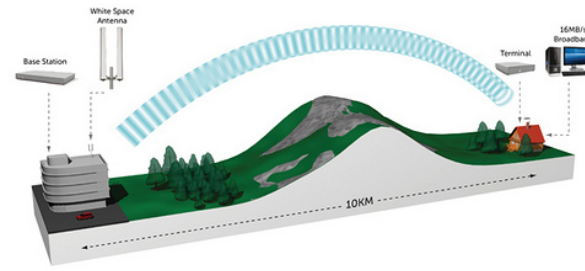
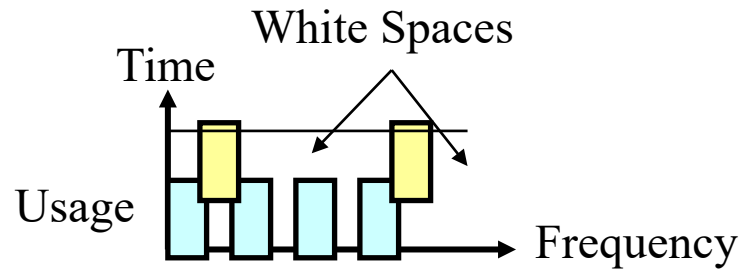


Wireless Networking in White Spaces



Raj Jain

Professor of Computer Science and Engineering
Washington University in Saint Louis
Saint Louis, MO 63130
Jain@cse.wustl.edu

Audio/Video recordings of this class lecture are available at:

<http://www.cse.wustl.edu/~jain/cse574-22/>

Student Questions

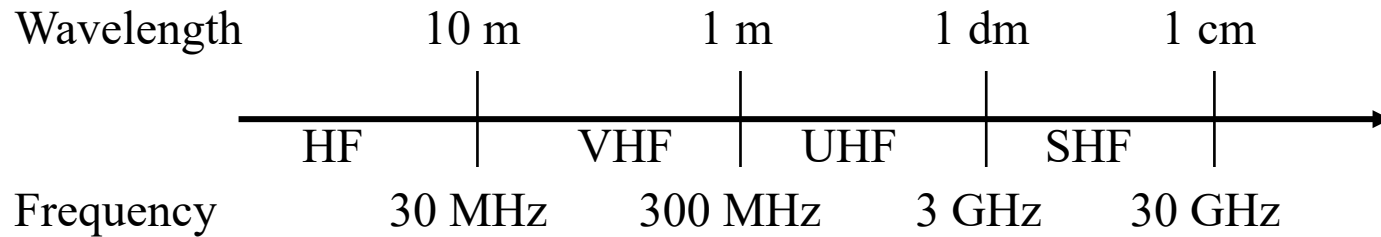


1. Television Channels
2. Software Defined and Cognitive Radios
3. Spectral White Spaces
4. FCC Rules for White Spaces
5. Wireless Standards for White Spaces:
802.11af, 802.19.1, PAWS

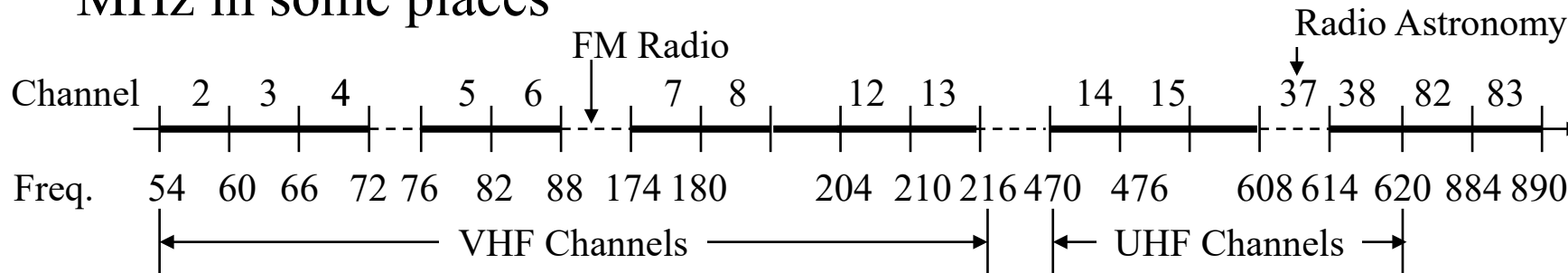
Note: IEEE 802.22 Regional Area Network and 802.15.4m Personal Area Network are not covered here but are available in the previous offerings of this course.

Student Questions

Over-the-Air Television Channels



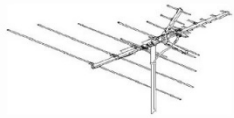
- ❑ Television channels use Very High Frequency (VHF) and Ultra High Frequency (UHF) bands
- ❑ Each channel uses 6 MHz in the USA, 8 MHz in Europe, and 7 MHz in some places



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

Student Questions

- ❑ Does white space only come from unused television bands?
Yes, It is designed only for the 700 MHz TV band.



Digital Television



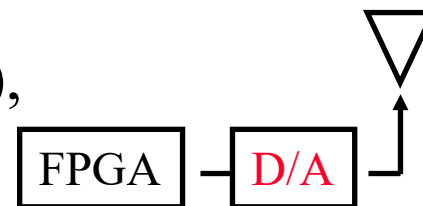
- ❑ Converting pixels to bits
⇒ Can easily encrypt, multiplex, and mix with data
- ❑ Change Standard Definition (SD), High Definition (HD)
- ❑ Do not need empty channels between neighbors
- ❑ Need about 19 Mbps ⇒ Can transmit 6-8 channels in 6-8 MHz.
- ❑ US FCC stopped analog transmissions on June 12,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

Student Questions

- ❑ How does satellite TV play into this?
Satellites use a very different set of frequencies 19 GHz band.
- ❑ Does digital TV have a protocol?
Are TVs just receivers?
Digital TV is a one-way Phy-layer stream of MPEG-encoded bits on the air. There is no Layer 2 protocol to ack, control, go back, or forward like the old analog TV. Most of us now use streaming TV, which comes via the Internet and has a protocol.

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 the desired band.



Student Questions

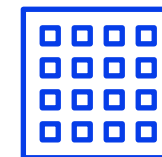
- ❑ What's an FPGA, and how does it compare to standard hardware circuitry?

Field Programmable Gate Array is an integrated chip whose function can be programmed. More expensive than pre-programmed logic chips but suitable for low-volume use.

- ❑ In point 4, why do we need to digitize as close as possible to the antenna?

The signal on the air is analog. It isn't easy to handle. So it is converted to Digital as soon as possible and handled digitally.

- ❑ What is a small pixel antenna?



Vs.



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/USRP-Bu>

Student Questions

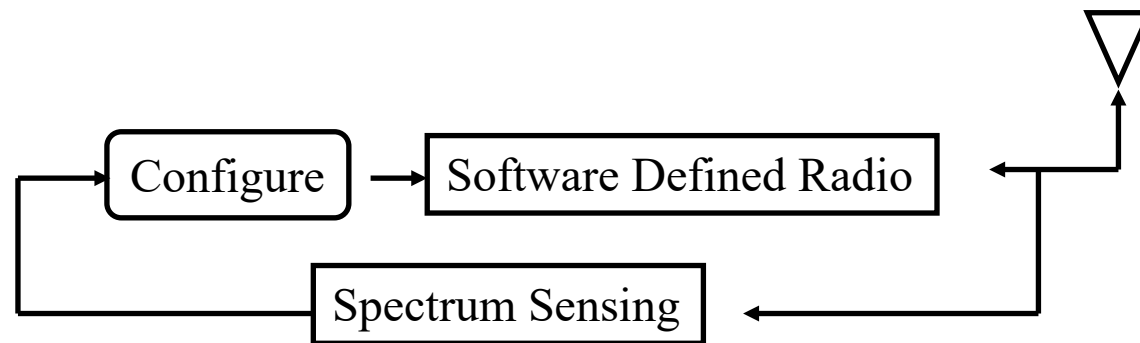
- ❑ Are there versions of software-defined radio available for a Mac?

Yes, the software is available, but you must buy SDR hardware.

<https://www.computerworld.com/article/2985518/how-to-get-started-with-software-defined-radio-on-mac-os-x.html>

Cognitive Radio

- ❑ Cognition = Perception = Sense
- ❑ Cognitive Radio: A radio that can sense the radio environment and select the proper frequency, bandwidth, power, and 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
⇒ FCC allowed such operations in certain bands.



Student Questions

- ❑ If the transmitter is operating with cognitive radio, how does the receiver know which radio spectrum to listen to?
The AP sends out periodic announcements on the frequency it has selected. The receivers look for beacons. The AP also announces a switch over on the old frequency if switching over.
 - ❑ How does the radio receiver know which frequency the broadcast is being done on, if the sender can pick any frequency?
Same question as above.
-

Effect of Frequency

- ❑ Higher Frequencies have a higher attenuation, e.g., 18 GHz has 20 dB/m more than 1.8 GHz
- ❑ Higher frequencies need a 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.

Student Questions

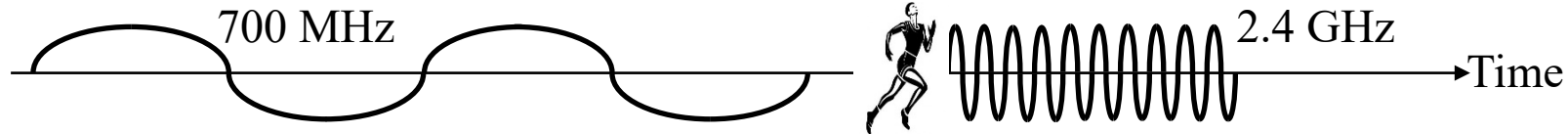
- ❖ How did we get the 2800 MHz?
Is it just an example?
800 MHz is the wavelength. Yes as an example.

Effect of Frequency (Cont)

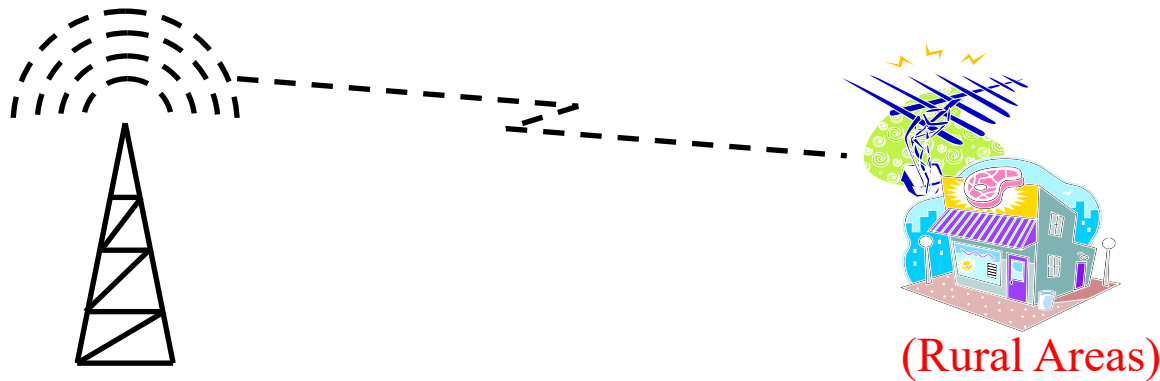
- ❑ Lower frequencies have a longer reach
- ❑ Lower frequencies require larger antenna and antenna spacing
⇒ MIMO is difficult particularly on mobile devices
- ❑ Lower frequencies ⇒ Smaller channel width
⇒ Need aggressive MCS, e.g., 256-QAM
- ❑ Doppler shift = vf/c = Velocity × Frequency / (speed of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

Student Questions

700 MHz Band



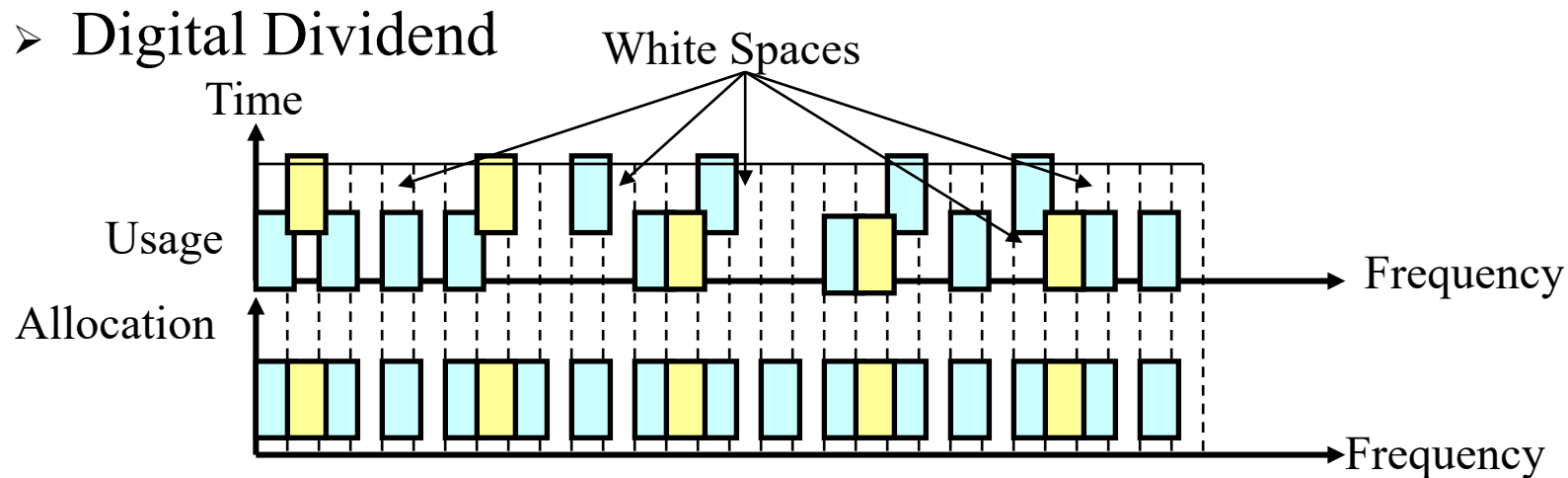
- ❑ Lower attenuation ($1/7^{\text{th}}$ to $1/9^{\text{th}}$ of 1800/1900/2100 MHz)
⇒ Lower transmission power
⇒ Longer mobile battery life
- ❑ Larger Cell radius ⇒ Smaller number of towers
- ❑ Long distance propagation ⇒ Good for rural areas.



Student Questions

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



Student Questions

- ❑ Is "white space" specific to the TV spectrum, or any spectrum not being used?

Specific to the TV spectrum because of its high power, low usage, and low cost.

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

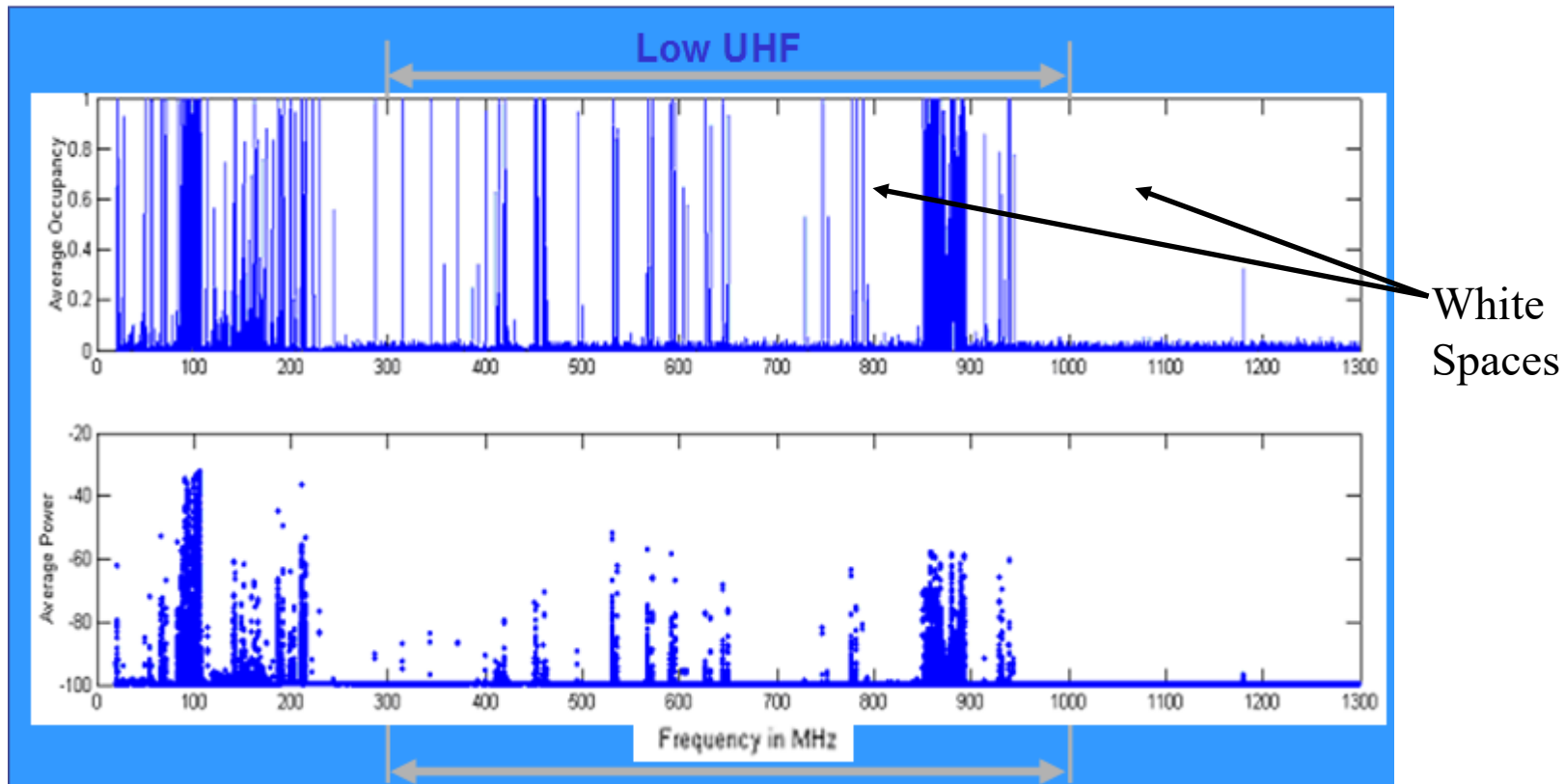
Washington University in St. Louis

<http://www.cse.wustl.edu/~jain/cse574-22/>

©2022 Raj Jain

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)



Student Questions

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

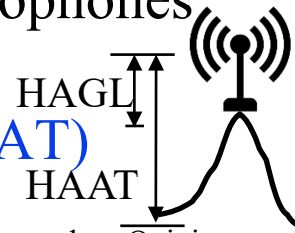
Washington University in St. Louis

<http://www.cse.wustl.edu/~jain/cse574-22/>

©2022 Raj Jain

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 is not required.
 - Get Channel availability daily using national databases (operated by third parties)
 - Must register with the database. Get a grant for *up to* 48 hrs.
 - White spaces in channels 2, 5-36, and 38-51 are available
 - White spaces in channels 3, 4, and 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

Student Questions

- ❑ So white spaces are spaces which are not used for long periods of time (which is why you can get a 48 hour grant)? On the last slide it seemed like this happened at a second-by-second or minute-by-minute basis.

These are channels which are scheduled. E.g., a TV channel may not broadcast in night.

- ❑ What is “spectrum sensing” and why is it not required on fixed devices?

Spectrum sensing is when you try to find an unused channel by listening to the signals in that channel. Fixed devices operate by the database and not sensing.

- ❑ Why do Fixed Devices not require Spectrum sense?

It is done at the time of installation.

- ❑ Is the antenna height=HAAT-HAGL?

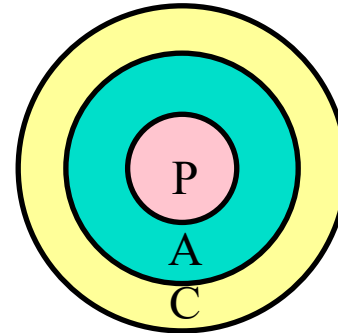
Yes, for receivers on the lower ground level.

- ❑ Points 5 and 6 are for which frequencies?

All of these are TV channels (700 MHz band)

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 a fixed device
- ❑ Distance from protected contour:
 - 4-31 km in co-channel, and 0.4-2.4 km in the adjacent channel depending upon the HAAT.
 - Higher antenna \Rightarrow Longer separation to avoid interference
 - Contours: Protected, Co-channel, Adjacent Channel



Student Questions

- ❑ Can you re-explain the diagram and what each contour is?

There are three contours shown here as circles (but may be odd shaped in reality):

P: Protected – Your Channel

A: Adjacent – No man's land

C: Co-Channel – Other transmitter's channel

- ❑ The distance from the protected contour applies to portable and fixed devices, correct?

Yes, both.

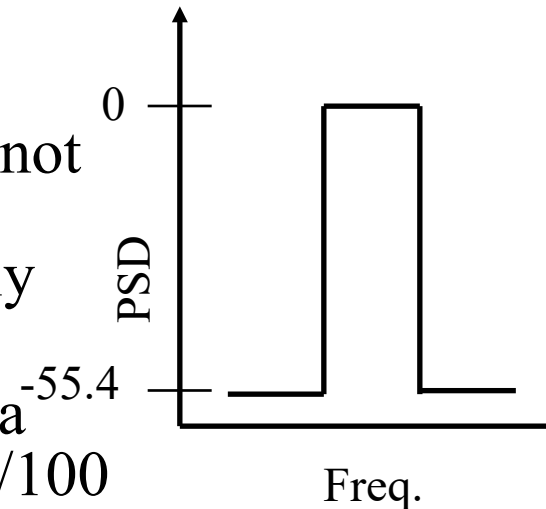
- ❑ How did they get this "106 m" limit for Mode I devices?

Similar to D^{-4} computation

FCC Emission Limits

Type	Power Limit (6 MHz)	PSD Limit (100 kHz)	Adjacent Channel PSD Limit (100 kHz)
Fixed	30 dBm (1W)	12.6dBm	-42.8 dBm
Portable (in Adjacent Channel)	16 dBm (40mW)	-1.4dBm	-56.8 dBm
Sensing only	17 dBm (50 mW)	-0.4dBm	-55.8 dBm
All other	20 dBm (100 mW)	2.6 dBm	-52.8 dBm

- ❑ FCC changed the transmit power limit to “power spectral density (PSD)” per 100 kHz. This way, many devices can not collude and transmit in the same channel resulting in total power over that previously specified in 6 MHz.
- ❑ The spectral mask was also changed from a fixed -55 dBm to a PSD limit of -55.4 dBm/100 kHz. Too costly to achieve.



Student Questions

❑ For PSD, does dBm specify mW/m^2 ?

No. PSD is total power over the specified bandwidth. So it is measured in mW or dBm.

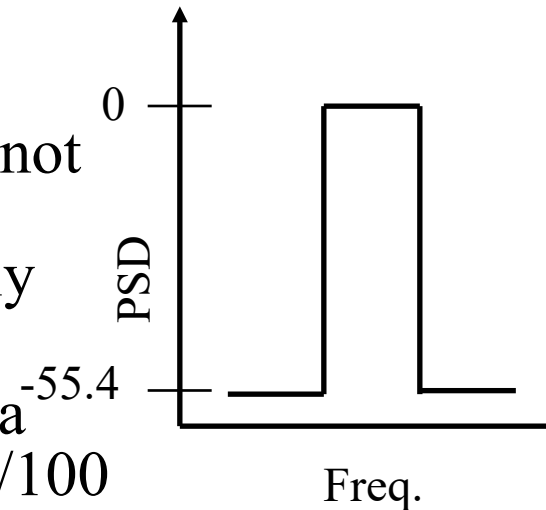
❑ What is a spectral mask?

It was introduced in Slide 7-26 on 60-GHz and shown in the figure here.

FCC Emission Limits

Type	Power Limit (6 MHz)	PSD Limit (100 kHz)	Adjacent Channel PSD Limit (100 kHz)
Fixed	30 dBm (1W)	12.6dBm	-42.8 dBm
Portable (in Adjacent Channel)	16 dBm (40mW)	-1.4dBm	-56.8 dBm
Sensing only	17 dBm (50 mW)	-0.4dBm	-55.8 dBm
All other	20 dBm (100 mW)	2.6 dBm	-52.8 dBm

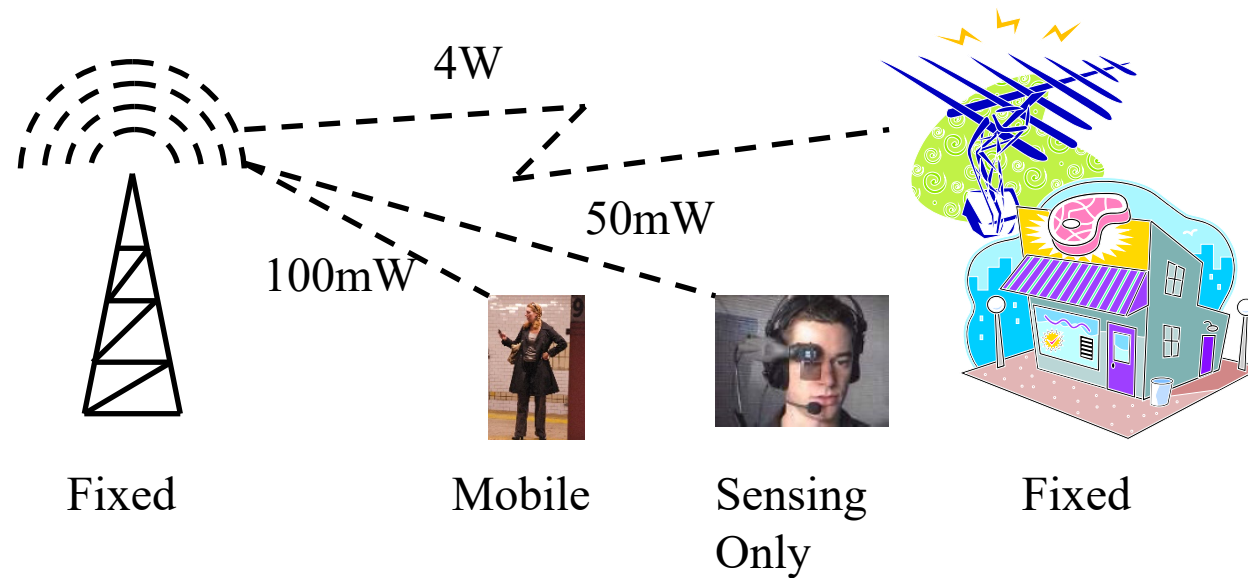
- ❑ FCC changed the transmit power limit to “power spectral density (PSD)” per 100 kHz. This way, many devices can not collude and transmit in the same channel resulting in total power over that previously specified in 6 MHz.
- ❑ The spectral mask was also changed from a fixed -55 dBr to a PSD limit of -55.4 dBm/100 kHz. Too costly to achieve.



Student Questions

- ❖ For the table we assume that the channel spacing is 100 kHz?
Yes, as indicated in the top row.
- ❖ In this table are we expected to calculate one cell from the other for the same type?
No. This is specified by FCC.
- ❖ Do we need to remember FCC emission limits?
No.

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

Student Questions

TVWS Databases

- ❑ FCC has authorized ten companies to administer TVWS databases.
 - Get info from the 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
⇒ Continuous multimedia
- ❑ Europe requires devices to check every two hours and allows higher power transmission but requires spectral sensing (closed loop system)

Student Questions

- ❑ Why does Europe use spectral sensing if the US doesn't? Is it because they have a more recent implementation?

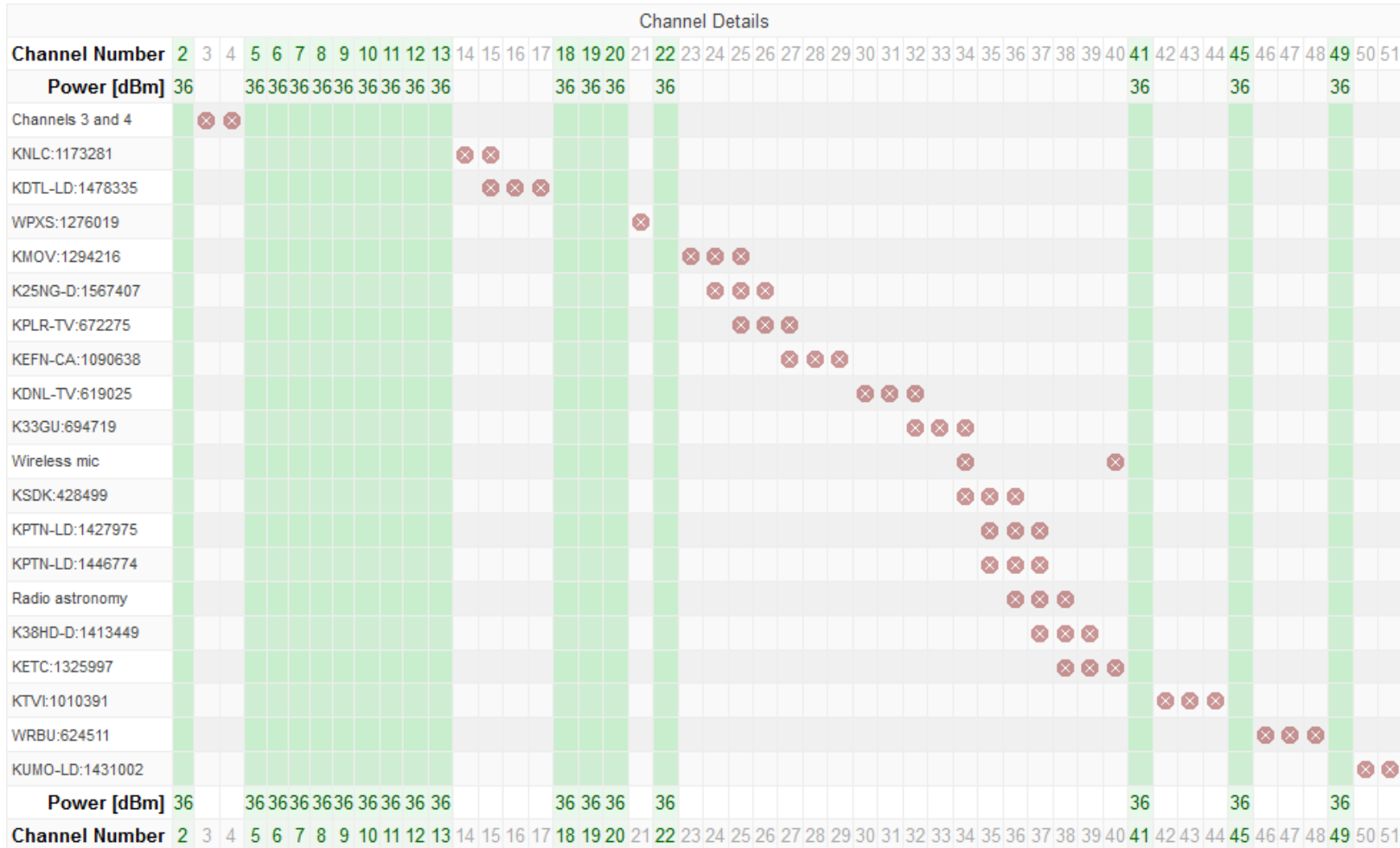
They are extra careful but costly.

Also, may be difficult to synchronize databases due to close national boundaries (not sure).

- ❑ Is it a closed-loop system because no information needs to be retrieved from the outside? Would you say this is a better system?

The US system is an open-loop system. Yes, it is better.

White Spaces Near WUSTL



17 channels. Zipcode 63130.

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

Washington University in St. Louis

<http://www.cse.wustl.edu/~jain/cse574-22/>

©2022 Raj Jain

Student Questions

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

Student Questions

802.11af-2014: White-Fi

- ❑ A.k.a. Super-Fi (initially incorrectly called super Wi-Fi)
Both MAC and PHY are different from 802.11 \Rightarrow Not WiFi
- ❑ The final standard in March 2014.
- ❑ White-space wireless using cognitive radios up to 5 km
- ❑ 256-QAM, 5/6, 3 μ s Guard Interval
 \Rightarrow 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
- ❑ four spatial streams \times four channels \Rightarrow 426.7 Mbps

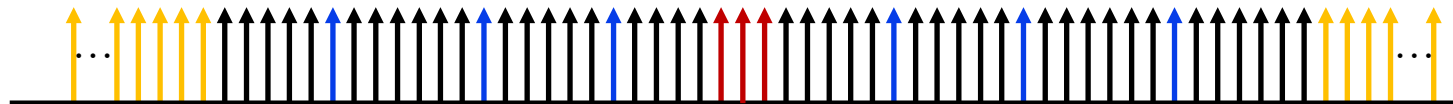
Student Questions

- ❑ If White-Fi is not Wi-Fi compliant, would 802.11af ever gain market traction?

Yet to be seen.

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



Student Questions

- ❑ What is down-clocking? Is it just running 7.5x slower baud rate?

More subcarriers in smaller frequency band

Contraction in frequency

⇒ Expansion in time

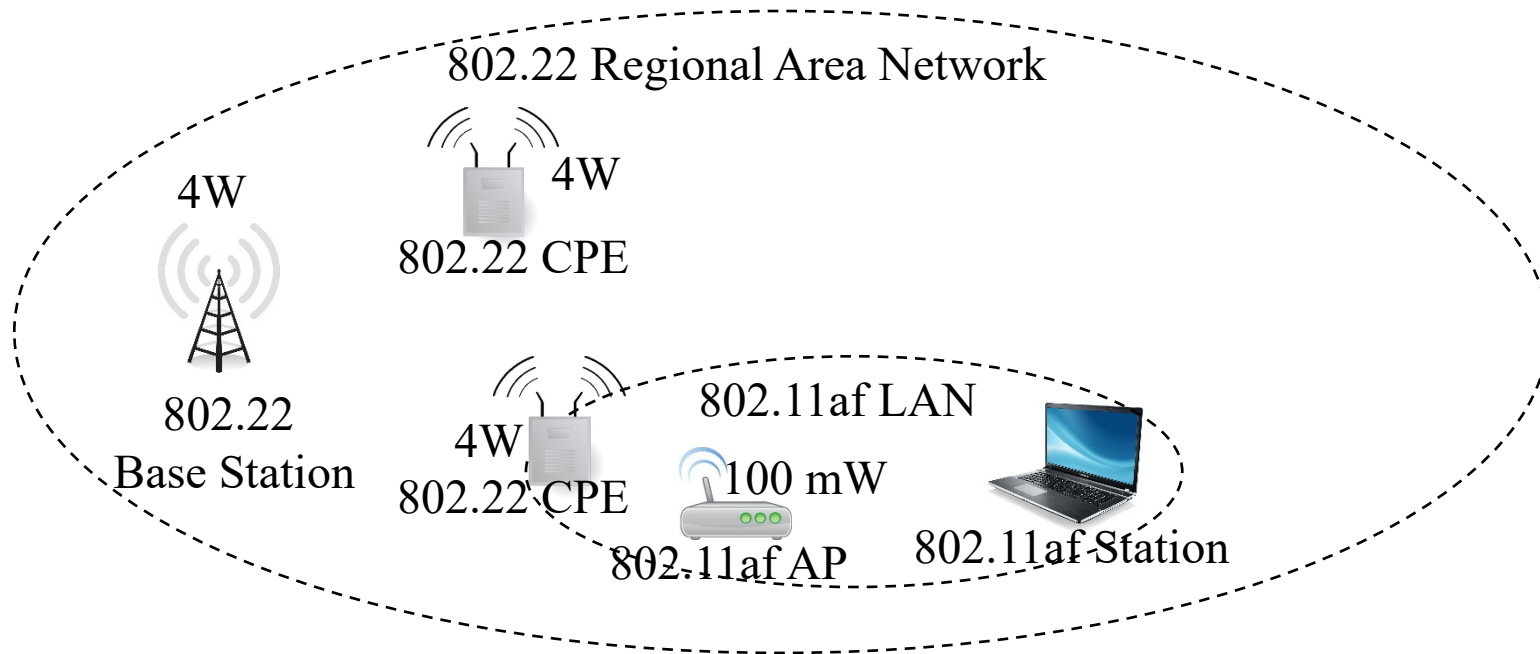
⇒ feels like slower clock

- ❑ Is the figure correct? Should it be corrected to show 3 DC?

It has been corrected and color-coded.

Coexistence Problem

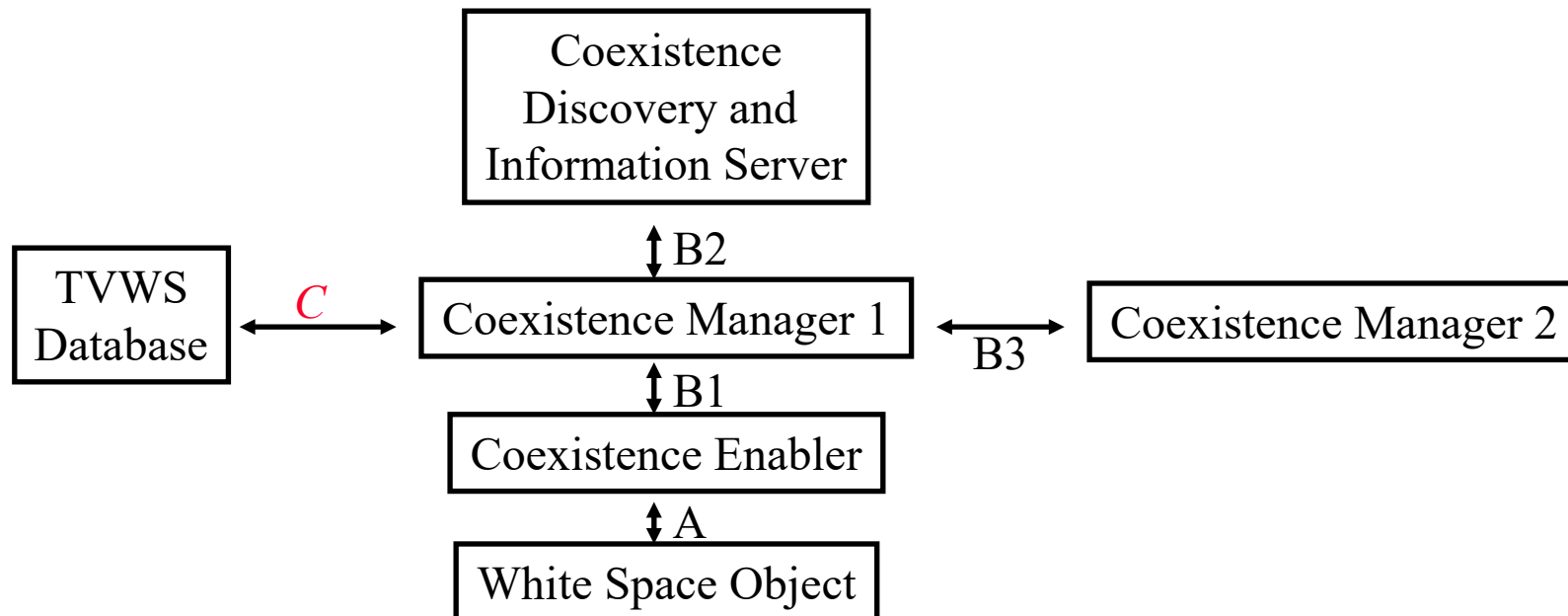
- ❑ Exposed Terminal: 802.11af can not transmit because 802.22 keeps the channel busy
- ❑ Hidden Terminal: 802.11af interferes with 802.22 transmissions



Student Questions

IEEE 802.19.1-2014

- ❑ IEEE 802.19: Radio access technology (RAT) independent methods of coexistence \Rightarrow 802.11, 802.15, 802.22 can all use one standard method for coexistence.
- ❑ IEEE 802.19.1: Coexistence in TV white spaces.



Student Questions

- ❑ How is the registration enforced? i.e. how can Coexistence Managers know when a new device is introduced to the system?

Everyone is required to tell the manager

- ❑ Where is PAWS in this diagram (Interface C)?

Shown now.

- ❑ In this slide, do you mean A, B1, B2, and B3 specified in 802.19.1 and C specified in PAWS?

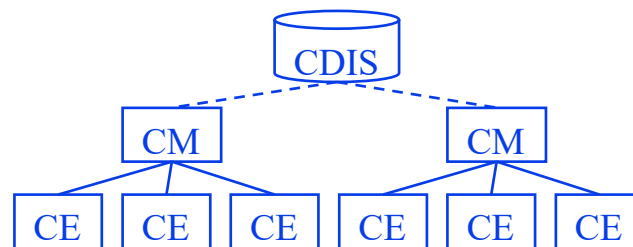
Yes.

- ❑ Are these interfaces physical links between stations, or are they wireless?

Application Programming Interfaces (APIs) are call parameters in software modules inside one device.

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 the 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.

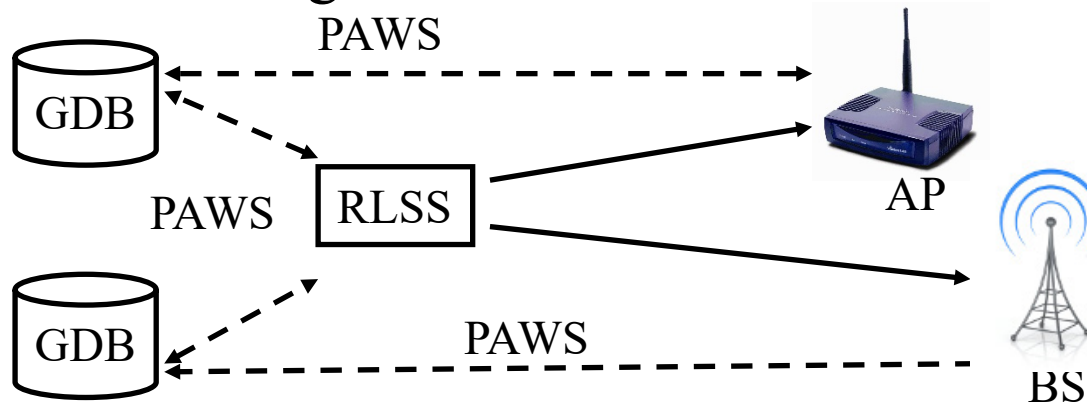


Student Questions

- ❑ What are the differences between CE and CM?
Like client-server or employee-manager. 1 CM serves n CEs.
- ❑ What are the interfaces A, B1, B2, and B3? Are they different?
See previous Slide 9-23.
- ❑ Are CM1 and CM2 geographically apart?
Yes.
- ❑ How does CDIS work in reality?
Can you give us some examples?
See the new figure. It is like cities and counties in a state.

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 the database
- ❑ Slave Device: WSD that gets 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/>

Student Questions

- ❑ Can you explain the functions of the GDB and RLSS?

GDB = Geo Database

RLSS = Registered Location Secure Server

This allows many local servers and fewer national databases.

- ❖ What is being conveyed in this diagram? (PAWS, RLSS, GDB)
Entities and the protocol between them.

PAWS (Cont)

- ❑ Stations should be able to discover WS Database and its regulatory domain. It may be preconfigured, similar to DNS or Certification Authorities.
- ❑ Listing Server: Web page listing all national database servers. Highly static \Rightarrow Can be cached by master
- ❑ Master may register with the database (model, serial, owner, ...)
- ❑ 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 the discovery mechanism, access method, and query/response

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

Student Questions

- ❑ So is Whitespace Server some server always running somewhere? Like the top level domain name servers? Who maintains those?

Yes. Several (8?) companies have received license to operate this service in the USA.

- ❑ When the master is checking the GDB, are they using designated channels for pull and push transmissions, so they are not interfering with other WP transmissions?

CMs communicate with GDB via the wired Internet since they are not mobile.

PAWS (Cont)

- ❑ Stations should be able to discover WS Database, and its regulatory domain. It may be preconfigured, similar to DNS or Certification Authorities.
- ❑ Listing Server: Web page listing all national database servers. Highly static \Rightarrow 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 the 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>

Student Questions

- ❑ How many users are currently using WS? Will there be spectrum reallocation requests sometimes, given the number of users more than the number of channels available?

Not many.

For license-exempt use, Carlson Rural Connect TV White Space Radio uses inter-channel guard bands.

<https://carlsonwireless.com/ruralconnect/>

PAWS (Cont)

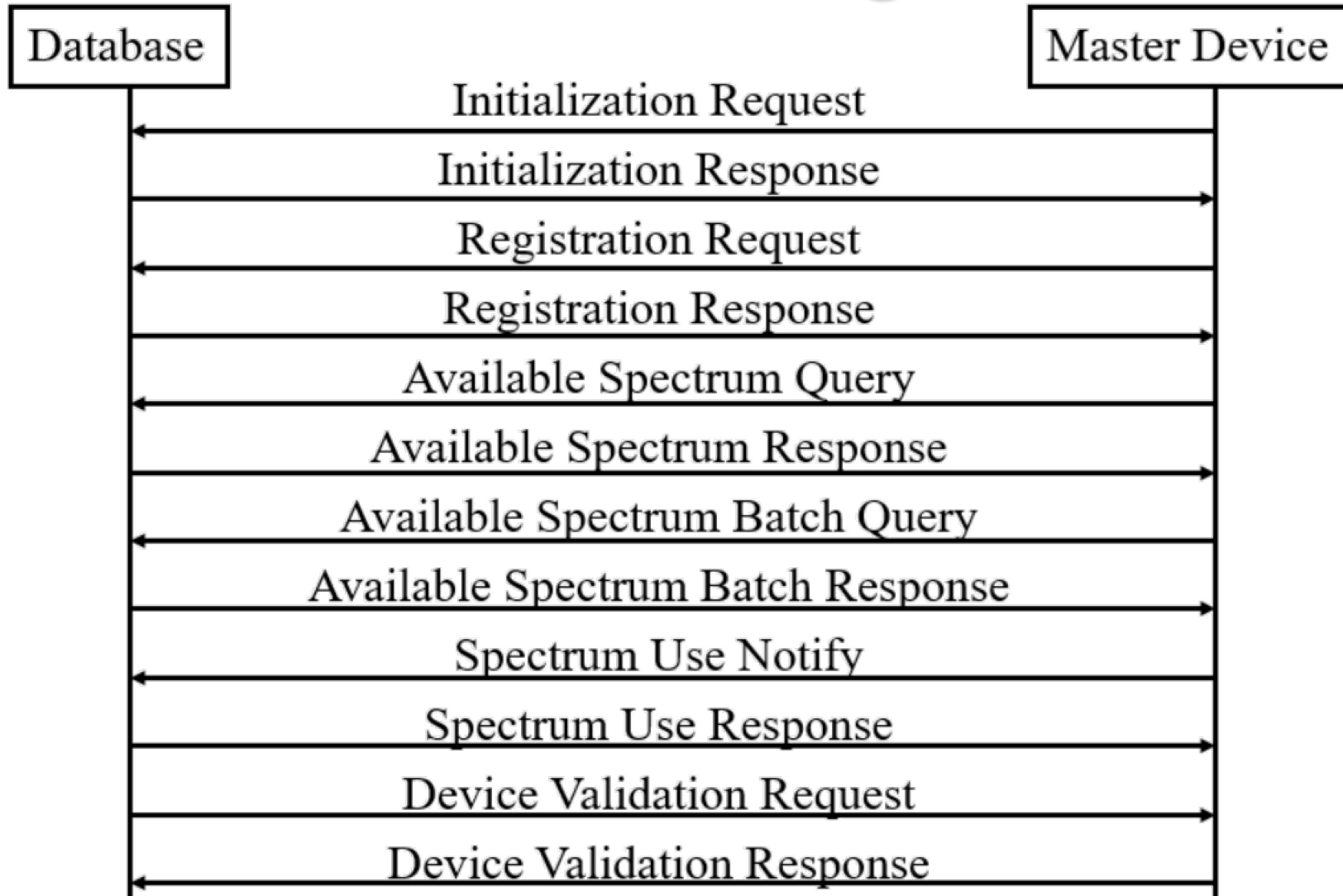
- ❑ Allows WSD to specify geolocation, height, serial number, Certificates, device class, radio access technology (RAT), antenna gain, maximum EIRP, radiation pattern, spectrum mask, owner contact information
- ❑ Allows database to specify available spectrum, available area, allowed power levels
- ❑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

Student Questions

Ref: V. Chen, et al, ed. "Protocol to access White-Space (PAWS) Databases," IETF RFC 7445, May 2015, 90 pp.

<https://www.rfc-editor.org/rfc/pdf/rfc/rfc7545.txt.pdf>

PAWS Messages



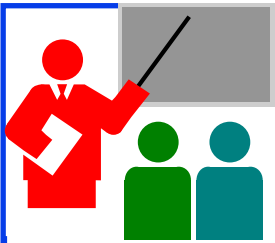
Student Questions

- How much latency it is for accessing the spectrum while following this procedure?
A few ms. Similar to DNS.

PAWS Messages (Cont)

- ❑ Listing Request/Response: To/from the 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: The database may ask masters to authenticate slaves

Student Questions



Summary

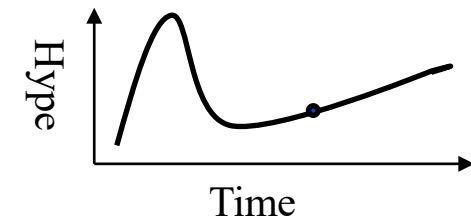
1. Analog to Digital conversion of TV channels has freed up spectrum in 700 MHz band \Rightarrow White Space.
2. FCC has allowed license-exempt use of some white space in TV bands. Requires a cognitive radio.
3. IEEE 802.11af White-Fi spec uses 5, 10, and 20 MHz channels to give up to 426.7 Mbps using 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. PAWS provides the protocol for access to National white space databases.

Student Questions

I wonder where TV white space is in the hype cycle.

Most of the 700-MHz band was auctioned to telecom providers and used in LTE.

It is off the chart on the extreme right—some products.



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>
- ❑ A. Mancuso, Ed., et 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/>
- ❑ 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
- ❑ 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>

Student Questions

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/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

Student Questions

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/>

Student Questions

References (Cont)

- ❑ 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

Student Questions

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>

Student Questions

Acronyms

- ❑ AM Amplitude Modulation
- ❑ AP Access Point
- ❑ BCU Basic Channel Unit
- ❑ BRAN Broadband Radio Access Network
- ❑ BS Base Station
- ❑ BSS Basic Service Set
- ❑ 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

Student Questions

Acronyms (Cont)

- ❑ CPE Customer Premise Equipment
- ❑ CPU Central Processing Unit
- ❑ 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
- ❑ FM Frequency Modulation

Student Questions

Acronyms (Cont)

- ❑ FPGAs Field Programmable Gate Arrays
- ❑ GDB Geolocation Database
- ❑ GHz Giga Hertz
- ❑ GNU GNU is Not Unix
- ❑ GPS Global Positioning System
- ❑ HAAT Height above average terrain
- ❑ HAGL Height above ground level
- ❑ 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

Student Questions

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
- ❑ 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

Student Questions

Acronyms (Cont)

- ❑ RAT Radio Access Technology
- ❑ RFC Request for Comment
- ❑ RLSS Registered Location Secure Server
- ❑ SCC Standards Coordinating Committee
- ❑ SD Standard Definition
- ❑ SDR Software Defined Radio
- ❑ SE Spectrum Engineering
- ❑ SHF Super High Frequency
- ❑ SIG Special Interest Group

Student Questions

Acronyms (Cont)

- ❑ STBC Space Time Block Coding
- ❑ TDMA Time Division Multiple Access
- ❑ TV Television
- ❑ TVWS Television White Spaces
- ❑ 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

Student Questions

Acronyms (Cont)

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

Student Questions

Scan This to Download These Slides



Raj Jain

<http://rajjain.com>

http://www.cse.wustl.edu/~jain/cse574-22/j_09wsp.htm

Student Questions

- Can you update the slide on the webpage? It is not working right now.

Done.

- Project Guidelines Part 3 was also due today but was not posted. It is now due with the next module on Monday.*

Related Modules



CSE567M: Computer Systems Analysis (Spring 2013),
https://www.youtube.com/playlist?list=PLjGG94etKypJEKjNAa1n_1X0bWWNyZcof

CSE473S: Introduction to Computer Networks (Fall 2011),
https://www.youtube.com/playlist?list=PLjGG94etKypJWOSPMh8Azcg5e_10TiDw



Recent Advances in Networking (Spring 2013),
<https://www.youtube.com/playlist?list=PLjGG94etKypLHyBN8mOgwJLHD2FFIMGq5>

CSE571S: Network Security (Fall 2011),
<https://www.youtube.com/playlist?list=PLjGG94etKypKvzfVtutHcPFJXumyyg93u>



Video Podcasts of Prof. Raj Jain's Lectures,
<https://www.youtube.com/channel/UCN4-5wzNP9-ruOzQMs-8NUw>

Student Questions