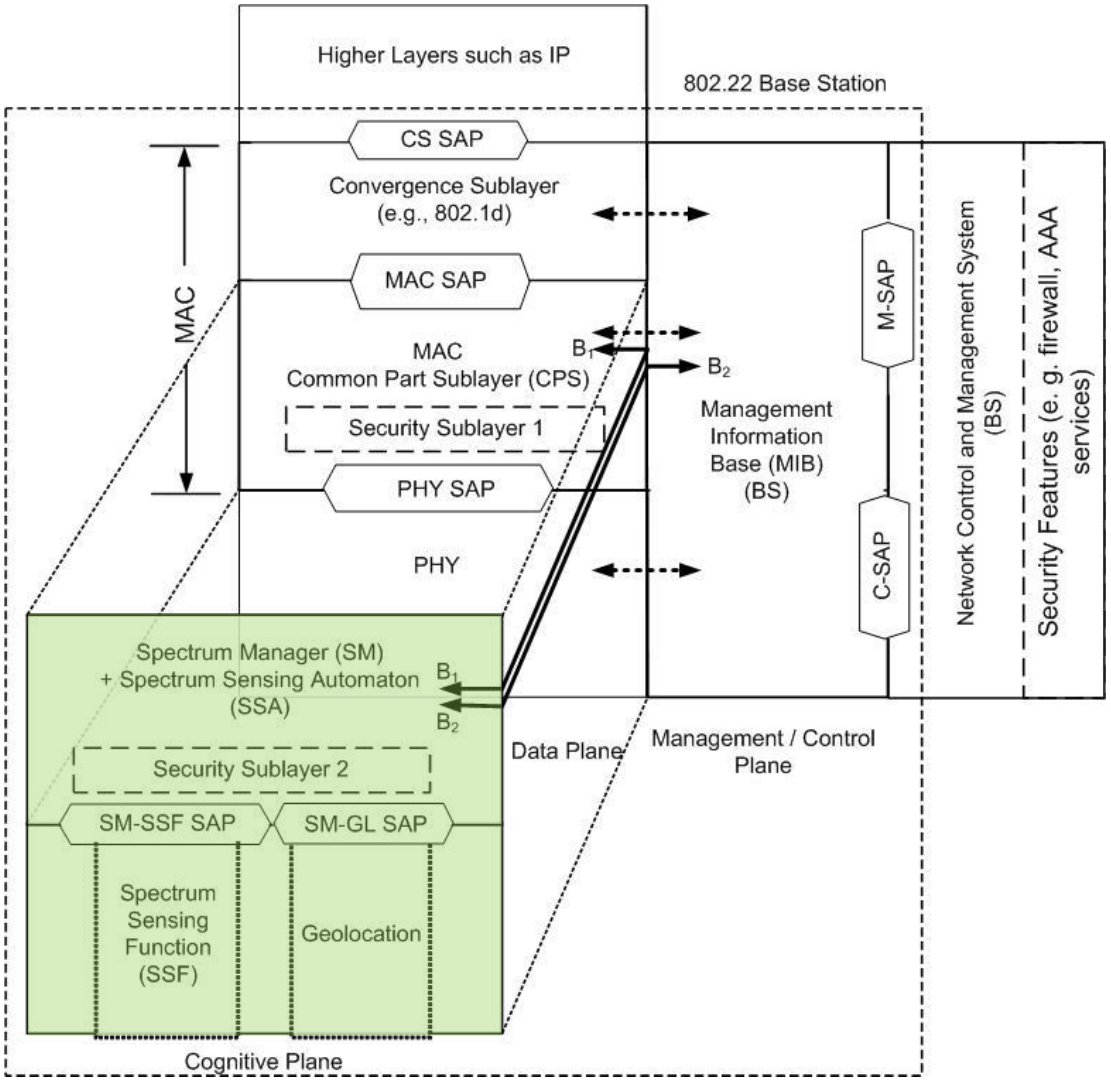
IEEE 802.22 Cognitive Node: Reference Architecture

- The proposed Protocol Reference Model (PRM) separates the Cognitive Plane from the Data, Control and Management planes

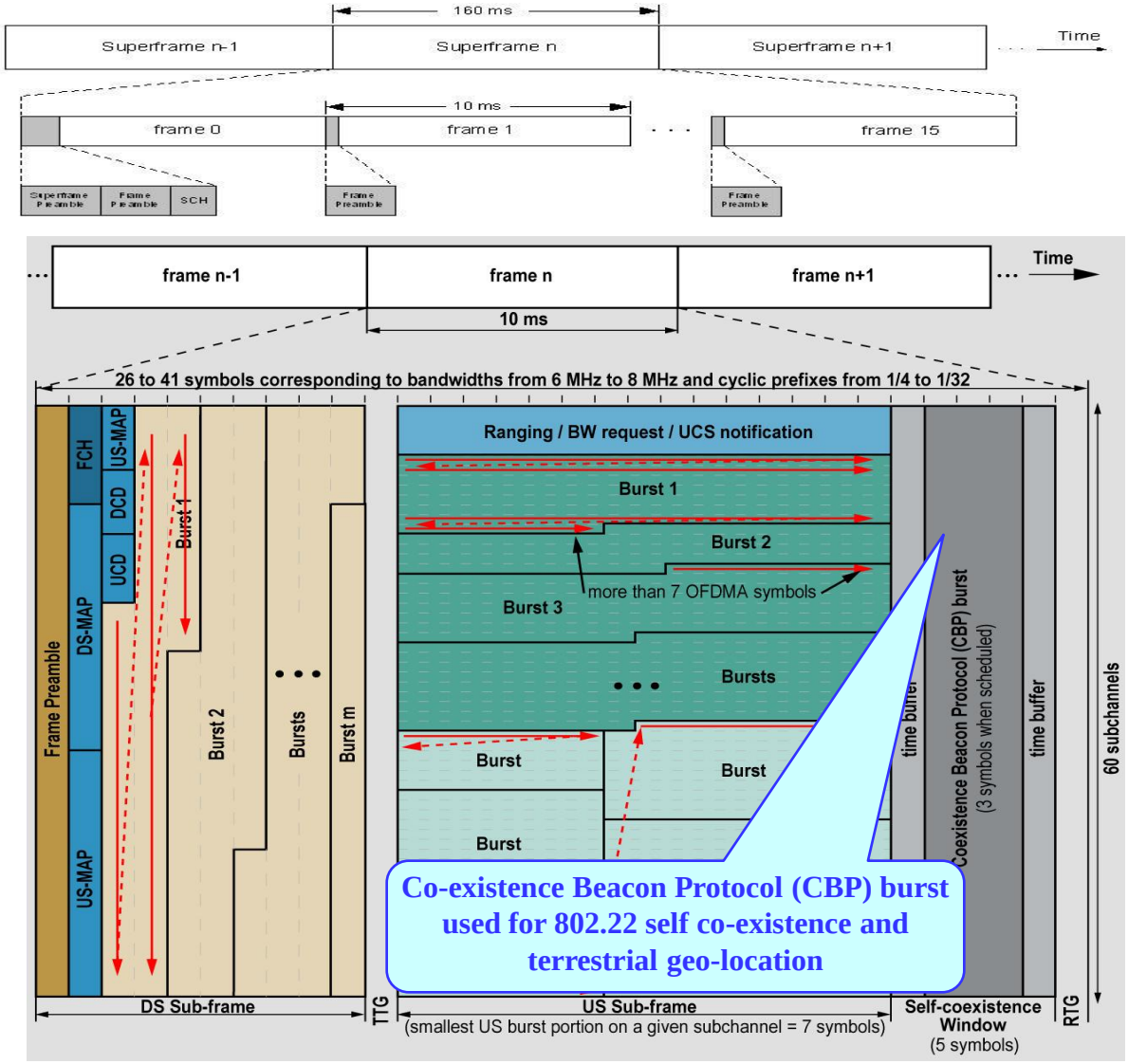
IEEE 802.22 Provides Three Mechanisms for Incumbent Protection

- **Sensing**
- **Database Access**
- **Specially Designed Beacon**

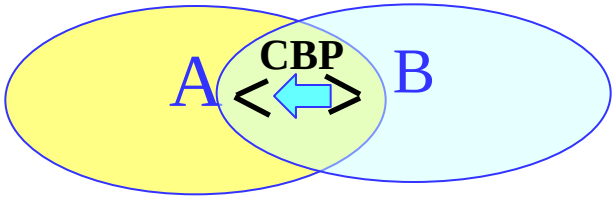
One or more protection mechanisms can be adopted based on the regulatory domain requirements.



IEEE 802.22 – Frame Structure



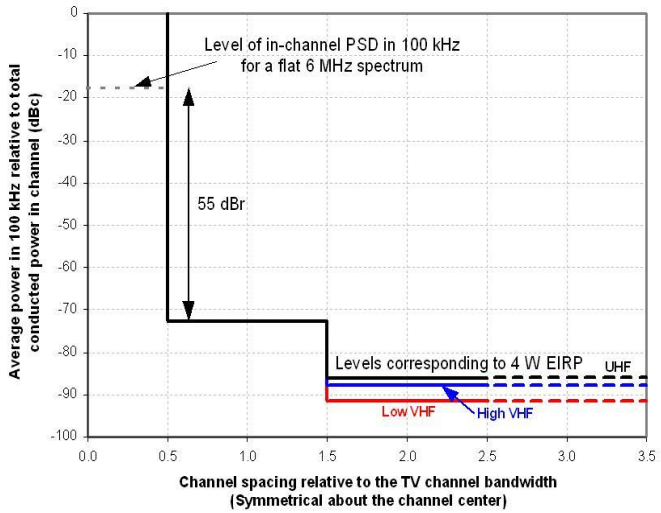
- 802.22 supports Time Division Duplex (TDD) frame structure
- Super-frame: 160 ms, Frame: 10 ms
  - Each frame consists of downlink (DL) sub-frame, uplink (UL) sub-frame, and the Co-existence Beacon Protocol (CBP) burst
  - Lengths of DL and UL sub-frames can be adjusted .
- Self Co-existence Window: BS commands subscribers to send out CBPs for 802.22
  - self co-existence – CBP bursts contain information about the backup channel sets and sensing times
  - terrestrial geo-location and
  - whitespace device identification as required by the regulatory domain rules.



IEEE 802.22 – PHY Features

- PHY Transport - 802.22 uses Orthogonal Frequency Division Multiplexing (OFDM) as transport mechanism. Orthogonal Frequency Division Multiple Access (OFDMA) is used in the UL
- Modulation - QPSK, 16-QAM and 64-QAM supported
- Coding – Convolutional Code is Mandatory. Turbo, LDPC or Shortened Block Turbo Code are Optional but recommended.
- Pilot Pattern - Each OFDM / OFDMA symbol is divided into sub-channels of 28 sub-carriers of which 4 are pilots. Pilot symbols are inserted once every 7 sub-carriers. Pilots cycle through all 7 sub-carriers over 7 symbol duration. No frequency domain interpolation is required.
- Net Spectral Efficiency - 0.624 bits/s/Hz – 3.12 bits/s/Hz
- Spectral Mask - 802.22 has adopted the Spectral Mask requirements proposed by FCC. (200 tap FIR filter may be needed for implementation).

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



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)

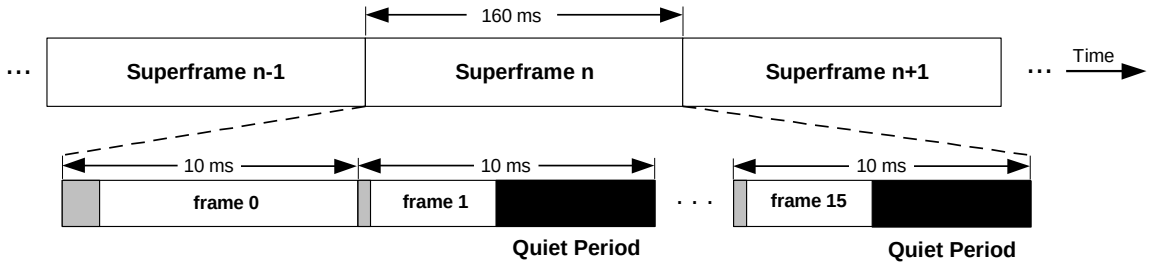
Mod.	Rate	SNR
QPSK	1/2	4.3
	2/3	6.1
	3/4	7.1
	5/6	8.1
16QAM	1/2	10.2
	2/3	12.4
	3/4	13.5
	5/6	14.8
64QAM	1/2	15.6
	2/3	18.3
	3/4	19.7
	5/6	20.9

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

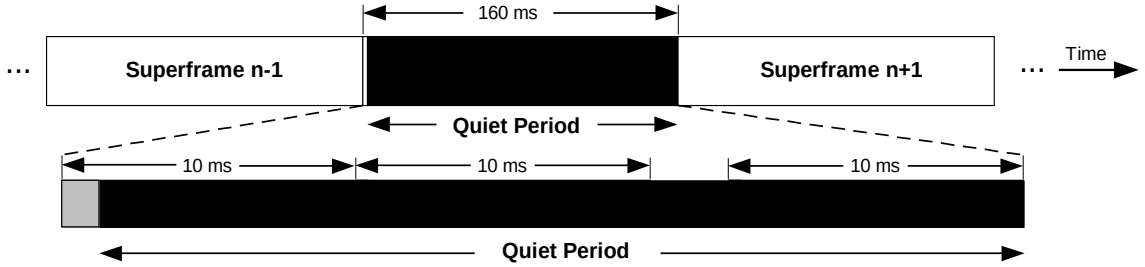
IEEE 802.22 – MAC Features

- Connection-oriented MAC, establishes connection IDs and service flows which are dynamically created
- QoS – Various types of QoS services are supported (See below). ARQ supported. Uni-cast, Multi-cast and broadcast services are supported.
- Cognitive functionality –
  - Dynamic and adaptive scheduling of quiet periods to allow the system to balance QoS requirements of users with the need to quiet down the network to support spectrum sensing. Quiet periods range from 1 symbol (approx. 1/3 ms) to one super-frame
  - Subscribers can alert the BS, the presence of incumbents in a number of ways. Dedicated - Urgent Co-existence Situation (UCS) messages or low priority MAC messages
  - BS can ask one or more subscribers to move to another channel in a number of ways using Frame Control Header (FCH) or dedicated MAC messages

QoS	Application
UGS	VoIP, T1 / E1
rtPS	MPEG video streaming
nrtPS	FTP
BE	E-mail
Contention	BW request etc.



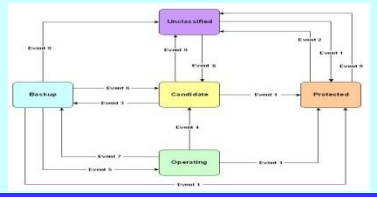
Intra-frame quiet period scheduling



Inter frame quiet period scheduling

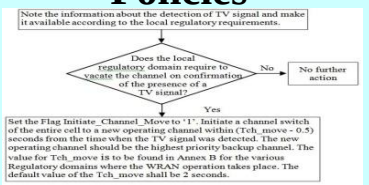
IEEE 802.22 – Cognitive Radio Capability

Channel Set Management

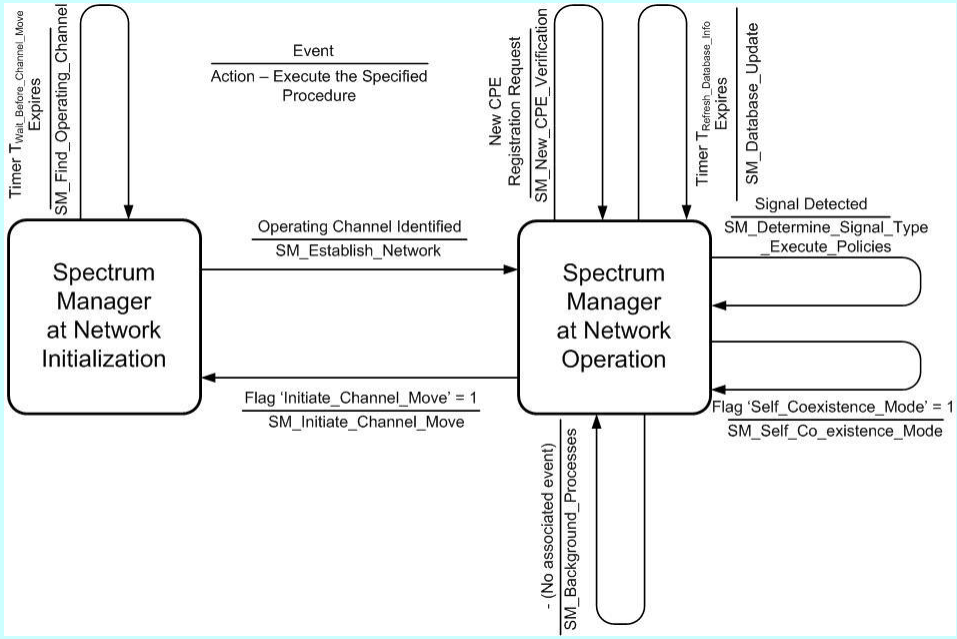


Subscriber Registration and Tracking

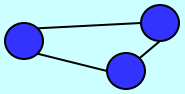
Policies



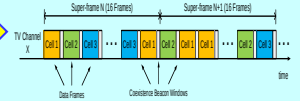
Spectrum Manager



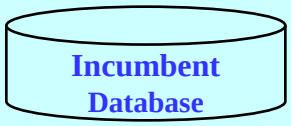
Geo-location



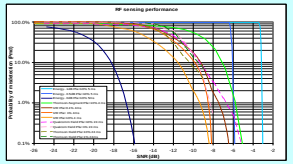
Self Co-existence



Incumbent Database Service



Spectrum Sensing



IEEE 802.22 – Spectrum Sensing

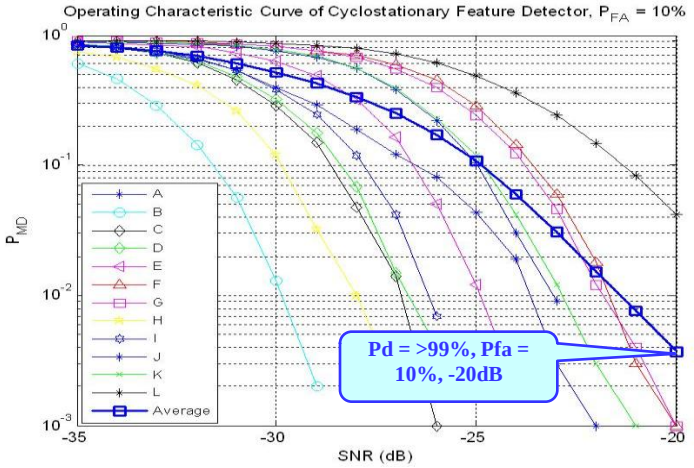
TV and Wireless Microphone Protection Using Spectrum Sensing

- FCC R&O requires
  - DTV protection at -114 dBm in 6 MHz of bandwidth. This amounts to an SNR of -19 dB for equivalent receiver noise figure of 11 dB and 22 dB safety margin at edge of coverage
  - Wireless microphone protection at -114 dBm in 200 kHz bandwidth. This amounts to an SNR of -3 dB for equivalent. recceiver noise figure of 11 dB.
  - Several blind and signal specific feature-based sensing schemes have been proposed and thoroughly evaluated using TV Broadcaster supplied over-the-air collected signals
    - ► Spectral correlation based sensing,
      Time domain cyclostationarity,
      Eigen value based sensing,
      FFT – based pilot sensing,
      Higher order statistics based sensing, etc.

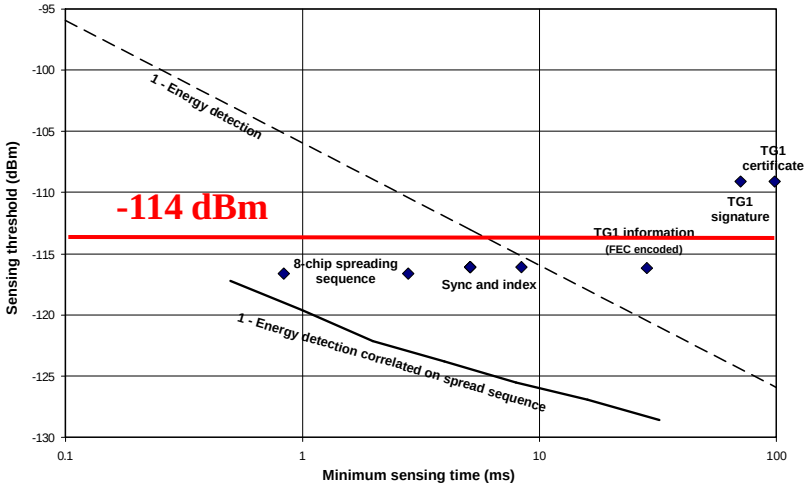
Wireless Microphone Protection Using Beacon (IEEE 802.22.1 Standard – Nearly Complete)

- Many studies have suggested that FCC R&O target for wireless microphones is not sufficient to protect wearable microphones (where body attenuation of as much as 27dB is possible according to the manufacturers)
- 802.22 has designed a beacon signal which will be transmitted from wireless microphone base stations with 250 mW (as compared to 10 mW for microphones). These beacon signals consist of repeated pseudo-noise (PN) sequences and occupy a bandwidth of 78 kHz.
- Security features are provided for beacon authentication

DTV Detection Results based Cyclostationary Feature Detection



Wireless Microphone Beacon Sensing Results



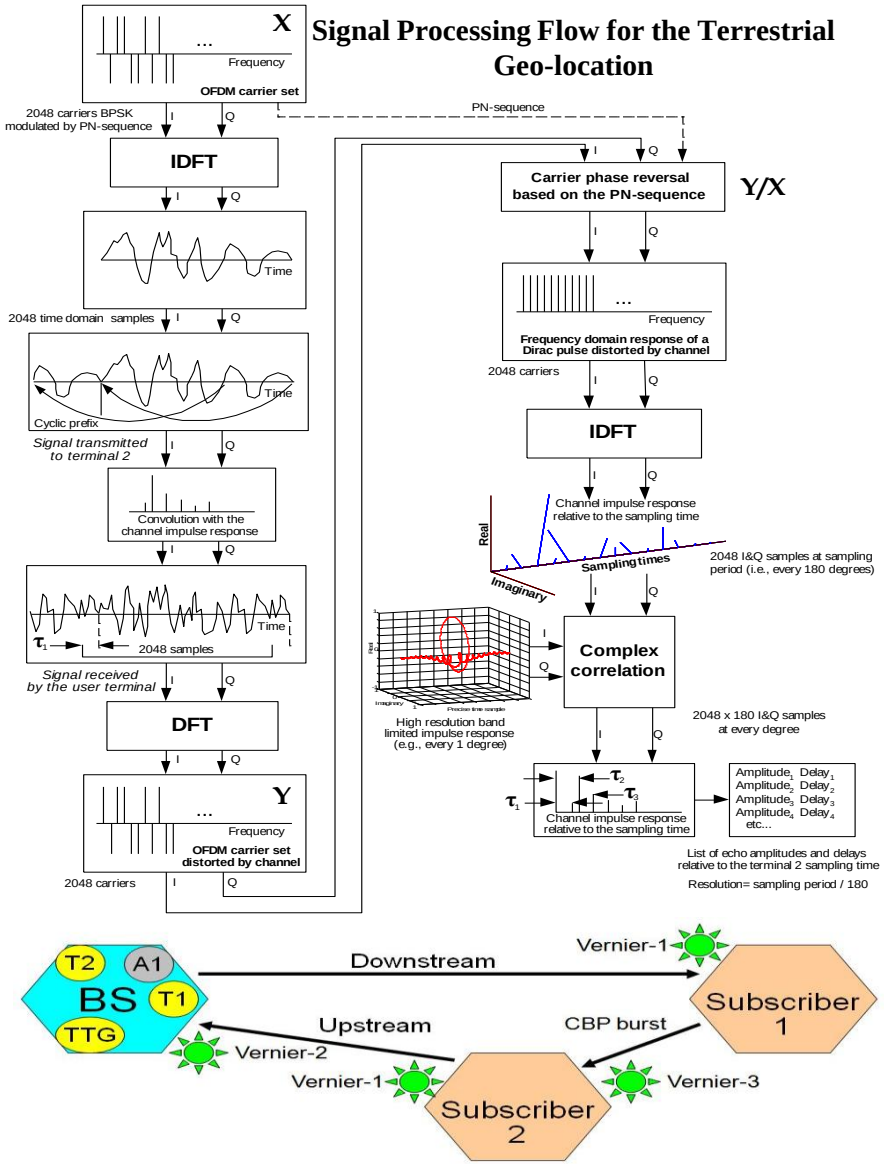
IEEE 802.22 – Geo-location

Satellite-based geo-location

- Requires GPS antenna at each terminal
- NMEA 0183 data string used to report to BS
- Poor accuracy in Northern hemispheres.

Terrestrially-based geo-location:

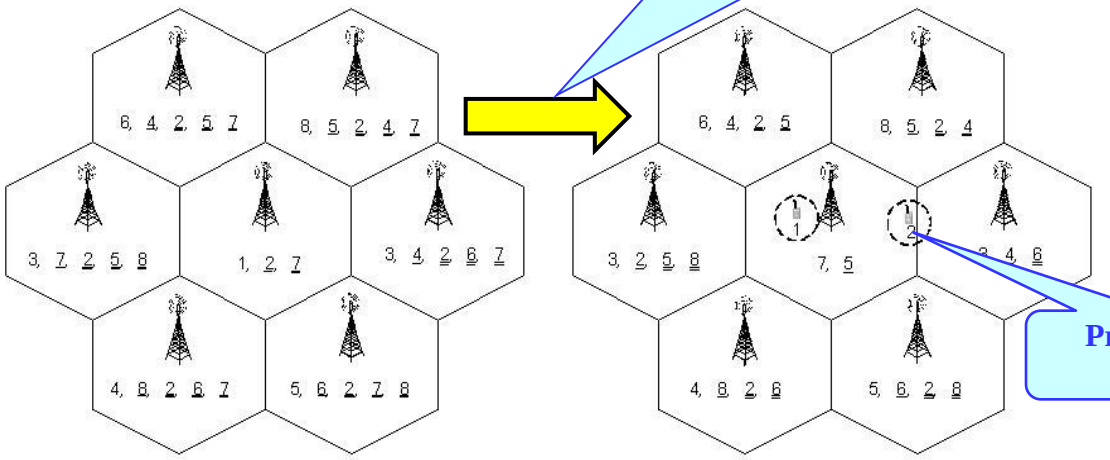
- A new scheme has been proposed requiring no additional hardware and using the characteristics and capabilities of the 802.22 standard.
- Normal BS-CPE ranging process: provides coarse ranging to an accuracy of 147.8 ns (44.3 m)
- Extended BS-CPE ranging process: augments the accuracy of the ranging process to 1 ns (0.3 m) by a more accurate scheme using the complex channel impulse response received at the CPE (Vernier-1) and at the BS (Vernier-2)
- Extended CPE-CPE ranging process: new scheme using the preamble of the CBP burst transmitted by a CPE and captured by another CPE in the surrounding area to acquire the distance between CPEs with a high level of accuracy (Vernier-3)
- Off-line geo-location calculation: All the information acquired at the CPEs is transmitted to the BS which can delegate the calculation of the CPE geo-location to a server. Calculation is based on usual triangulation using some CPEs as waypoints.



IEEE 802.22 – Self Co-existence

Spectrum Etiquette
(Enough channels available)

Requires that information on operating, backup and candidate channels of each cell is shared amongst WRAN cells: exchanged by CBP bursts.

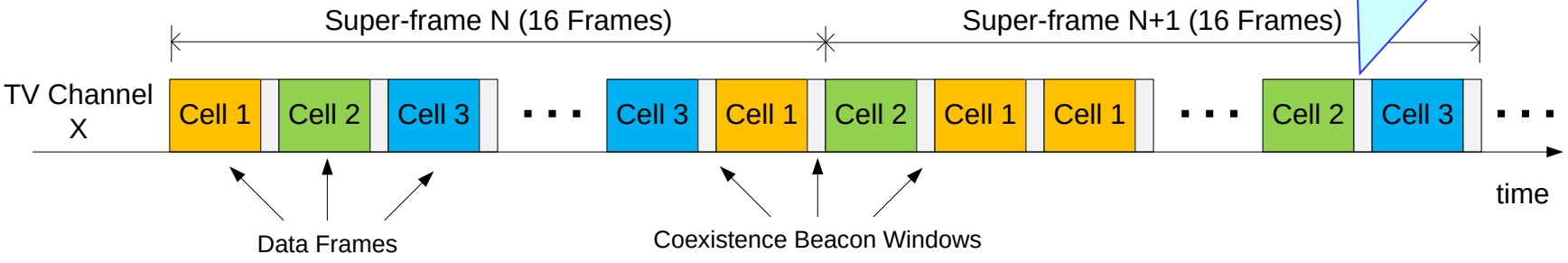


Primary user appears

On Demand Frame Contention
(Two or more cells need to co-exist on the same channel)

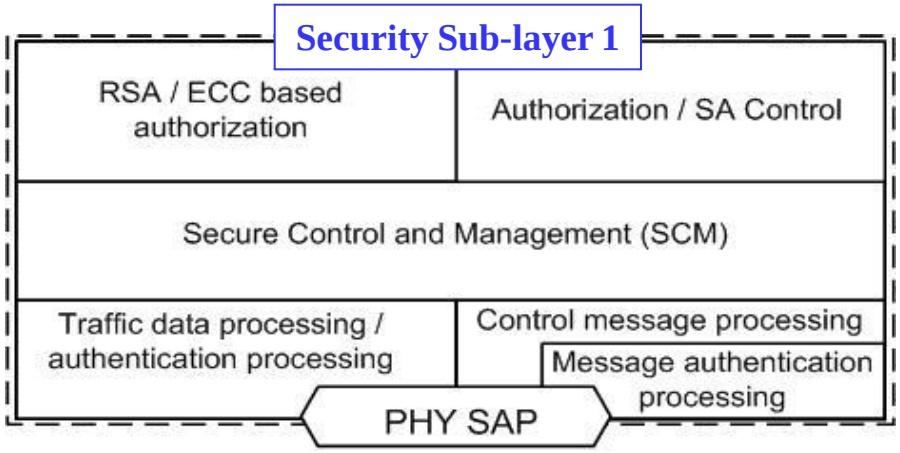
Number x – represents operating channel
Number y – represents backup channel
Number z (double underline) – represents candidate channel

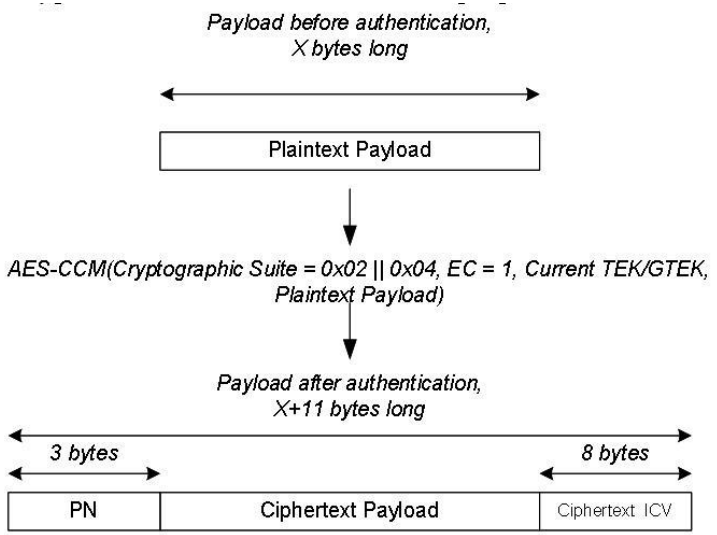
Self-coexistence window (SCW) does not have to be allocated at each frame.



IEEE 802.22 – Security Sub-layer 1 (Non-Cognitive)

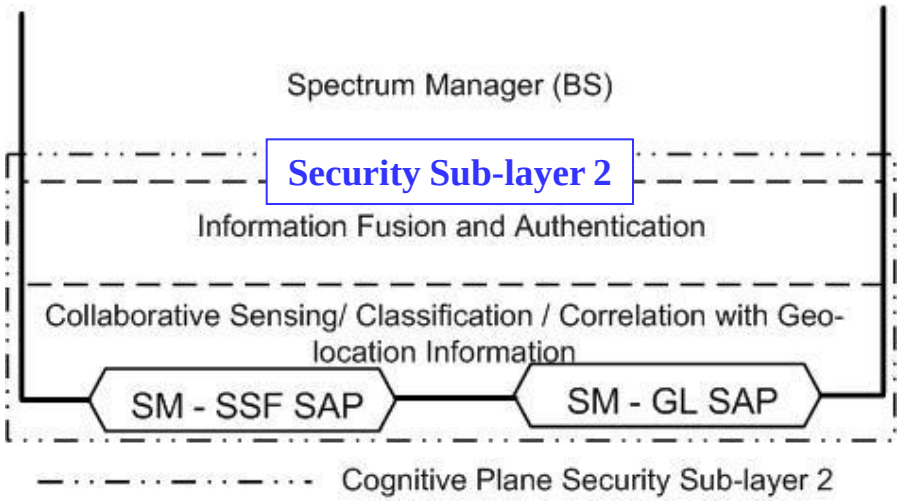
- Confidentiality and Privacy – AES (128) GCM is used for encryption and authentication
- Network Authorization - RSA and ECC based X.509 certificates are used for mutual authentication / network entry authorization.
- Integrity – AES-GCM is used to compute Integrity Check Vector (ICV). PN sequence numbers are appended to each packet.
- Authentication – Signals such as wireless microphone beacon and CBP are authenticated using ECC based digital signatures. No encryption is provided for these packets
- Key Management - Secure Control and Management Protocol is used for key management.
- Management Messages – All management messages except for the broadcast, initial ranging and basic CID are protected.
- Device Security - Trusted Computing Group, Trusted Platform Module specifications are recommended to enable tamper-proof capability for hardware and software.

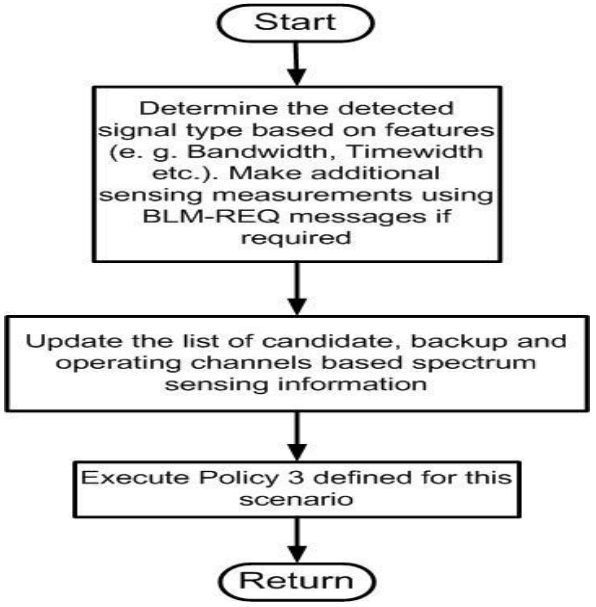




IEEE 802.22 – Security Sub-layer 2 (Cognitive)

- Spectrum Availability -
  - Spectrum Sensing used to ensure spectrum availability for primary users.
  - Various types of signal specific and feature based sensing algorithms have been included into the standard
  - Standard recommends sensing algorithms to determine the signal type (Signal Classification)
  - Collaborative Sensing - The group in general thinks that collaborative sensing will be useful. FCC R&O requires 'OR' rule based collaborative sensing.
  - Correlation with Geo-location Information – Closely tied to collaborative sensing. It tries to cross check the spectral footprint of the detected signal based on location of the sensor
- Spectrum Access Authorization –
  - BS is capable of de-authorizing a subscriber at any time. Sensing and incumbent database service used for spectrum access authorization
  - Capability Check – The Spectrum Manager (SM) is capable of prohibiting a subscriber from registering if it does not have adequate sensing capabilities.
- Radio Behavior Control
  - IEEE 802.22 is policy driven. Policies are rule-based.





Signal classification and policy based behavior control of the 802.22 devices

References

- **IEEE 802.22 Working Group Website – www.ieee802.org/22**
- J. Mitola, *Cognitive Radio: An Integrated Agent Architecture for Software Defined Radio, Ph. D. Thesis, Royal Insti*tute of Technology, Sweden, Spring 2000.
- Gerald Chouinard, Communications Research Center, 802.22 Overview presentation to the 802 Whitespaces Study Group https://mentor.ieee.org/802-sg-whitespace/dcn/09/sg-whitespace-09-0058-00-0000-802-22-presentation-to-ecsg.ppt
- IEEE 802.22 Draftv3.0 – Members only Documents of the IEEE 802.22 Working Group (www.ieee802.org/22)
- Other Contributions to the IEEE 802.22 Standard (www.ieee802.org/22)