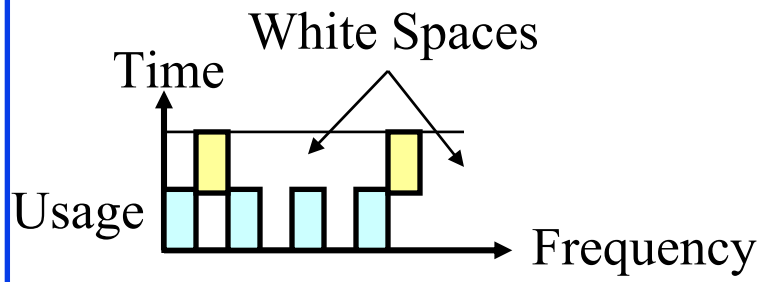
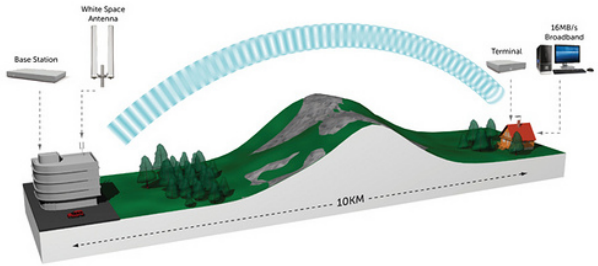
Wireless Networking in White Spaces





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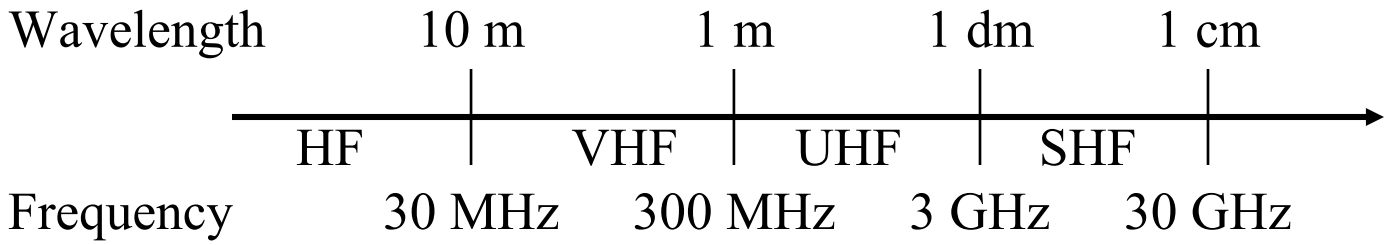
Audio/Video recordings of this class lecture are available at:
http://www.cse.wustl.edu/~jain/cse574-14/

Overview

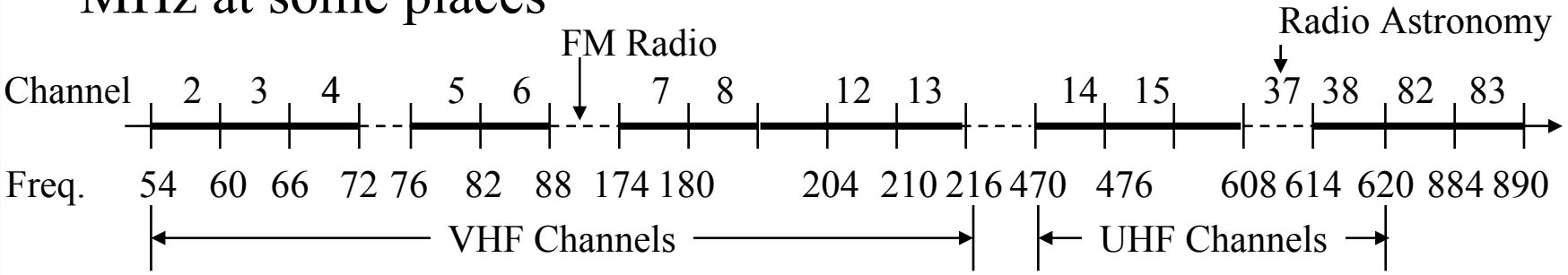
1. Television Channels
2. Software Defined and Cognitive Radios
3. Spectral White Spaces
4. FCC Rules for White Spaces
5. Wireless Standards for White Space: 802.11af, 802.19.1, 1900.4, PAWS

Note: IEEE 802.22 Regional Area Network and 802.15.4m Personal Area Network are covered in other modules

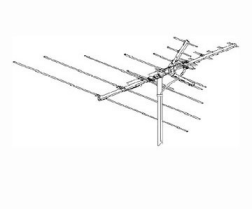
Over-the-Air Television Channels



- Television channels use Very High Frequency (VHF) and Ultra High Frequency (UHF) bands
- Each channel uses 6 MHz in USA, 8 MHz in Europe, and 7 MHz at some places



- At least one channel is skipped between two analog stations in neighboring areas to avoid interference

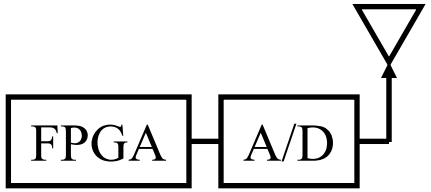


Digital Television

- Converting pixels to bits
  ⇒ Can easily encrypt, multiplex, mix with data
- Change Standard Definition (SD), High Definition (HD)
- Do not need empty channels between neighbors
- Need about 19 Mbps ⇒ Can transmit 6-8 channels in 6-8 MHz.
- US FCC stopped analog transmissions on June 12, 2009
- A lot of TV spectrum became available ⇒ **Digital Dividend**
- Big demand for this "new" spectrum in **700 MHz band**:
  - Cellular, Emergency Services, ISM, every one wants it
  - Government raised $19.5 billion from auction to cellular companies and saved some for unlicensed use

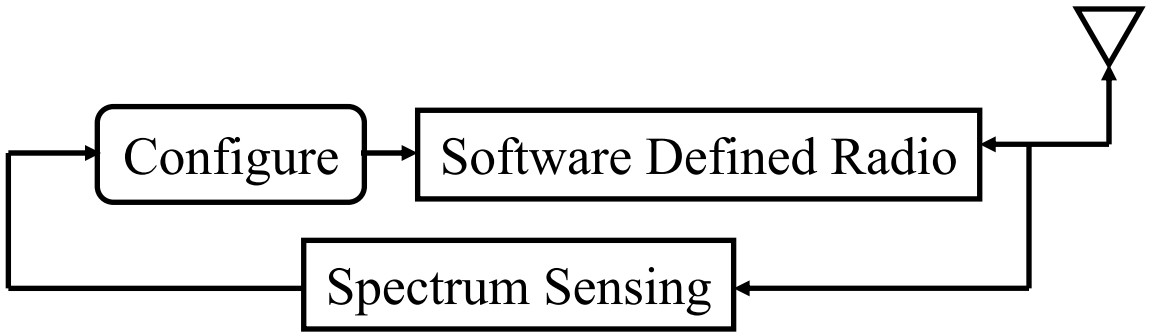
Software Defined Radio

- Analog radio circuits are specific to frequency, channel width, data rate, modulation (AM, FM), multiplexing (FDMA, TDMA, CDMA, OFDMA)
- Need multi-mode radios: Multiband, multi-channel, multi-carrier, multi-mode (AM, FM, CDMA), Multi-rate (samples per second) ⇒ Possible using digital computation
- Generally using Digital Signal Processing (DSP) or field programmable gate arrays (FPGAs)
- Signal is digitized as close to the antenna as possible. Logic reconfigured on demand.
- Software reconfigurable radio
- Flexibility, Upgradability, Lower cost (digital), Lower power consumption.
- **Software Defined Antenna**: Small pixel elements reconfigured by software for desired band.



Cognitive Radio

- Cognition = Perception = Sense
- Cognitive Radio: A radio that can sense the radio environment, select the proper frequency, bandwidth, power, modulation to avoid interference.
- Continue to sense and reconfigure when necessary
- Allows using even licensed spectrum when no one is using it
  Reduces waste of unused spectrum
  $\Rightarrow$ FCC allowed such operation in certain bands



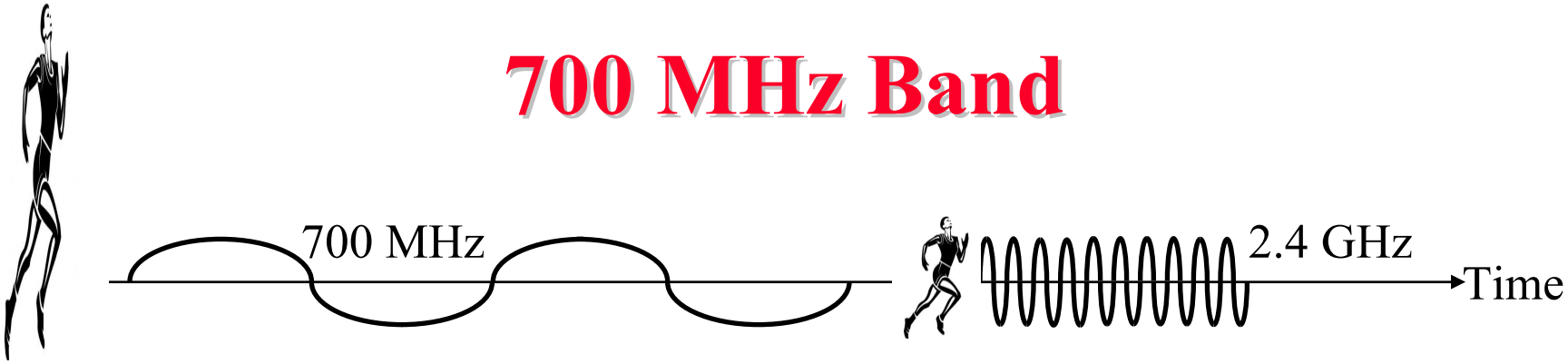
Effect of Frequency

- Higher Frequencies have higher attenuation,
  e.g., 18 GHz has 20 dB/m more than 1.8 GHz
- Higher frequencies need smaller antenna
  Antenna $\geq$ Wavelength/2, 800 MHz $\Rightarrow$ 6”
- Higher frequencies are affected more by weather
  Higher than 10 GHz affected by rainfall
  60 GHz affected by absorption of oxygen molecules
- Higher frequencies have more bandwidth and higher data rate
- Higher frequencies allow more frequency reuse
  They attenuate close to cell boundaries. Low frequencies propagate far.

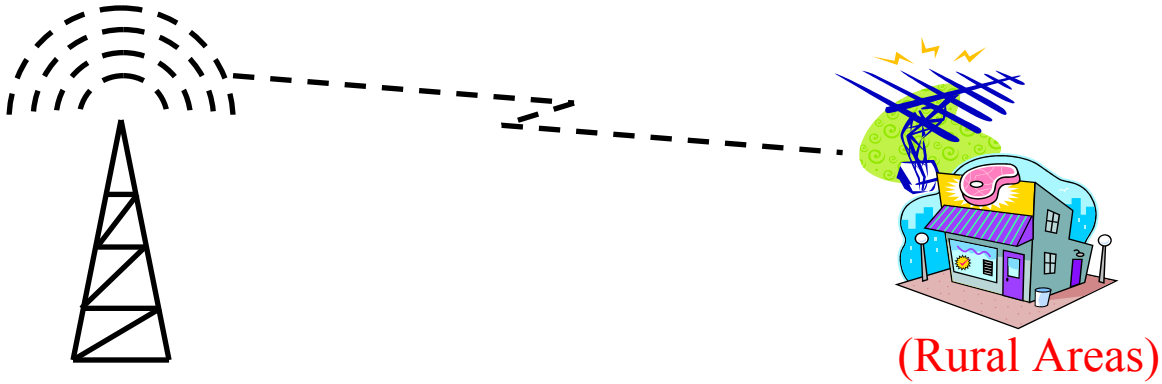
Effect of Frequency (Cont)

- Lower frequencies have longer reach
- Lower frequencies require larger antenna and antenna spacing
  ⇒ MIMO difficult particularly on mobile devices
- Lower frequencies ⇒ Smaller channel width
  ⇒ Need aggressive MCS, e.g., 256-QAM
- Doppler shift = vf/c = Velocity ×Frequency/(speed of light)
  ⇒ Lower Doppler spread at lower frequencies
- Mobility ⇒ Below 10 GHz

700 MHz Band



- Lower attenuation (1/7th to 1/9th of 1800/1900/2100 MHz)
  ⇒ Lower transmission power
  ⇒ Longer mobile battery life
- Larger Cell radius ⇒ Smaller number of towers
- Long distance propagation ⇒ Good for rural areas.

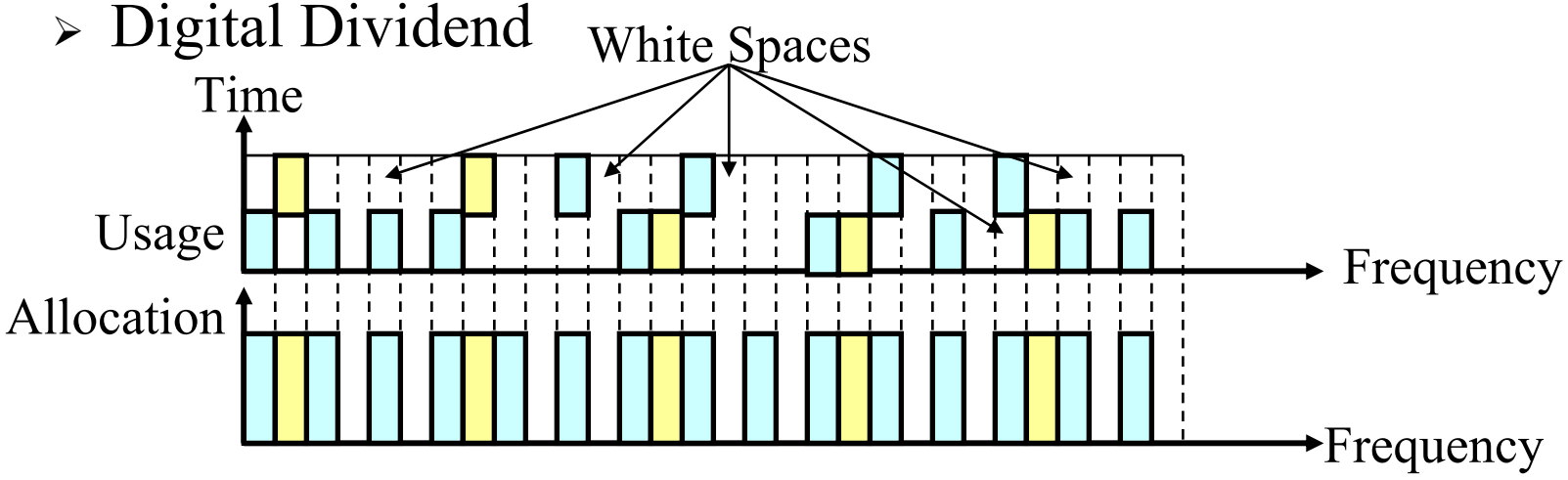


(Rural Areas)

Ref: Adam LaMore, "The 700 MHz Band: Recent Developments and Future Plans," http://www.cse.wustl.edu/~jain/cse574-08/700mhz.htm

Spectral White Spaces

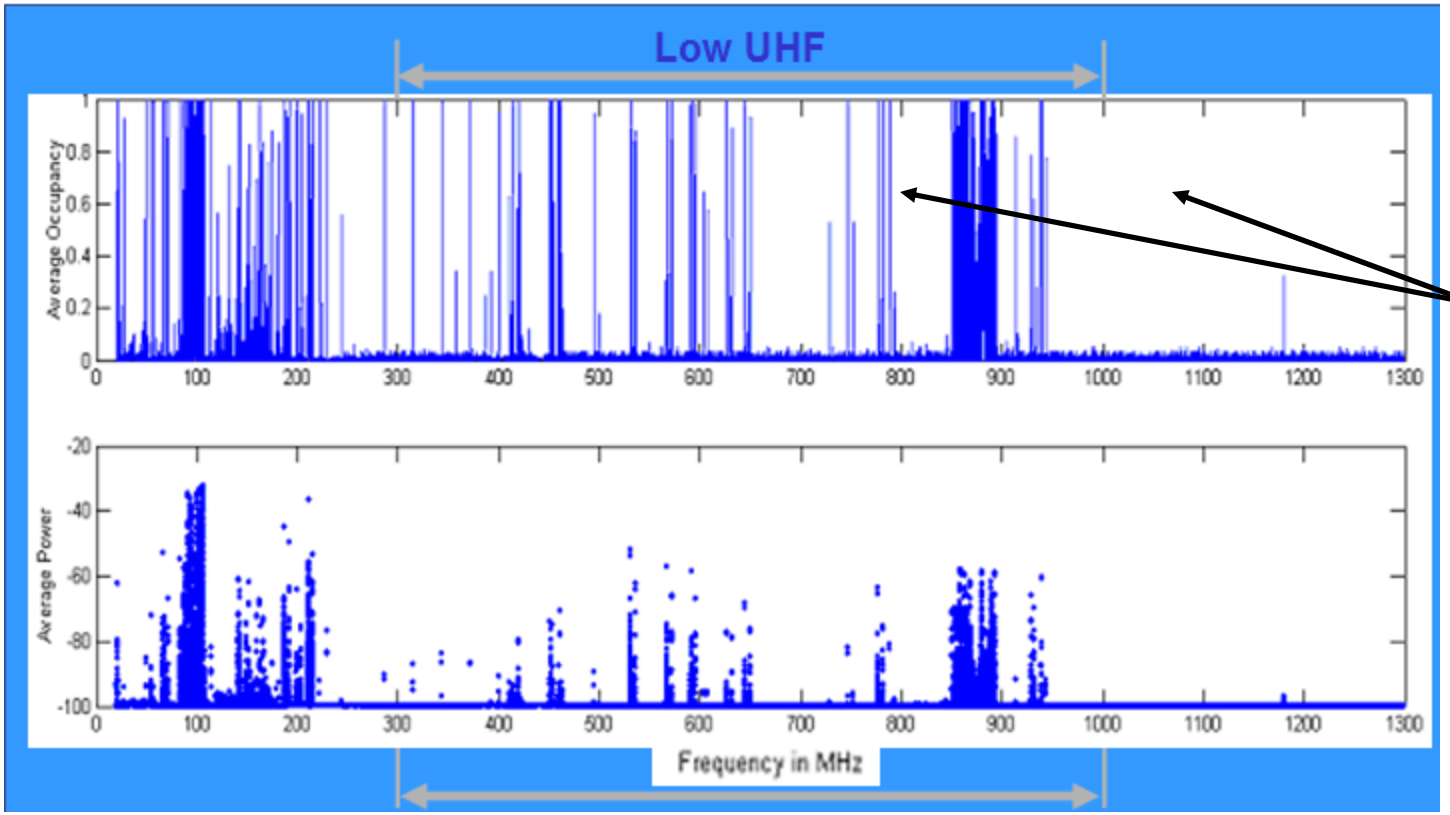
- Any spectrum at a given area at a given time available for use on a non-interfering basis:
  - Unallocated spectrum
  - Allocated but under-utilized
  - Channels not used to avoid interferences in adjacent cells
  - Digital Dividend



Ref: C. Gomez, "White Spaces for Rural Broadband," April 2013, http://www.itu.int/ITU-D/asp/CMS/Events/2013/PacificForum/ITU-APT-S3_Cristian_Gomez.pdf

Spectrum Usage Example

(Test conducted with antenna at a height of 22.1 metres above the ground in the rural sector west of Ottawa, Canada)

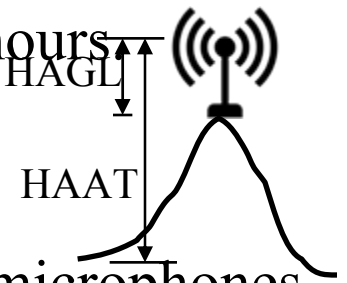


White Spaces

Ref: C. Stevenson, et al., "Tutorial on the P802.22.2 PAR for: *Recommended Practice for the Installation and Deployment of IEEE 802.22 Systems"* http://www.ieee802.org/802_tutorials/06-July/Rec-Practice_802.22_Tutorial.ppt

FCC Rules for White Spaces

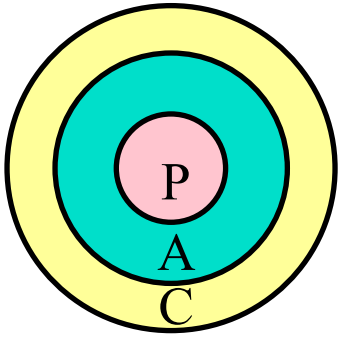
- Two types of devices: Fixed, Portable
- **Fixed Devices**:
  - Must include geo-location (i.e., GPS) with 50m accuracy.
  - Must verify location periodically. Spectrum sensing not required.
  - Get Channel availability daily using national databases (operated by third parties)
  - Must register with the database. Get grant for 48 hours
  - White spaces in channels 2, 5-36, 38-51 available
  - White spaces in channels 3, 4, 37 for backhaul
  - Two channels in every area reserved for wireless microphones
  - Outdoor antenna max 30m height above ground level (HAGL) and 250 m height above average terrain (HAAT)



Ref: *FCC, "Unlicensed Operation in the TV Broadcast Bands*," ET Docket No. 04-186, and 02-380 Third Memorandum Opinion and Order, April 4, 2012, available at http://transition.fcc.gov/Daily_Releases/Daily_Business/2012/db0405/FCC-12-36A1.pdf

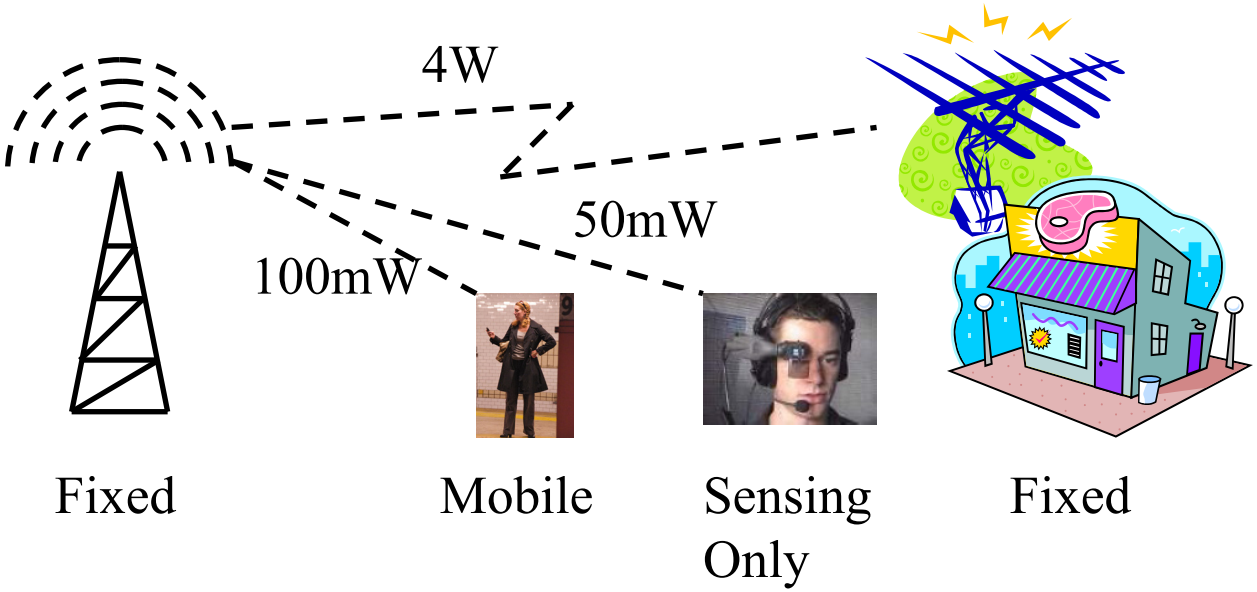
FCC Rules (Cont)

- Portable/Mobile Devices: w GPS (Mode II), w/o GPS (Mode I)
  - Mode II devices register with the database
  - Mode I devices: Not required to register with FCC
    - Must obtain channel availability from Mode II or fixed at HAAT less than 106 m.
    - Must receive a Channel Verification Signal from Mode II or fixed device
- Distance from protected contour:
  - 4-31 km in co-channel, and 0.4-2.4 km in adjacent channel depending upon the HAAT.



  - Higher antenna ⇒ Longer separation to avoid interference
  - Contours: Protected, Co-channel, Adjacent Channel

TVWS Device Examples

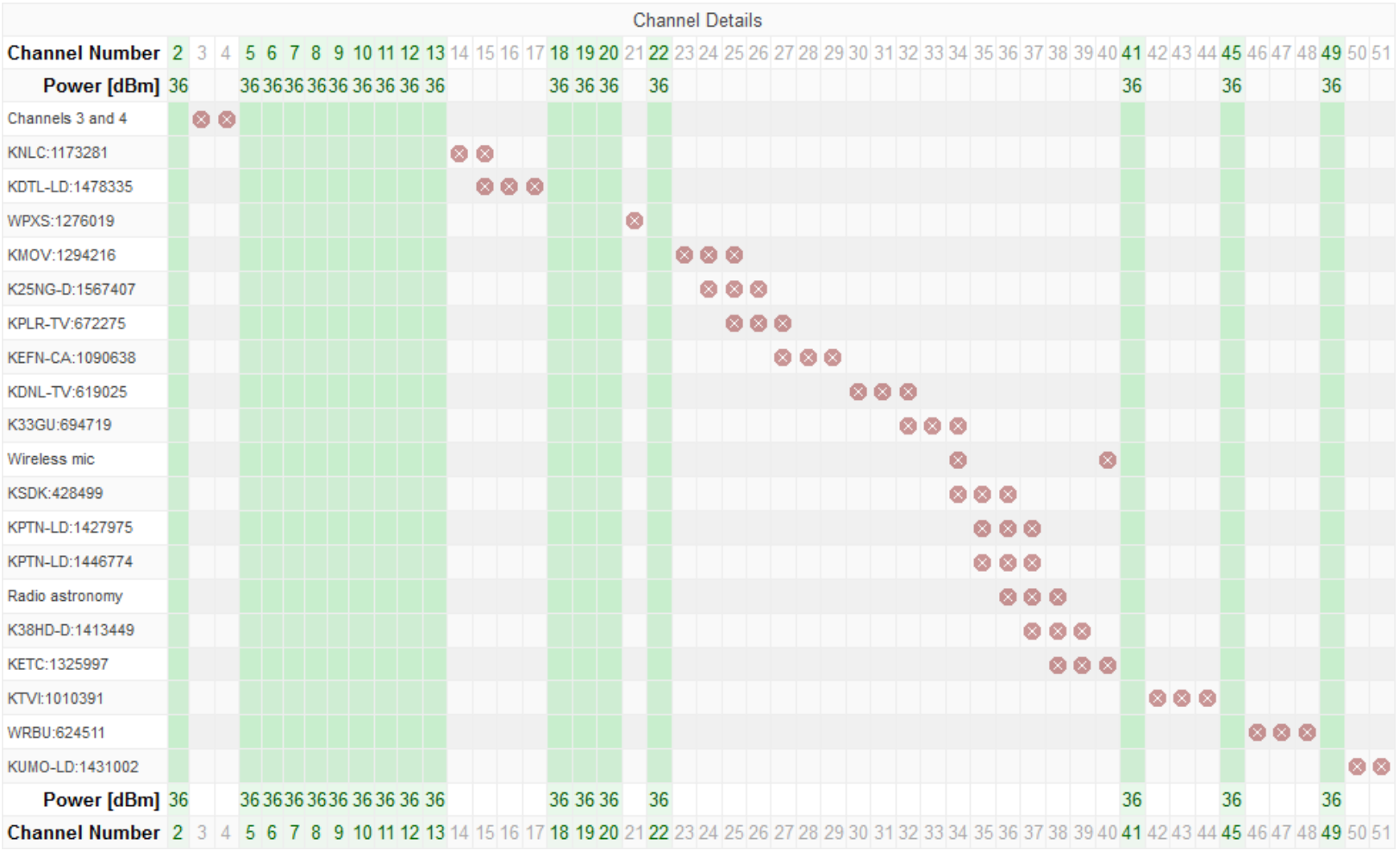


- Can offload bulk cellular data traffic to white spaces (similar to WiFi currently)
- Combined VHF+UHF band is too wide to cover with a single radio frontend and antenna

TVWS Databases

- FCC has authorized 10 companies to administer TVWS databases.
  - Get info from FCC database
  - Register fixed TVWS devices and wireless microphones
  - Synchronize databases with other companies
  - Provide channel availability lists to TVWS devices
- FCC does not require spectral sensing.
  No need to stop transmission and sense
  $\Rightarrow$ Continuous multimedia
- Europe requires devices to check every two hours and allows higher power transmission but requires spectral sensing (closed loop system)

White Spaces Near WUSTL



- 17 channels. Zipcode 63130.

Ref: Google Spectrum Database, https://www.google.com/get/spectrumdatabase/channel/

Standards for White Space Wireless

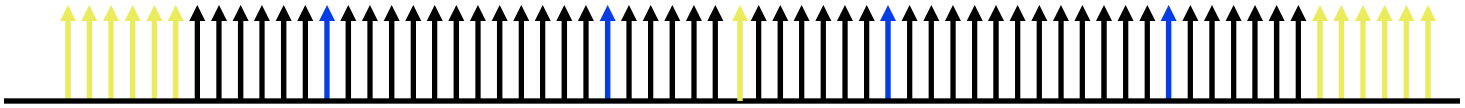
- **IEEE 802.11af-2014**: Wireless Local Area Network
- **IEEE 802.22-2011**: Cognitive Wireless Regional Area Network
- **IEEE 802.15.4m-2011**: Wireless Personal Area Network
- **IEEE 802.19.1**: Coexistence
- **IEEE 1900.4a**: Resource Optimization
- **IETF PAWS**: Database access
- ETSI BRAN: European Telecommunications Standards Institute Broadband Radio Access Networks
- Weightless SIG: Special Interest Group
- CEPT ECC SE43: European Conference of Postal and Telecommunications Administrations Electronics Communications Committee Spectrum Engineering
- ITU-WP1B: International Telecommunication Union Working Party 1B – Spectrum Management Methodologies

802.11af-2014: White-Fi

- A.k.a. Super-Fi (initially incorrectly called super Wi-Fi)
  Both MAC and PHY different from 802.11⇒ Not WiFi
- Draft approved by the Working Group and 802 Executive Committee. Final approved standard expected March 2014.
- White-space wireless using cognitive radios up to 5 km
- 256-QAM, 5/6, 3 us Guard Interval
  ⇒ 26.7 Mbps per 6 MHz channel
- Up to 4 channels may be bonded in one or two contiguous blocks
- MIMO operation with up to 4 streams using space-time block code (STBC) or multi-user MIMO
- 4 spatial streams × 4 channels ⇒ 426.7 Mbps

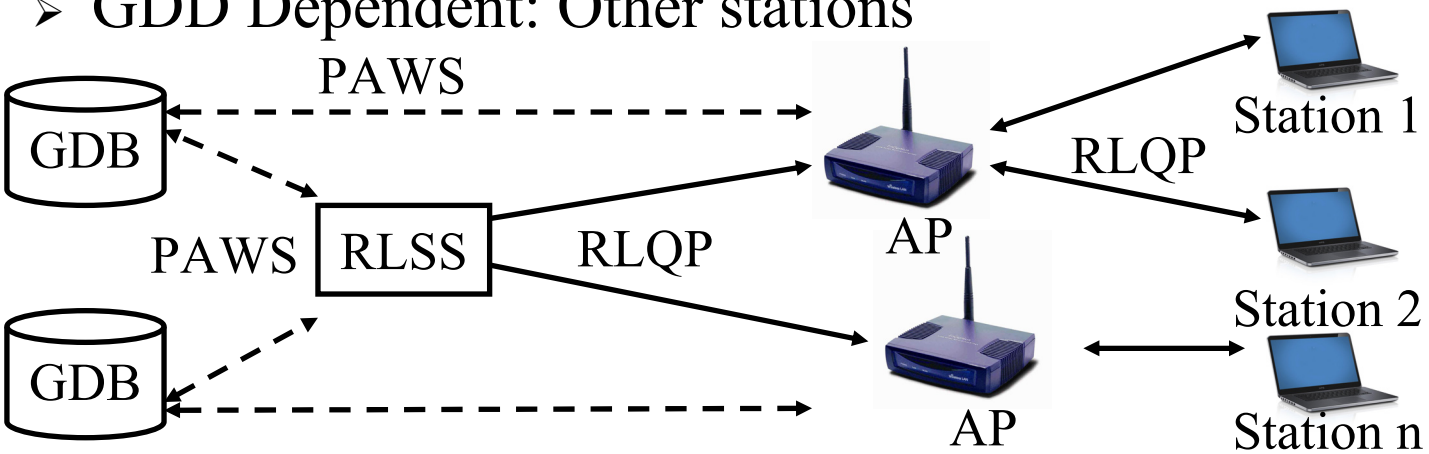
IEEE 802.11af PHY

- Basic Channel Unit (BCU): One TV Channel
  W = 6 MHz in USA
- Single channel mandatory
- Channel Bonding: Optional
  - Contiguous: 2W, 4W
  - Non-contiguous: W+W, 2W+2W
- MIMO with 4x Space Time Block Coding (STBC)
  or MU-MIMO with 4x
- OFDM similar to 40 MHz in 802.11n down-clocked by 7.5x to give a 5.33 MHz waveform
  - 108 Data, 3 DC, 6 pilots, 36 Guard =144 carriers in 6 MHz



802.11af Database Operation

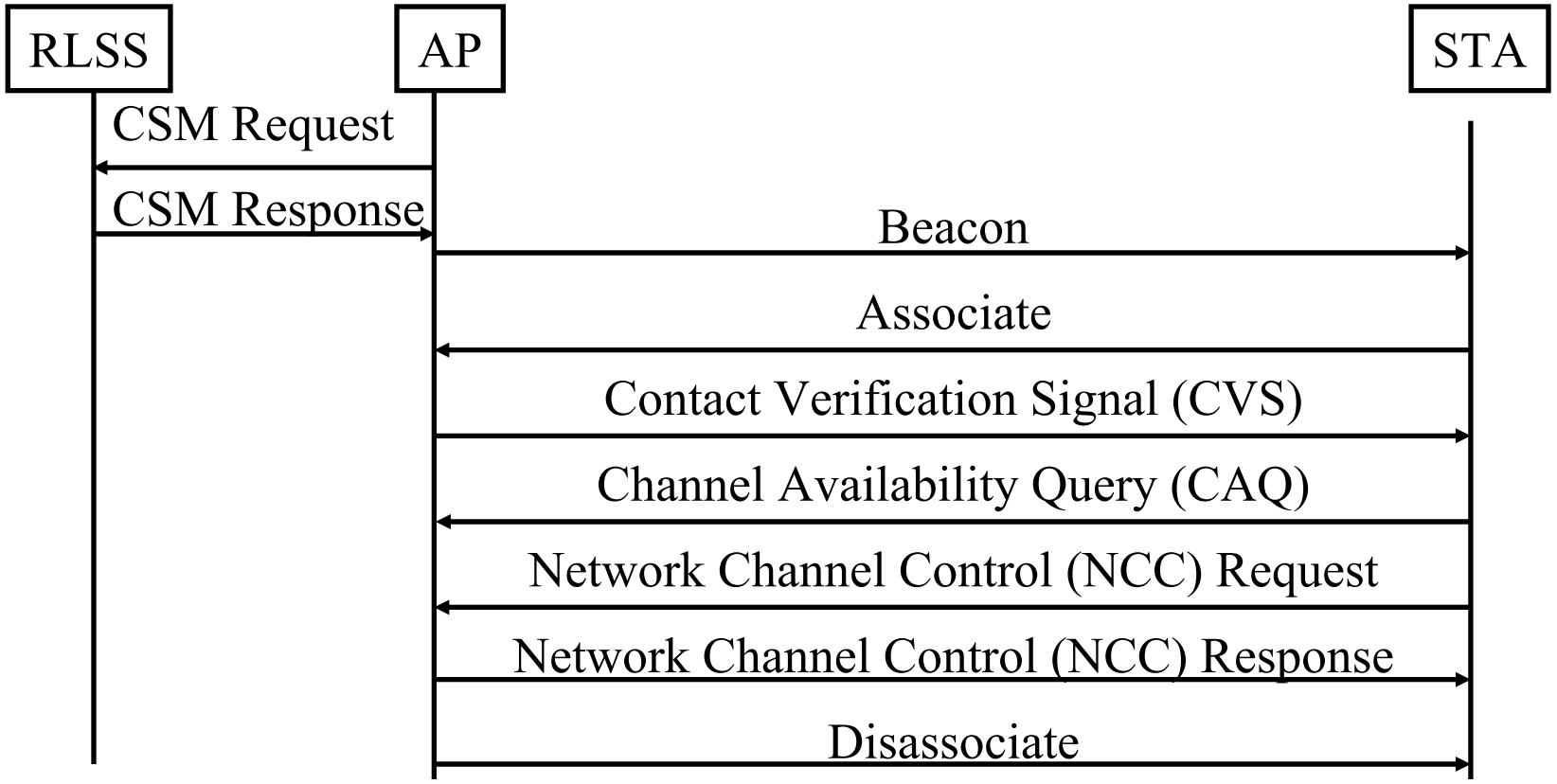
- Geolocation Database (GDB)
- Registered Location Secure Server (RLSS):
  - Provide faster response to access points (APs) locally in a campus.
  - May be Internet Service Provider (ISP) owned.
- Geolocation Database Dependent (GDD) entities:
  - GDD Enabling: Access Point
  - GDD Dependent: Other stations



Ref: A. Flores, et al., "IEEE 802.11af: A Standard for TV White Space Spectrum Sharing," http://networks.rice.edu/papers/FINAL_article_80211af.pdf

Registered Location Query Protocol (RLQP)

- Protocol for exchange of white space map (WSM) among RLSS, APs, and stations, aka, Channel Schedule Management (CSM)

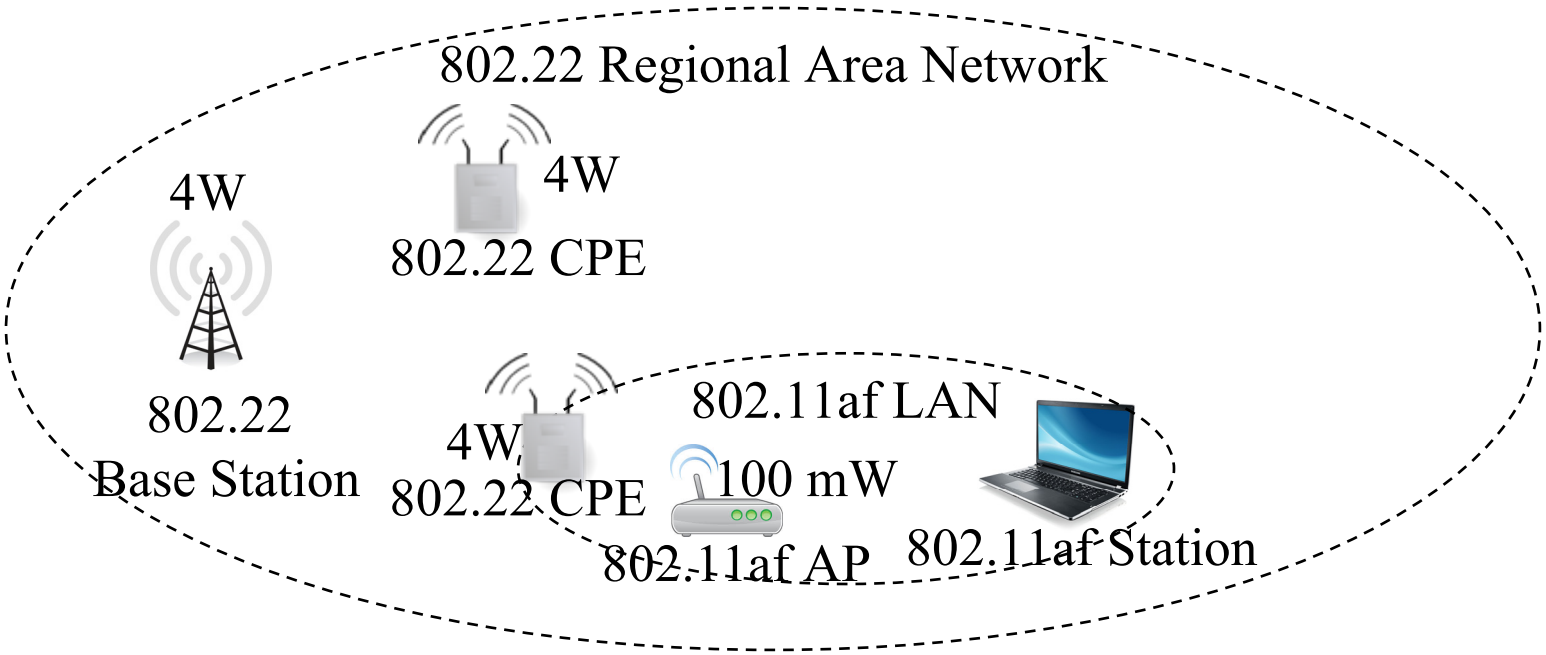


RLQP (Cont)

- CSM Request: APs ask other APs or RLSS about white space map
- APs broadcast beacons on all channels selected.
- Stations associate with the APs.
- Contact Verification Signal (CVS): APs tell their stations white space map and confirm that stations are still associated
- Contact Availability Query (CAQ): Stations ask AP, if they do not receive the map within a timeout interval
- CAQ Response
- Network Channel Control (NCC) Request: Sent by stations to APs requesting use of a channel. AP may forward to RLSS.
- NCC Response: Permission to transmit on requested channel
- Stations may be disassociated by APs if necessary

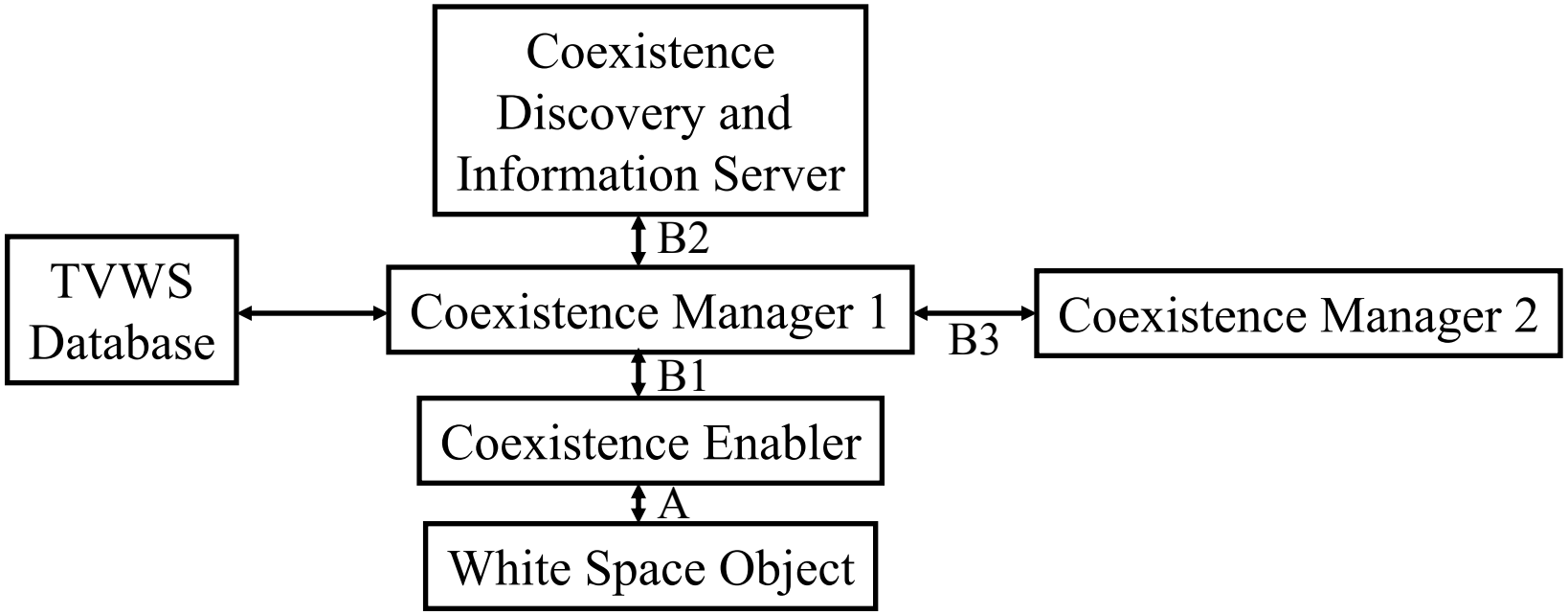
Coexistence Problem

- Exposed Terminal: 802.11af can not transmit because 802.22 keeps the channel busy
- Hidden Terminal: 802.11af interferes with 802.22 transmissions



IEEE 802.19.1

- IEEE 802.19: Radio access technology (RAT) independent methods of coexistence ⇒ 802.11, 802.15, 802.22 can all use one common method for coexistence.
- IEEE 802.19.1: Coexistence in TV white spaces. (Current Draft 5 Dated Feb 2014. Final expected Sept 2014)



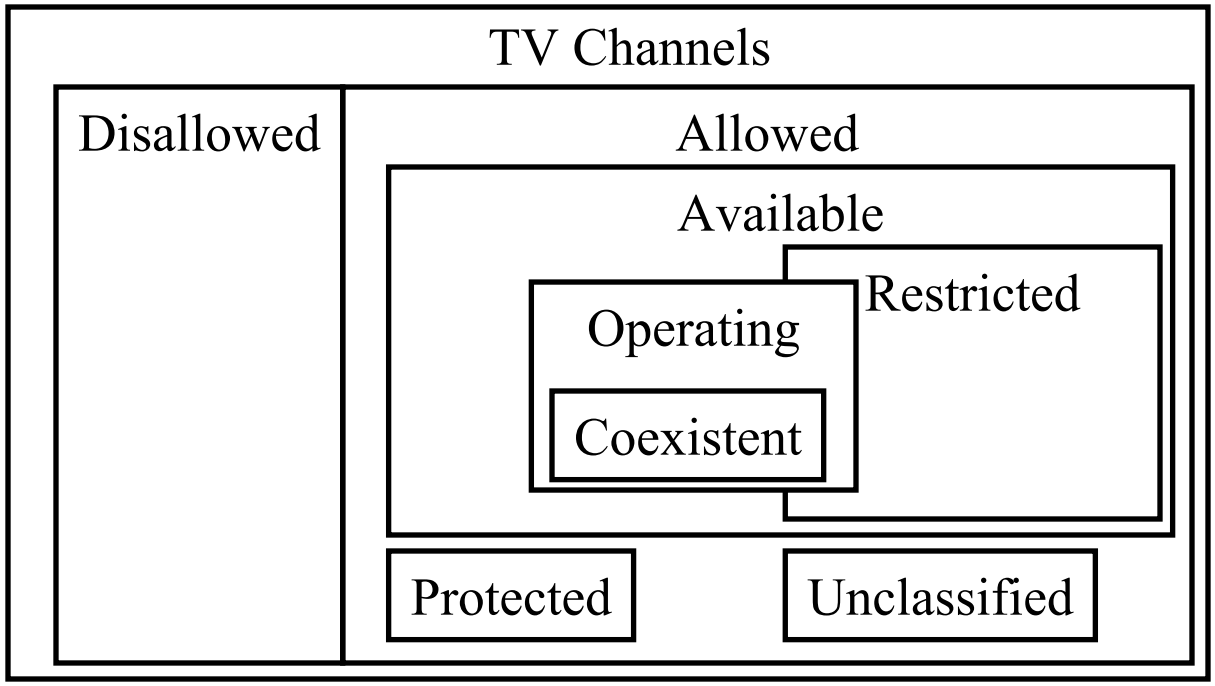
IEEE 802.19.1 (Cont)

- White Space Object (WSO): A WS device or a network
- Coexistence Enabler (CE): Represents a WSO in the coexistence system
- Coexistence Manager (CM): Makes decisions about configuration of a set of WSOs so that they can coexist
- Coexistence Discovery and Information Server (CDIS): Notifies CMs about potential neighbors of its WSOs.
- Interfaces B, B1, B2, and B3 are specified in IEEE 802.19.1 Interface C is PAWS.
- Each WSO registers with a CM
- CM collects data about its members and gets data about other CMs from CDIS.

IEEE 802.19.1 Algorithms

- Coexistence Discovery Algorithms: Find WSOs that may affect each other's performance
  - Statistical analysis of interference to see if the interference is expected to be more than a threshold
  - Compare distances between WSOs to a threshold distance based on technology
- Coexistence Decision Algorithm:
  - Operating Channel: All channels are classified as: disallowed (e.g., 3, 4, 37), allowed, available, protected (incumbent active), restricted (e.g., adjacent), unclassified, operating (under use), and coexistent (being shared)

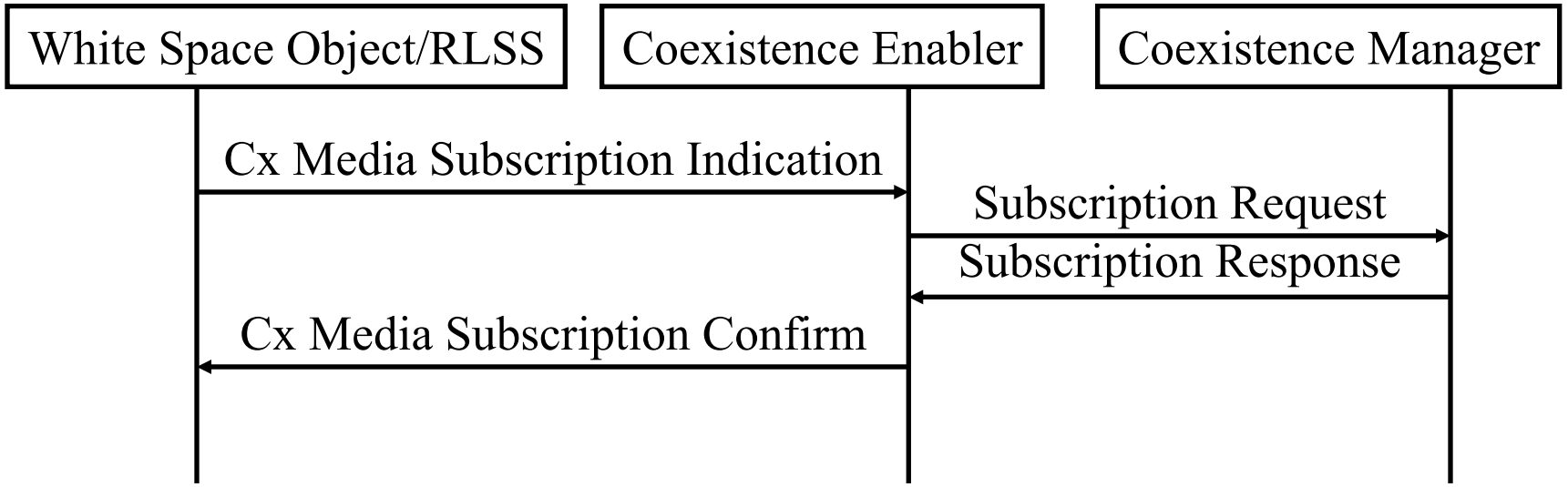
IEEE 802.19.1 Algorithms (Cont)



- Negotiations: Used different channel, or share a channel fairly using round-robin
- Re-organize CMs as Master-Slaves and load balance
- Priority Allocation
- Max-Min allocation
- Power Control

IEEE 802.19.1 Algorithms (Cont)

- WSO Subscription Procedure:



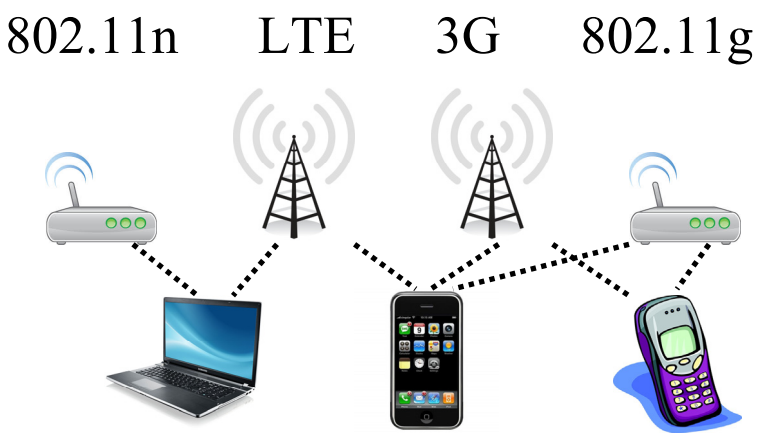
- Similarly, CMs subscribe with CDIS
- WSO Registration procedure
- Obtain Coexistence set information

IEEE DYSPAN SC

- Dynamic Spectrum Access Networks Standards Committee Formerly Standards Coordinating Committee 41 (SCC41)
- IEEE 1900.1 through 1900.7 standards related to dynamic spectrum access
- **IEEE 1900.4**: Optimize resource usage
- **IEEE 1900.4a**: Amendment for White Spaces
- IEEE 1900.7: Radio Interface for White Space Fixed and Mobile Operation (PAR approved June 2011)

IEEE 1900.4-2009

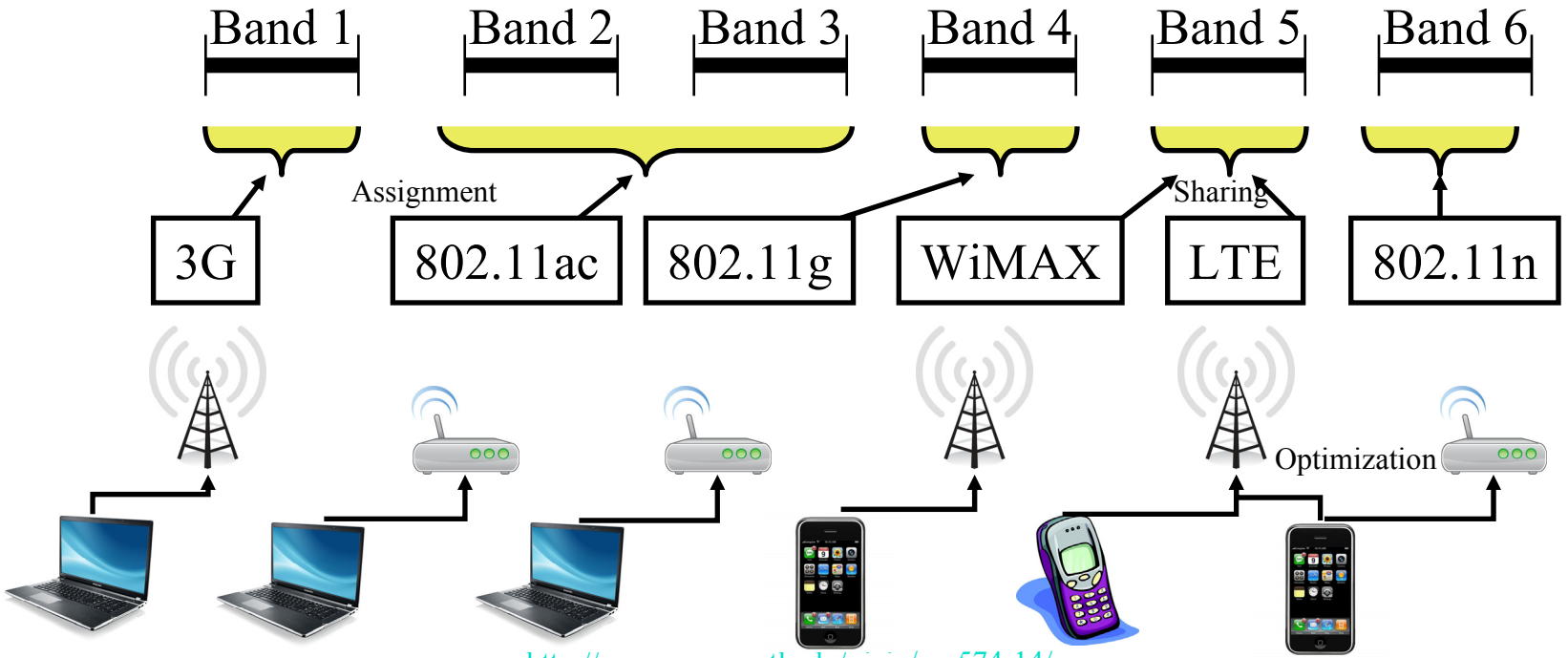
- Optimize radio resource usage
- Problem:
  - Multiple wireless networks are available, 802.11n, 802.11ad (60 GHz), White-Fi, 3G, 4G, …
  - A device has multiple wireless interfaces
  - Each interface has multiple spectrum bands (2.4, 5.8, …)
  - How to select the optimal radio access network (RAN) and optimal spectrum resources?



Ref: S. Buljore, et al, "Architecture and Enablers for Optimized Radio Resource Usage in Heterogeneous Wireless Access Networks: The IEEE 1900.4 Working Group," IEEE Communications Magazine, Jan 2009, pp. 122-129, http://ieeexplore.ieee.org/iel5/35/4752663/04752689.pdf?arnumber=4752689

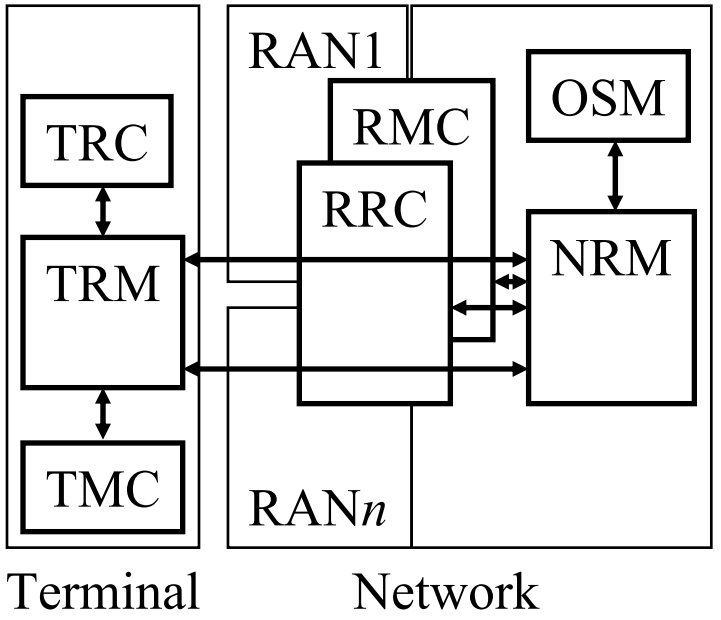
IEEE 1900.4 Use Cases

- Dynamic Spectrum Assignment: Select bands
- Dynamic Spectrum Sharing: Share a band
- Distributed Resource Usage Optimization: Optimize global objectives while meeting individual requirements



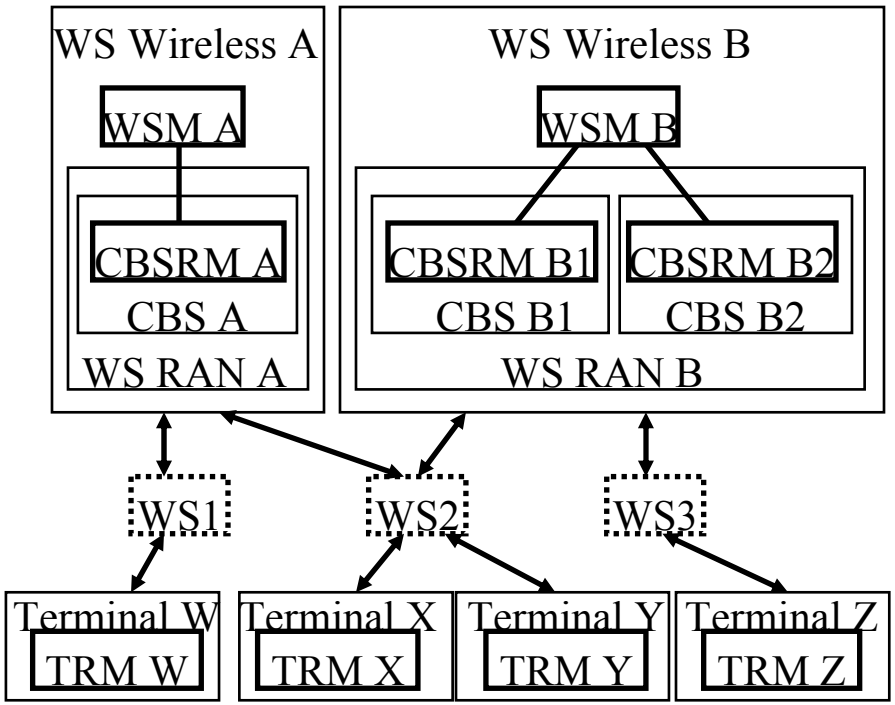
IEEE 1900.4 Architecture

- Composite Wireless Network (CWN)
  - Operator Spectrum Manager (OSM): Controls spectrum assignment
  - Radio Access Network (RAN)
  - RAN Measurement Collector (RMC): Provides context info to NRM
  - Network Reconfiguration Manager (NRM): Determines the optimal configuration and passes to RRC
  - RAN Reconfiguration Controller (RRC)
- Terminal:
  - Terminal measurement collector (TMC): Passes context to TRM
  - Terminal Reconfiguration Manager (TRM): Works with NRM to decide the configuration and passes to TRC
  - Terminal Reconfiguration Controller (TRC)



IEEE 1900.4a-2011

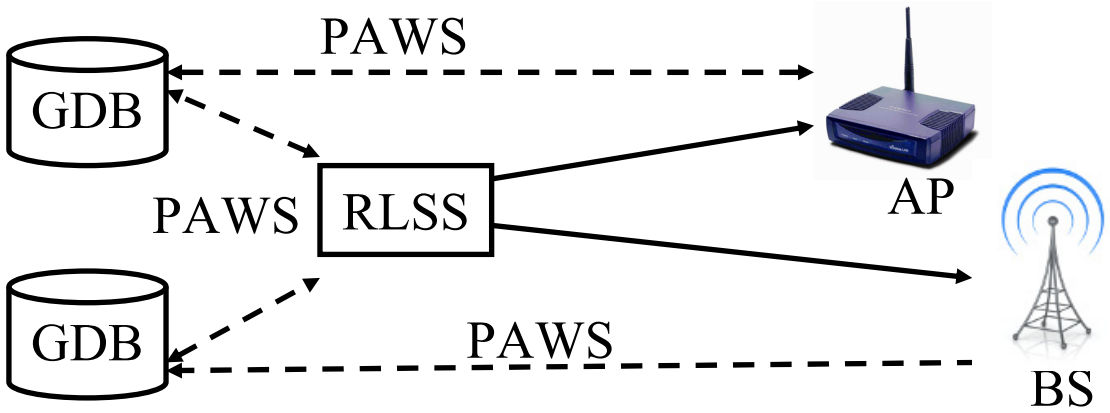
- Amendment for White Space Frequency Bands by defining additional components
- White Space Manager (WSM): Provides regulatory context
- Cognitive Base Station (CBS) Measurement Collector (CBSMC): Senses spectrum. Like RMC
- CBS Reconfiguration Controller (CBSRC): Like RRC
- CBS Reconfiguration Manager (CBSRM): Manages base stations and terminals



Ref: IEEE 1900.4a-2011, http://ieeexplore.ieee.org/iel5/6022705/6022706/06022707.pdf?arnumber=6022707

Protocol to Access White-Space (PAWS)

- IETF working group
- Mechanism to discover white space database
- Protocol to communicate with the database
- Interface Agnostic: 802.11af, 802.15.4m, 802.22, …
- Spectrum agnostic: 6 MHz, 7 MHz, 8 MHz, …
- Master Device: White-Space Device (WSD) connects to database
- Slave Device: WSD that get info from master devices



Ref: V. Chen, et al, ed. "Protocol to access White-Space (PAWS) Databases," Feb 2014, http://datatracker.ietf.org/doc/draft-ietf-paws-protocol/

PAWS (Cont)

- Stations should be able to discover WS Database, its regulatory domain. May be preconfigured similar to DNS or Certification Authorities.
- Listing Server: Web page listing all national database servers. Highly static ⇒ Can be cached by master
- Master may register with the database (model, serial, owner, …) of itself and its slaves
- Mutual authentication and authorization using certificates or passwords
- Master can then query the database
- The database should be able to push updates on channel availability changes
- Ensure security of discovery mechanism, access method, and query/response

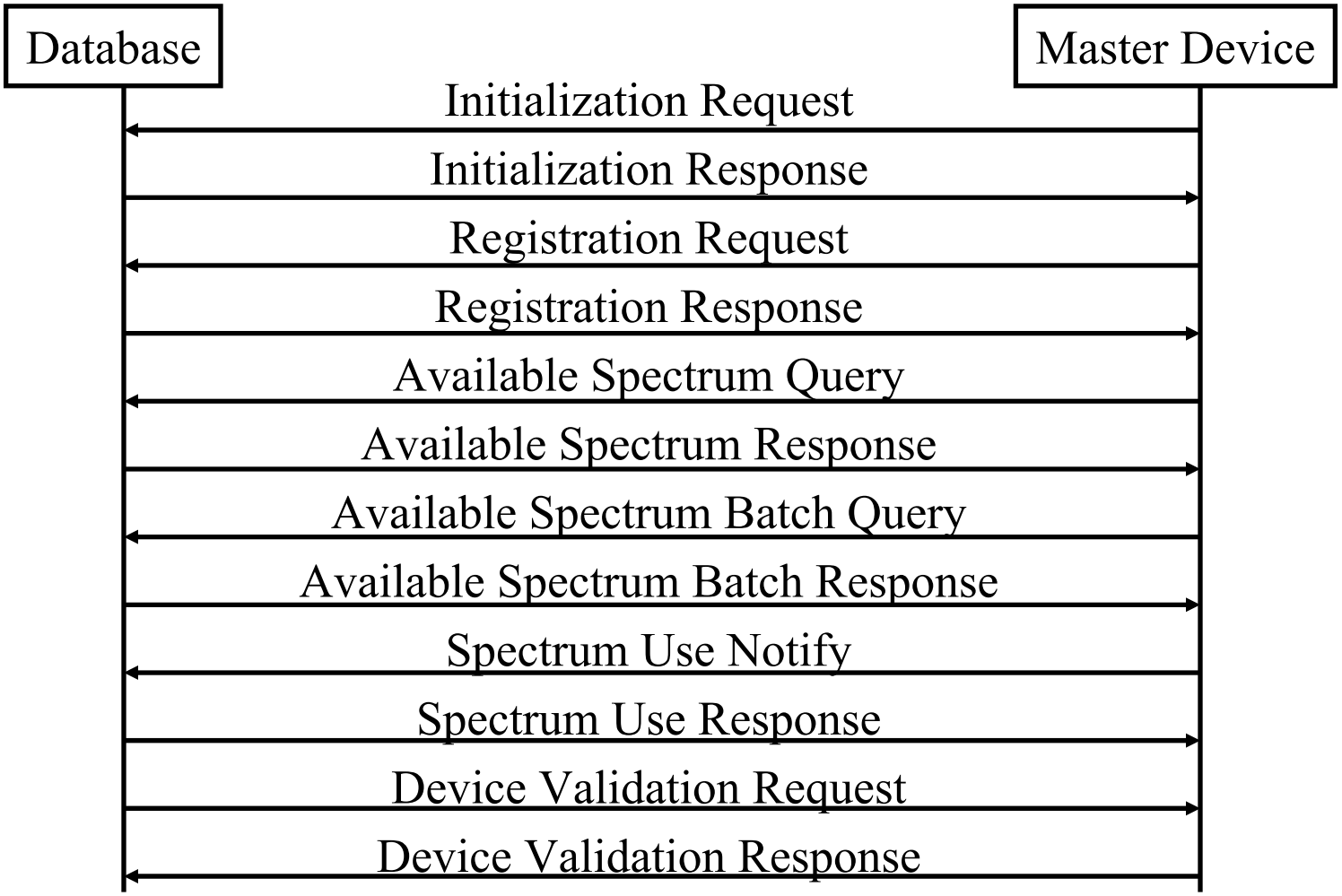
Ref: A. Mancuso, Ed., at al, "Protocol to Access White-Space (PQWS) Databases: Use Cases and Requirements," IETF RFC 6953, May 2013, http://tools.ietf.org/pdf/rfc6953

PAWS (Cont)

- Allows WSD to specify geolocation, height, serial number, Certificates, device class, radio access technology (RAT), antenna gain, maximum EIRP, radiation pattern, spectrum mask, owner contact information
- Allows database to specify available spectrum, available area, allowed power levels
- Allows WSD to register its selected spectrum for use
- Allows privacy to WSD (encryption)

Ref: V. Chen, et al, ed. "Protocol to access White-Space (PAWS) Databases," Feb 2014, http://datatracker.ietf.org/doc/draft-ietf-paws-protocol/

PAWS Messages



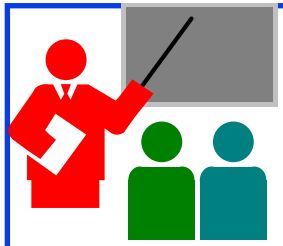
PAWS Messages (Cont)

- Listing Request/Response: To/from listing server (not shown)
- Initialization: Exchange capability, location, get rules
- Registration: Model, serial, antenna characteristics, owner, etc
- Available Spectrum: individual or batch request
- Spectrum Use: register used spectrum, location, antenna etc. Get time limits in response.
- Device Validation: Database may ask masters to authenticated slaves

GNU Radio

- Open-source software defined radio toolkit
- Uses Python and C++ on Linux
- Performance critical signal processing in C++
- Universal Software Radio Peripheral (USRP): General purpose computer for SDRs.
  - Host CPU for waveform specific processing, like modulation, demodulation
  - High-Speed operations in Field Programmable Gate Arrays (FPGAs)

Ref: GNU Radio, http://gnuradio.org/redmine/,
http://en.wikipedia.org/wiki/GNU_Radio
http://en.wikipedia.org/wiki/Universal_Software_Radio_Peripheral
Ettus Research, "USRP Bus Series Products," https://www.ettus.com/product/category/



Summary

1. Analog to Digital conversion of TV channels has freed up spectrum in 700 MHz band ⇒ White Space.
2. FCC has allowed license-exempt use of some of the white space in TV bands. Requires a cognitive radio.
3. IEEE 802.11af White-Fi spec uses 5, 10, 20 MHz channels to give up to 426.7 Mbps using OFDM, MU-MIMO, and 256-QAM.
4. IEEE 802.19.1 solves the coexistence problem by coordinating spectrum usage by several networks in the same area.
5. IEEE 1900.4 and 1900.4a helps optimize the resource usage when many different types of networks are available.
6. PAWS proves the protocol for access to National white space databases.

Reading List

- C. Sum, et al., "Cognitive Communication in TV White Spaces: An Overview of Regulations, Standards, and Technology," IEEE Communications Magazine, July 2013, pp. 138-145, http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=6553690
- S. Buljore, et al, "Architecture and Enablers for Optimized Radio Resource Usage in Heterogeneous Wireless Access Networks: The IEEE 1900.4 Working Group," IEEE Communications Magazine, Jan 2009, pp. 122-129, http://ieeexplore.ieee.org/iel5/35/4752663/04752689.pdf?arnumber=4752689
- A. Mancuso, Ed., at al, "Protocol to Access White-Space (PQWS) Databases: Use Cases and Requirements," IETF RFC 6953, May 2013, http://tools.ietf.org/pdf/rfc6953
- V. Chen, et al, ed. "Protocol to access White-Space (PAWS) Databases," Feb 2014, http://datatracker.ietf.org/doc/draft-ietf-paws-protocol/
- Adam LaMore, "The 700 MHz Band: Recent Developments and Future Plans," http://www.cse.wustl.edu/~jain/cse574-08/700mhz.htm
- A. Flores, et al., "IEEE 802.11af: A Standard for TV White Space Spectrum Sharing," http://networks.rice.edu/papers/FINAL_article_80211af.pdf

Reading List (Cont)

- M. Sherman, et al., "TV Whitespace Tutorial Intro," March 2009, http://www.ieee802.org/802_tutorials/2009-03/2009-03-10%20TV%20Whitespace%20Tutorial%20r0.pdf
- T. Aiheryhma, "Cognitive Radio/TV White Space Standardization," January 2013, http://tinyurl.com/kmu7uxv
- Telesystem Innovations Inc., "TV White Spaces: Unlicensed Access Spectrum in Sub-700 MHz Band," http://frankrayal.files.wordpress.com/2012/04/tv-white-space-whitepaper.pdf

Wikipedia Links

- http://en.wikipedia.org/wiki/Software-defined_radio
- http://en.wikipedia.org/wiki/Cognitive_radio
- http://en.wikipedia.org/wiki/White_spaces_(radio)
- http://en.wikipedia.org/wiki/Super_Wi-Fi
- http://en.wikipedia.org/wiki/IEEE_802.11af
- http://en.wikipedia.org/wiki/IEEE_802.19
- http://en.wikipedia.org/wiki/DySPAN
- http://en.wikipedia.org/wiki/Software_defined_antenna
- http://en.wikipedia.org/wiki/Digital_television_transition
- http://en.wikipedia.org/wiki/Television_channels
- http://en.wikipedia.org/wiki/Wireless_Innovation_Forum
- http://en.wikipedia.org/wiki/GNU_Radio
- http://en.wikipedia.org/wiki/Universal_Software_Radio_Peripheral
- http://en.wikipedia.org/wiki/Ultra_high_frequency
- http://en.wikipedia.org/wiki/TV-band_device

References

- C. Gomez, "White Spaces for Rural Broadband," April 2013, http://www.itu.int/ITU-D/asp/CMS/Events/2013/PacificForum/ITU-APT-S3_Cristian_Gomez.pdf
- http://www.whitespacealliance.org
- FCC, ET Docket 08-260, "Second Report and Order and Memorandum Opinion and Order, in the Matter of Unlicensed Operation in the TV Broadcast Bands Additional Spectrum for Unlicensed Devices Below 900 MHz and in the 3 GHz Band," Nov. 14, 2008.
- FCC, Second Memorandum and Order, September 23, 2010, http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-10-174A1.pdf
- GNU Radio, http://gnuradio.org/redmine/ ,
- Ettus Research, "USRP Bus Series Products," https://www.ettus.com/product/category/USRP-Bus-Series
- Google Spectrum Database, https://www.google.com/get/spectrumdatabase/channel/

References (Cont)

- http://www.wirelessinnovationalliance.org/
- *FCC, "Second Memorandum Opinion and Order in the Matter of Unlicensed Operation in the TV Broadcast Bands," ET Docket 10-174, September 23, 2010, http://tinyurl.com/kxpkt68*
- *FCC, "Unlicensed Operation in the TV Broadcast Bands*," ET Docket No. 04-186, and 02-380 Third Memorandum Opinion and Order, April 4, 2012, available at http://transition.fcc.gov/Daily_Releases/Daily_Business/2012/db0405/FCC-12-36A1.pdf
- Ofcom (UK), "Regulatory requirements for white space devices in the UHF TV band," July 4, 2012, http://www.cept.org/Documents/se-43/6161/
- ETSI EN 301 598, "White Space Devices (WSD); Wireless Access Systems operating in the 470 MHz to 790 MHz frequency band; Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive," V1.0.0, July 2013, http://www.etsi.org/deliver/etsi_en/301500_301599/301598/01.00.00_20/en_301598v010000a.pdf
- United Kingdom Office of Communications (OfCom) - www.ofcom.org.uk

References (Cont)

- R. Abdelhallem Saeed, S. Shellhammer, Eds., "TV White Space Spectrum Technologies: Regulations, Standards, and Applications," CRC Press, Feb 2012, 509 pages, ISBN: 1439848793, Google eBook.
- A. Wyglinski, M. Nekovee, and T. Hou, "Cognitive Radio Communications and Networks," Academic Press, 2009, ISBN:0123747150, Safari Book
- IEEE 1900.4a-2011, http://ieeexplore.ieee.org/iel5/6022705/6022706/06022707.pdf?arnumber=6022707

Acronyms

- AM Amplitude Modulation
- AP Access Point
- BCU Basic Channel Unit
- BRAN Broadband Radio Access Network
- BS Base Station
- BSS Basic Service Set
- CAQ Channel Availability Query
- CBS Cognitive Base Station
- CBSMC CBS Measurement Collector
- CBSRC CBS Resource Controller
- CBSRM CBS Resource Manager
- CDIS Coexistence Discovery and Information Server
- CDMA Code Division Multiple Access
- CE Coexistence Enabler
- CEPT European Conference of Postal and Telecommunications Administrations
- CM Coexistence Manager

Acronyms (Cont)

- CPU Central Processing Unit
- CSM Channel Schedule Management
- CVS Contact Verification Signal
- CWN Composite Wireless Network
- dB deci-Bel
- dBm deci-Bel milli-watt
- dBr deci-Bel relative
- DC Direct Current
- DNS Domain Name System
- DSP Digital Signal Processing
- DYSPAN Dynamic Spectrum Access Networks
- ECC Electronics Communications Committee
- EIRP Equivalent Isotropically Radiated Power
- ETSI European Telecommunications Standards Institute
- FCC Federal Communications Commission
- FDMA Frequency Division Multiple Access

Acronyms (Cont)

- FM Frequency Modulation
- FPGAs Field Programmable Gate Arrays
- GDB Geolocation Database
- GDD Geolocation Database Dependent
- GHz Giga Hertz
- GNU GNU is Not Unix
- GPS Global Positioning System
- HD High Definition
- HF High Frequency
- IEEE Institution of Electrical and Electronic Engineers
- IETF Internet Engineering Task Force
- ISM Instrumentation, Scientific, and Medical
- ISP Internet Service Provider
- ITU International Telecommunications Union
- LAN Local Area Network
- MAC Media Access Control

Acronyms (Cont)

- MCS Modulation and Coding Scheme
- MHz Mega Hertz
- MIMO Multi-Input Multi-Output
- MU Multi-User
- mW milli Watt
- NCC Network Channel Control
- NRM Network Reconfiguration Manager
- OFDM Orthogonal Frequency Division Multiplexing
- OFDMA Orthogonal Frequency Division Multiple Access
- OSM Operator Spectrum Manager
- PAN Personal Area Network
- PAR Project Authorization Request
- PAWS Protocol to access White-Space
- PHY Physical Layer
- QAM Quadrature Amplitude-Phase Modulation
- R&TTE Radio and Terminal Test Equipment

Acronyms (Cont)

- RAN Radio Access Network
- RAT Radio Access Technology
- RFC Request for Comment
- RLQP Registered Location Query Protocol
- RLSS Registered Location Secure Server
- RMC RAN Measurement Collector
- RRC RAN Reconfiguration Controller
- RRS Reconfigurable Radio Systems
- SC Standards Committee
- SCC Standards Coordinating Committee
- SD Standard Definition
- SDR Software Defined Radio
- SE Spectrum Engineering
- SHF Super High Frequency
- SIG Special Interest Group
- STA Station

Acronyms (Cont)

- STBC Space Time Block Coding
- TDMA Time Division Multiple Access
- TMC Terminal measurement collector
- TRC Terminal Reconfiguration Controller
- TRM Terminal Reconfiguration Manager
- TVWS Television White Spaces
- TXOP Transmit Opportunity
- UHF Ultra High Frequency
- UK United Kingdom
- US United States
- USRP Universal Software Radio Peripheral
- VHF Very High Frequency
- WiFi Wireless Fidelity
- WP Working Party
- WS White Space
- WSD White-Space Device

Acronyms (Cont)

- WSM White Space Manager
- WSO White Space Object
- WUSTL Washington University in Saint Louis