IEEE 802.22 –Cognitive Radio-based Regional Area and Smart Utility Networks

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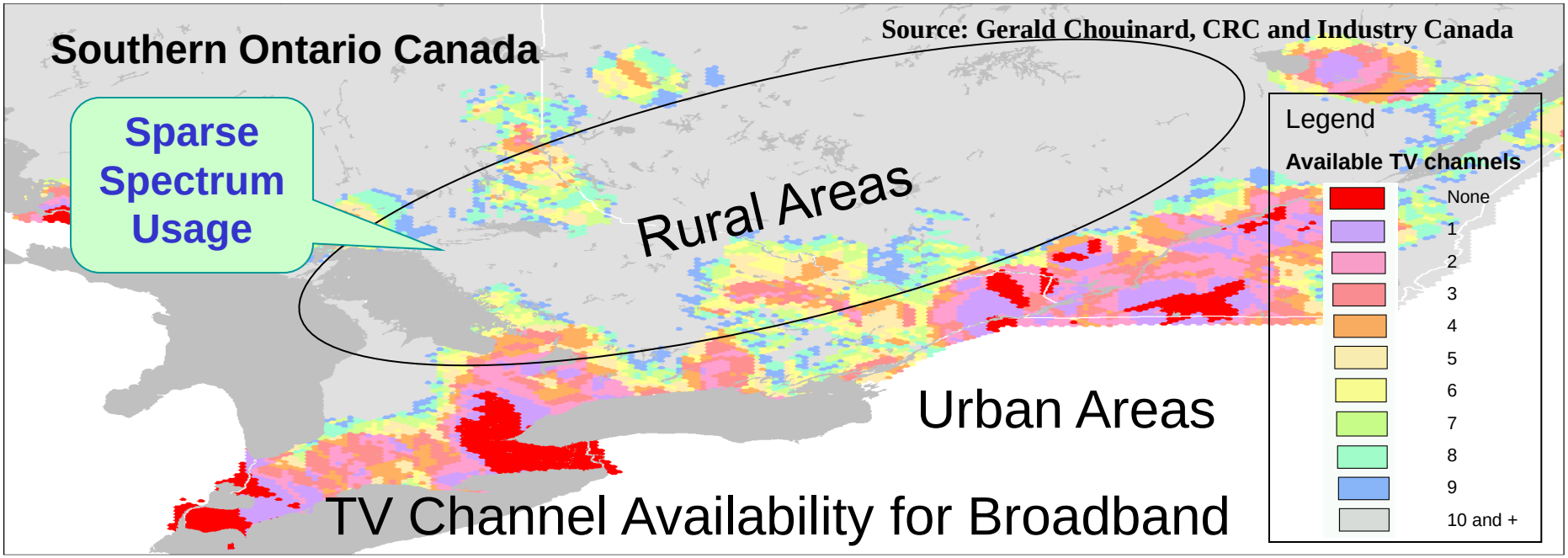
Opportunity: Digital Divide Exists Today

- According to the TIME Magazine, 73% of the world population (5.1 Billion people) has No Internet Access
- 49.5% of the 7 Billion people in the world (~3.5 Billion) live in rural areas with hardly any access to high speed internet.
- It is expensive to lay fiber / cable in rural and remote areas with low population density. *Wireless is the most economically viable solution*
- Traditional wireless carriers have focused on urban areas with high population density (faster Return on Investment) using licensed spectrum
- **This has created a significant opportunity**
- **Cognitive M2M** - Other machine to machine applications will drive up the volumes
  - It has been projected there may be 20-50 times more machine to machine applications as compared to human to human applications.

Television Whitespaces: A New Hope



- VHF / UHF bands traditionally reserved to broadcasters have highly favorable propagation characteristics. Penetrating through foliage and structures, they reach far and wide
- The worldwide move from analog to digital TV frees up spectrum creating what is called ‘WhiteSpaces’
- These WhiteSpaces will deliver quality high speed internet access
- **WhiteSpaces offer ten times the coverage and three times the capacity of the Wi-Fi™ spectrum**

TVWS Regulations Around the World

Canada Regulations completed – Total 300 MHz (Ch. 2-51) being considered for license-exempt operation, of which 180 MHz (ch. 21-51) have already been open for light-licensing for remote rural broadband access since June 2009

Brazil – DTV transition on-going. Realizes the importance of broadband for rural (e. g. Res. 558, Operation in 450 – 470 MHz)

USA Regulations completed – Total 288 MHz freed up (Sept 2010) for license-exempt operation. Geolocation database, sensing driven. Some of this band may be auctioned off

UK Final Rules to be released this year – License-exempt database driven approach

ITU – Several study groups are discussing cognitive radio based operation. TVWS will be a discussion topic in 2015 WRC. IEEE 802 is providing inputs

Egypt – Participating in IEEE 802.22

EU (CEPT) Discussions on-going – license-exempt, collaborative sensing, database approaches considered. Variable transmit power based on device capabilities, microphone protection beacon

India Discussions on-going – 368 – 380 MHz for rural. 470 MHz – 585 MHz for fixed and mobile. Further discussions in 2015 time-frame

Japan (MIC) Discussions on-going Final rules before 2015. 10 WS projects under way – WS Test Area to be allocated

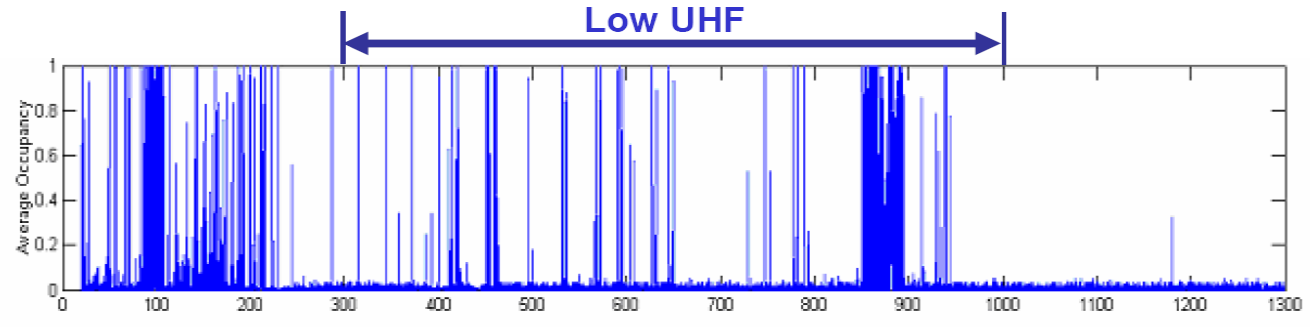
Singapore Testing devices on-going (IDA)– Final rules before 2015. 12 channels for testing. May allow bonding of up to 8 channels. Sensing , database required

What can Television Whitespaces do?

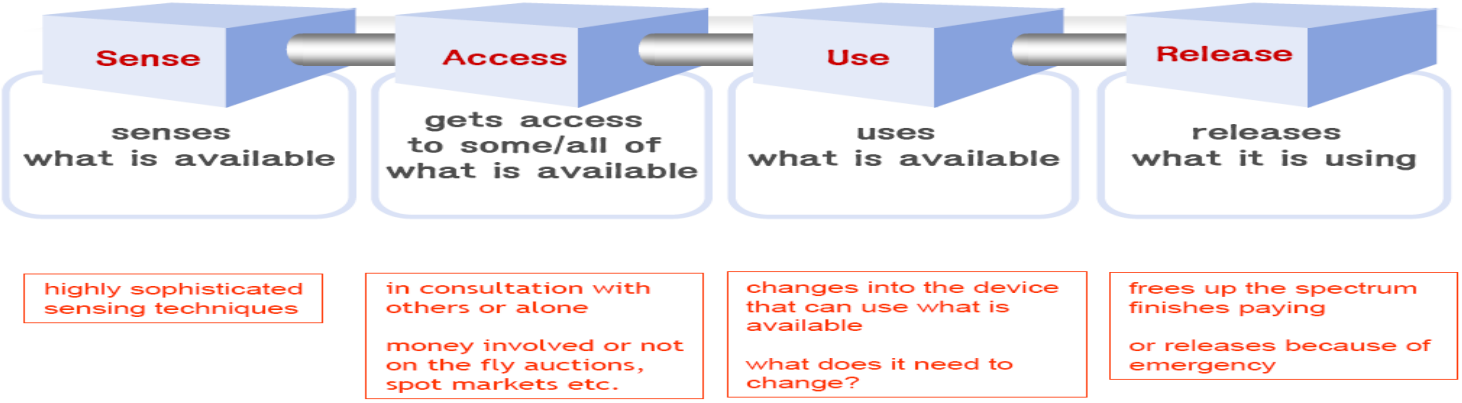
Wireless Regional Area Networks such as IEEE 802.22 systems using TV Whitespaces can connect rural areas in emerging markets.

- Television Whitespaces (TVWS) will allow broadband wireless access to regional, rural and remote areas under Line of Sight (LoS) and Non Line of Sight (NLoS) conditions.
- Other Applications:
  - Smart grid
  - Cheap backhaul using multi-profile RAN stations
  - Triple play for broadcasters (e. g. video, voice and data),
  - Off-loading cellular telephony traffic to un-licensed spectrum,
  - Distance learning, civic communications, regional area public safety and homeland security, emergency broadband services,
  - Monitoring rain forests, monitoring livestock, border protection,
  - Broadband service to multiple dwelling unit (MDU), multi tenant unit (MTU), small office home office (SoHo), campuses, etc.

Need for Cognitive Radio and Dynamic Spectrum Access Technologies



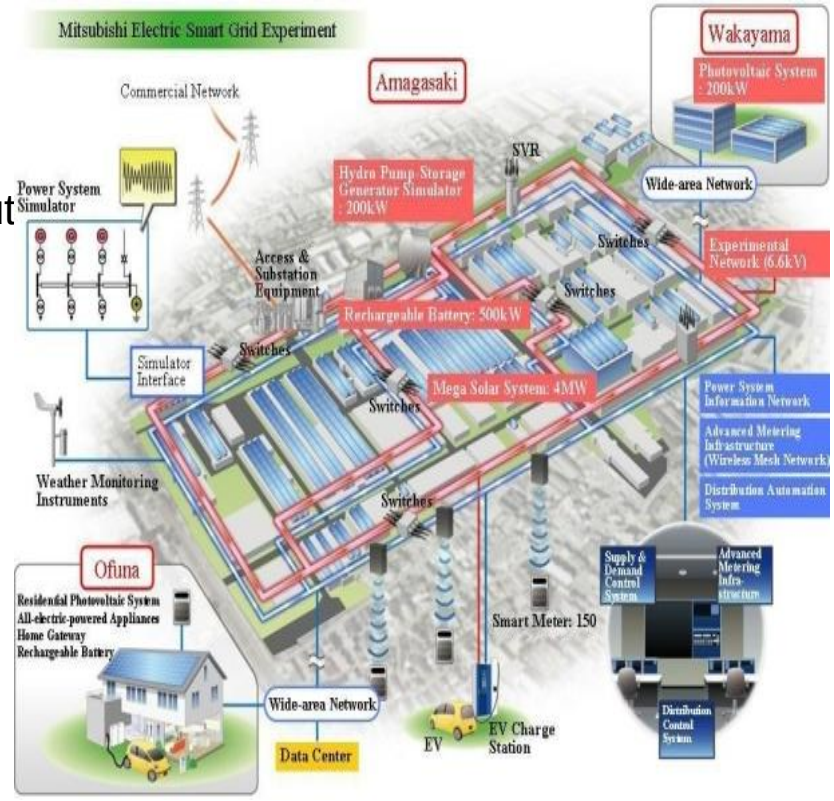
- Figure shows the average spectrum occupancy in the VHF / UHF bands
- It is found that less than 14% of the spectrum is effectively utilized – 86% of the spectrum is not used or scarcely used
- Dynamic Spectrum Access (DSA) allows opportunistic usage of the spectrum and co-existence with the incumbents: thus improving the spectrum utilization through the use of these **Whitespaces**



Cognitive M2M

Machine to Machine Communications Systems may face many challenges

- Licensed AND license-exempt spectrum (has to tolerate interference)
- In general low cost
- Demanding environment – fixed, portable AND mobile devices that may suffer from wide link margins requirements due to shadowing and fading
- Dense deployments – Dense deployments that require advanced technologies such as
  - Ad hoc networks and mesh
  - Co-existence
  - Security
- High throughput video monitoring and low throughput meter monitoring and control
- Use of Cognitive radio techniques makes a lot of sense for M2M applications.
- Cognitive M2M communications will sense the environment and identify the best strategy to transport the information from source to the destination – (licensed, license-exempt, which channel, DSSS, FSK, OFDM etc.)
- Key challenge – Need to meet the low cost and complexity requirements



Activities in IEEE 802.22 - Wireless Regional Area Networks

Apurva N. Mody, Chair of IEEE 802.22 Standard WG

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

IEEE 802.22 Standard – Wireless Regional Area Networks: Cognitive Radio based Access in TVWS: Published in July 2011

- **IEEE 802.22 Standard was completed in July 2011**
- **Over 150 people have participated in this standardization activity**

802.22.1 – Std for Enhanced Interference Protection in TVWS: Published in Nov. 2010

802.22.2 – Std for Recommended Practice for Deployment of 802.22 Systems: Expected completion - Dec 2012

802.22a – Enhanced Management Information Base and Management Plane Procedures: Expected Completion - Dec. 2013

802.22b RASGCIM – Regional Area Smart Grid and Critical Infrastructure Monitoring

Solution - IEEE 802.22 Standard

- IEEE 802.22 provides Broadband Wireless Access to Regional, Rural and Remote Areas Under Line of Sight (LoS) and Non Line of Sight (NLoS) Conditions using Cognitive Radio Technology (*without causing harmful interference to the incumbents*).

- Cognitive Radio technology added to a simple and optimized OFDMA waveform (similar to the OFDMA technology used in other broadband standards

- Meets all the regulatory requirements such as protection of incumbents, access to the database, accurate geolocation, spectrum mask, control of the EIRP etc.

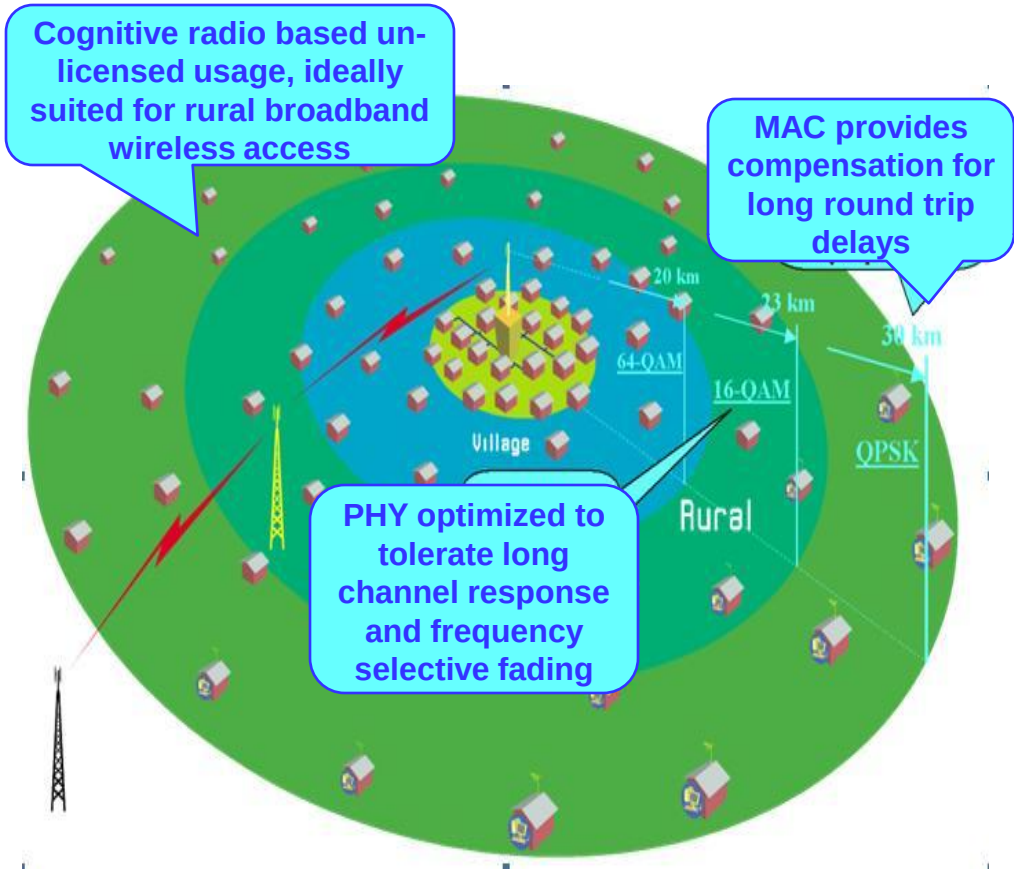
- Large regional area foot can allow placement of the Base Station closer to the area with cheaper internet backhaul / backbone.

802.22 Unique Proposition

- *First* IEEE Standard for operation in Television Whitespaces
- *First* IEEE Standard that is specifically designed for rural and regional area broadband access
- *First* IEEE Standard that has all the Cognitive Radio features
- IEEE 802.22b Amendment will benefit M2M Control and Monitoring Applications

Overview of the IEEE 802.22 Standard

- Core Technology - Cognitive radio technology used to co-exist with and protect the primary users (incumbents).
- Representation – Commercial industry, Broadcasters, DoD, Regulators, and Academia
- Membership – 30 on an average (over 5 years)
- CONOPS - VHF and UHF band operation allows long range propagation and cell radius of 10 – 30 km, exceptionally extensible to 100 km 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 Cognitive Radio based operation: spectrum sensing, spectrum management, incumbent protection, coexistence, geo-location and security



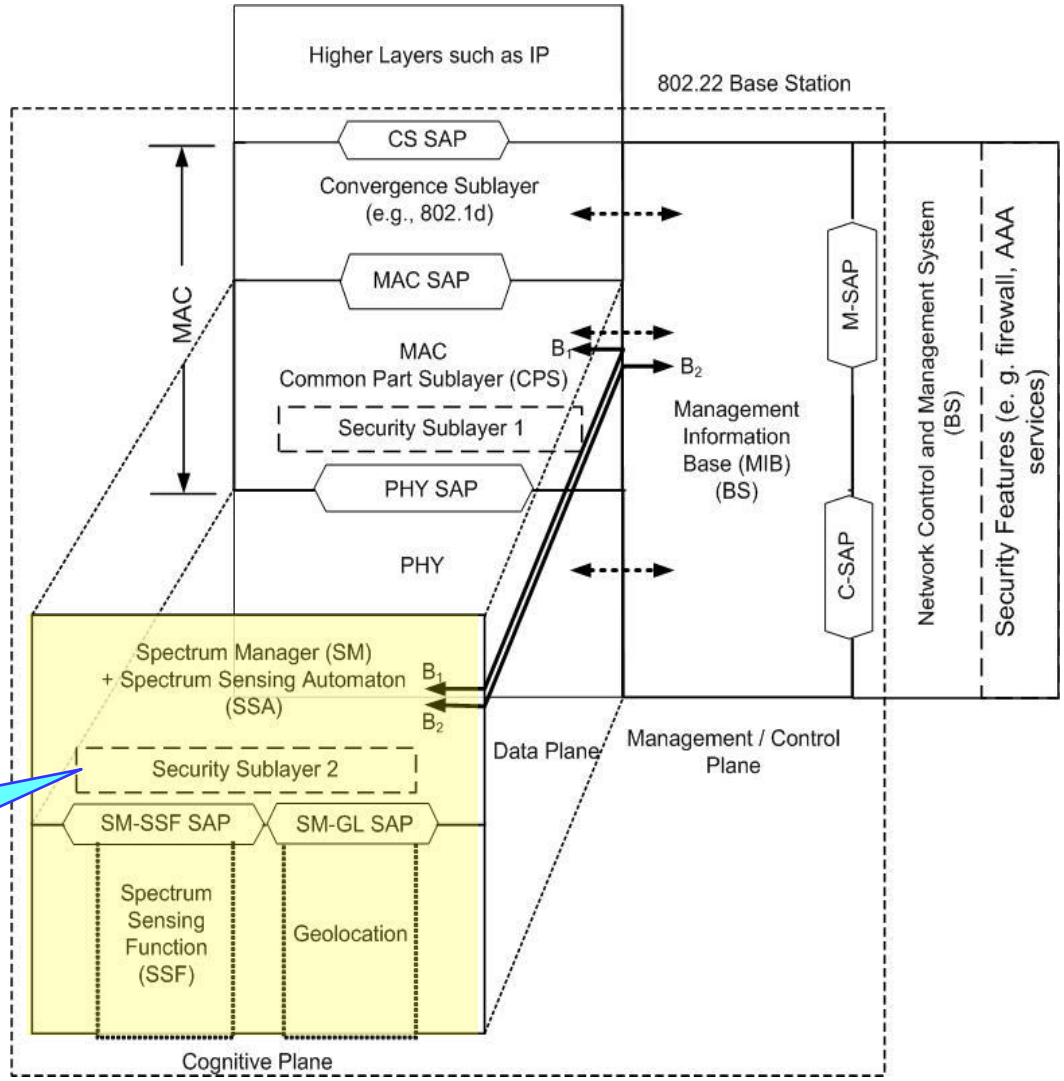
- Portability – IEEE 802.22 allows portability (nomadic use). In case the rules do change, IEEE 802.22 PHY is designed to support mobility of up to 114 km/h (no hand-off is included in the current version).

IEEE 802.22
Cognitive Node: Reference Architecture

IEEE 802.22 Provides Three Mechanisms for Incumbent Protection

- Sensing
- Database Access
- Specially Designed Beacon

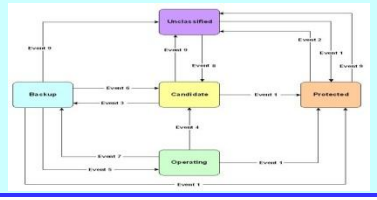
Security Sub-layers are introduced to protect non-cognitive as well as cognitive functions



Cognitive Plane is used to control the Cognitive Radio Operation. Security Sublayer 2 is introduced for protection against Cognitive Threats

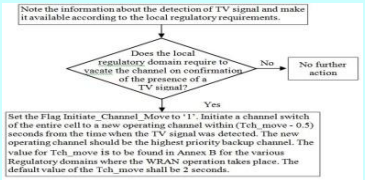
IEEE 802.22 – Cognitive Radio Capability

Channel Set Management



Subscriber Station Registration and Tracking

Policies



Spectrum Manager

Timer $T_{Wait\_Before\_Channel\_Move}$ Expires
SM_Find_Operating_Channel

Event
Action – Execute the Specified Procedure

New CPE Registration Request
SM_New_CPE_Verification

Timer $T_{Refresh\_Database\_Info}$ Expires
SM_Database_Update

Spectrum Manager at Network Initialization

Operating Channel Identified
SM_Establish_Network

Spectrum Manager at Network Operation

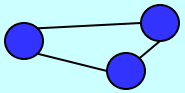
Signal Detected
SM_Determine_Signal_Type_Execute_Policies

Flag 'Initiate_Channel_Move' = 1
SM_Initiate_Channel_Move

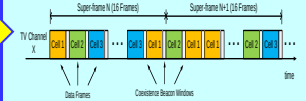
Flag 'Self_Coexistence_Mode' = 1
SM_Self_Co_existence_Mode

- (No associated event)
SM_Background_Processes

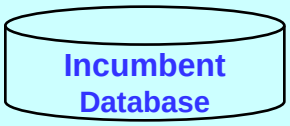
Geo-location



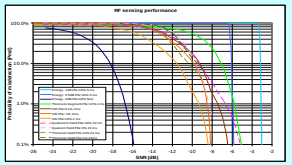
Self Co-existence



Incumbent Database Service



Spectrum Sensing



Kinsley, Kansas, USA

TV Channel Availability

Rural Town, Moderate Density

Enter your device type and location below

Fixed TVBD < 3m | Fixed TVBD < 10m | Fixed TVBD <= 30m | Portable 100mW | Portable 40mW | Protected

Kinsley, Kansas — Search

Best match:Kinsley, KS

The table shows all the 6 MHz TV channels between channels 2 and 51 that are potentially available for secondary use by White Space radios (i.e. TV Band Devices or TVBDs).

Channel Map Legend

- ✖ Your location is within the service area of a TV station or other licensed user and this channel cannot be used by a TVBD.
- ✔ This channel is vacant in your location, and can potentially be used by your TVBD.
- ✔ This channel is vacant in your location, and can potentially be used by your TVBD, but personal portable devices may not be used on channels 2-20.
- This channel is reserved for wireless microphone use.
- Warning: Height Above Average Terrain (HAAT) exceeds 76m! White Space Devices cannot be used at this location.

Available Channels

Fixed TVBD < 10m

HAAT: -08.75 meters

View Full Map

2 ✔	19 ✔	36 🎤
3 ✖	20 ✔	37 ✖
4 ✖	21 ✖	38 🎤
5 🎤	22 ✖	39 ✔
6 ✖	23 ✖	40 ✔
7 ✖	24 ✔	41 ✔
8 ✔	25 ✔	42 ✔
9 ✔	26 ✖	43 ✔
10 ✔	27 ✔	44 ✔
11 ✔	28 ✔	45 ✔
12 ✔	29 ✔	46 ✔
13 ✔	30 ✔	47 ✔
14 ✔	31 ✔	48 ✔
15 ✔	32 ✔	49 ✔
16 ✔	33 ✔	50 ✔
17 ✔	34 ✔	51 ✔
18 ✔	35 ✔	

Courtesy: Spectrum Bridge: http://spectrumbridge.com/whitespaces.aspx

Manhattan, New York TV Channel Availability

Urban City with very high population density

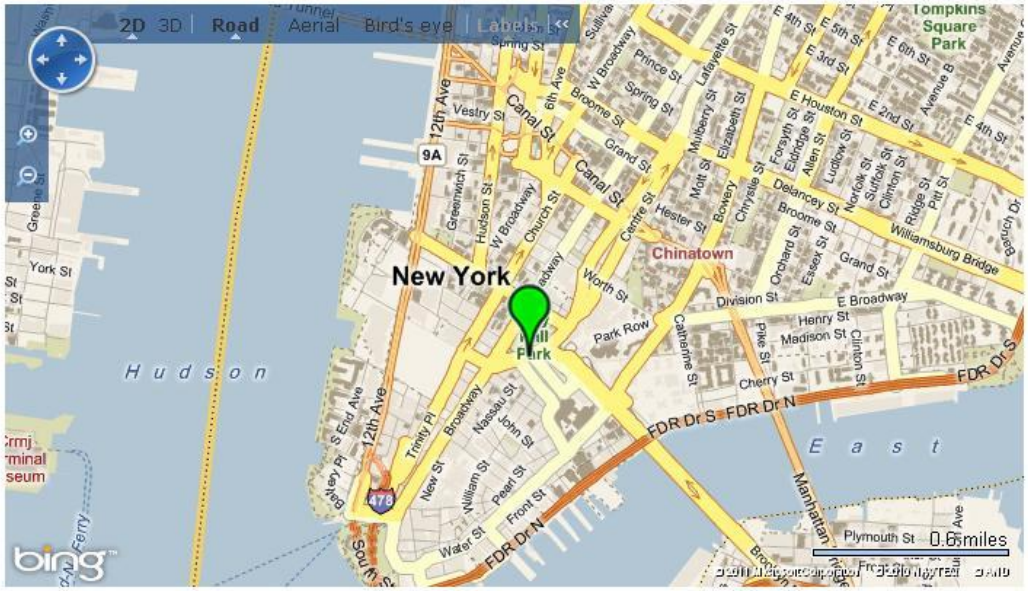
Cities like Manhattan are not potential deployment markets for IEEE 802.22 Technology

Enter your device type and location below

Fixed TVBD < 3m | Fixed TVBD < 10m | Fixed TVBD <= 30m | Portable 100mW

new york — Search

Best match:New York, NY



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Available Channels

Fixed TVBD < 10m

HAAT: -01.34 meters

View Full Map

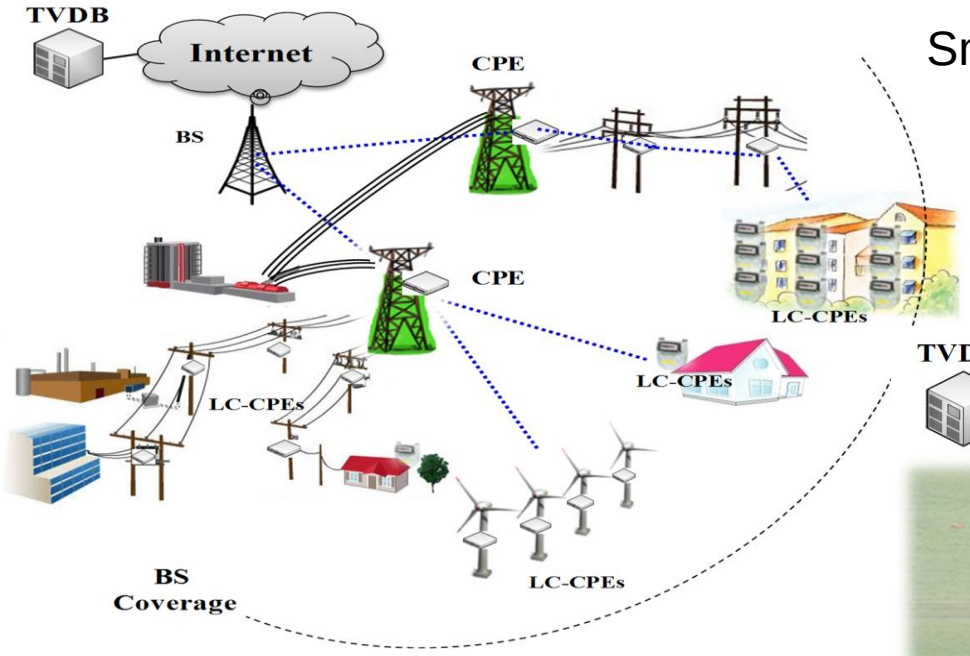
2	✗	19	✗	36	✗
3	✗	20	✗	37	✗
4	✗	21	✗	38	✗
5	mic	22	✗	39	✗
6	✗	23	mic	40	✗
7	✗	24	✗	41	mic
8	✗	25	✗	42	✓
9	✗	26	✗	43	✗
10	mic	27	✗	44	✗
11	✗	28	✗	45	✗
12	mic	29	✗	46	✗
13	✗	30	✗	47	✗
14	✗	31	✗	48	✗
15	✗	32	✗	49	✗
16	✗	33	✗	50	✗
17	✗	34	✗	51	✗
18	✗	35	✗		

Courtesy: Spectrum Bridge: http://spectrumbridge.com/whitespaces.aspx

Smart Grid Applications

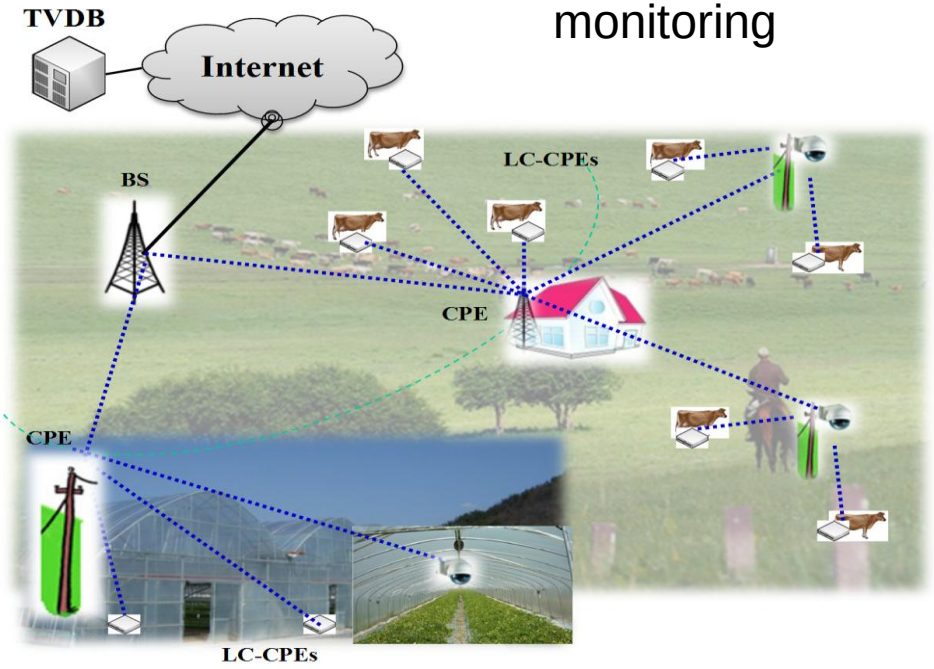
Smart Grid Applications	Requirements in General
Distribution Automation • Volt-VAR management • Conservation Voltage Reduction • Sensor monitoring, management and control	• Lower and higher speeds required • Reliability and security important • Low latency needed • Real and near-real time operation • Mesh may be desirable • Bi-directional communications
Smart Metering • AMI	• Hundreds of devices • Lower speeds are okay • Non real time is okay • Mesh operation

IEEE 802.22 User Cases



Smart Grid

Agricultural and livestock monitoring



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

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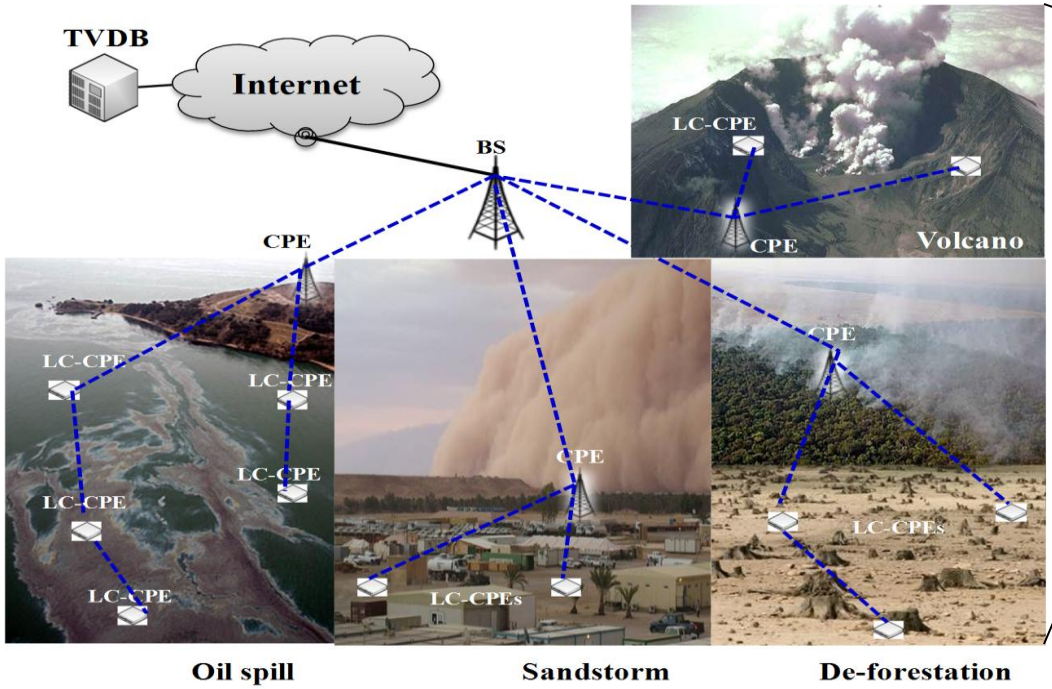
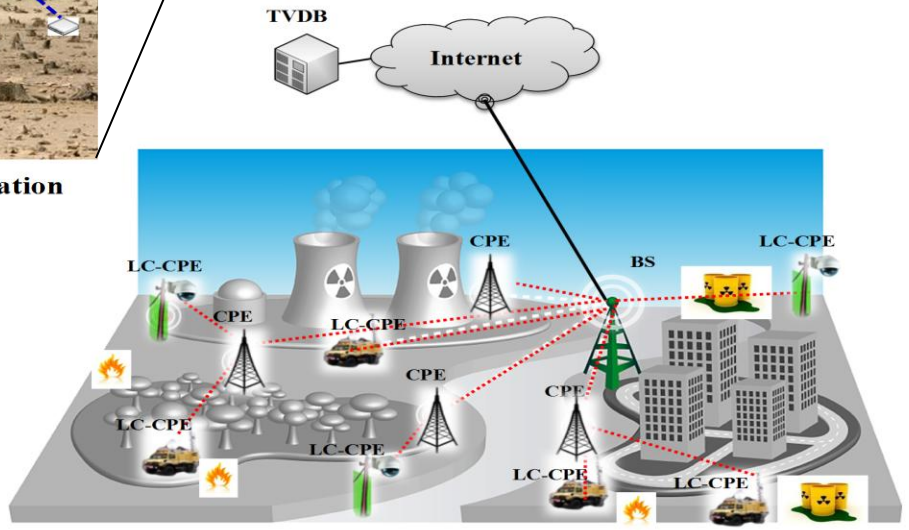
Enhanced Broadband and Monitoring Use Cases for Proposed P802.22b Project

Category	Usage Cases	Properties
A) Smart Grid & Monitoring	A1) Regional Area Smart Grid/Metering	• Low capacity/complexity CPEs • Very large number of monitoring CPEs • Fixed and Potable CPEs • Real time monitoring • Low duty cycle • High reliability and security • Large coverage area • Infrastructure connection
	A2) Agriculture/Farm House Monitoring	
	A3) Critical Infrastructure/Hazard Monitoring	
	A4) Environment Monitoring	
	A5) Homeland Security/Monitoring	
	A6) Smart Traffic Management and Communication	
B) Broadband Service Extension	B1) Temporary Broadband Infrastructure (e.g., emergency broadband infrastructure)	• Fixed and Portable CPEs • Higher capacity CPEs than Category A) • High QoS, reliability and security • Higher data rate than Category A) • Easy network setup • Infrastructure and Ad hoc connection
	B2) Remote Medical Service	
	B3) Archipelago/Marine Broadband Service	
C) Combined Service	C1) Combined Smart Grid, Monitoring and Broadband Service	• Category A) and B)

IEEE 802.22 User Cases



Environment monitoring – e. g. monitoring deforestation



Critical infrastructure and hazard monitoring

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

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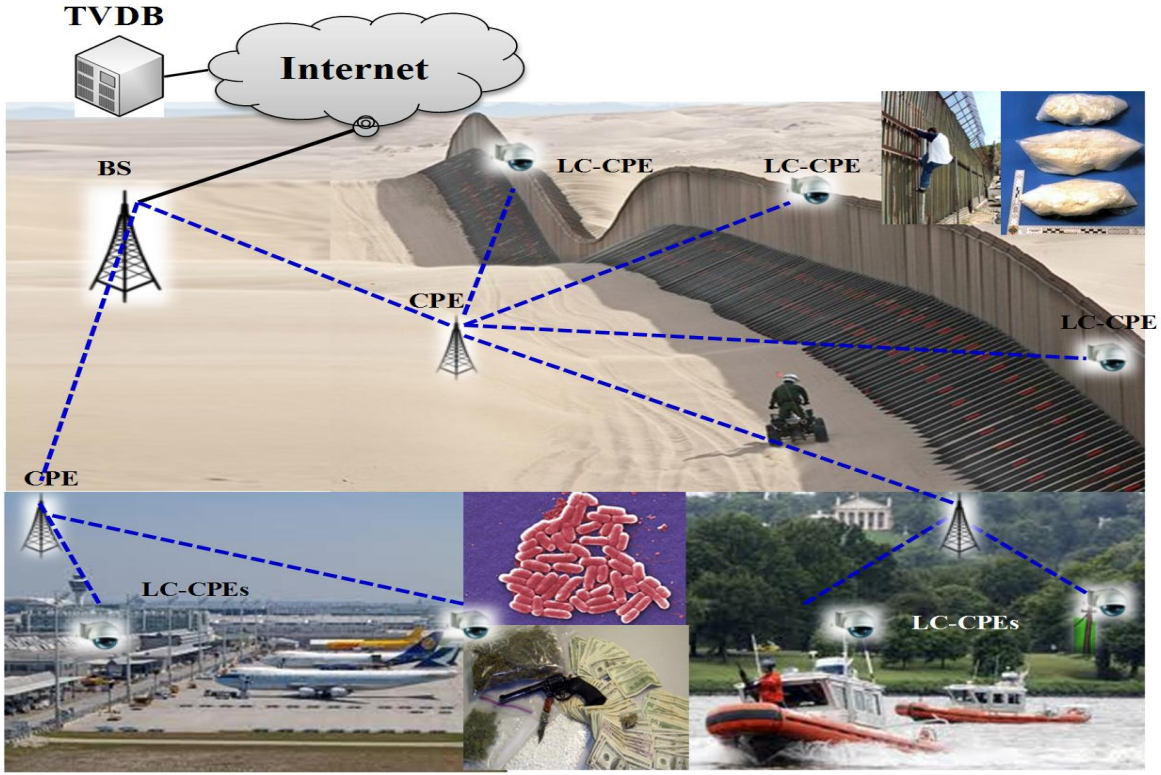
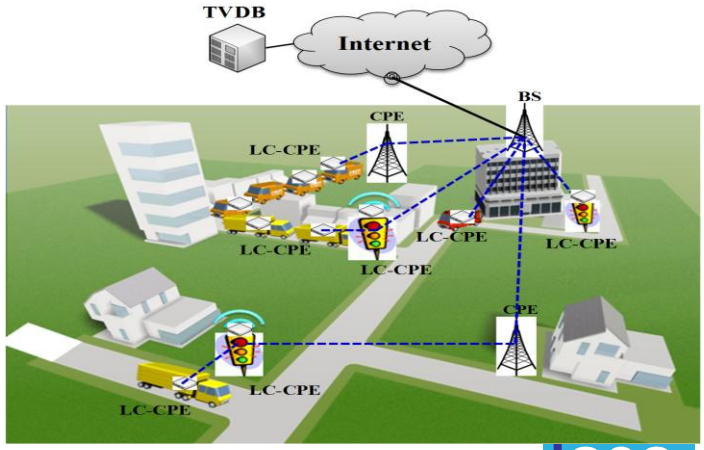
IEEE 802.22 User Cases



Homeland Security

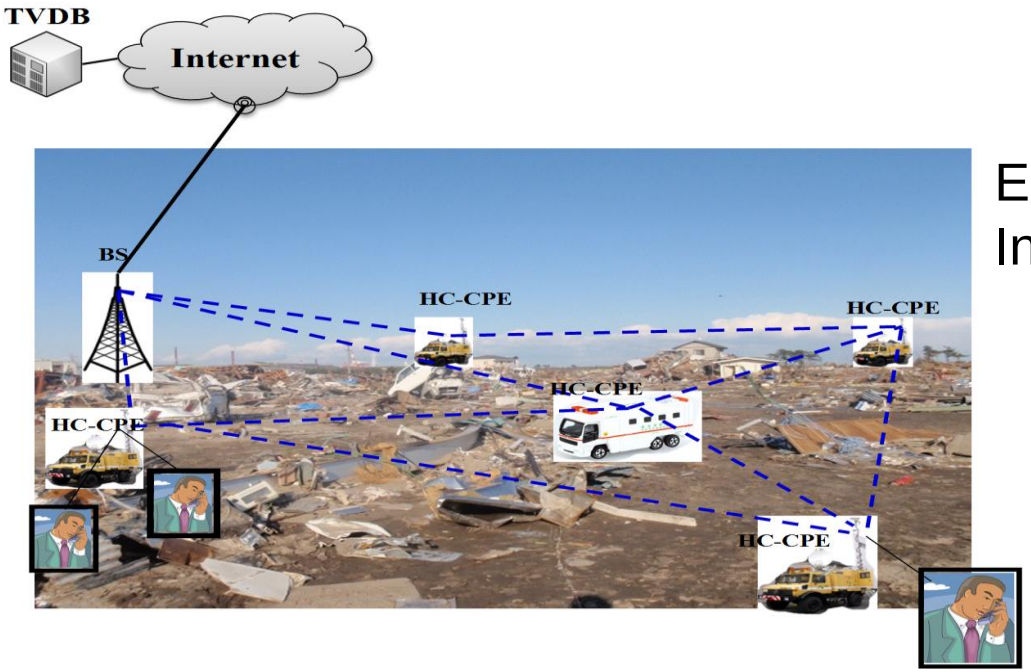
- TVDB = (TV Database)
- LC- CPE = Low Complexity CPE

Smart traffic management

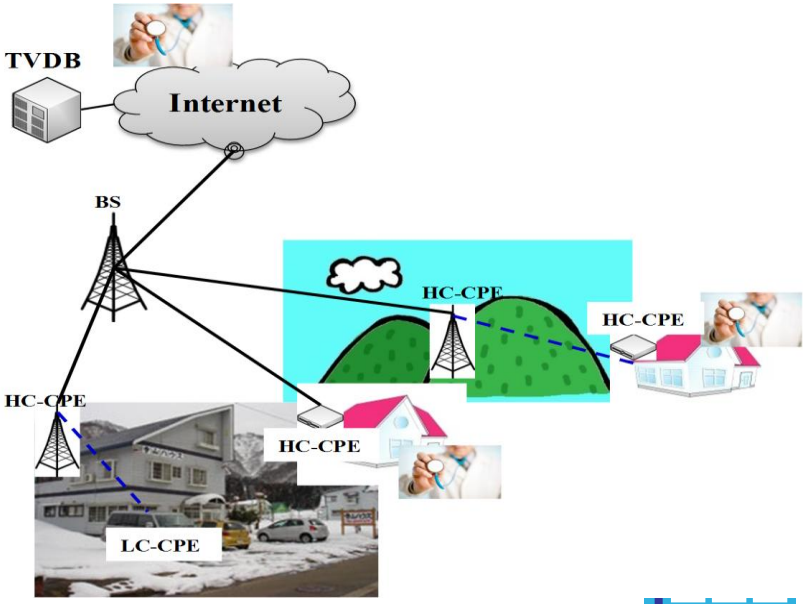


C. W. Pyo, A. Mody et al. Use Cases for IEEE 802.22 Smart Grid and Critical Infrastructure Monitoring

IEEE 802.22 User Cases



Emergency Broadband Infrastructure



- TVDB = (TV Database)
- HC- CPE = Higher Complexity CPE

Remote medical service

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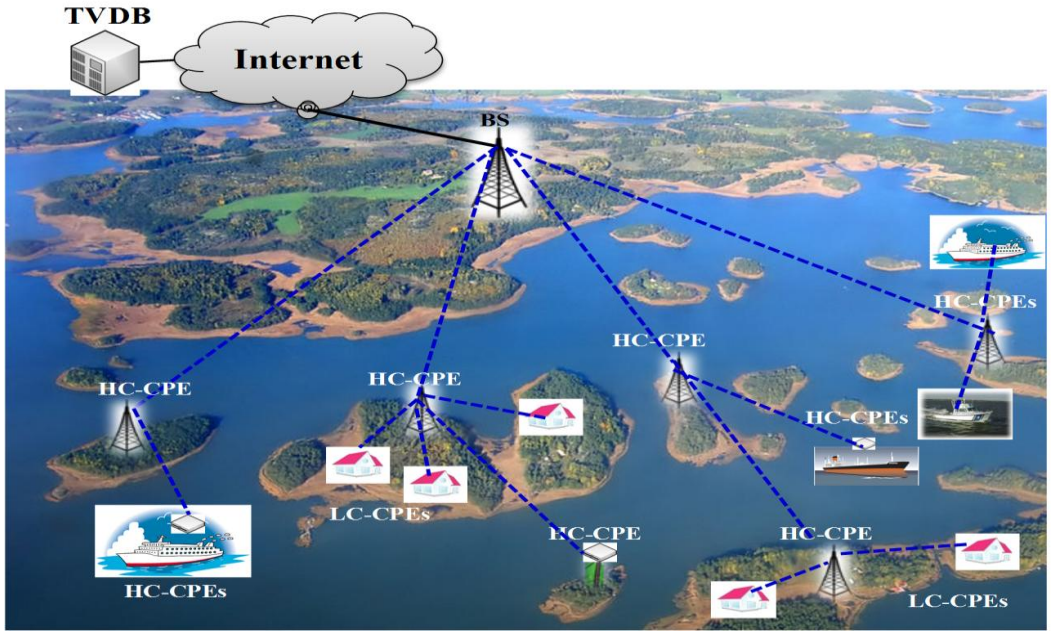
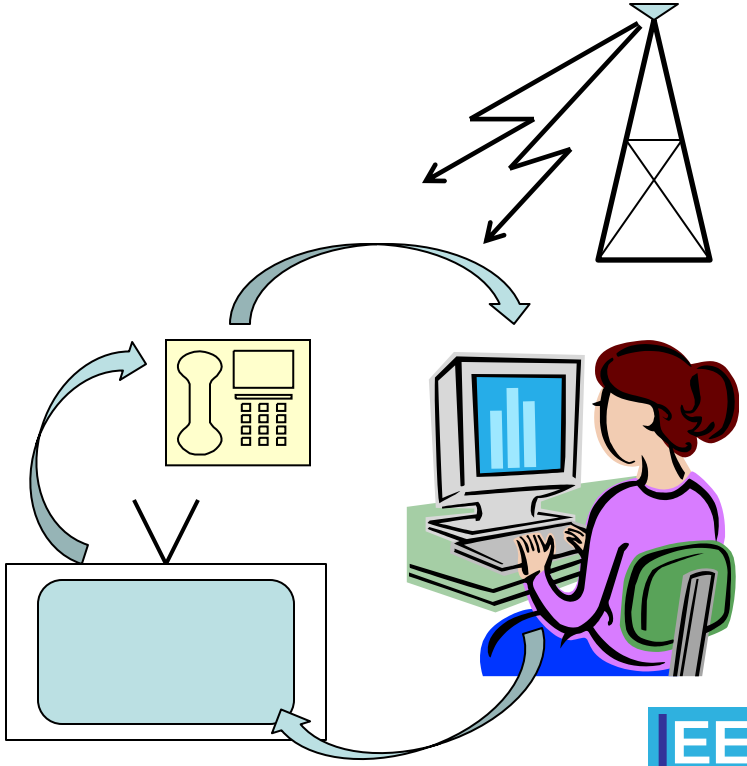
IEEE 802.22 User Cases



Archipelago and marine broadband service. Servicing oil rigs



Triple play (Bi-directional Video, Voice and Data) for traditional TV Broadcasters

- TVDB = (TV Database)
- HC- CPE = Higher Complexity CPE

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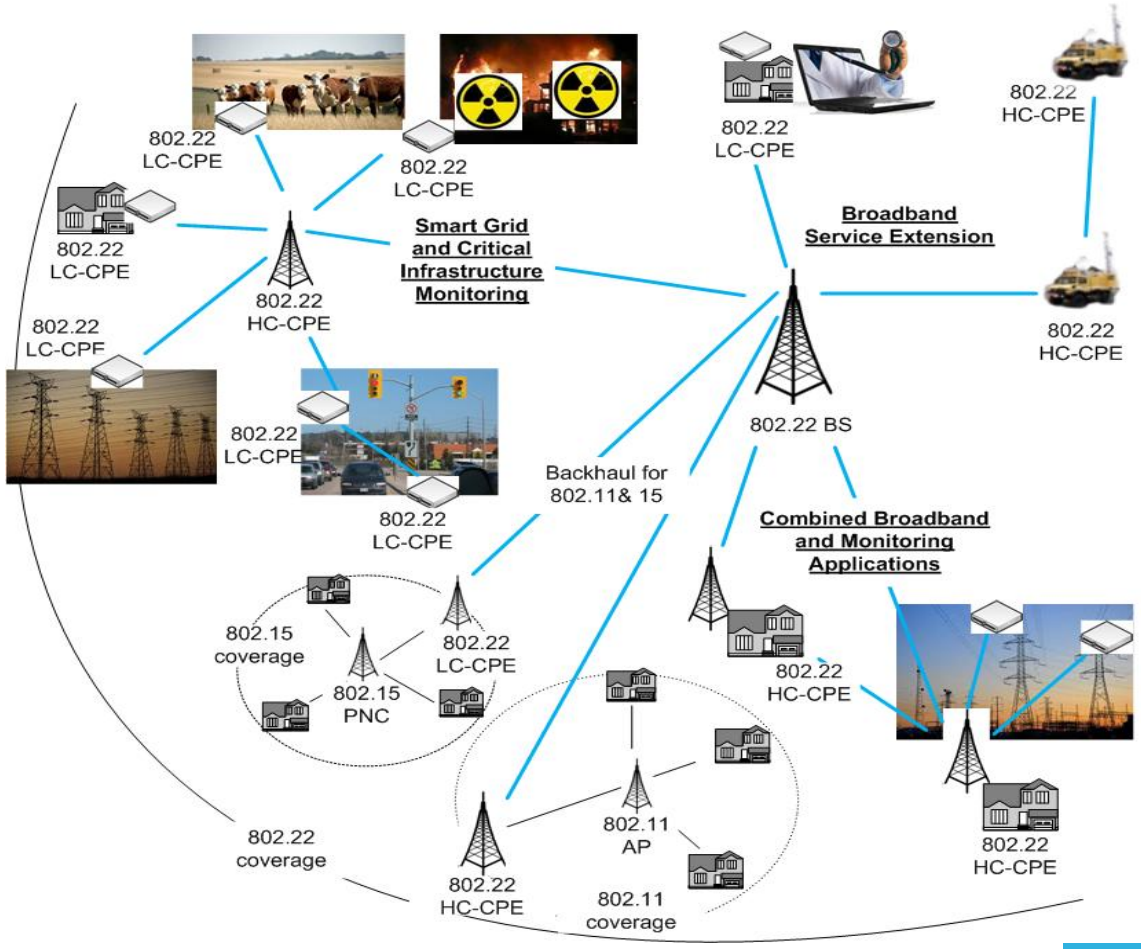
IEEE 802.22 User Cases

- IEEE 802.22 systems can provide backbone for Distribution Automation as well as other applications such as Smart Metering
- Broadband service extension – integrated smart grid and other applications



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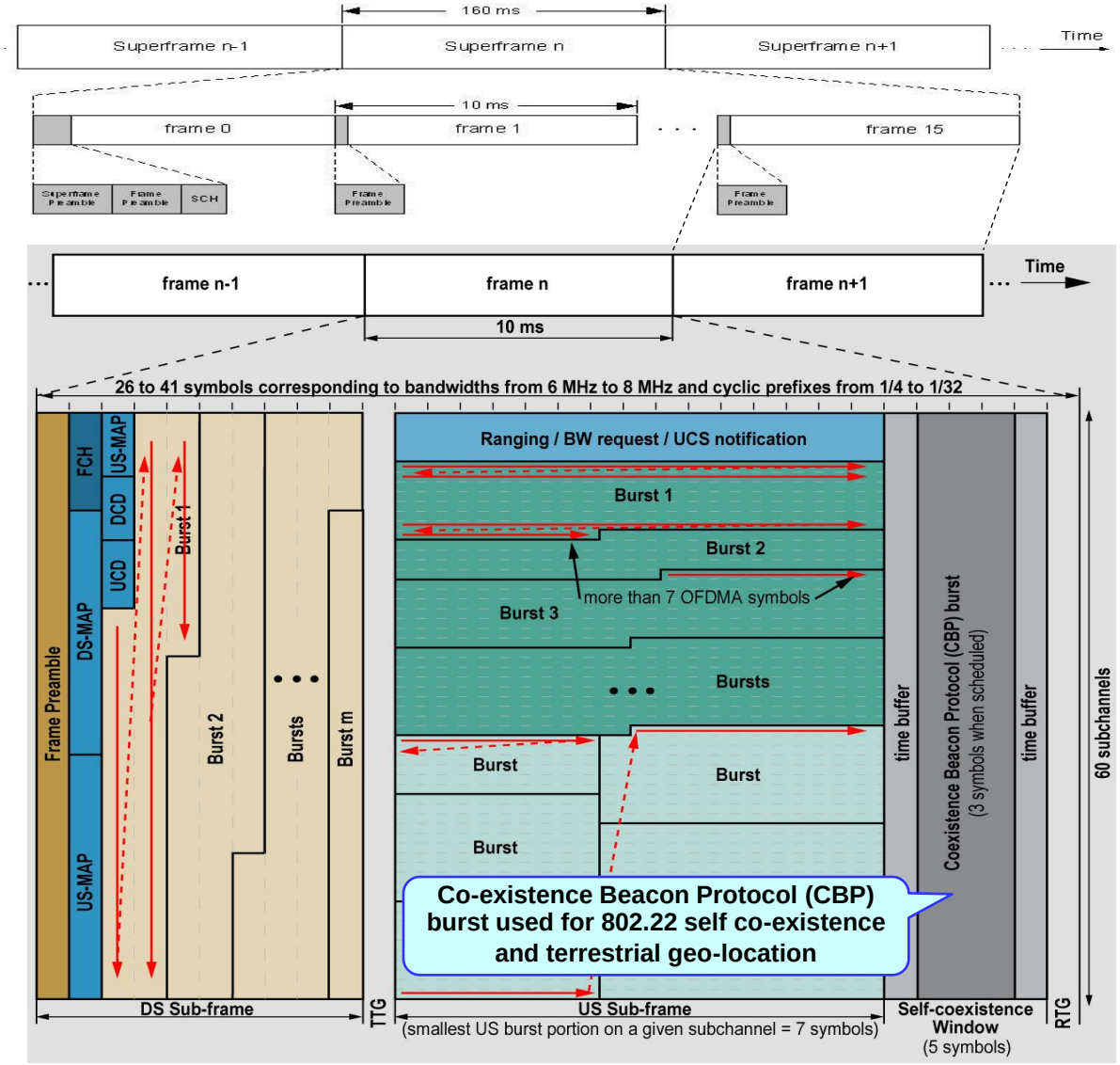
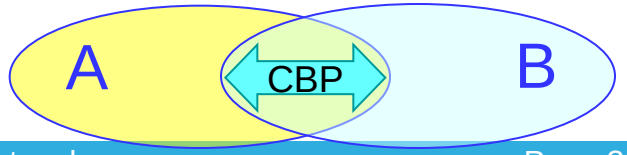
IEEE 802.22 – Frame Structure

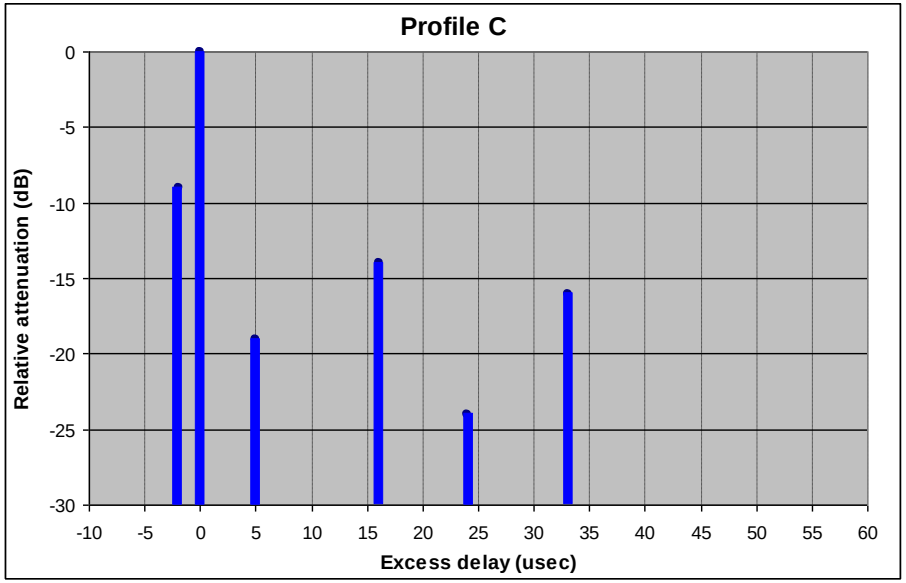


- 802.22 supports Time Division Duplex (TDD) frame structure
  - Super-frame: 160 ms, Frame: 10 ms
  - Each frame consists of downstream (DS) sub-frame, upstream (US) sub-frame, and the Co-existence Beacon Protocol (CBP) burst
  - Lengths of DS and US sub-frames can be adjusted.
- Self-coexistence Window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



TV Channels Characteristics

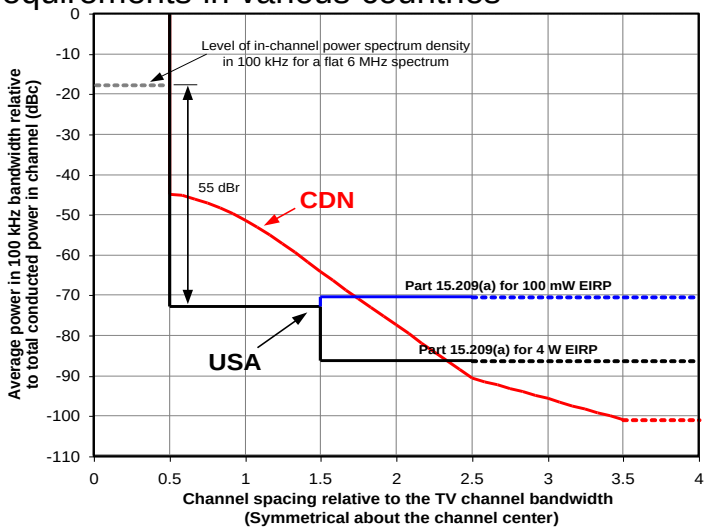
- Multipath Channel Characteristics
  - Frequency selective with large excessive delay
    - Excessive delay (measurements in US, Germany, France*)
      - Longest delay: >60 μsec
      - 85% test location with delay spread ~35 μsec
    - Low frequency (54~862 MHz)
    - Long range (up to 100 km)
  - **Slow fading**
    - Small Doppler spread
    - (up to a few Hz)



* WRAN Channel Modeling, IEEE802.22-05/0055r7, Aug 05

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 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
- Spectral Mask - IEEE 802.22 PHY flexible to meet Spectral Mask requirements in various countries



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)

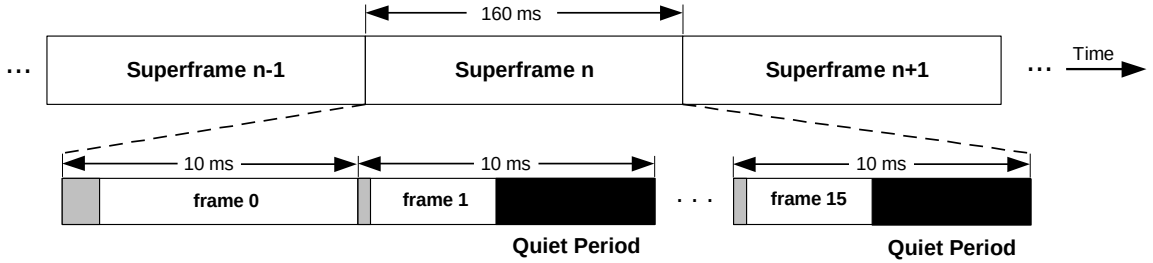
Mod.	Rate	SNR
QPSK	1/2	4.3
	2/3	6.1
	3/4	7.1
	5/6	8.1
16QAM	1/2	10.2
	2/3	12.4
	3/4	13.5
	5/6	14.8
64QAM	1/2	15.6
	2/3	18.3
	3/4	19.7
	5/6	20.9

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

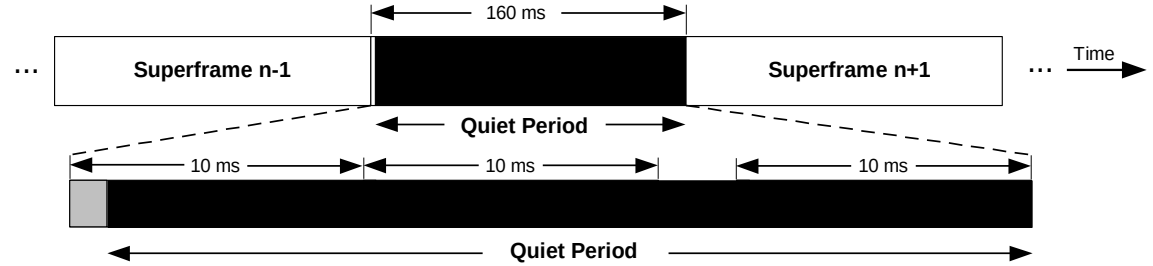
IEEE 802.22 – MAC Features

- 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 (160 ms)
  - Subscribers stations can alert the BS of the presence of incumbents in a number of ways. Dedicated - Urgent Co-existence Situation (UCS) messages or lower priority MAC messages
  - BS can ask one or more subscribers to move to another channel in a number of ways using the 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.



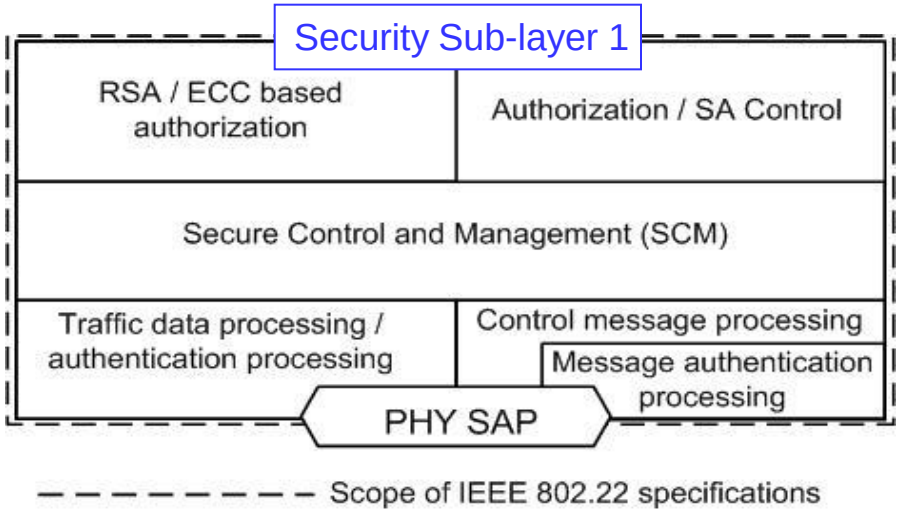
Intra-frame quiet period scheduling

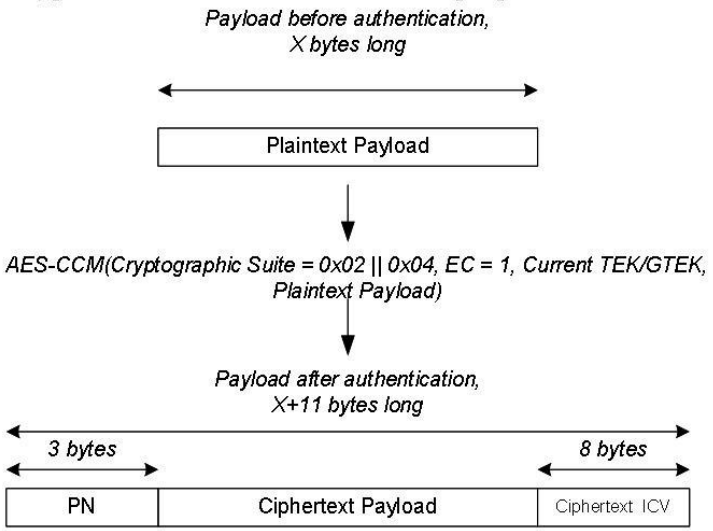


Inter frame quiet period scheduling

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

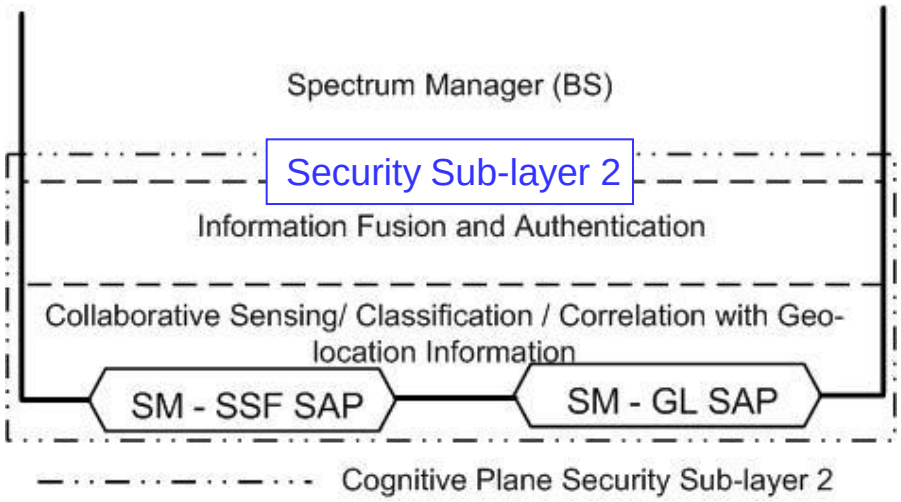
- Confidentiality and Privacy – AES (128) GCM is used for encryption and authentication
- Network Authorization – RSA and ECC based X.509 certificates are used for mutual authentication / network entry authorization.
- Integrity – AES-GCM is used to compute Integrity Check Vector (ICV). PN sequence numbers 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.

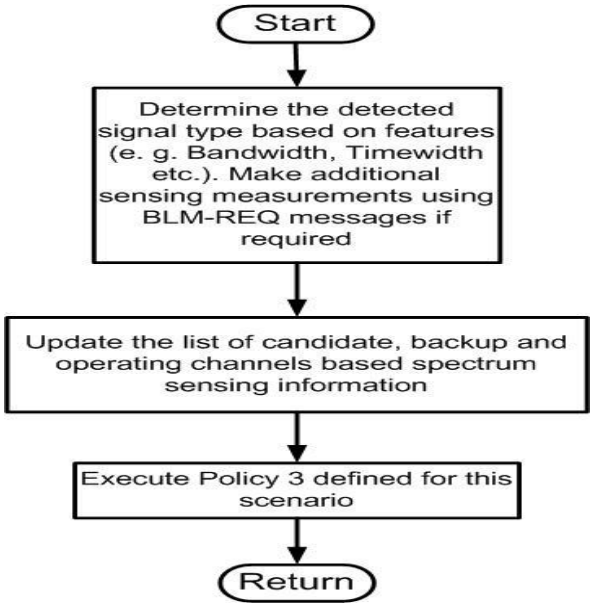




IEEE 802.22 – Security Sub-layer 2 (Cognitive)

- **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

Introducing the WhiteSpace Alliance

WhiteSpace Alliance™

www.WhiteSpaceAlliance.org

WhiteSpace Alliance Mission

The mission of the WhiteSpace Alliance is to:

- Act as a *technology neutral* organization and a *catalyst* in shaping the worldwide Whitespace ecosystem for delivering cost-effective wireless broadband solutions.
- Simplify existing standards and specifications for cost-effective deployment.
- Make enhancements where required.

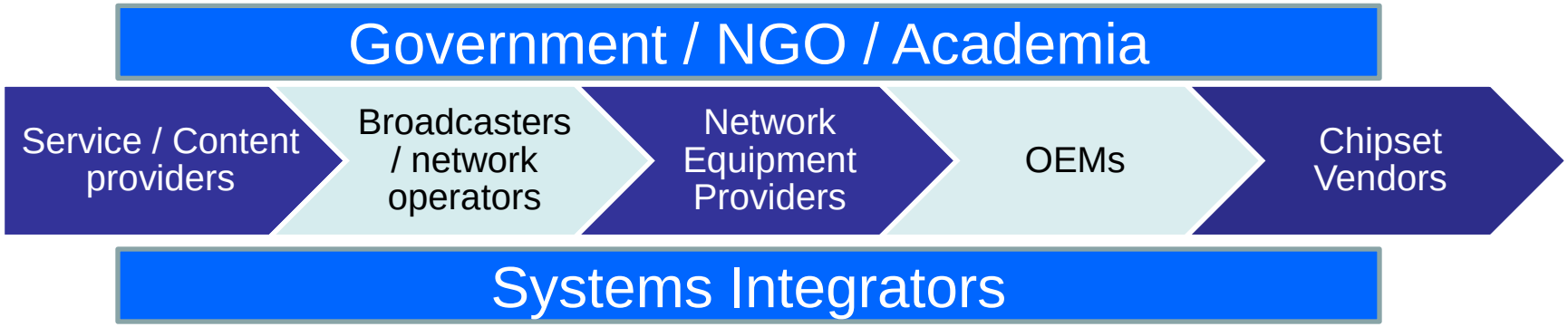
This will allow the members to gain:

- Market lead with early access to draft standards and specifications before they are made public.
- The ability to collectively educate and seed the market for WhiteSpace solutions and services to improve Return on Investment (ROI)
- Confidence in vendor interoperability through certification and interoperability testing.

Introducing the WhiteSpace Alliance

- WhiteSpace Alliance was launched on **Dec. 15th 2011**
- It is formed by companies with diverse needs but a common vision to collectively realize this opportunity
- Shape the worldwide WhiteSpace ecosystem and regulations to deliver cost-effective broadband solutions
- Promote the use of simplified standards, products and services that use WhiteSpace spectrum
- Ensures that the Alliance members benefit by leveraging peer and multi-disciplinary expertise with known IPR costs
- Does all this in a timely fashion with a shared and limited risk

WhiteSpace Alliance Value Chain and Vision



- Gain market lead with access to draft standards and specifications before they are made public
- Members gain the ability to collectively educate and seed the market for WhiteSpace solutions and services and improve Return on Investment (ROI)
- Gain confidence in vendor interoperability through certification and interoperability testing

www.WhiteSpaceAlliance.org

Leverage the Emerging Marketplace as a Technology Neutral Organization

- WhiteSpace Alliance will adopt, create and simplify Standards based protocols and waveforms for deployment in WhiteSpaces.
- Some of the standards based solutions may include:
- **IEEE 802.22-2011** Standard which is the *First* IEEE 802 Standard: Specific for WhiteSpace operation, *D*esigned for rural and regional area broadband access, *H*as all the required Cognitive Radio features. 802.22 WG is the recipient of the prestigious *IEEE Emerging Technology Award*
- **3GPP LTE** – WhiteSpace Alliance plans to complement the offering in higher density areas and offload the current market applications using 4G technologies such as 3GPP LTE. WhiteSpace Alliance recognizes the world-wide move towards 3GPP LTE as a 4G technology of choice, which can be deployed in WhiteSpaces.
- **IEEE 802.16** - WhiteSpace Alliance may also adopt solutions based on the IEEE 802.16 technology where significant investment has been made, and a mature ecosystem exists.
- **IEEE 802.19.1** – WhiteSpace Co-existence Solutions
- **IETF Protocol to Access WhiteSpaces (PAWS)**

Conclusions

- ***WhiteSpace and cognitive radio technologies*** are slowly but steadily gaining world-wide acceptance
- We see ***Cognitive Machine to Machine Communications*** as the next big phenomenon for research, development and application driver.
- ***IEEE 802.22 is the First*** IEEE Standard for operation in Television Whitespaces that has all the Cognitive Radio features
- The ***IEEE P802.22b Amendment*** will provide a standard based technology for Cognitive M2M Control and Monitoring Applications
- We urge you to participate, adopt, and develop WhiteSpace Ecosystem with Us

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