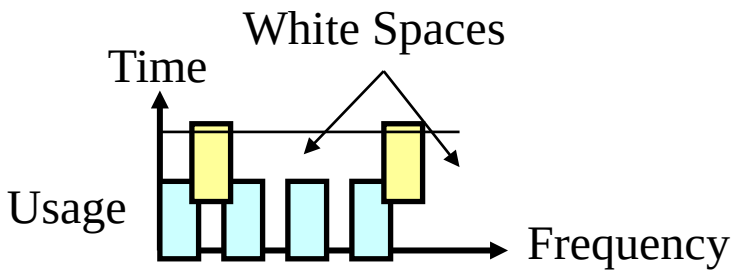
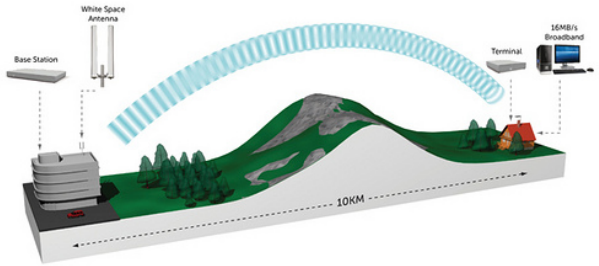
Wireless Networking in White Spaces





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Audio/Video recordings of this class lecture are available at:
http://www.cse.wustl.edu/~jain/cse574-24/

Student Questions

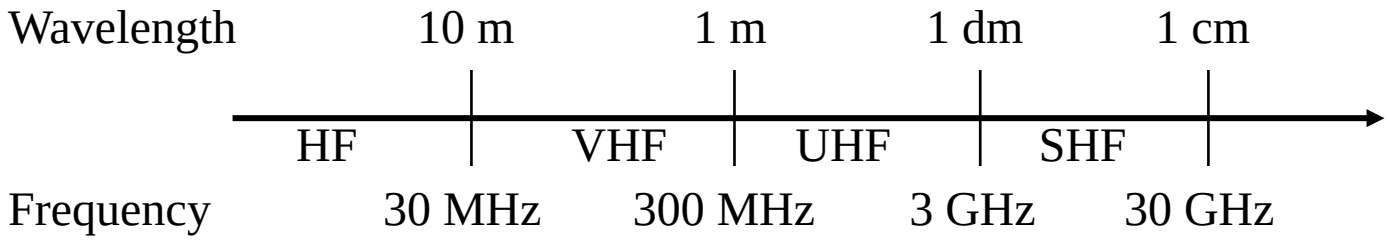
Overview

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

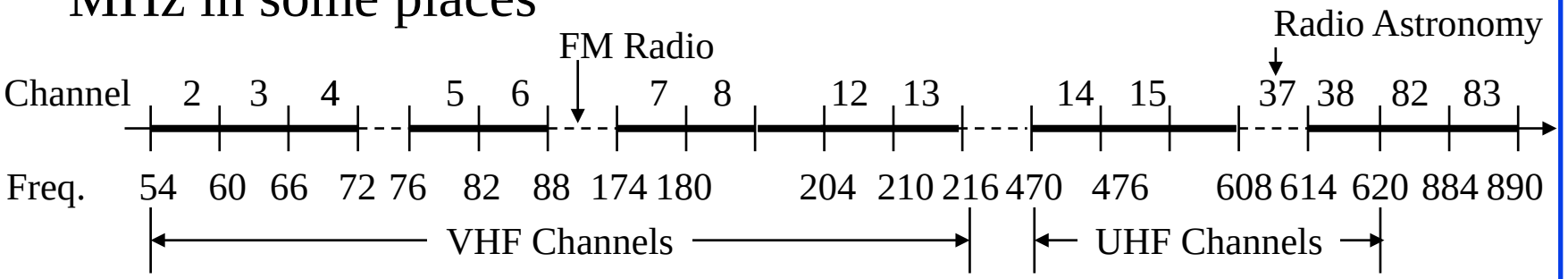
Note: IEEE 802.22 Regional Area Network and 802.15.4m Personal Area Network are not covered here but are available in the previous offerings of this course.

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

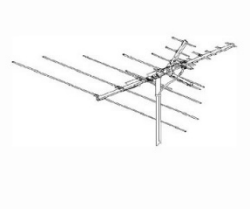


- At least one channel is skipped between two analog stations in neighboring areas to avoid interference

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?

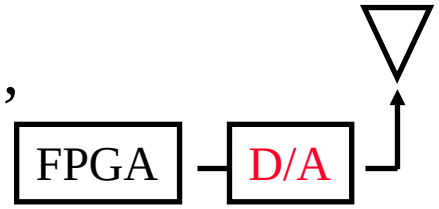
Satellites use a very different set of frequencies, the 19 GHz band.

- 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

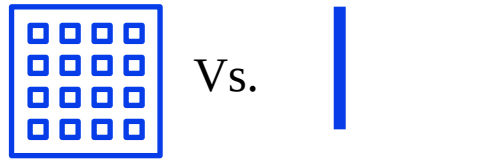
- What's an FPGA, and how does it compare to standard hardware circuitry?

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

- In point 4, why must we 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?



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

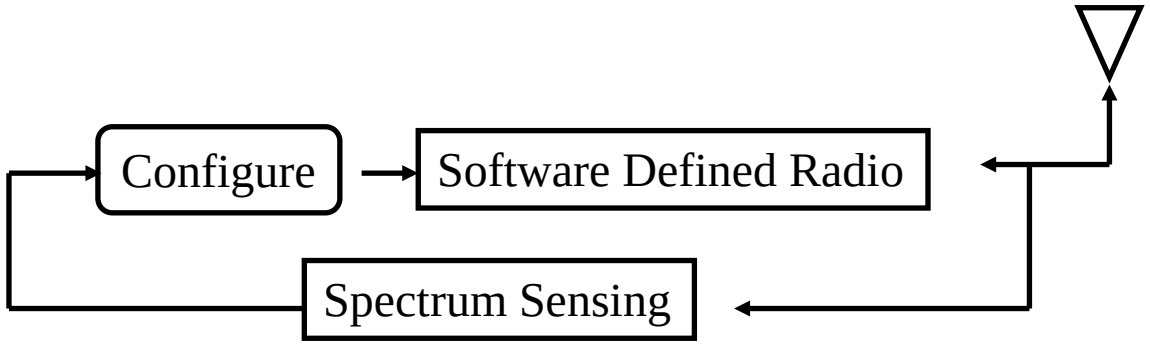
Student Questions

- 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 operates 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 broadcasted 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?

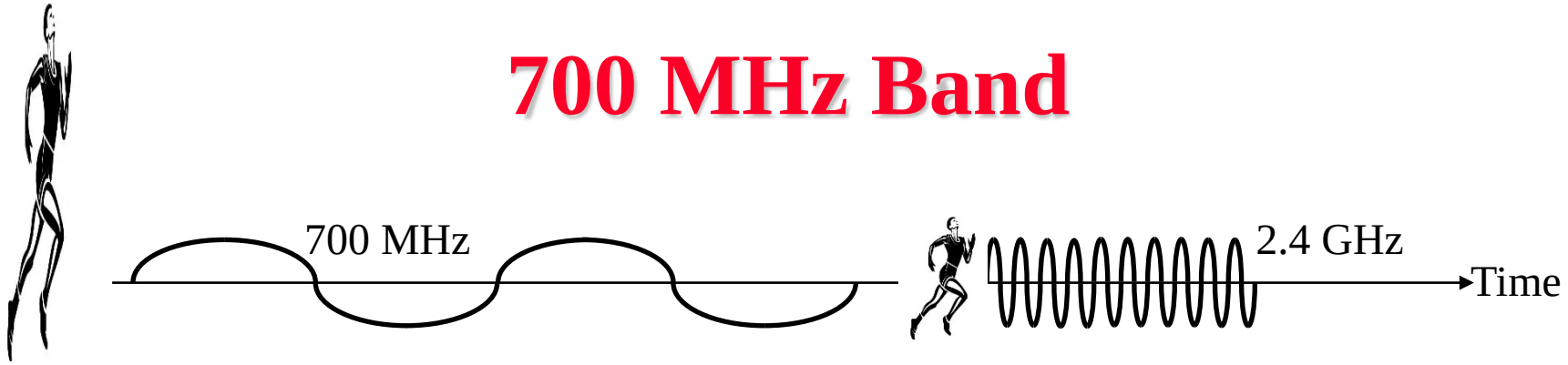
800 MHz is the wavelength. Yes, as an example.

Effect of Frequency (Cont)

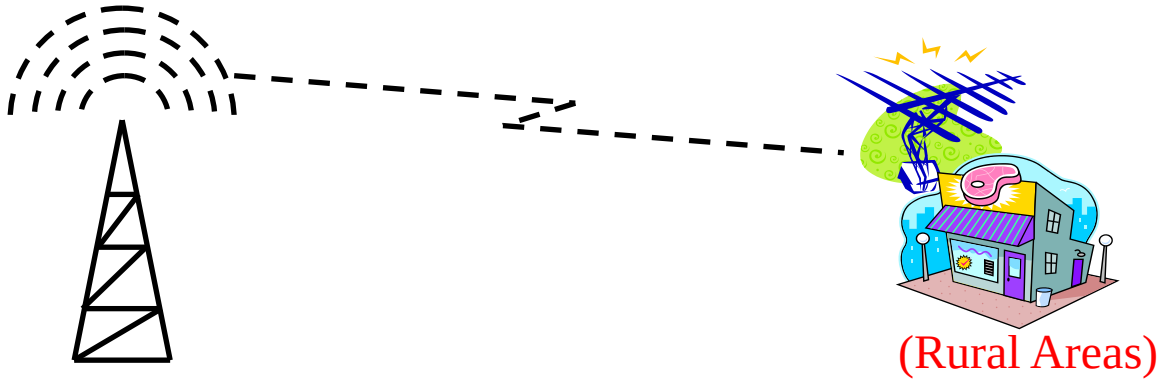
- Lower frequencies have a longer reach
- Lower frequencies require larger antenna and antenna spacing
  ⇒ MIMO is difficult, particularly on mobile devices
- Lower frequencies ⇒ Smaller channel width
  ⇒ Need aggressive MCS, e.g., 256-QAM
- Doppler shift = vf/c = Velocity ×Frequency/(speed of light)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

Student Questions

700 MHz Band



- Lower attenuation (1/7th 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.

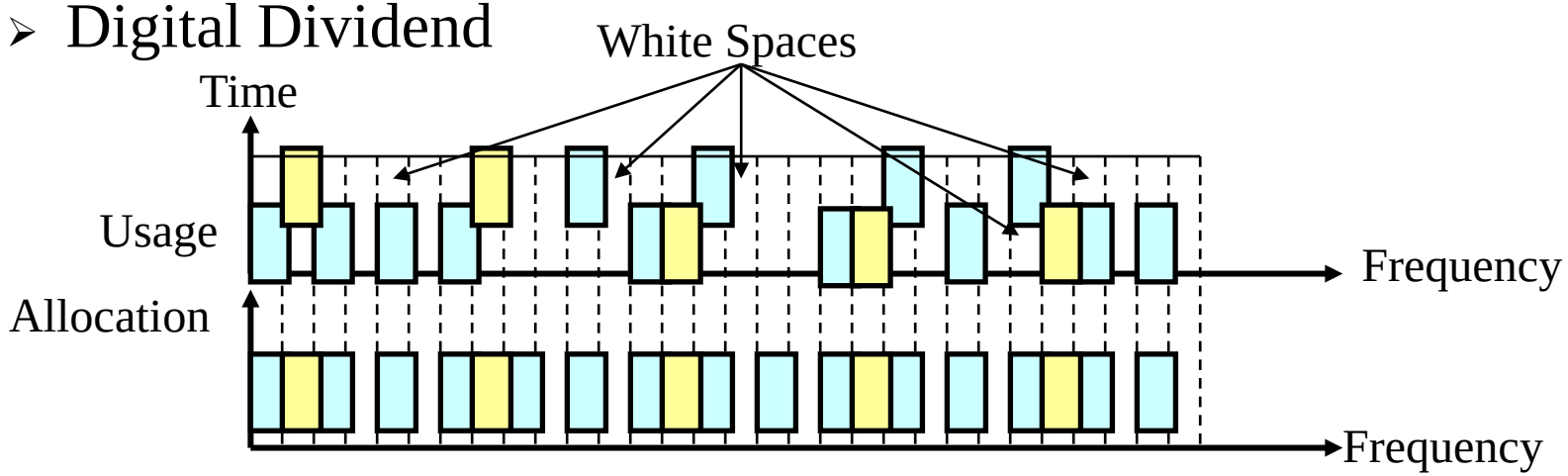


(Rural Areas)

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



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

Student Questions

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

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

- Why do the blue and yellow ones overlap slightly? Is it common for signals to behave this way in real-world scenarios?

1. Slightly = Sub-second.

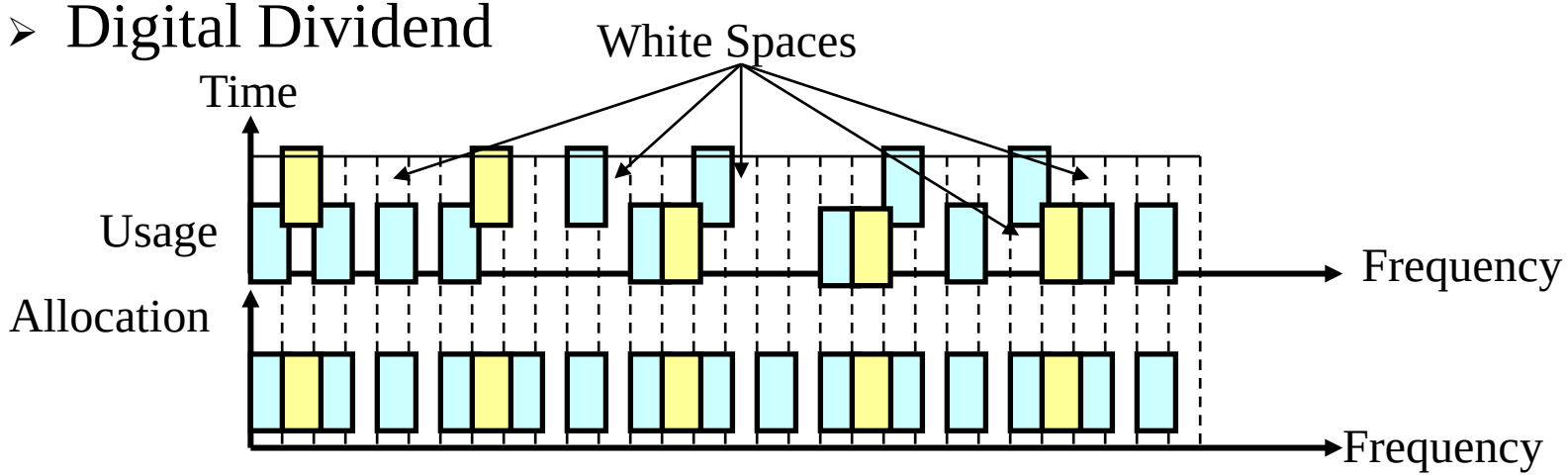
2. Overlap is mostly sensing only

- How do senders and receivers agree on which white space to use?

The secondary devices hunt for unoccupied spaces.

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

Student Questions

- As almost everything can connect to the internet now, will the amount of white space eventually diminish to zero one day in the future?

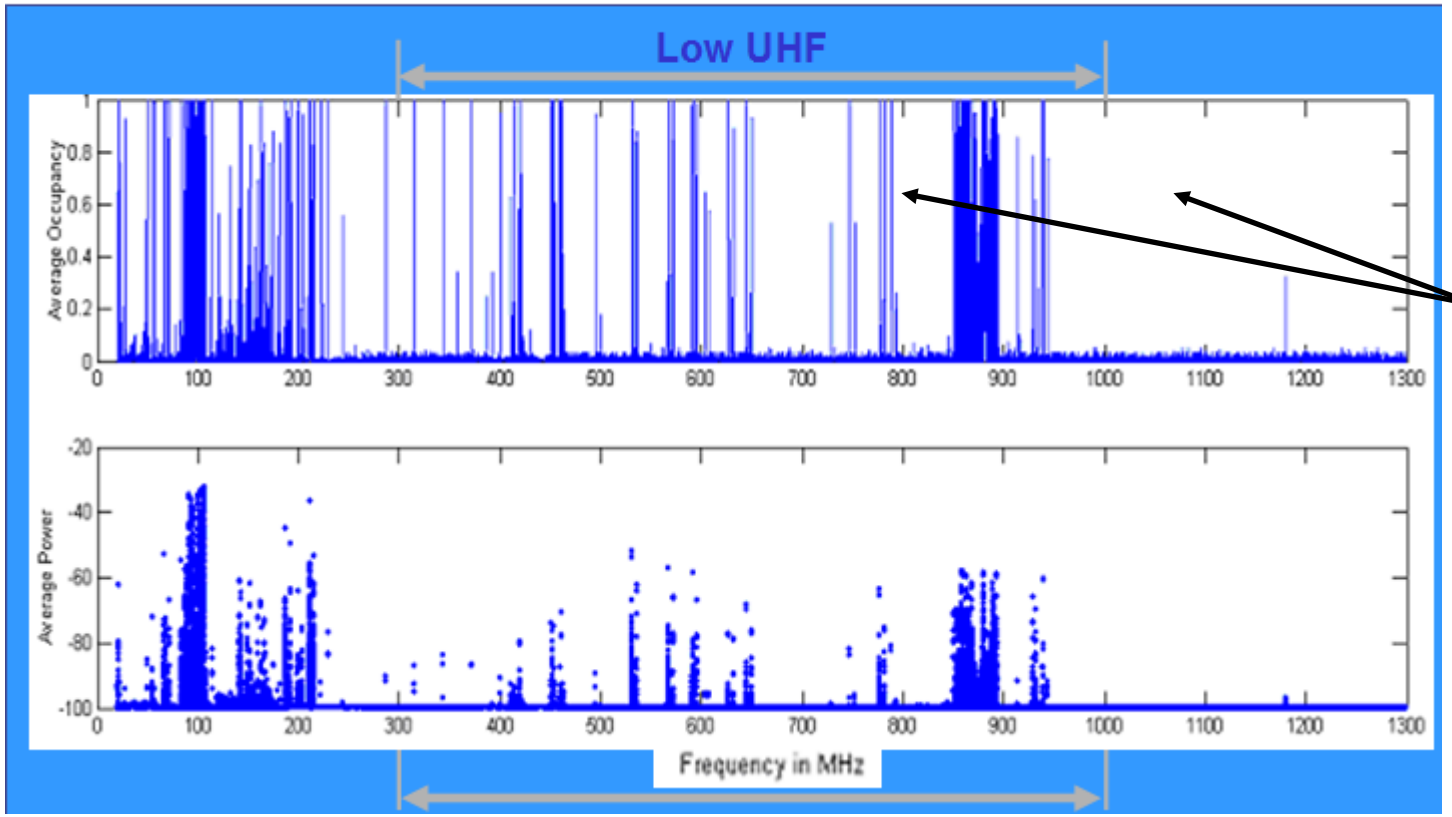
Congestion has its way of resolving, as in 2.4GHz. The usage will not go up.

- If you're allowed to use a spectrum someone else owns, what happens if two people try using the same spectrum but neither owns rights to it?

They follow the multi-access rules as in Wi-Fi.

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)



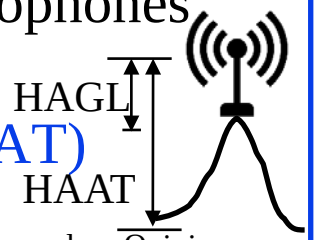
White Spaces

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

Student Questions

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 (which is why you can get a 48 hour grant)? On the last slide, it seemed like this happened on a second-by-second or minute-by-minute basis.

These are channels that are scheduled. E.g., a TV channel may not broadcast at 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 do not sense.

- 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.

- Which frequencies are points 5 and 6 for?

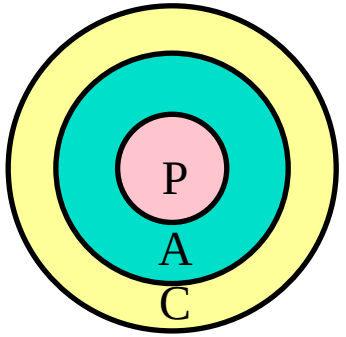
All of these are TV channels (700 MHz band)

- What will happen if we don't follow the FCC rules for white space?

FCC will fine you and take away your license.

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 ⇒ 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 they 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

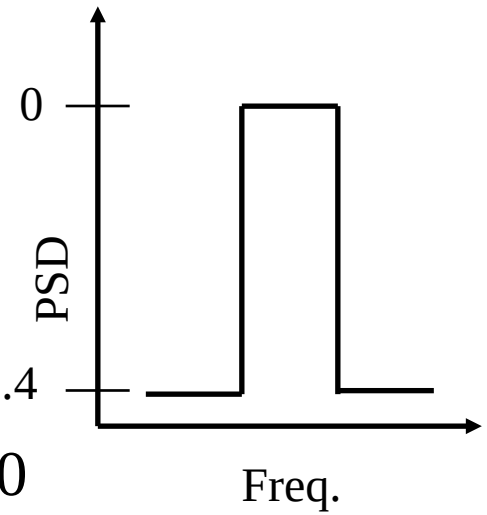
- For a Mode 1 device to work, does it need to be within range of a Mode 2 device? If not, then what?

Mode 1 cannot operate then.

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 the previously specified 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 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.

- For the table, we assume that the channel spacing is 100 kHz.

Yes, as indicated in the top row.

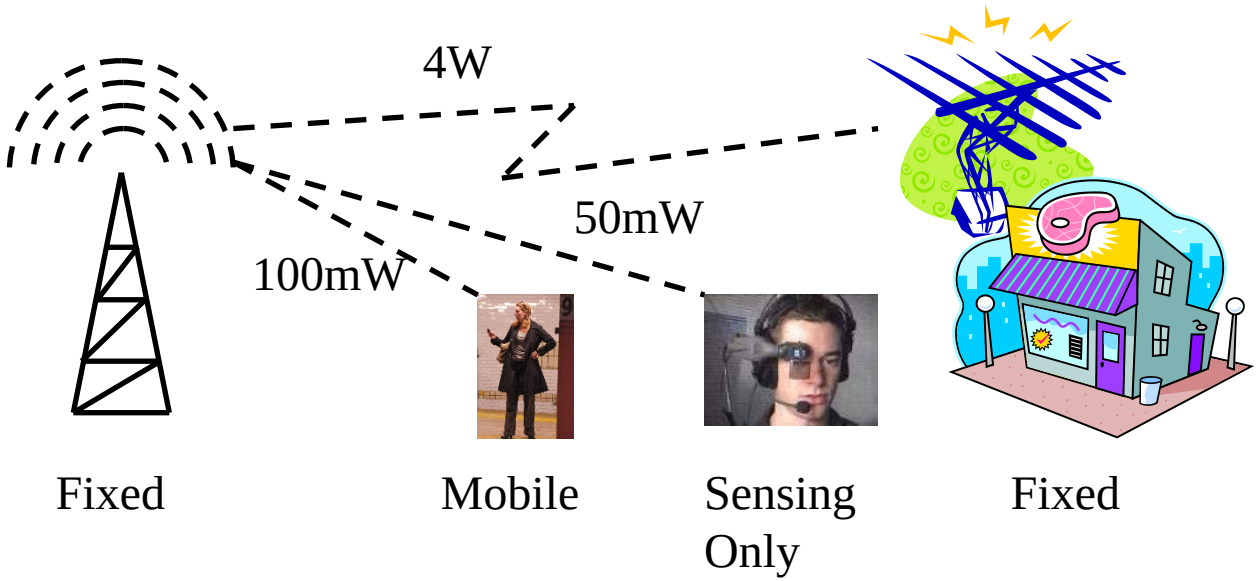
- In this table, are we expected to calculate one cell from the other for the same type?

No. FCC specifies this.

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

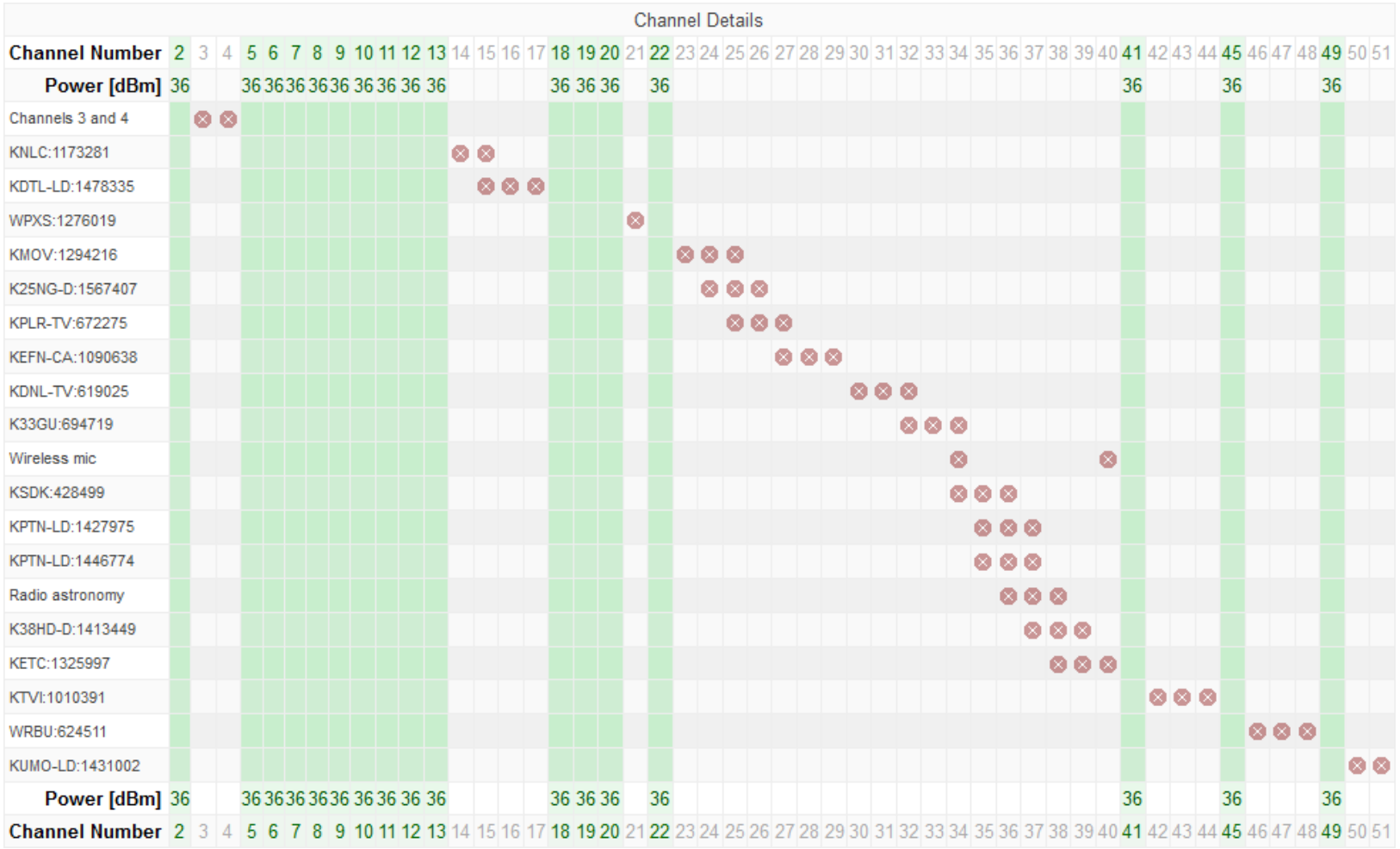
- Is it a closed-loop system because no information needs to be retrieved from the outside? Would you say this is a better system?

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

- Do the US and EU agree on a "global" standard for white-space utilization? If not, why?

This has been quite common in the communications industry. Latecomers have the benefit of better knowledge.

White Spaces Near WUSTL



- 17 channels. Zipcode 63130.

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

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⇒ Not Wi-Fi
- The final standard in 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
- four spatial streams × four channels ⇒ 426.7 Mbps

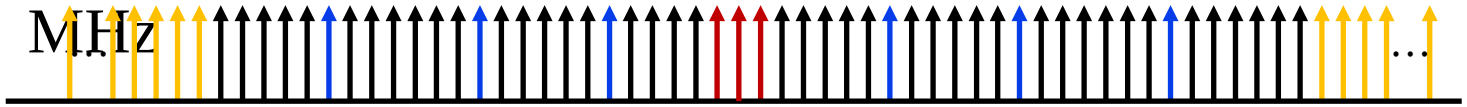
Student Questions

- If White-Fi is not Wi-Fi compliant, would 802.11af 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, six pilots, 36 Guard =144 carriers in 6 MHz



Student Questions

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

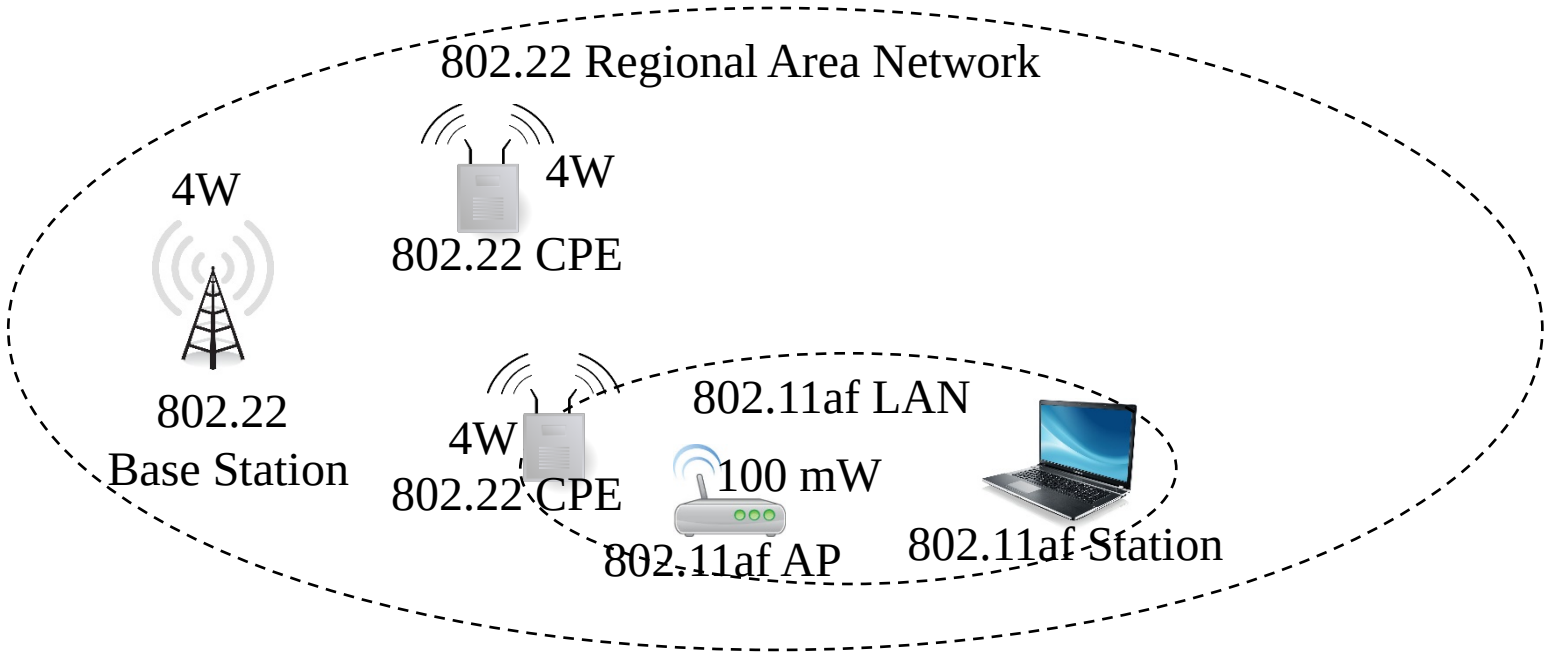
More subcarriers in the smaller frequency band
Contraction in frequency
⇒ Expansion in time
⇒ feels like the slower clock

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

It has been corrected and color-coded.

Coexistence Problem

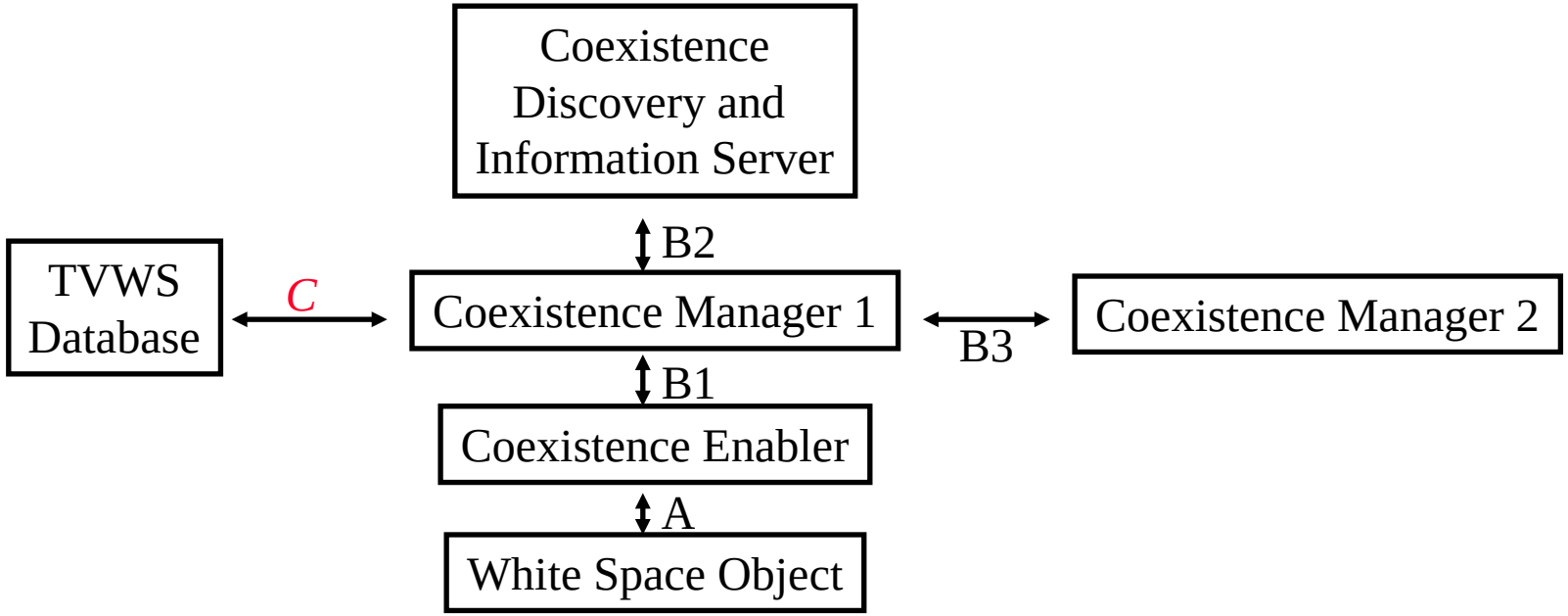
- Exposed Terminal: 802.11af can not transmit because 802.22 keeps the channel busy
- Hidden Terminal: 802.11af interferes with 802.22 transmissions



Student Questions

IEEE 802.19.1-2014

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



Student Questions

- How is registration enforced? 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)?

It is shown now.

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

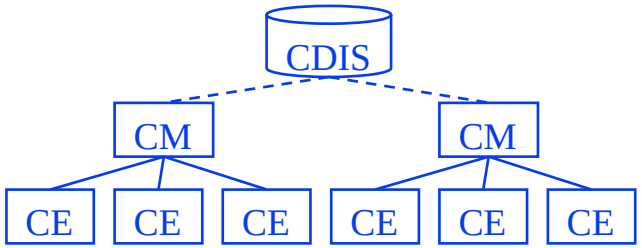
Yes.

- 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?

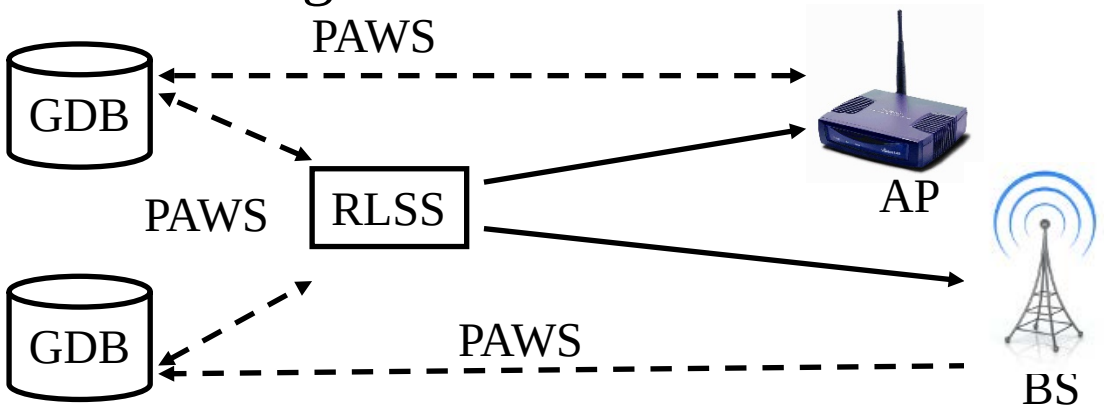
Yes.

- 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.

- What practical applications or scenarios could PAWS be particularly useful in wireless communication?

PAWS is required iff white spaces take off.

PAWS (Cont)

- Stations should be able to discover the 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 ⇒ 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

- 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 licenses to operate this service in the USA.

- When the master checks the GDB, are they using designated channels for pull and push transmissions so they do not interfere with other WP transmissions?

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

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

Only a few.

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

https://carlsonwireless.com/ruralconnect/

PAWS (Cont)

- Stations should be able to discover the 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 ⇒ Can be cached by master
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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

- Do stations have to use a trusted third-party Certificate Authority to verify that a public key belongs to the correct server?

Almost always.

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)

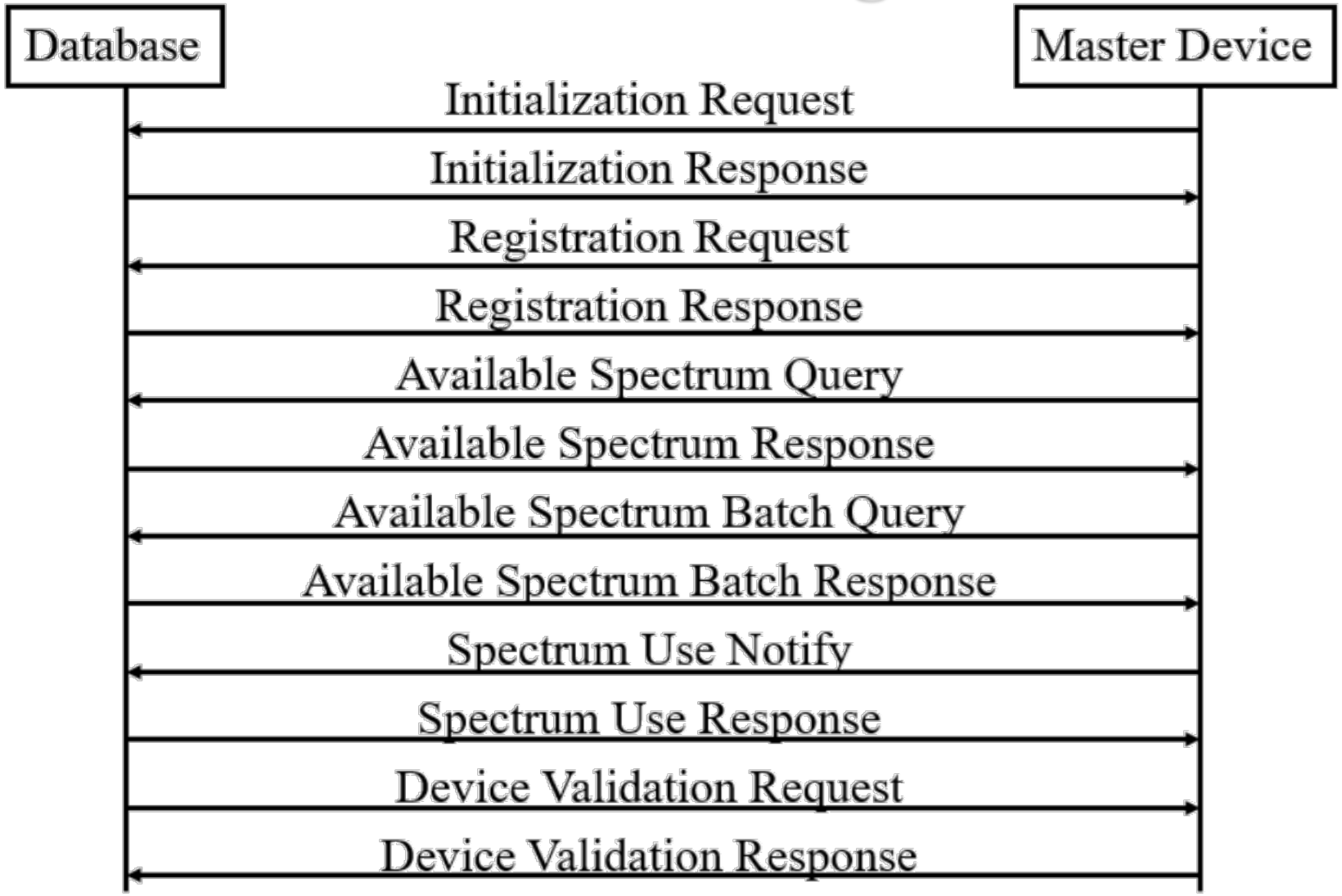
Student Questions

- How does a device ensure it is accessing the correct white spaces in real-time, especially if there are multiple databases?

The databases are synchronized.

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/pdfrfc/rfc7545.txt.pdf

PAWS Messages



Student Questions

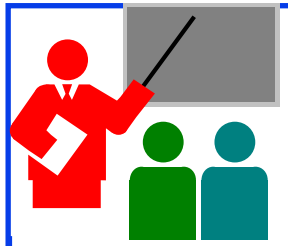
- How much latency it is for accessing the spectrum while following this procedure?

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 validate/authenticate slaves.

Student Questions



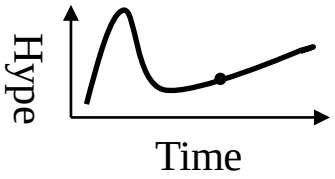
Summary

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 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., 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/
- 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/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/cse574-24/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=PLjGG94etKypJWOSPMh8Azcgy5e_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