Introduction to IEEE Std. 802.22-2011 and its Amendment PAR for P802.22b: Broadband Extension and Monitoring

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Abstract

This tutorial is to be presented during the IEEE 802 Plenary session in November 2011 in Atlanta.

Outline

- Digital divide: Today' s problem and its solution
- Television Whitespace (TVWS): A New Hope
- Overview of the IEEE 802.22-2011 Standard
  - PHY Characteristics
  - MAC Characteristics and Cognitive Radio Characteristics
- Broadband Extension and Monitoring Use-cases
- P802.22b PAR – Broadband Extension and Monitoring

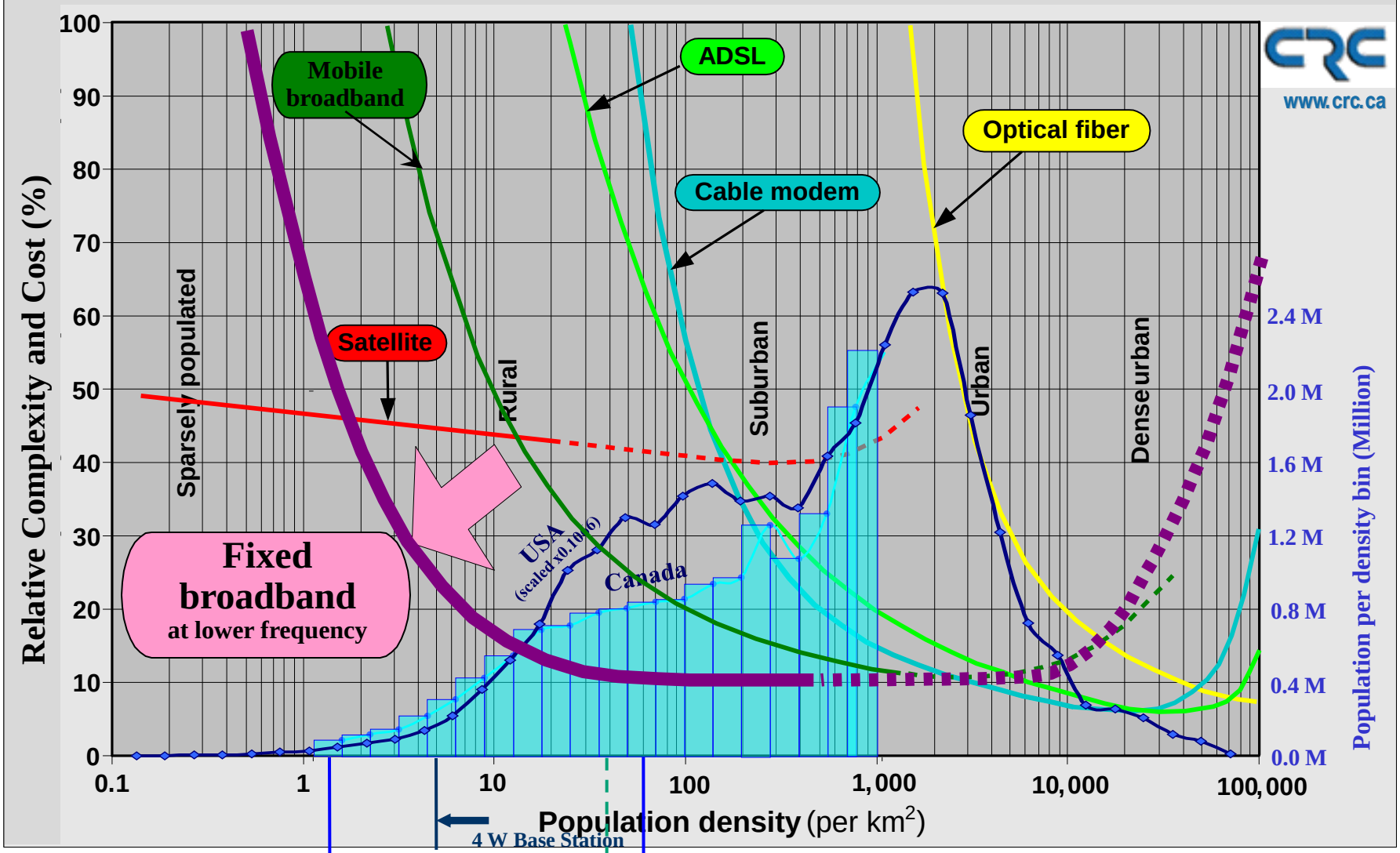
Problem: Digital Divide has Resulted in an Opportunity

- **According to the recent TIME Magazine article (October 31st issue), 73% of the world population (5.1 Billion people) does not have access to internet**
- **49.5% of the people (3.465 Billion) in the world live in rural areas.**

- It is expensive to lay fiber / cable in rural and remote areas with low population density. Wireless is the only solution.
- Backhaul / backbone internet access for rural areas is very expensive (50% of the cost)
- Traditional wireless carriers have focused on urban areas with high populations density (faster Return on Investment) using licensed spectrum

- **This has created a DIGITAL DIVIDE and an OPPORTUNITY**
- **Other Machine to Machine Applications will Drive Up the Volumes**

Relative Cost and Complexity of Various Technologies for Rural and Regional Area Broadband Service



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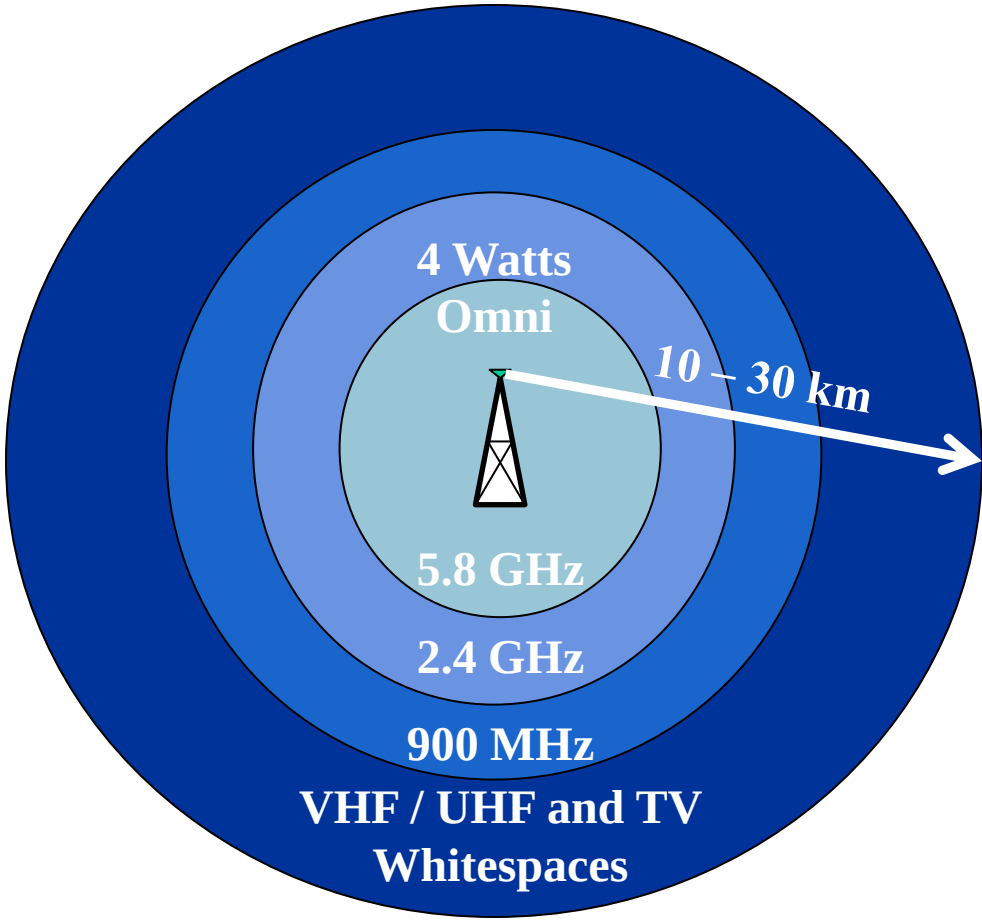
High Range and NLoS Operation are Necessary for Broaband to Rural

- **Range**: VHF/ UHF Bands and Television Whitespaces with appropriate transmit / receive power allowance are ideally suited to deploy large Regional Area Networks (RANs) due to favorable propagation characteristics.
- Deployment of Wireless Regional Area Networks with greater range allows more users per Base Station, resulting in a viable business model



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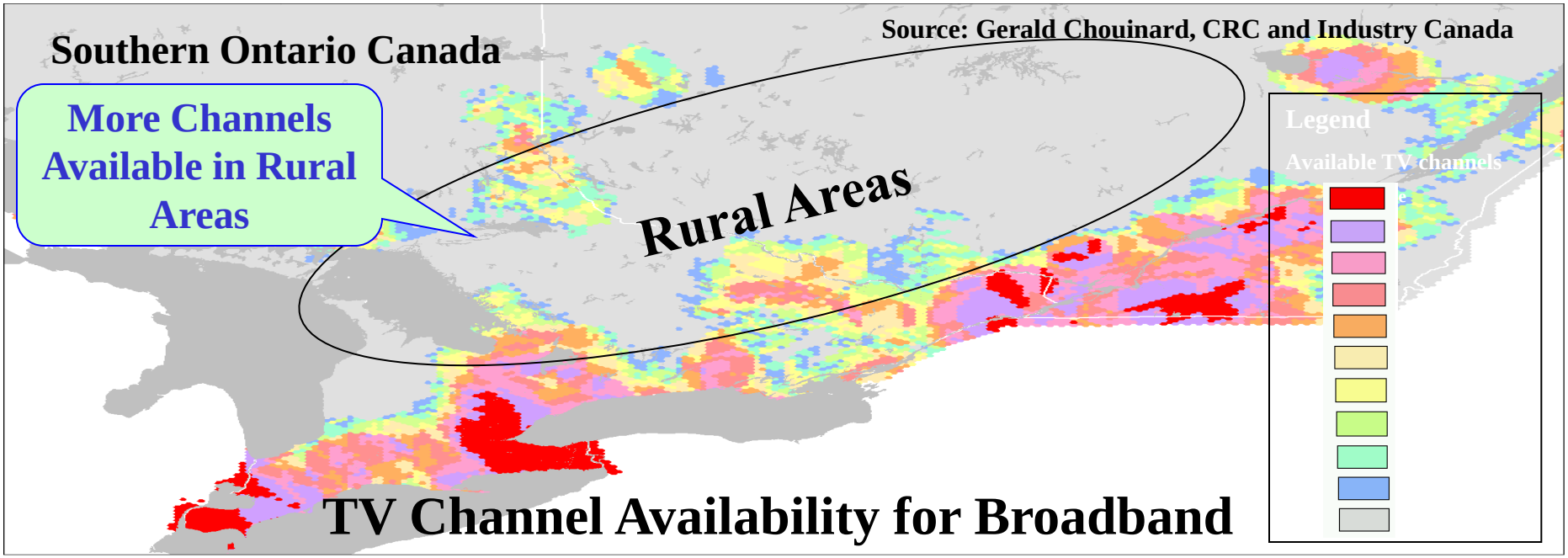
Television Whitespaces: A New Hope



- TV Channels in VHF / UHF bands have highly favorable propagation characteristics
- Analog TV will be transitioned world-wide to Digital TV which is more spectrum efficient.
- Excess spectrum is called the *digital dividend* and it can be used to provide broadband access while ensuring that no interference is caused to primary users.
- In some administrations like the United States, *opportunistic license-exempt usage* of the spectrum used by the incumbents is allowed on a non-interfering basis using *cognitive radio techniques.*

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:
  - Triple play for broadcasters (e. g. video, voice and data),
  - Smart grid
  - Cheap backhaul using multi-profile RAN stations
  - 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.

Plenty of TV channels are available in rural areas for broadband deployment

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

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

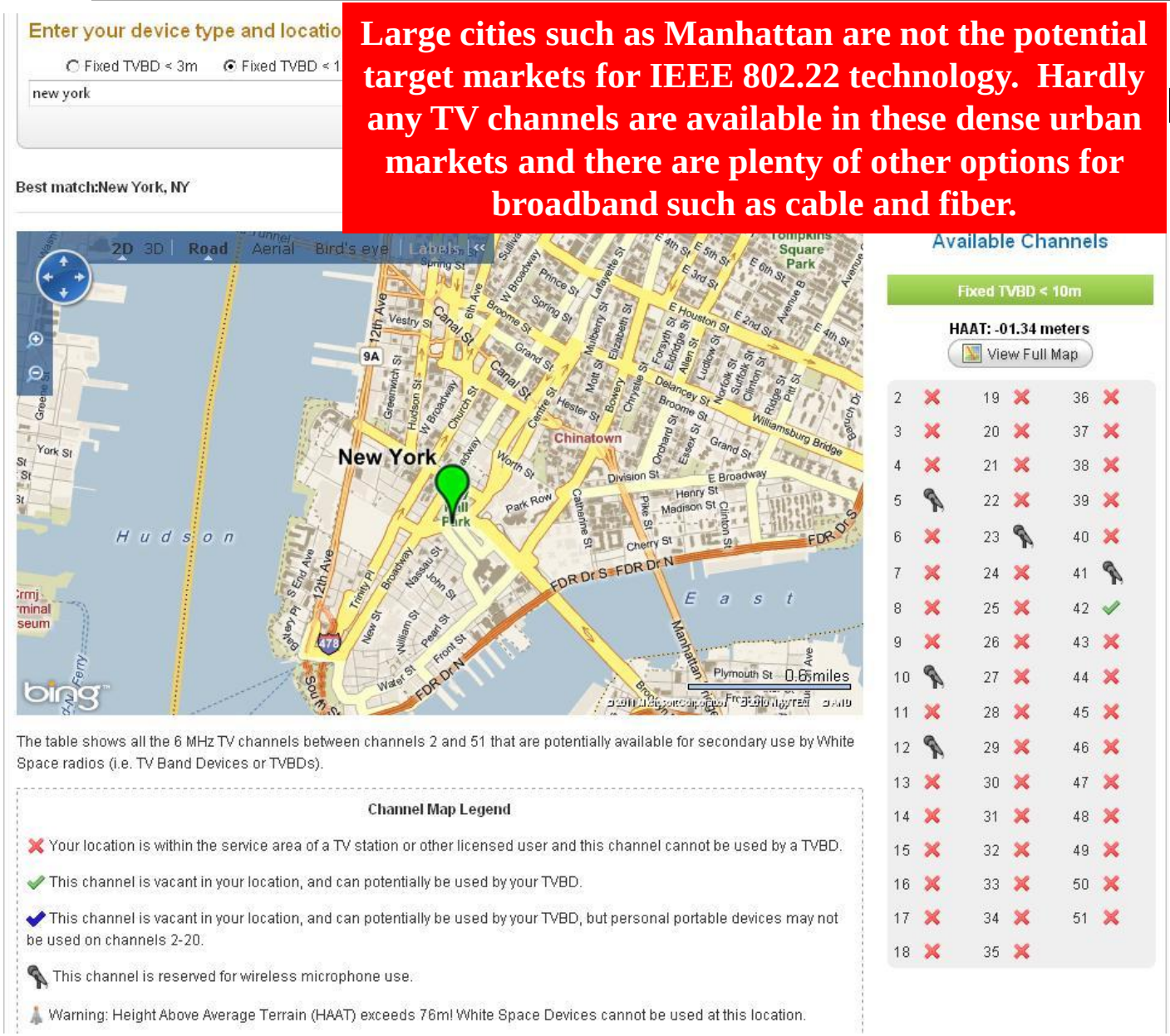
2 ✔	19 ✔	36 🎤
3 ✖	20 ✔	37 ✖
4 ✖	21 ✖	38 🎤
5 🎤	22 ✖	39 ✔
6 ✖	23 ✖	40 ✔
7 ✖	24 ✔	41 ✔
8 ✔	25 ✔	42 ✔
9 ✔	26 ✖	43 ✔
10 ✔	27 ✔	44 ✔
11 ✔	28 ✔	45 ✔
12 ✔	29 ✔	46 ✔
13 ✔	30 ✔	47 ✔
14 ✔	31 ✔	48 ✔
15 ✔	32 ✔	49 ✔
16 ✔	33 ✔	50 ✔
17 ✔	34 ✔	51 ✔
18 ✔	35 ✔	

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

Large cities such as Manhattan are not the potential target markets for IEEE 802.22 technology. Hardly any TV channels are available in these dense urban markets and there are plenty of other options for broadband such as cable and fiber.

Manhattan, New York TV Channel Availability

Urban City with very high population density



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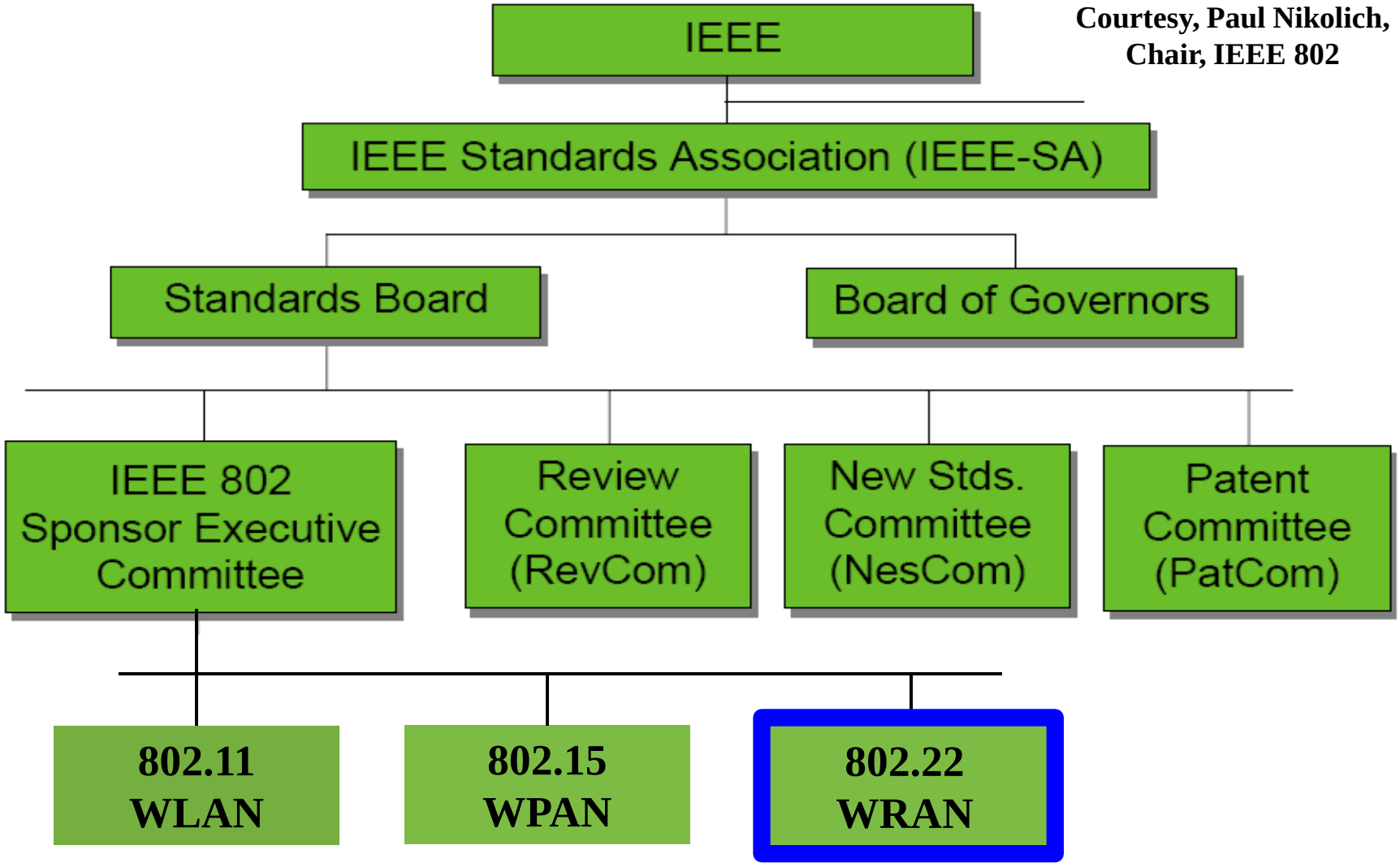
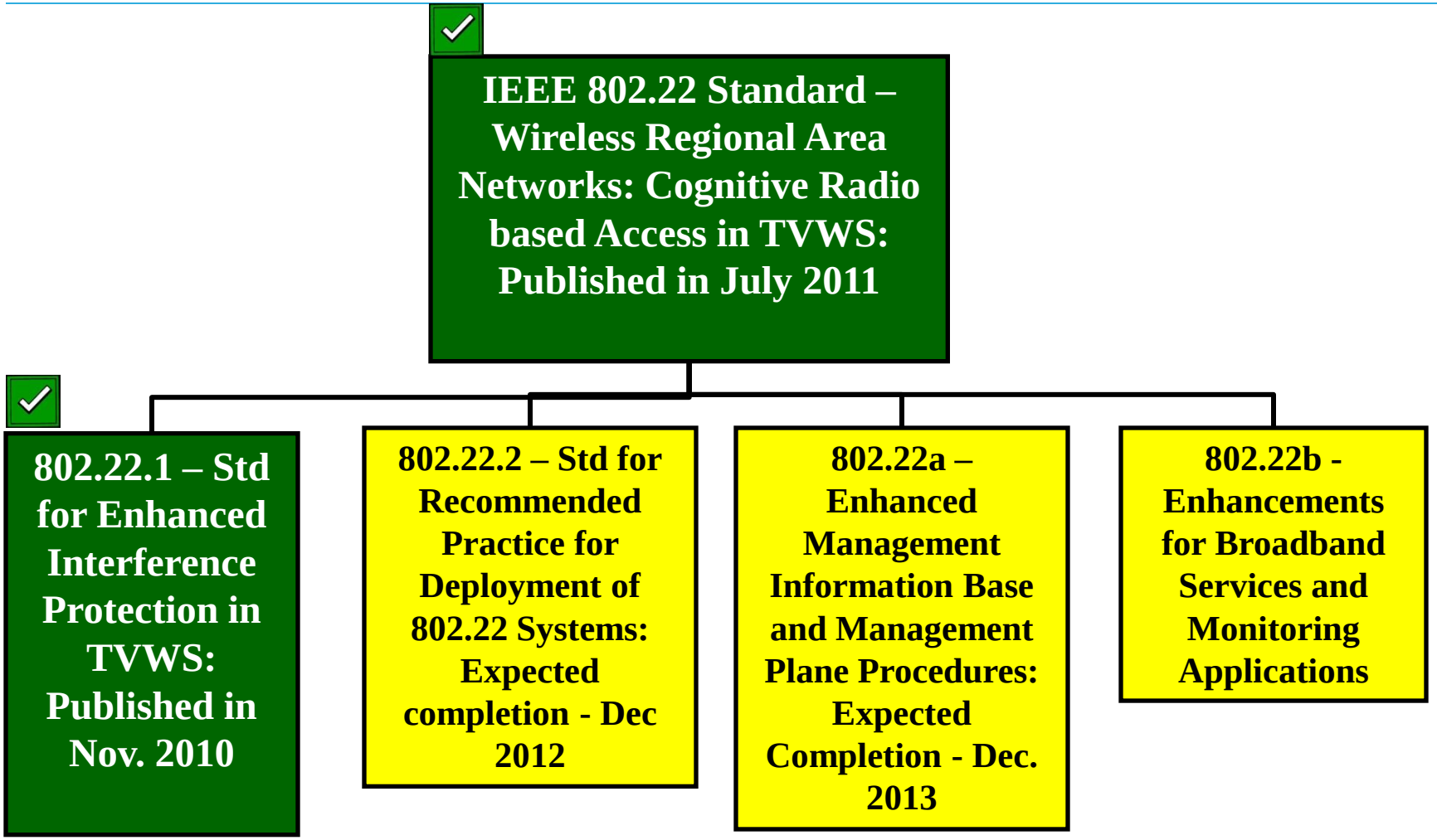
IEEE Standards Association Hierarchy

Courtesy, Paul Nikolich, Chair, IEEE 802



IEEE 802.22 WG on Wireless Regional Area Networks



www.ieee802.org/22

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 aimed at removing the digital divide
- *First* IEEE Standard that has all the Cognitive Radio features
- Recipient of the IEEE SA *Emerging Technology of the Year Award*

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TV Channel Characteristics

IEEE 802.22 PHY Features

Conclusions

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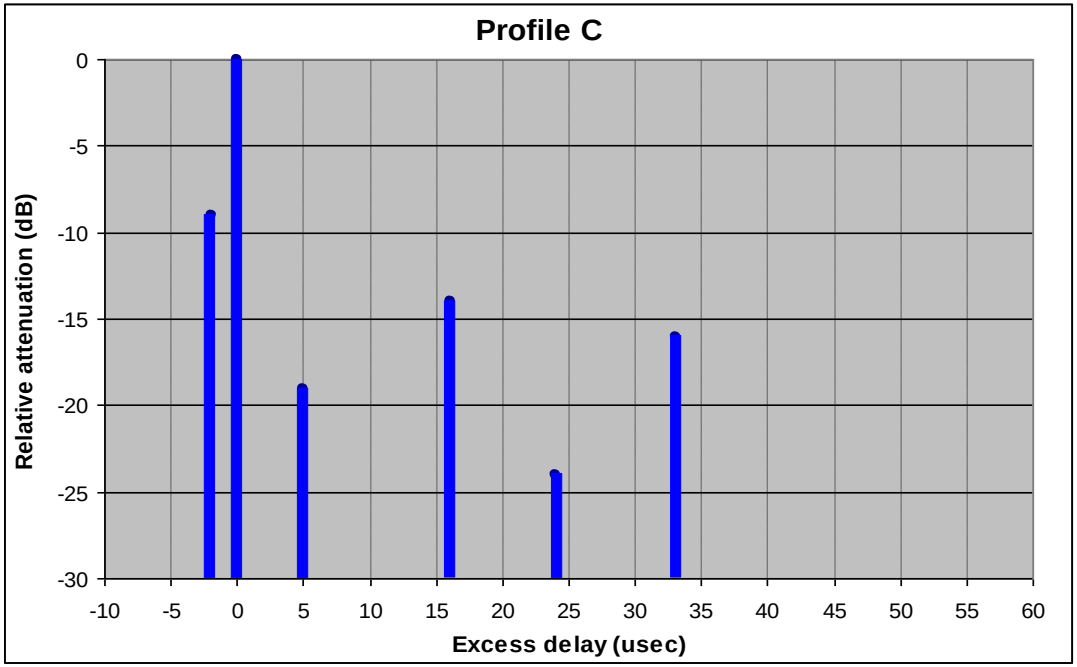
TV Channels

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)

IEEE802.22-05/0055r7, Aug 05



PHY Features

- Worldwide Operation (6, 7, and 8 MHz Bandwidths supported)
- Simple and Light Specs
- Robust OFDMA and High throughput
- Adaptive Modulation and Coding
- Preamble, Pilot Pattern and Channelization

Worldwide Operation

- Support worldwide TV channels (6, 7, or 8 MHz) in the VHF/UHF broadcast bands from 54 MHz to 862 MHz
- Same frame/symbol structure, preamble/pilot pattern, FFT size, number of data/pilot subcarriers, modulation and coding, interleaving etc.
- Sampling frequency, carrier spacing, symbol duration, signal bandwidth, and data rates are scaled by channel bandwidth
- TDD

Simple and Light Specs

- Single PHY mode: OFDMA
- Single FFT mode: 2048
- Single antenna spec
  - Heavy multiple antennas specs (MIMO or beamforming) are not supported due to physical sizes of antenna structures at lower frequencies
- Linear burst allocation
  - DS: little time diversity gain could be achieved across symbols due to channel changes slowly
  - US: allocated across symbols to minimize the number of subchannels used by a CPE, hence reducing (EIRP) to mitigate potential interference to incumbent systems

Robust OFDMA Design with High Throughput

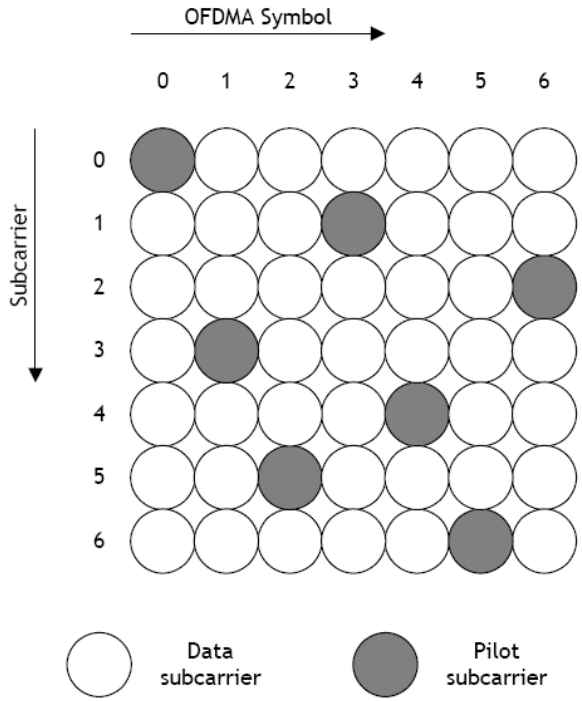
- Robust OFDMA Design
  - Longer symbol time
    - $1/\Delta f \sim 300$ μsec*; $CP_{max} \sim 75$ μsec
    - WiMAX: CP ~ 11.2 μsec
  - Slow fading
    - $\Delta f \sim 3.3$ kHz (Robustness to ICI better than WiMax in 3.5 GHz)
    - WiMAX: $\Delta f \sim 11$ kHz (Overkill in VHF/UHF band)
- High throughput
  - Peak data rate per channel: 22.69 Mb/s (rate 5/6, 64-QAM)
  - WiMAX: 15.84 Mb/s (rate 5/6, 64-QAM)

Adaptive Modulation and Coding

- 4 CP factors: 1/4, 1/8, 1/16, and 1/32
- 3 modulations (QPSK, 16QAM, 64QAM) with 4 coding rates (1/2, 2/3, 3/4, 5/6)
- Mandatory CC + optional turbo (CTC or SBTC) and LDPC codes
- Turbo-block bit interleaver and subcarrier interleaver
  - Maximize the distance between adjacent samples to achieve better frequency diversity

Preamble, Pilot Pattern and Channelization

- 3 types preambles
  - Superframe
  - Frame
  - CBP
- Tile pilot pattern
  - For each symbol, every 7 useful subcarriers has a pilot
  - For each subcarrier, every 7 symbols has a pilot
  - Robust channel estimation combining 7 OFDMA symbols.



Conclusions - PHY

- IEEE 802.22 standard is optimized for VHF/UHF TV channels to provide broadband services with up to 100km coverage
  - Simple and light specs
  - Robust to large delay spread
  - Robust to Doppler spread

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This contribution summarizes the MAC and Cognitive Capability (CC) features in the IEEE 802.22-2011 Standard.

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Contents

MAC Introduction (1)

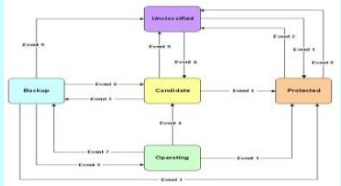
- Some aspects of IEEE 802.22-2011 MAC have been inspired from the IEEE 802.16 MAC standard
- Combination of polling, contention and unsolicited bandwidth grants mechanisms
- Support of Unicast/Multicast/Broadcast for both management and data
- Connection-oriented MAC
  - Connection identifier (CID) is a key component
    - IEEE 802.22-2011 CID can be constructed from Station ID (SID) and Flow Identifier (FID) [1]. This new CID definition can reduce overhead and storage requirements [2].
  - Defines a mapping between peer processes
  - Defines a service flow (QoS provisioning)

MAC Introduction (2)

- However, major enhancements have been made
  - Support of Cognitive functionality
    - Dynamic and adaptive scheduling of quiet periods
    - Various incumbent user detection and notification methods
  - Coexistence with both incumbents and other 802.22 systems (self-coexistence)
    - Measurements (incumbents and 802.22 operation)
    - Spectrum management (time, frequency and power)
    - The Coexistence Beacon Protocol (CBP)
    - The Incumbent Detection Recovery Protocol (IDRP)
    - Wireless microphone beacon mechanism (IEEE 802.22.1)
  - Self-coexistence mechanisms
    - Spectrum Etiquette
    - On-demand Frame Contention

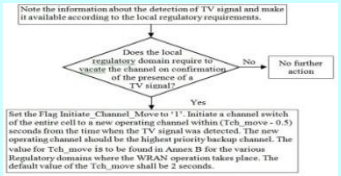
Summary of Cognitive Capabilities

Channel Set Management

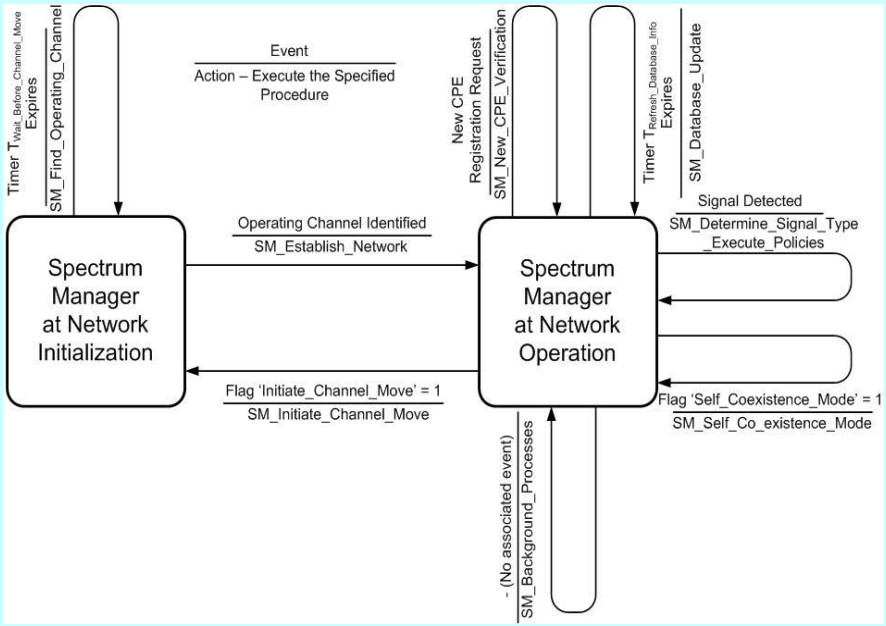


Subscriber Station Registration and Tracking

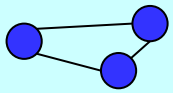
Policies



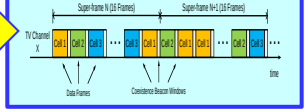
Spectrum Manager



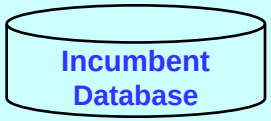
Geo-location



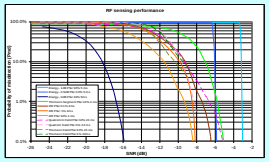
Self Co-existence



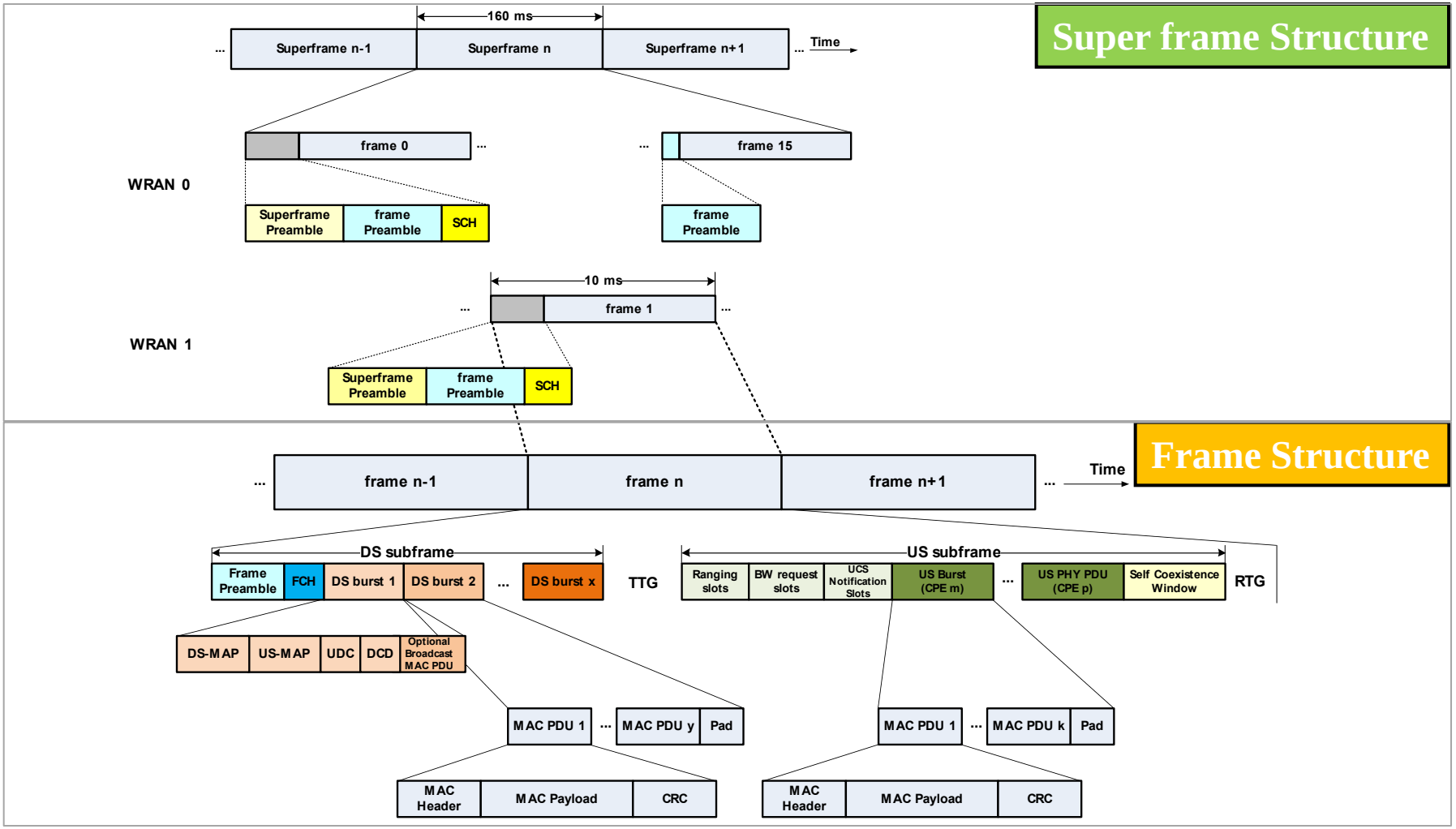
Incumbent Database Service



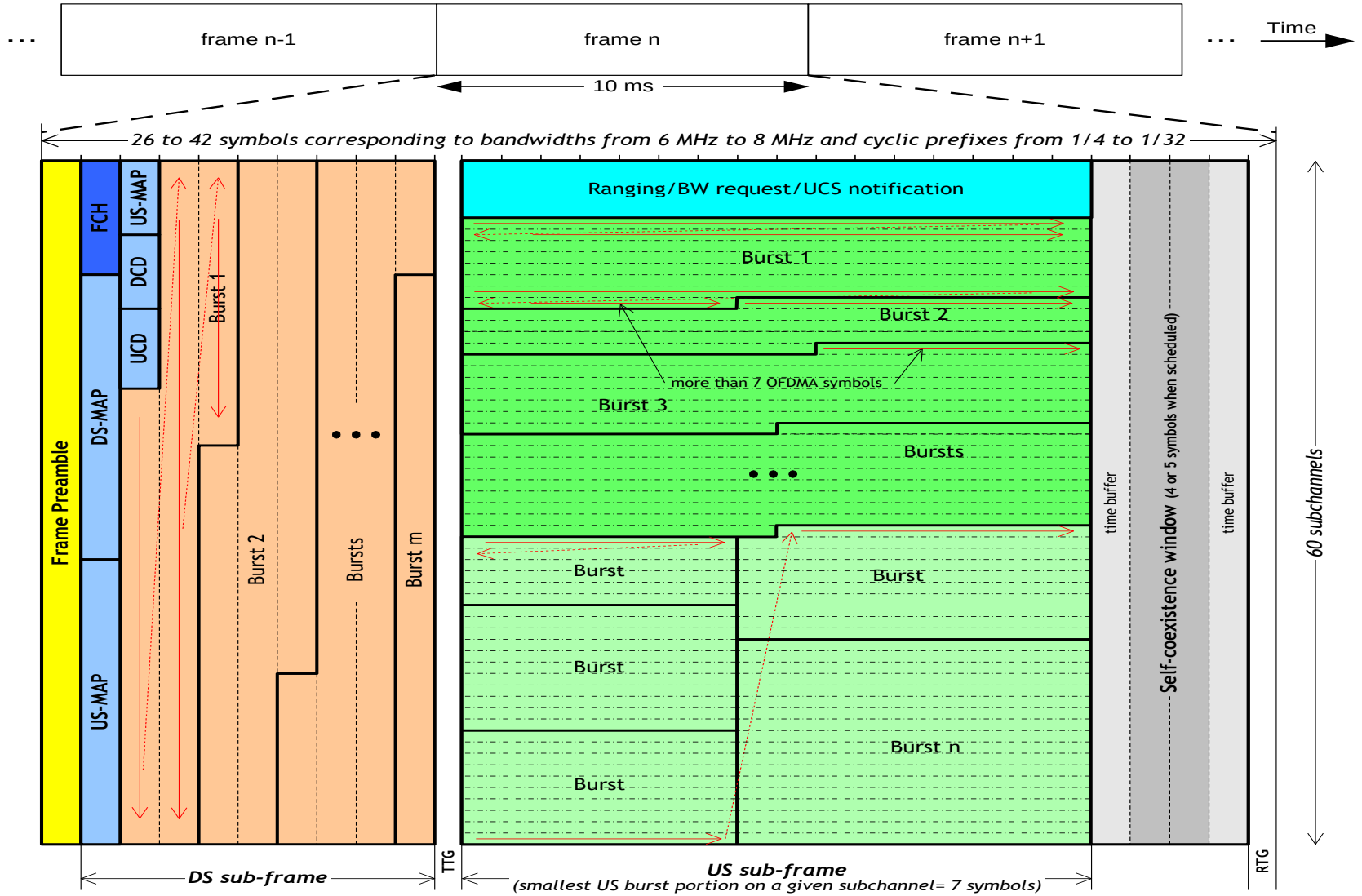
Spectrum Sensing



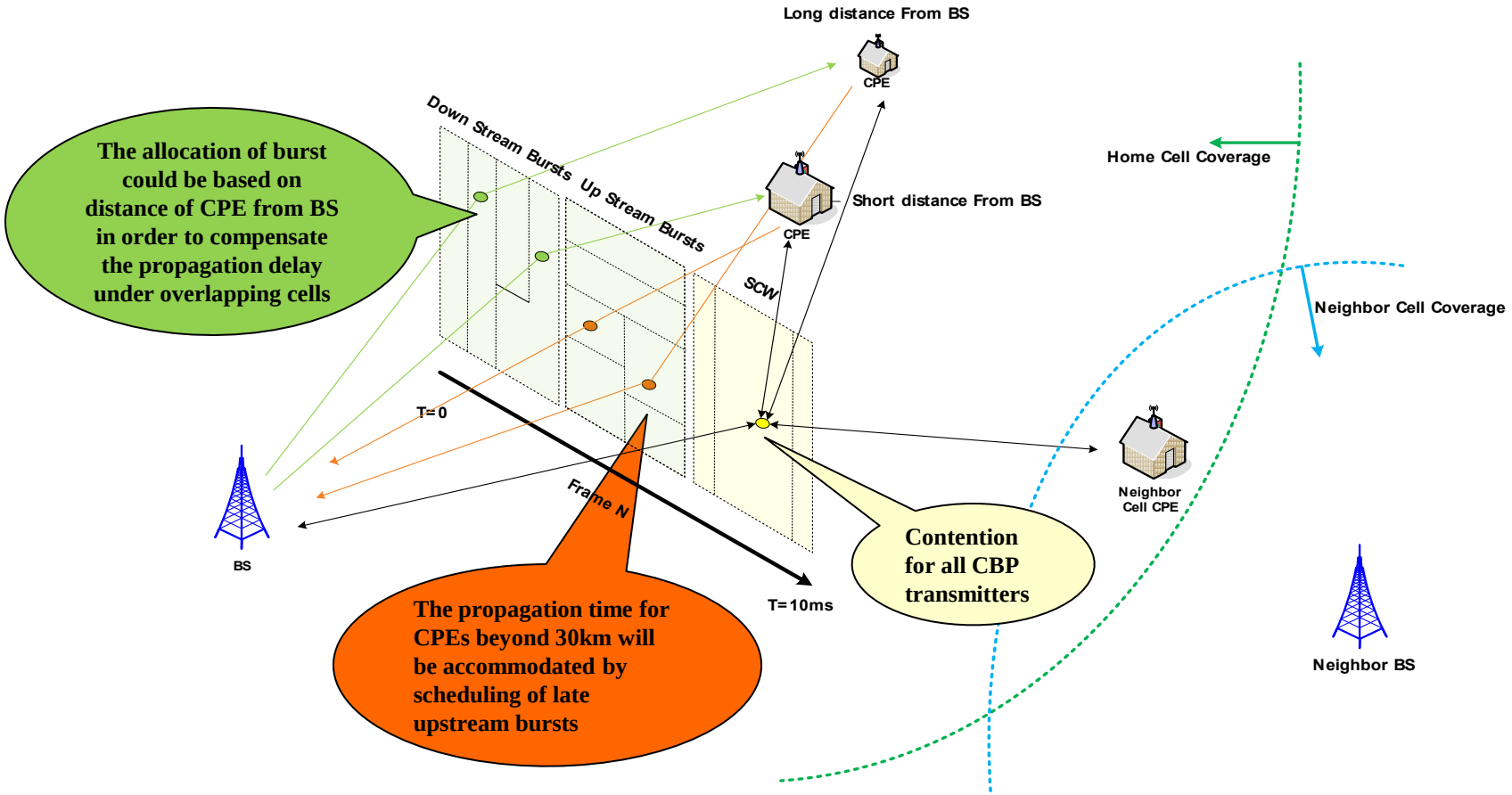
IEEE 802.22 Frame Structure
(Logical View)



IEEE 802.22 Frame Structure
(Physical View)



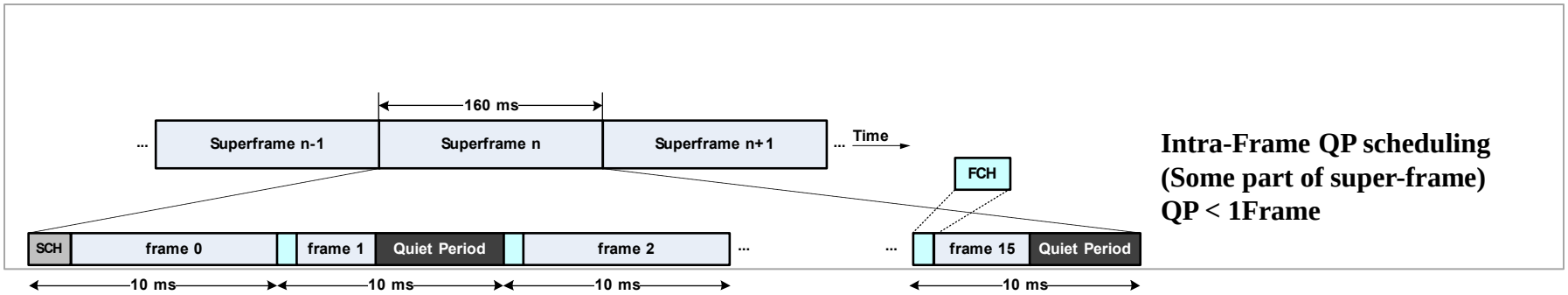
Concept of 802.22 Frame Operation



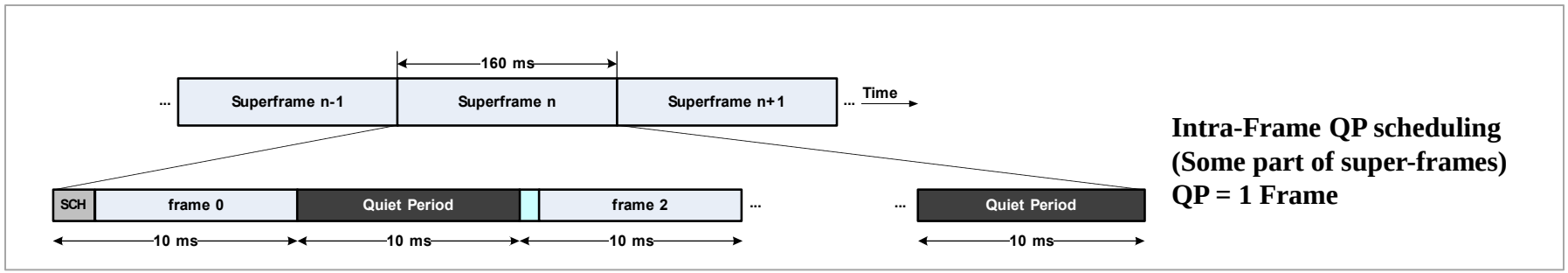
SCH and CBP Features

- The Super-frame Control Header (SCH)
  - Provides the control information for a WRAN cell
  - Support the intra-frame and inter-frame quiet periods management mechanisms for sensing
  - Support coexistence with incumbents and other WRAN cells (self coexistence)
- An SCH can include various CBP (Coexistence Beacon Protocol) IEs
  - Backup channel information IE
  - Frame Contention information IE
  - Terrestrial Geo-location information IE
  - Signature IE, Certificate IEs (CBP frame security)
- Using SCH, WRAN BS can intelligently manage the operation of its associated CPEs
- Also, using CBP (Extended version of SCH), WRAN BS can intelligently manage the operation of neighboring WRAN cell under co-existence situation

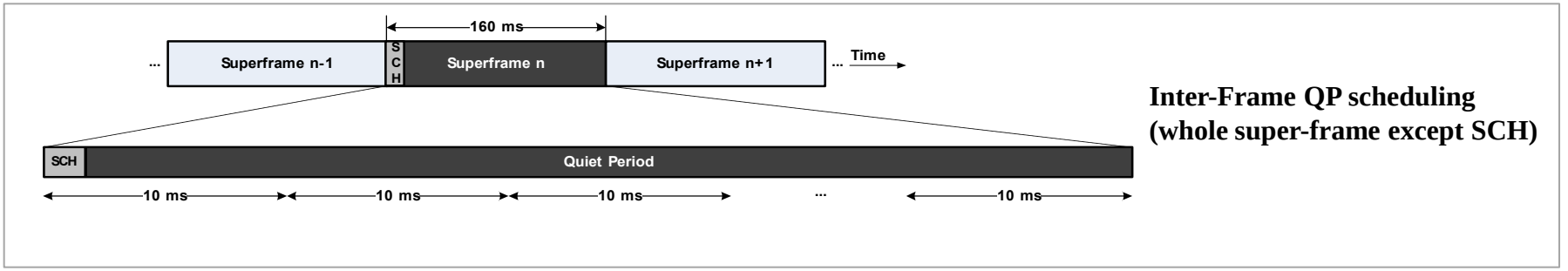
Dynamic Quiet Period Scheduling



Intra-Frame QP scheduling (Some part of super-frame) QP < 1Frame



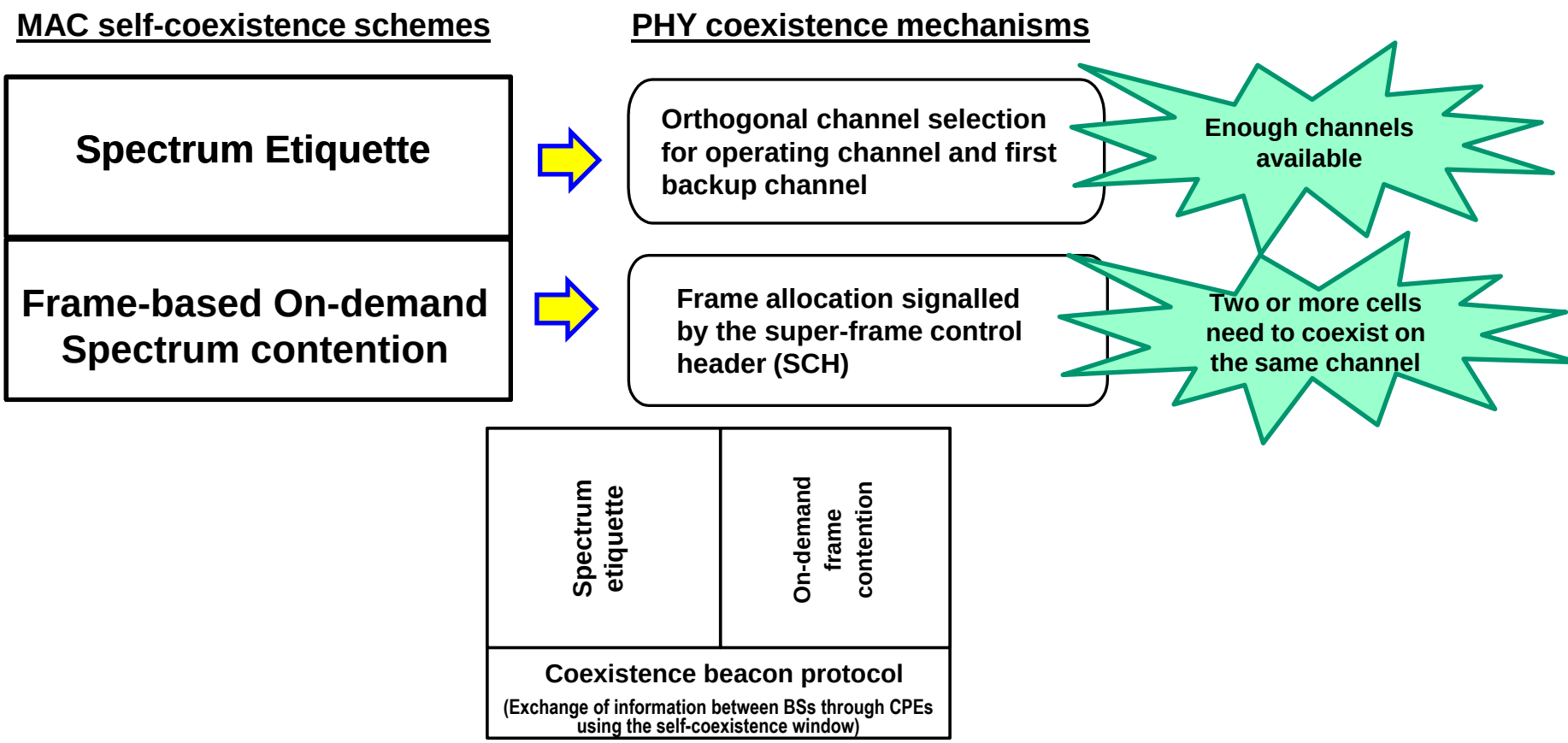
Intra-Frame QP scheduling (Some part of super-frames) QP = 1 Frame



Inter-Frame QP scheduling (whole super-frame except SCH)

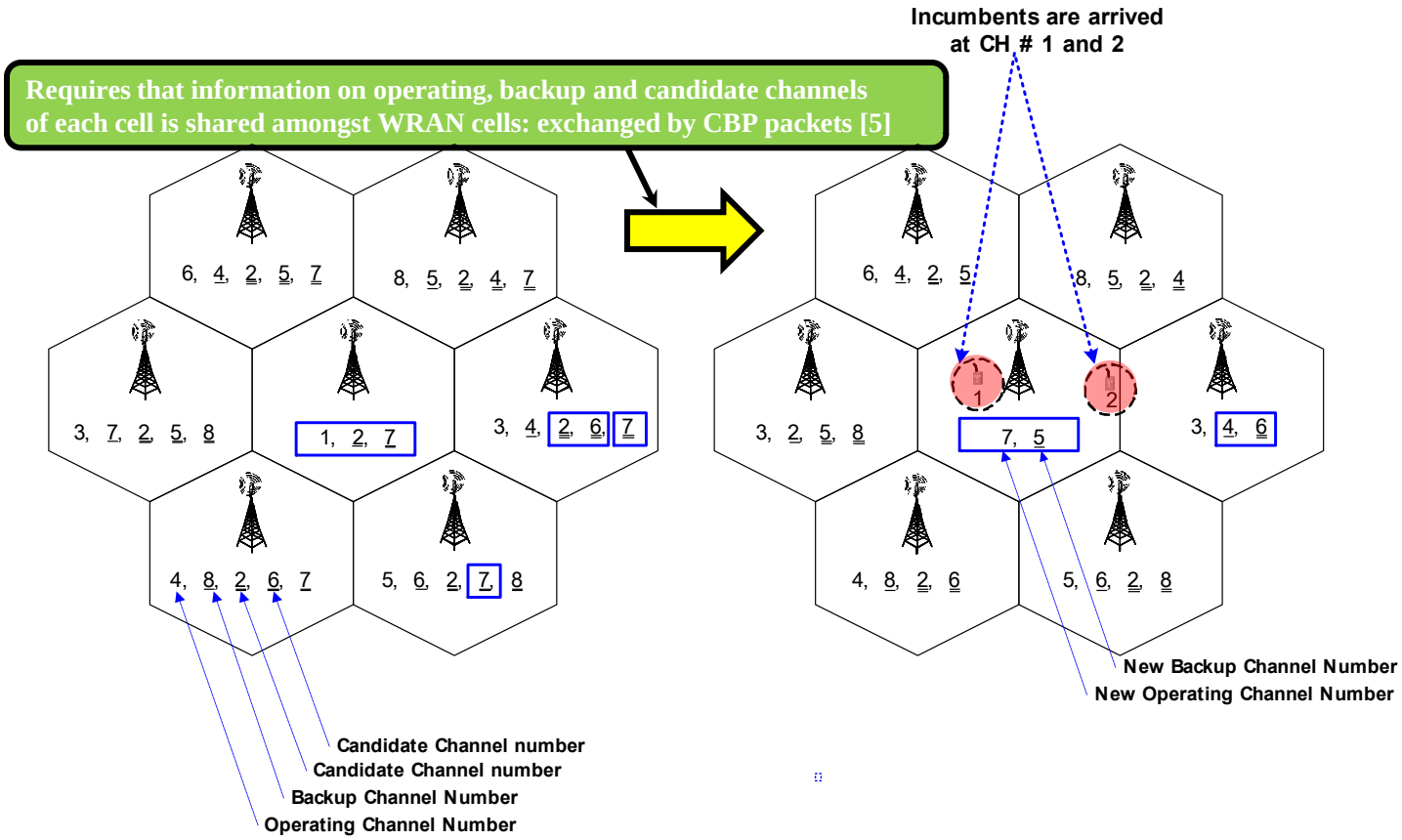
Self-Coexistence Mechanism (1)

- **Self-Coexistence: Co-existence among WRAN Systems [4]**



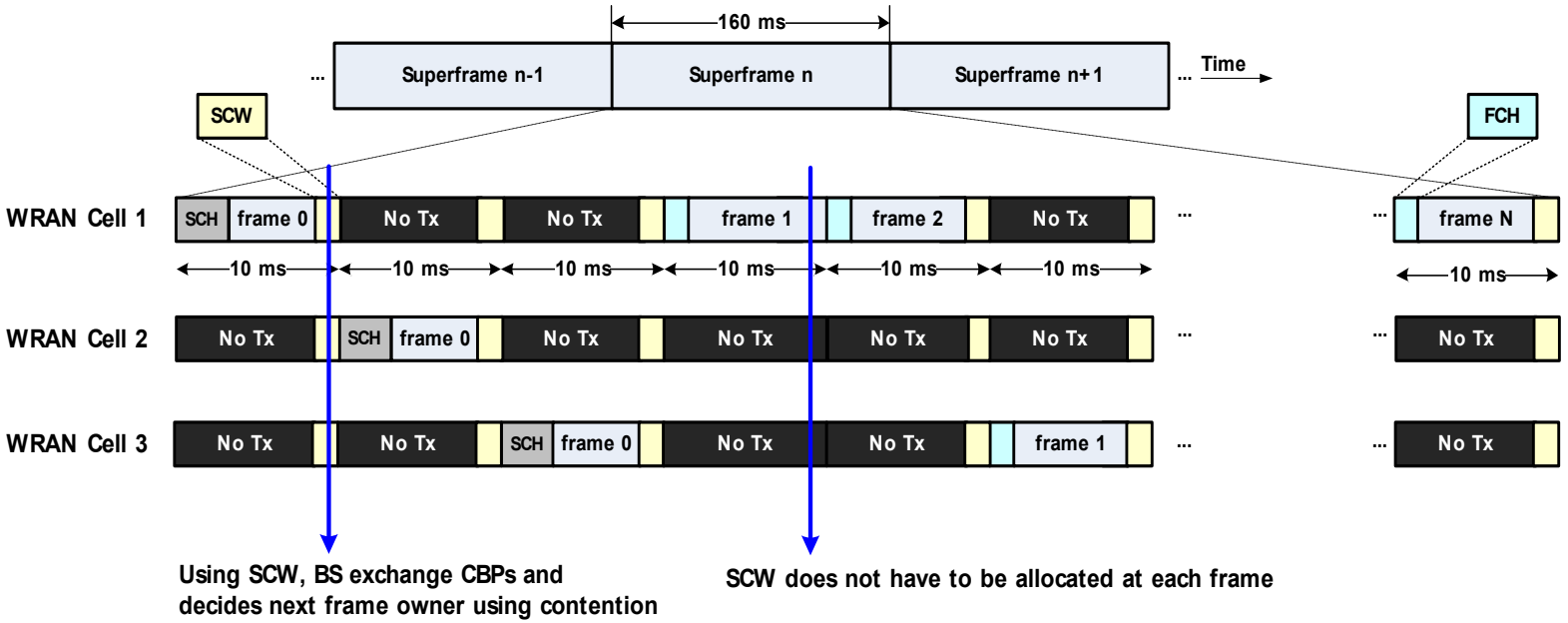
Self-Coexistence Mechanism (2)

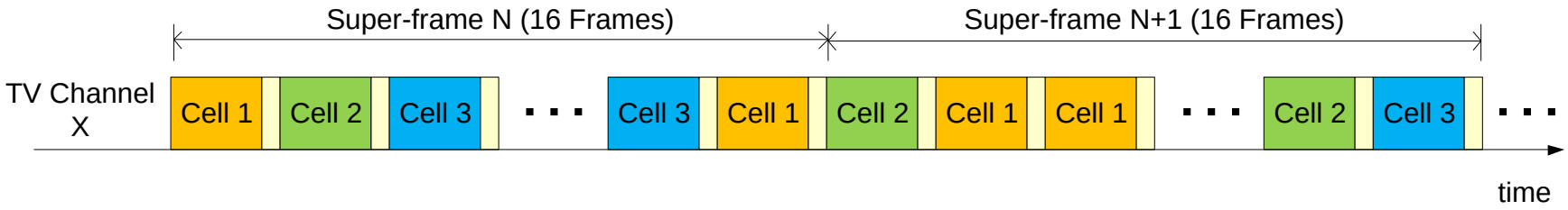
- **Spectrum Etiquette**
  - Orthogonal channel assignment scheme between adjacent cells
    - different operating channel for overlapping or adjacent cells
    - different first backup channel



Self-Coexistence Mechanism (3)

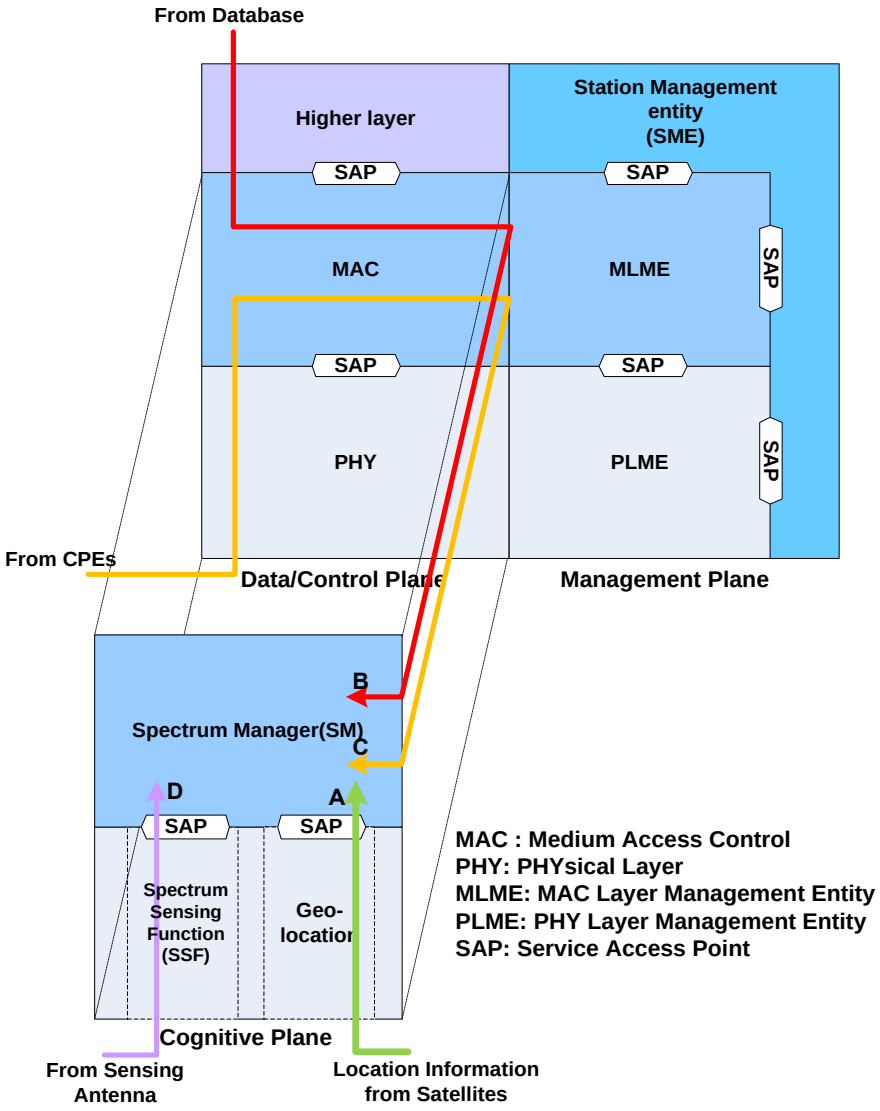
- **On-demand Frame Contention**
  - Two or more cells need to co-exist on the same channel



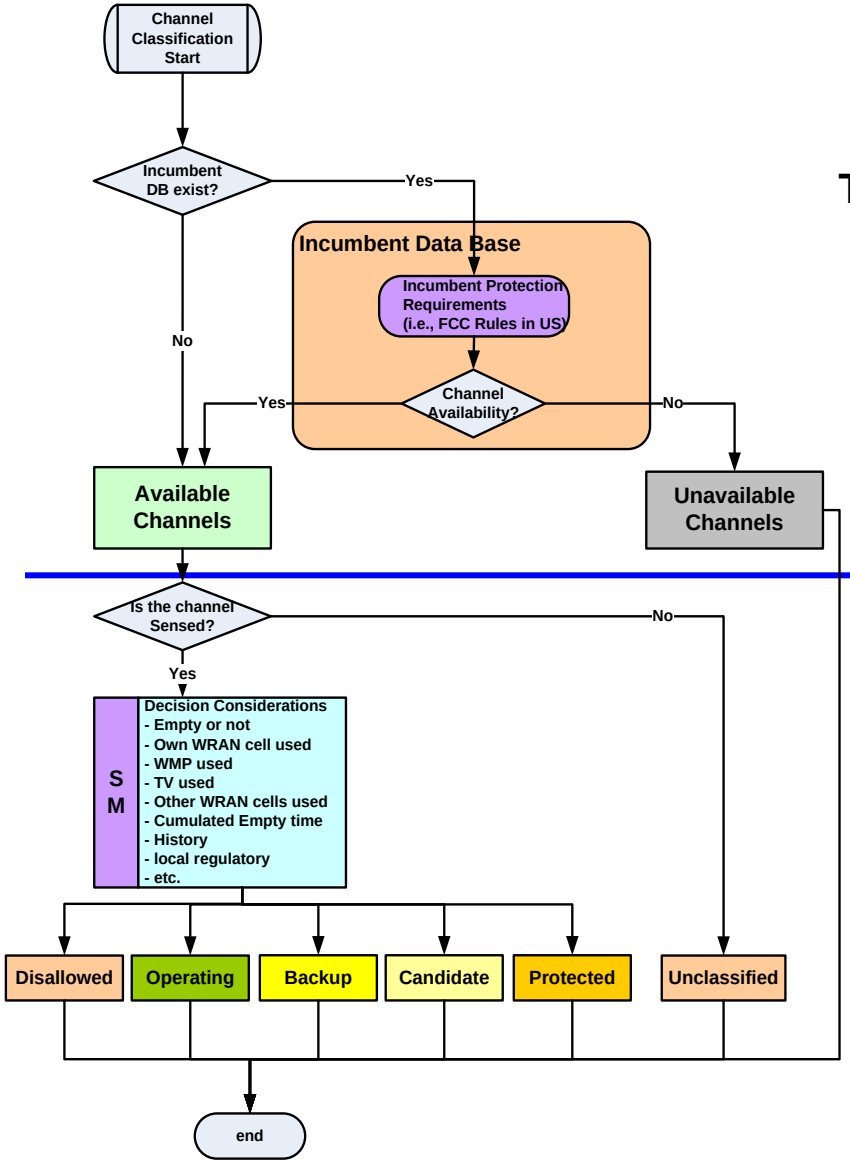


Cognitive Capability

- Collection of Spectrum Information
  - Geo-location information (A)
  - TVWS Database (B)
  - CPE Spectrum Sensor (C)
  - BS Spectrum Sensor (D)
- Cognitive Engine (Decision Maker)
  - Spectrum Manager (BS)
  - Spectrum Automation (CPE)
- Configurable Communication System
  - 802.22 PHY
  - 802.22 MAC



SM Channel Classification [5]



Two step channel decision

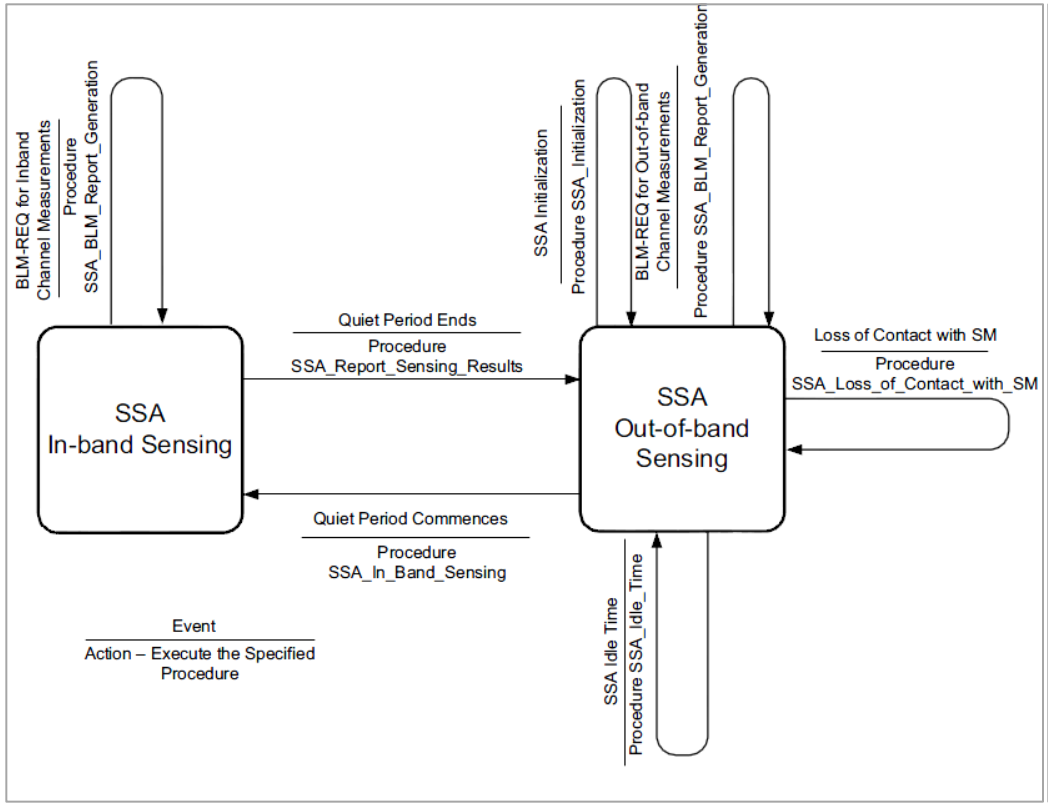
External to IEEE 802.22 System

Internal to IEEE 802.22 System

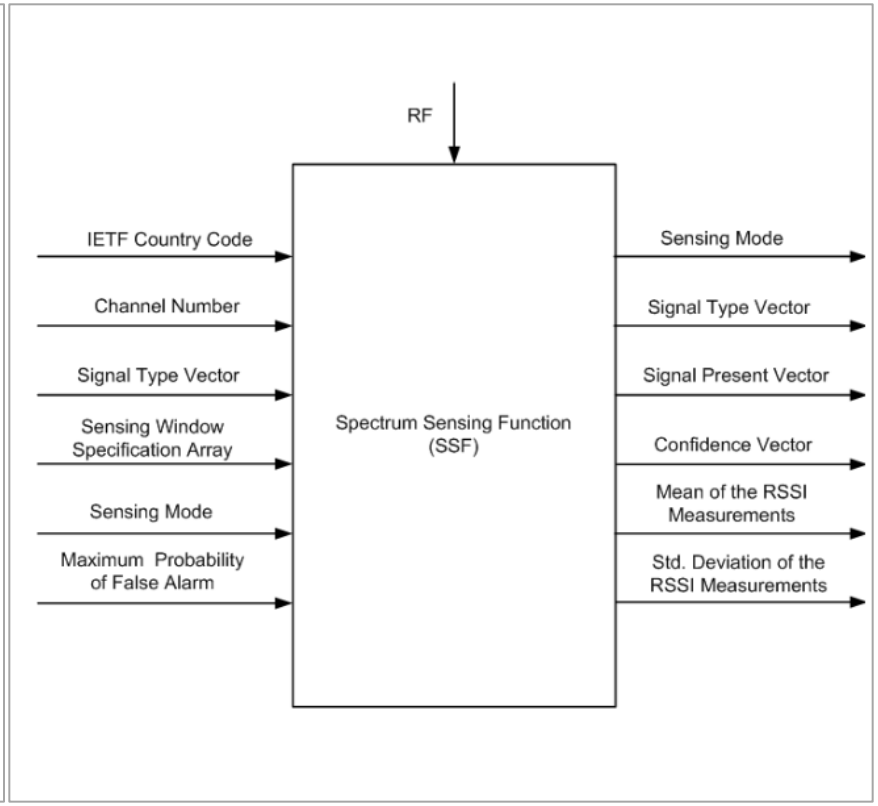
Spectrum Sensing

- IEEE 802.22 supports spectrum sensing capability by using SSA and SSF
- Spectrum Sensing Automation (SSA, sensing manager)
  - All the IEEE 802.22 devices (BS and CPEs) shall also have an entity called the Spectrum Sensing Automaton (SSA). The SSA interfaces to the Spectrum Sensing Function (SSF) and executes the commands from the SM to enable spectrum sensing
- Spectrum Sensing Function (SSF, sensor)
  - Spectrum sensing is the process of observing the RF spectrum of a television channel to determine its occupancy (by either incumbents or other WRANs).
  - The base station and all CPEs shall implement the Spectrum Sensing Function (SSF)
  - The SSF shall be driven by the SSA. The SSF shall observe the RF spectrum of a television channel and shall report the results of that observation to the SM (at the BS) via its associated SSA

Spectrum Sensing



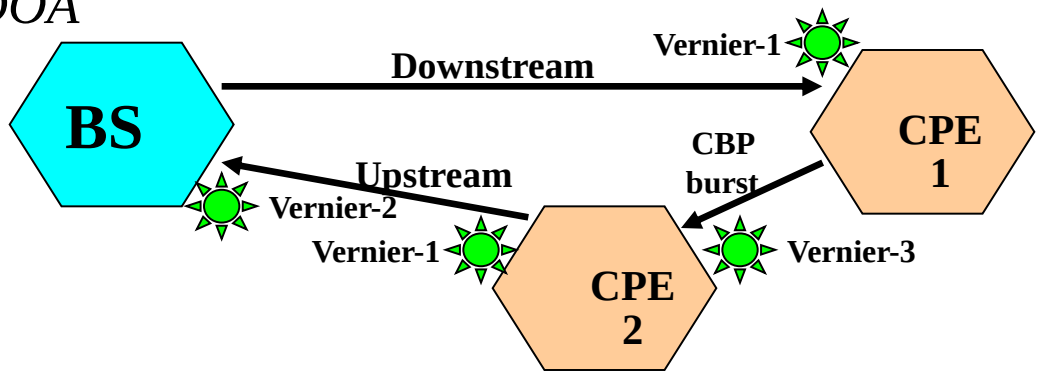
Spectrum Sensing Automation state machine



Input/Output of the Spectrum Sensing Function

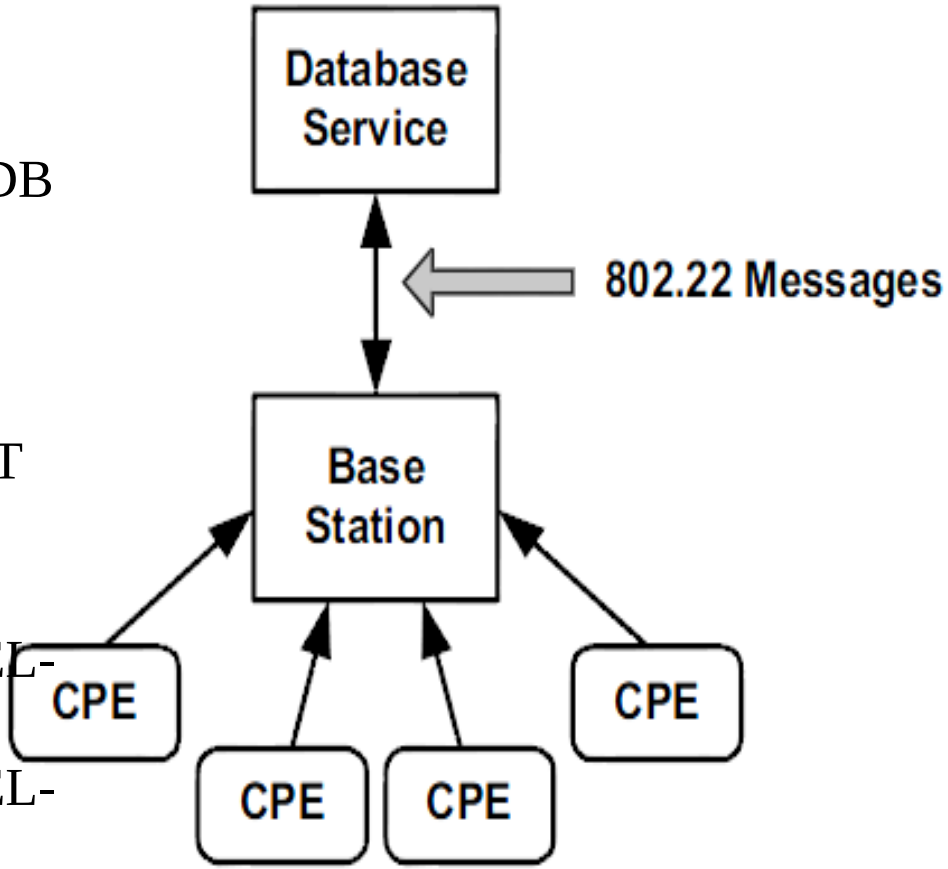
Geo-Location

- Satellite based geo-location
  - Requires GPS antenna at each device
  - NMEA 0183 data string used to represent geo-location
  - Poor accuracy in Northern hemispheres
- Terrestrial based geo-location
  - Besides satellite-based geo-location, the 802.22 standard includes terrestrial geo-location using inherent capabilities of the OFDM based modulation and the coexistence beacon protocol bursts transmitted and received among CPEs
  - Propagation time measured between BS and its CPEs and among CPEs of the same cell using *Fine Time Difference of Arrival: TDOA*



DB Access

- WRAN DB access
  - 802.22 WG defined DB access structure
  - Interfaces are defined between DB and BS
- Defined number of primitives for DB access
  - M-DB-AVAILABLE-REQUEST
  - M-DEVICE-ENLISTMENT-REQUEST
  - M-DB-AVAILABLE-CHANNEL-REQUEST
  - M-DB-AVAILABLE-CHANNEL-INDICATION
  - M-DB-DELIST-REQUEST
  - *Etc.*



Structure of the IEEE 802.22 WRAN access to the database service

Outline

- Digital divide: Today' s problem and its solution
- Television Whitespace (TVWS): A New Hope
- Overview of the IEEE 802.22-2011 Standard
  - PHY Characteristics
  - MAC Characteristics and Cognitive Radio Characteristics
- Broadband Extension and Monitoring Use-cases
- P802.22b PAR – Broadband Extension and Monitoring

Abstract

This document introduces *ten (10) usage cases for the 802.22 New SG* "regional area smart grid and critical infrastructure monitoring study group"

These usage cases are grouped by *three (3) categories*

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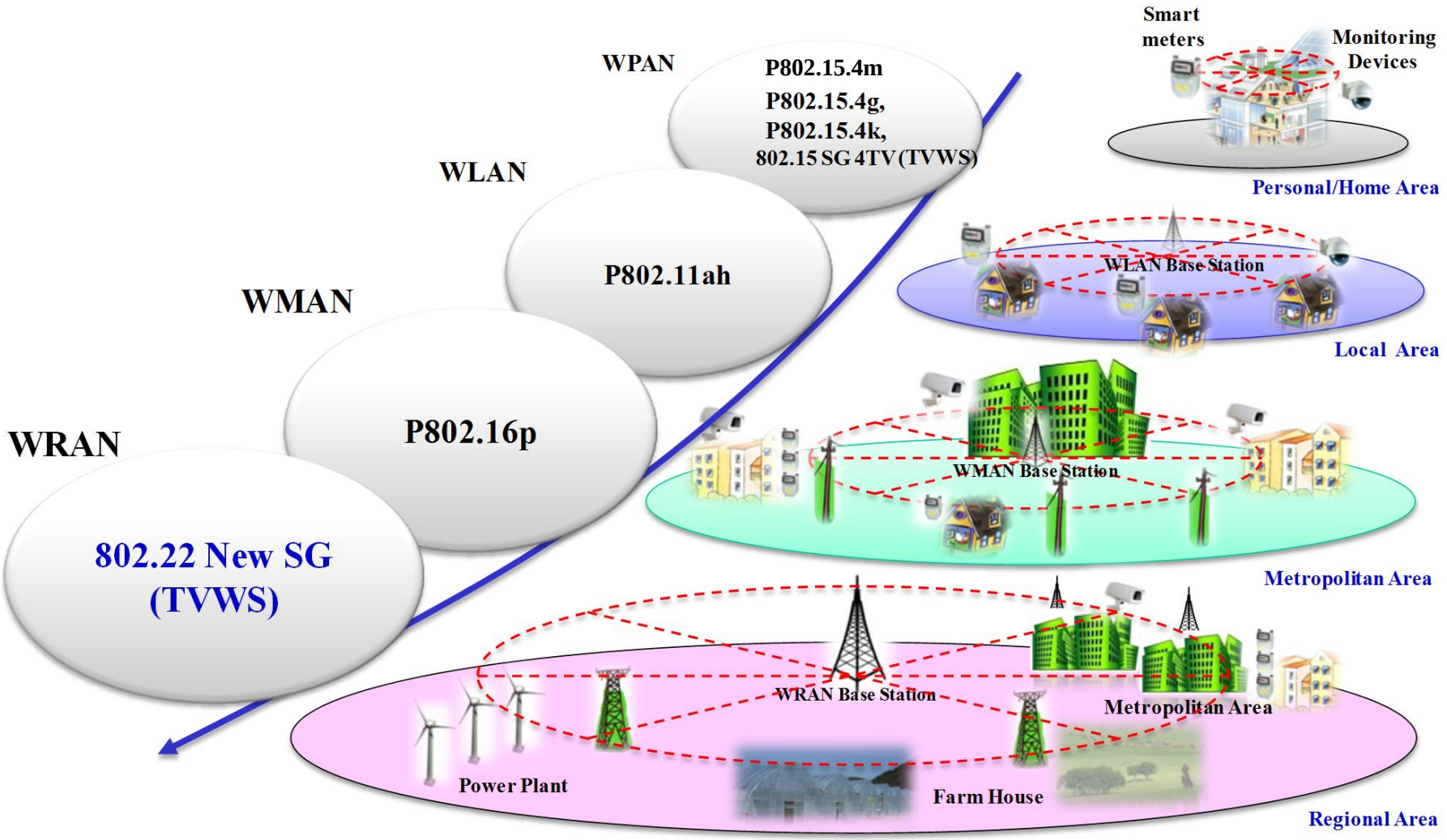
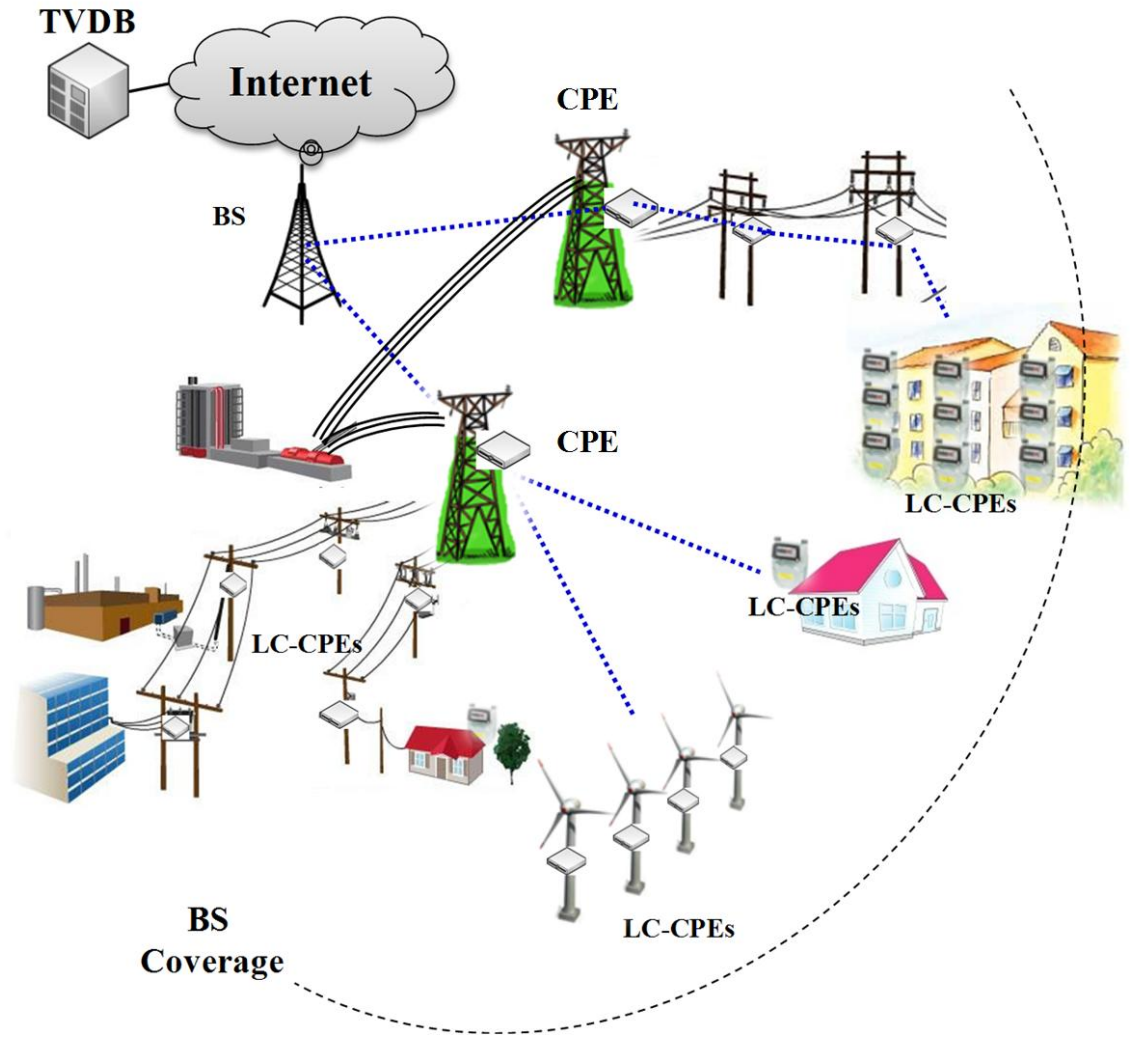
802 Standard Activities for Smart Grid and Critical Infrastructure Monitoring



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

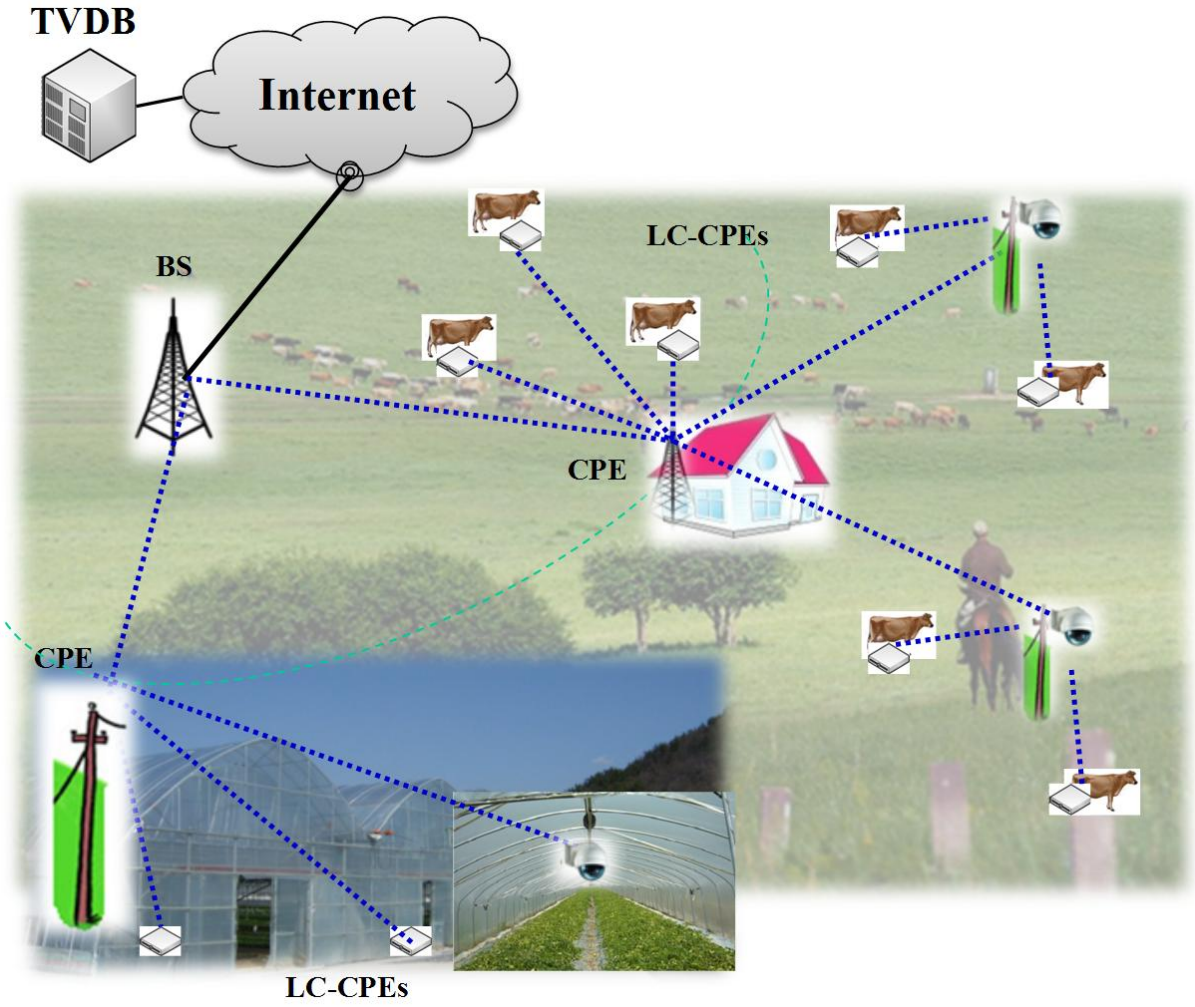
Category	Usage Cases	Properties
A) Smart Grid & Monitoring	A1) Regional Area Smart Grid/Metering	• Low capacity/complexity CPEs • Very large number of monitoring CPEs • Fixed and Potable CPEs • Real time monitoring • Low duty cycle • High reliability and security • Large coverage area • Infrastructure 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)

A1) Regional Area Smart Grid/Metering



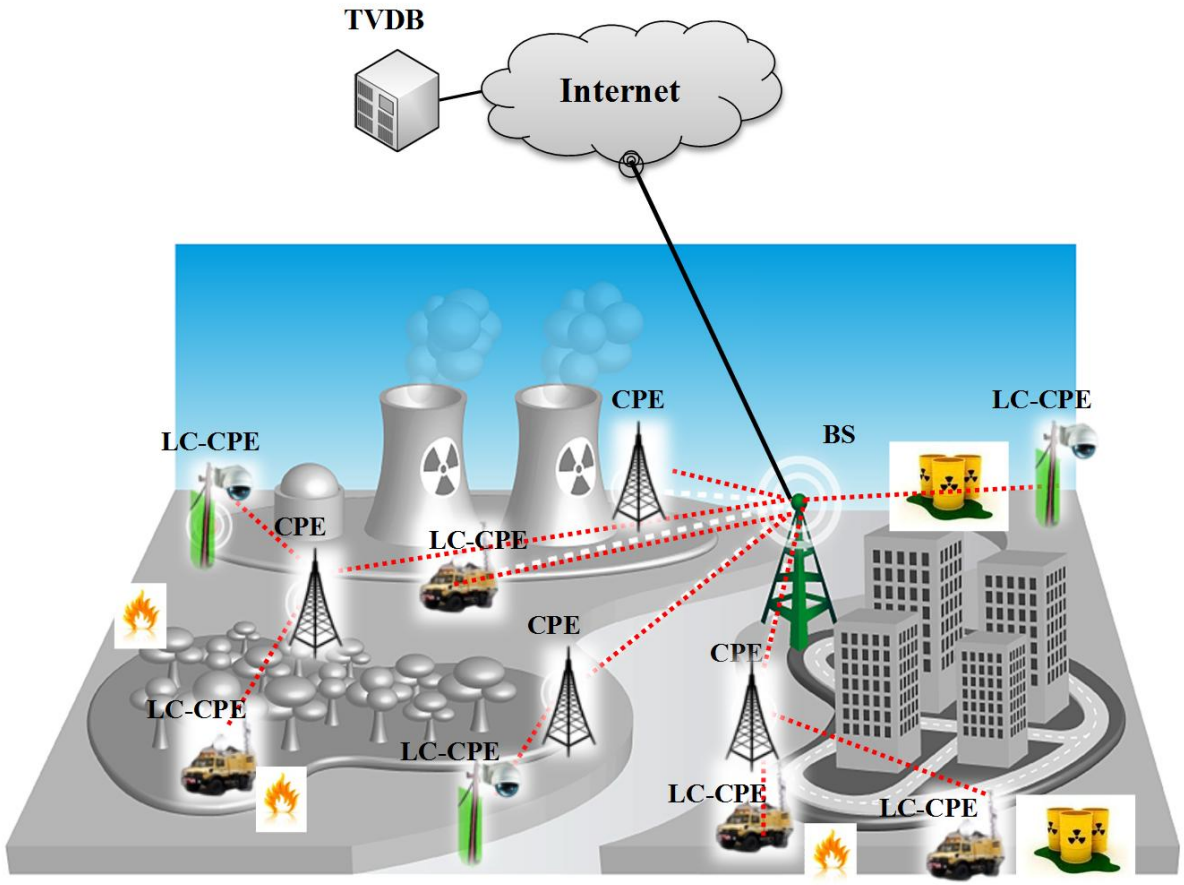
Usage
Regional Area Smart Grid/Metering by Low Capacity/Complexity CPEs (LC-CPEs) such as smart meters
Properties
1) Low capability/ complexity CPE (LC-CPE) 2) Large number of fixed LC-CPEs 3) Low duty cycle, high reliability and security 4) CPEs may provide an infrastructure backhaul for LC-CPEs as well as perform monitoring
Topology
Fixed Infrastructure mode Fixed Point-to-Multipoints Communications

A2) Agriculture / Farm Monitoring



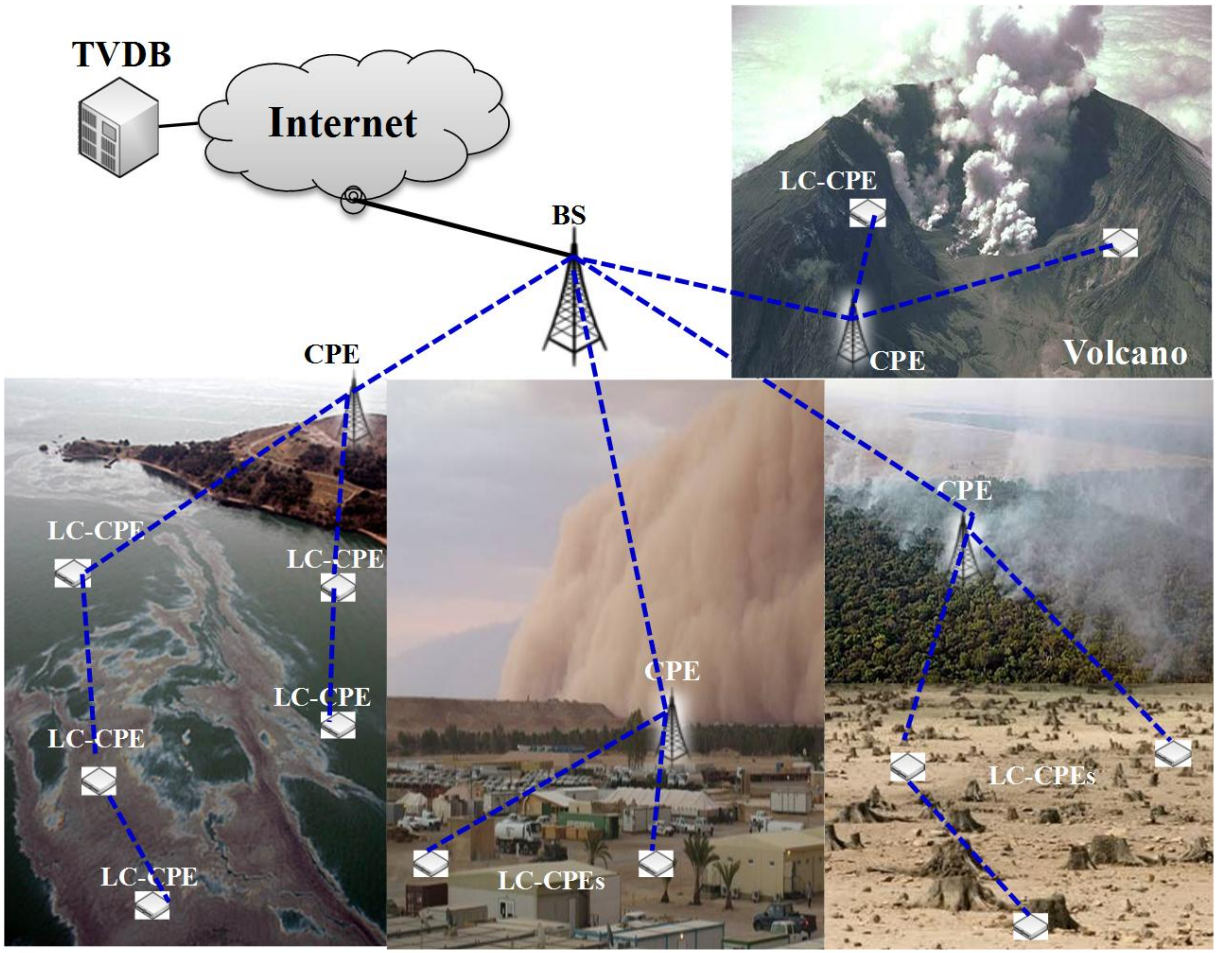
Usage
Agriculture/Farm house Monitoring by LC-CPEs, which may be attached in portable objects or fixed stations
Properties
1) Low capability/complexity CPE (LC-CPE) 2) Large number of fixed /portable LC-CPEs 3) Real-time monitoring 4) CPEs may provide an infrastructure backhaul for LC-CPEs as well as perform monitoring
Topology
Infrastructure mode Point-to-Fixed/Portable Multipoints Communications

A3) Critical Infrastructure/Hazard Monitoring



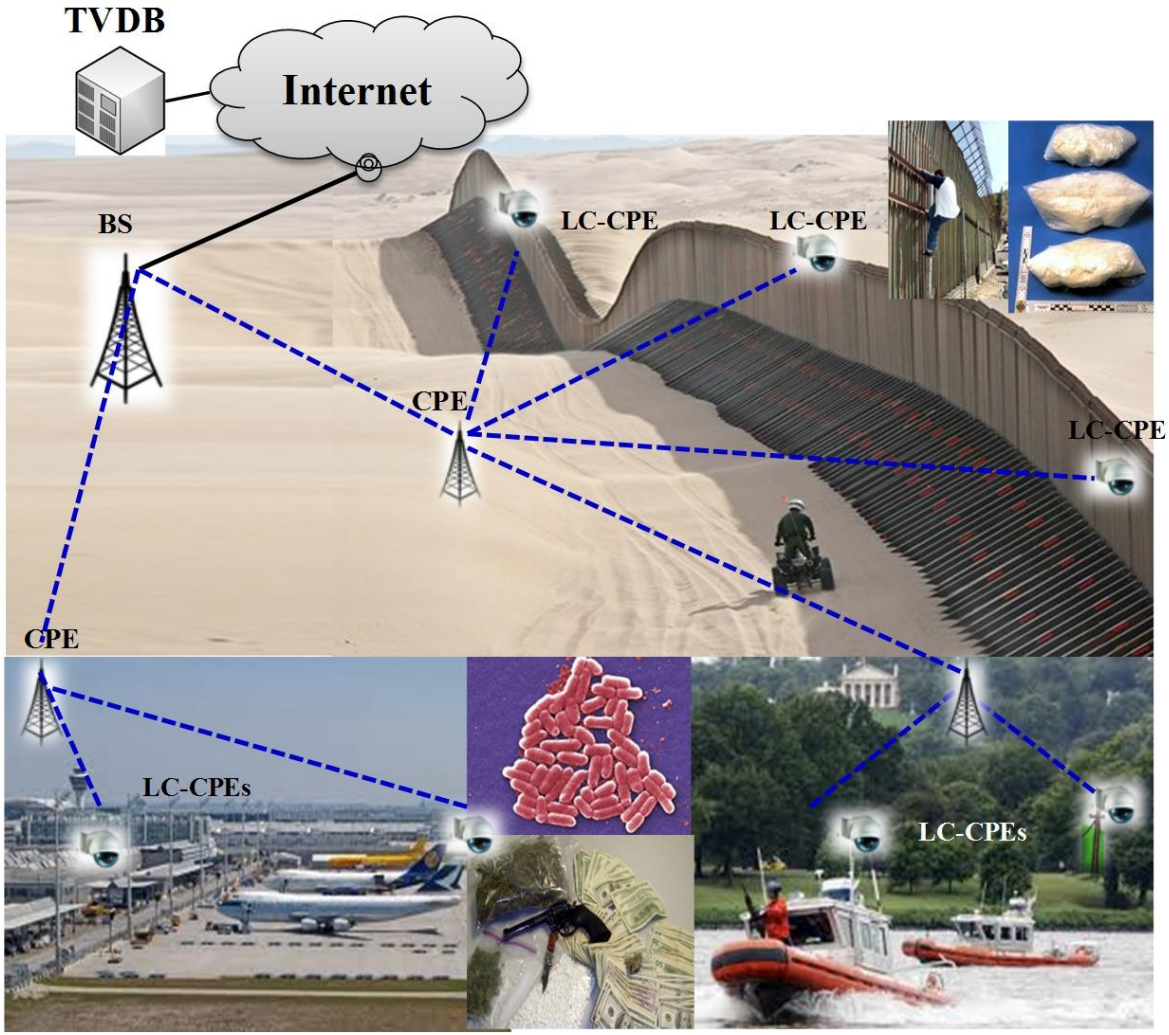
Usage
Critical Infrastructure/Hazard Monitoring by infrastructure monitoring CPEs, which may be attached in the portable stations
Properties
1) Low capability/ complexity CPE (LC-CPE) 2) Large number of fixed /portable LC-CPEs 3) Real-time monitoring 4) Low latency communication 5) High reliability and security 6) CPEs may provide an infrastructure backhaul for LC-CPEs
Topology
Infrastructure mode Point-to-Fixed/Portable Multipoints Communications

A4) Environment Monitoring



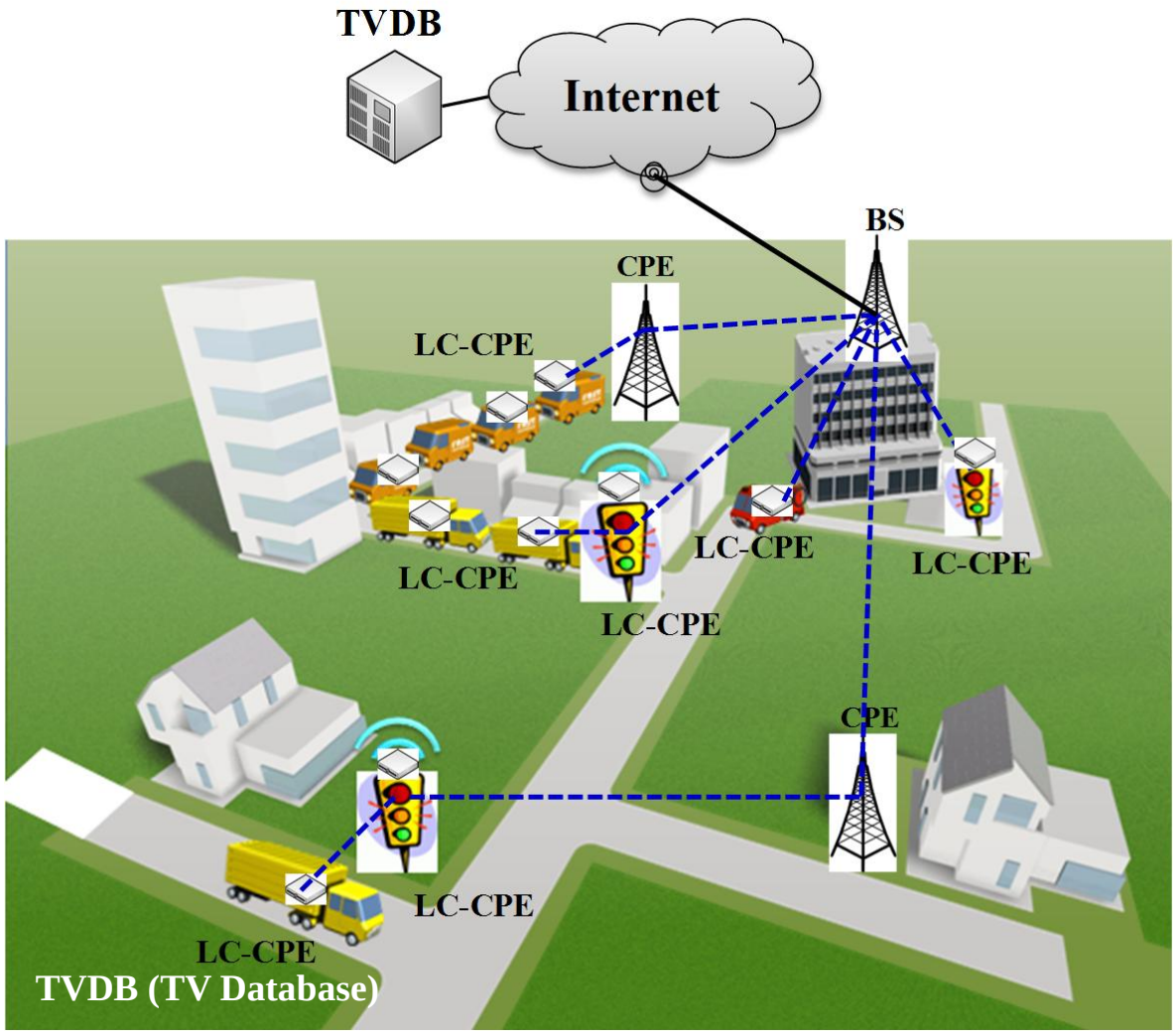
Usage
Environment monitoring by monitoring CPEs, which will detect the change of temperature, climate, or unintended events in a very wide area
Properties
1) Low capability/ complexity CPE (LC-CPE) 2) Very large number of fixed/portable LC-CPEs 3) Real-time monitoring 4) Low duty cycle, low latency communication 5) CPEs may provide an infrastructure backhaul for LC-CPEs
Topology
Infrastructure mode Point-to-Fixed/Portable Multipoints Communications

A5) Homeland Security/Monitoring



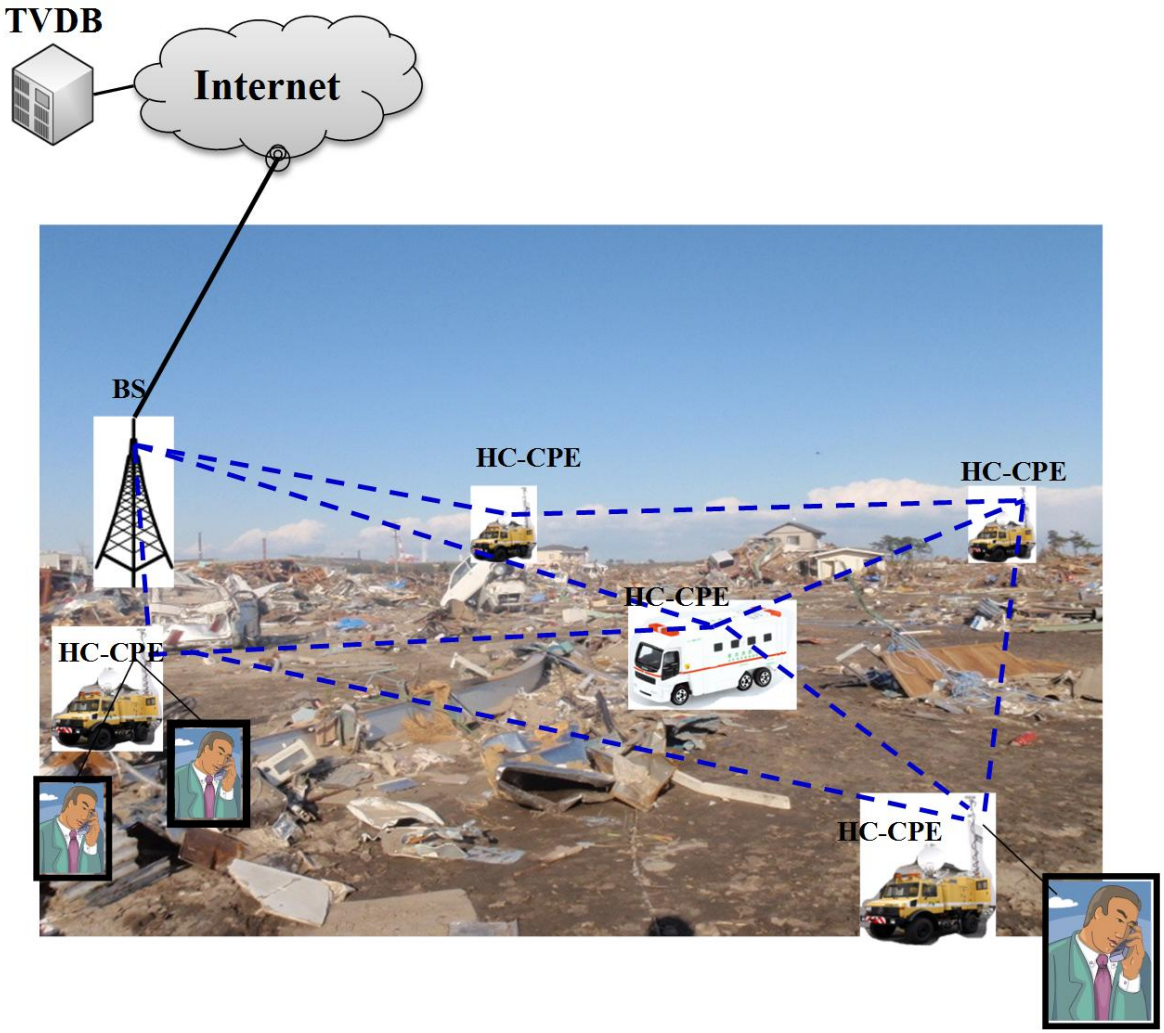
Usage
Homeland security or monitoring by security CPEs, which may be attached in the barrier of land, coast or airport to detect illegality or contaminants
Properties
1) Low capability/ complexity CPE (LC-CPE) 2) Fixed/Portable LC-CPEs 3) Real-time monitoring 4) Very low latency communication 5) High reliability and security 6) CPEs may provide an infrastructure backhaul for LC-CPEs
Topology
Infrastructure mode Point-to-Fixed/Portable Multipoints Communications

A6) Smart Traffic Management and Communication



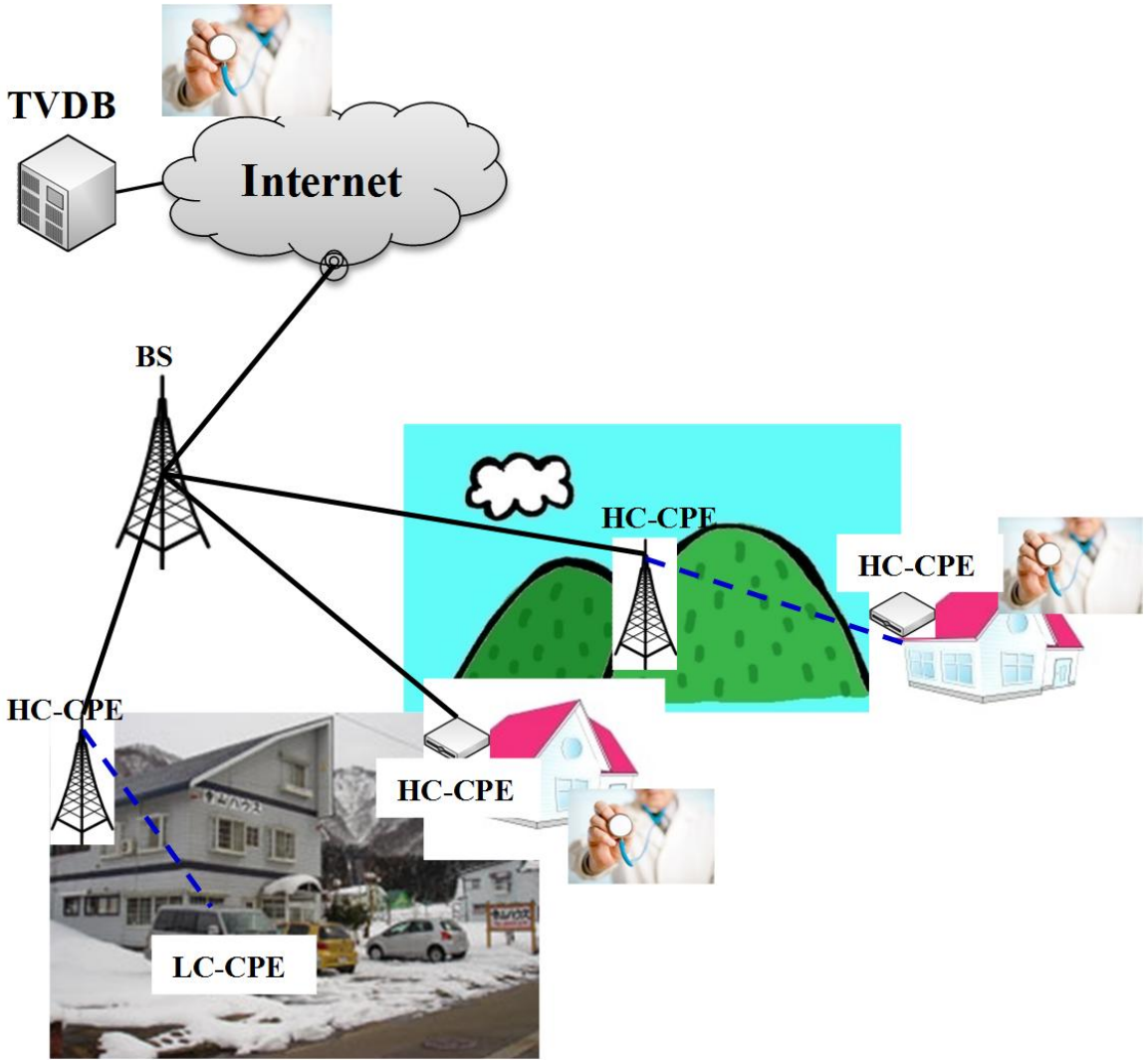
Usage
Smart Traffic Management and Communication by traffic CPEs, which may be attached in the traffic sign poles or cars
Properties
1) Low capability/ complexity CPE (LC-CPE) 2) Fixed/Portable LC-CPEs 3) Real-time monitoring 4) Very low latency communication 5) CPEs may provide an infrastructure backhaul for LC-CPEs
Topology
Infrastructure mode Point-to-Fixed/Portable Multipoints Communications

B1) Temporary Broadband Infrastructure



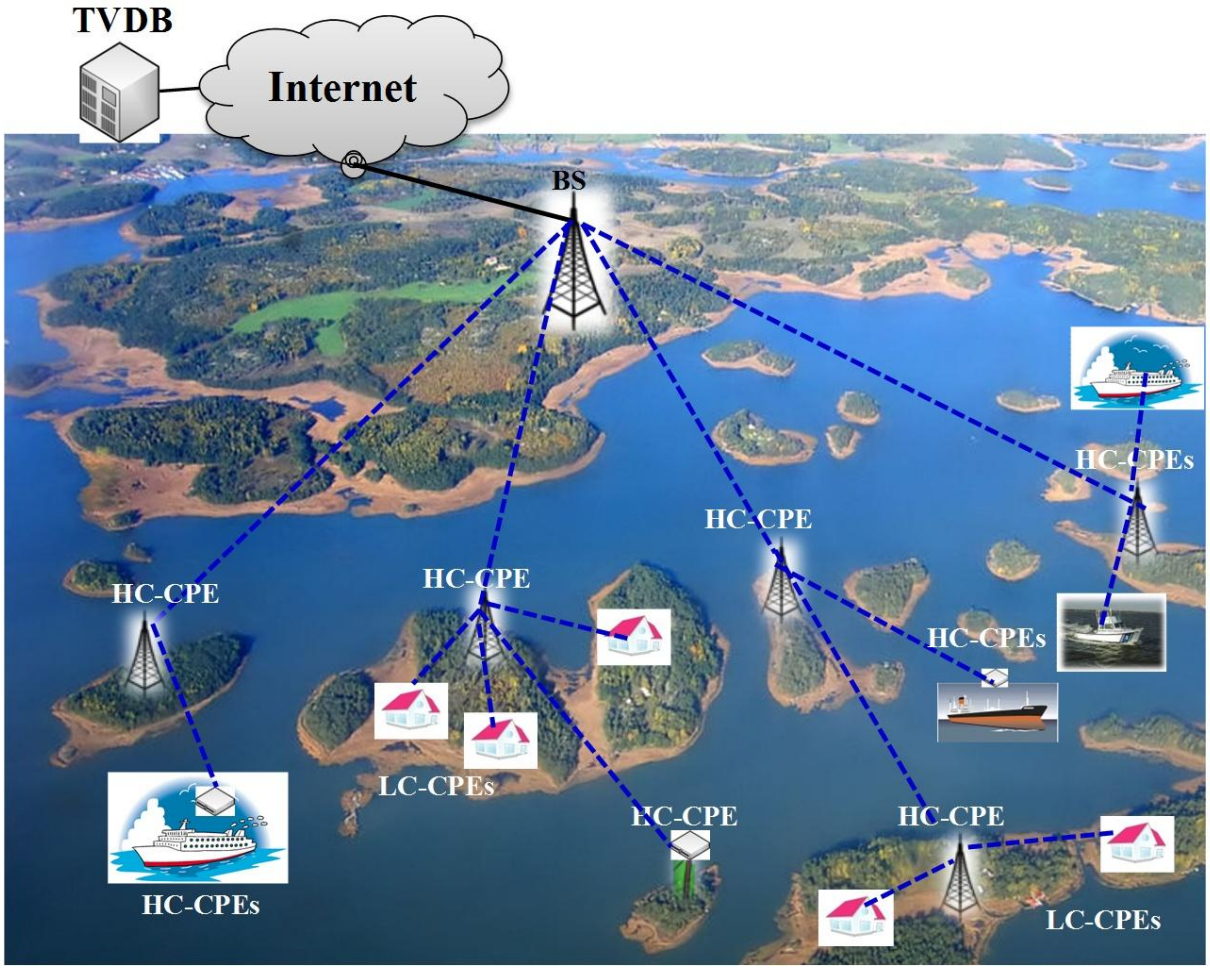
Usage
Temporary Broadband Infrastructure by portable HC-CPEs, which may be attached in the infrastructure vehicles on emergency
Properties
1) Higher capacity CPEs (HC-CPEs) rather than monitoring CPEs of A1~A6 2) Large number of portable CPEs 3) Easy network setup 4) High reliability of connections
Topology
Ad hoc connection Peer to Peer Communications

B2) Remote Medical Service



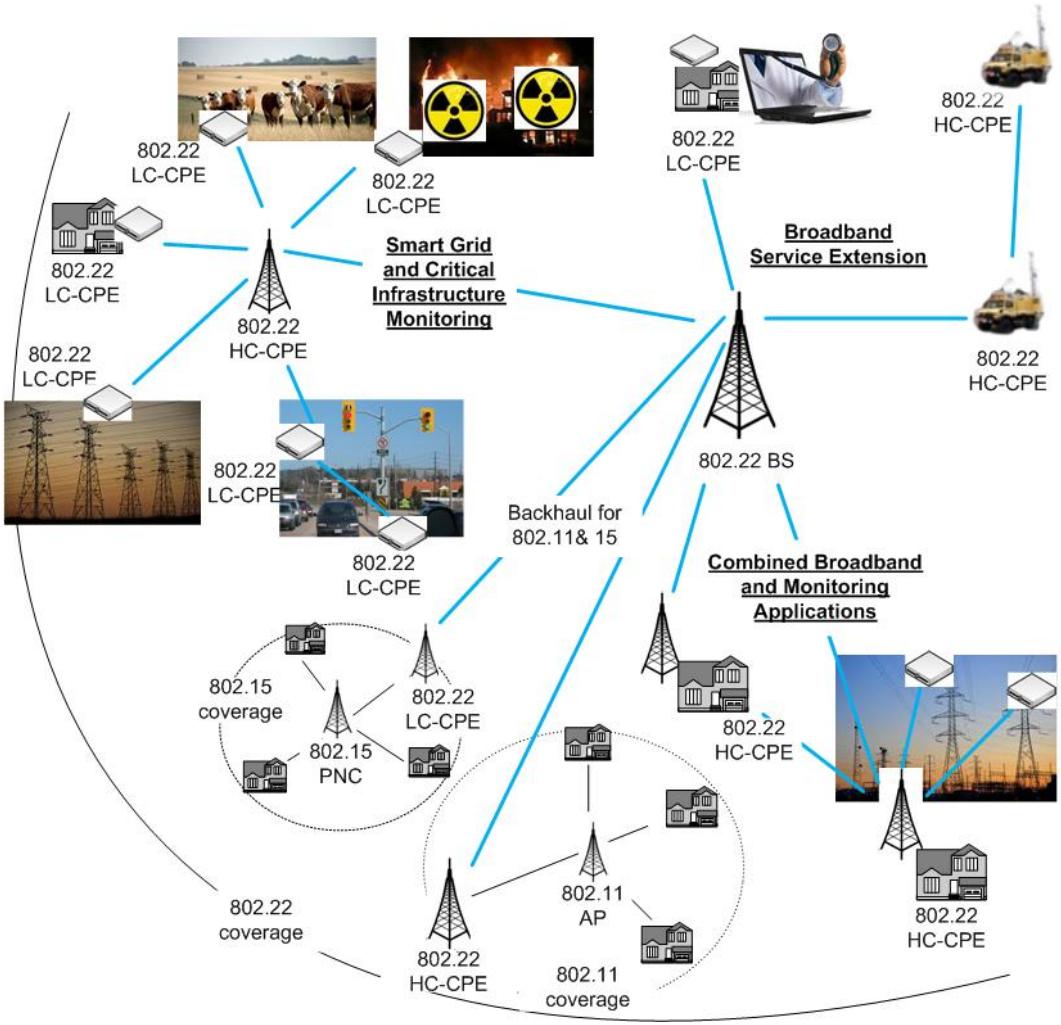
Usage
Remote Medical Service by medical service HC-CPEs, which may be applied in home media products
Properties
1) Higher capacity CPEs (HC-CPEs) rather than monitoring CPEs of A1~A6 2) Higher QoS and reliability 3) Real-time and low latency communication 4) HC-CPEs may provide an infrastructure backhaul to other HC-CPEs or LC-CPEs
Topology
Infrastructure mode Fixed Point-to-Multipoints Communications

B3) Archipelago/Marine Broadband Service



Usage
Archipelago/ marine broadband service by broadband HC-CPEs, which may be located in islands or be applied in ships.
Properties
1) Higher capacity CPEs (HC-CPEs) rather than monitoring CPEs of A1~A6 2) Fixed/Portable CPEs 3) Higher QoS and reliability of connections 4) HC-CPEs may provide an infrastructure backhaul to other HC-CPEs or LC-CPEs
Topology
Infrastructure mode Point-to-Fixed/Portable Multipoints Communications

C1) Combined Smart Grid, Monitoring and Broadband Services



Usage
Combined Smart Grid, Monitoring and Broadband Services by different types of CPEs
Properties
1) 802.22 RA smart grid and critical infrastructure monitoring application will be complimentary to other short range applications at the users' end 2) We may have different types of CPEs in 802.22 new SG 3) Currently CPEs can not communicate to each other. We need this capability 4) Improved broadband service by using wider bandwidth through channel aggregation
Topology
Infrastructure mode & Ad mode

Conclusion

Categories	Usage Case	End Device Capability	Num of Devices	Communication	Mobility	Topology
A) Smart Grid & Monitoring	A1) Regional Area Smart Grid/Metering	Low	Very large	Low duty cycle	Fixed	Infrastructure (Fixed point-to-multipoints)
	A2) Agriculture/Farm House Monitoring			High-reliability, Real-time, Low latency	Fixed/ Portable	Infrastructure (Point-to-fixed/portable multipoints)
	A3) Critical Infrastructure/Hazard Monitoring					
	A4) Environment Monitoring					
	A5) Homeland Security/Monitoring					
	A6) Smart Traffic Management and Communication					
B) Broadband Service Extension	B1) Emergency Temporary Broadband Infrastructure	High	Large	High reliability, Easy connection	Portable	Ad hoc (Portable-to-Portable)
	B2) Remote Medical Service			Real-time, Low latency	Fixed	Infrastructure (Fixed point-to-multipoints)
	B3) Archipelago/Marine Broadband Service			High QoS and reliability	Fixed/ Portable	Infrastructure (Point-to-fixed/portable multipoints)
C) Combined Service	C1) Combined Smart Grid, Monitoring and Broadband Service	High and Low	Very Large	Category A) and B)	Fixed/ Portable	Infrastructure and Ad-hoc

Outline

- Digital divide: Today’ s problem and its solution
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P802.22b PAR Approved by IEEE SA NESCOM

- The P802.22b PAR Amendment for Broadband Enhancements and Monitoring Applications was approved by the IEEE SA NESCOM.
- The press release can be found at the following URL:
- Click: IEEE 802.22b Press Release

Conclusions

- IEEE 802.22 standard is optimized for VHF/UHF TV channels to provide broadband services
- *First* IEEE Standard for operation in Television 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 Cognitive Radio features
- Recipient of the IEEE SA *Emerging Technology of the Year Award*
- The IEEE P802.22b Project will provide combined broadband services and monitoring applications aimed at a wide variety of applications such as smart grid, critical infrastructure monitoring, environment monitoring, emergency broadband etc.
- We look forward to your continued support and participation in the IEEE 802.22 Standards Development Process.

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