

# Introduction to 60 GHz Millimeter Wave Multi-Gigabit Wireless Networks



**Raj Jain**

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

These slides and Video recordings of this class lecture are at:

<http://www.cse.wustl.edu/~jain/cse574-20/>

⇒

**Student Questions**

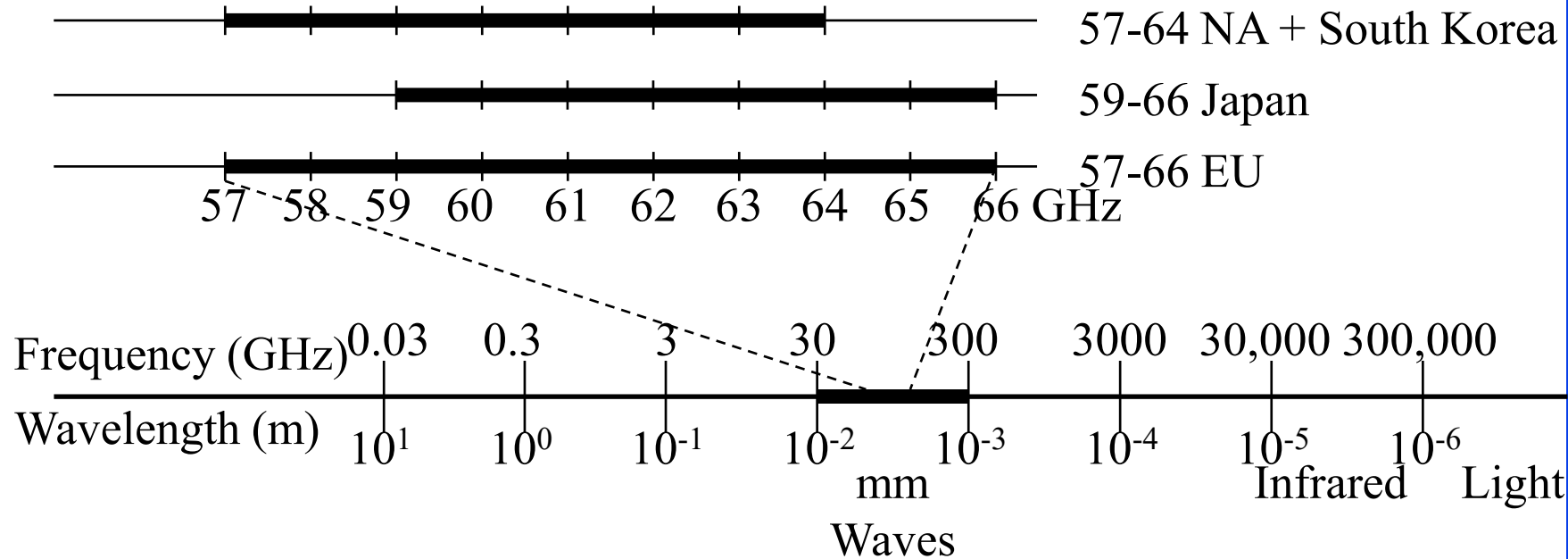


1. 60 GHz Frequency Allocations and characteristics
2. 60 GHz Wireless Standards
3. IEEE 802.11ad
4. WirelessHD
5. WirelessHD HRP OFDM Parameters

## Student Questions

# 60 GHz Frequency Allocations

- ❑ 7-9 GHz in 57-66 GHz (**millimeter** waves 30 GHz-300 GHz)
- ❑ 4 Channels of ~ 2 GHz
- ❑ Significant activity after FCC made 57-64 GHz license-exempt



## Student Questions

- ❑ So it is 7-9 GHz bandwidth in 57-66 GHz band?

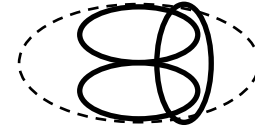
*Yes*

Ref: FCC, "Part 15 Rules for Unlicensed Operation in the 57-64 GHz Band," FCC13-112, August 2013,  
[http://hraunfoss.fcc.gov/edocs\\_public/attachmatch/FCC-13-112A1.pdf](http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-13-112A1.pdf)

# 60 GHz Power Limits

## ❑ Equivalent Isotropically Radiated Power (EIRP):

Power that an isotropic antenna would have to emit to match the directional reception



Region	GHz	Transmit dBm	EIRP dBm	Antenna Gain dBi
US/Canada	7	27	43	33 if 10dBm Transmit
Japan	7	10	58	47
Korea	7	10	27	17
Australia	3.5	10	51.7	41.8
Europe	9	13	57	30

## Student Questions

- ❑ You mean 16 dBm of antenna gain?

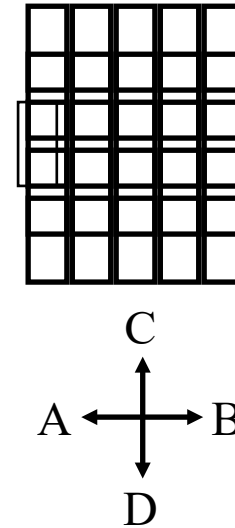
*Yes, if you transmit 27 dBm then maximum antenna gain you can have is 16 dBm.*

*However, if you transmit less, then you can have a higher gain antenna as long as EIRP is still below 43 dBm.*

Ref: S. Yong, P. Xia, A. Valdes-Garcia, "60 GHz Technology for Gbps WLAN and WPAN: From Theory to Practice," Wiley, Aug. 2011, 296 pp., ISBN:0470747706, Safari Book

# Advantages of 60 GHz Band

- 1. Large spectrum:** 7 GHz
  - 7 Gbps requires only 1 b/Hz (BPSK ok).
  - Complex 256-QAM not needed
- 2. Small Antenna Separation:**  
5 mm wavelength.  $\div 4 = 1.25$  mm
- 3. Easy Beamforming:** Antenna arrays on a chip.
- 4. Low Interference:** Does not cross walls.  
Good for urban neighbors
- 5. Directional Antennas:** Spatial reuse is easy
- 6. Inherent security:** Difficult to intercept
- 7. Higher power transmission:**
  - FCC allows up to 27 dBm at 60 GHz but amplifiers difficult
  - 60 GHz: 10 dBm+30 dBi Antenna gain = 40 dBm EIRP
  - 802.11n: 22 dBm+3 dBi Antenna gain = 25 dBm EIRP



## Student Questions

- Why we divided the wavelength in point 2 by 4?  
*The antenna size is related to the wavelength and how it is placed. A standard dipole antenna is generally  $l/2$ . However, it is possible to cut it down to  $l/4$  by using the printed circuit board as the other half.*

Ref:

<https://www.digikey.com/en/articles/understanding-antenna-specifications-and-operation>

# Disadvantages of 60 GHz Band

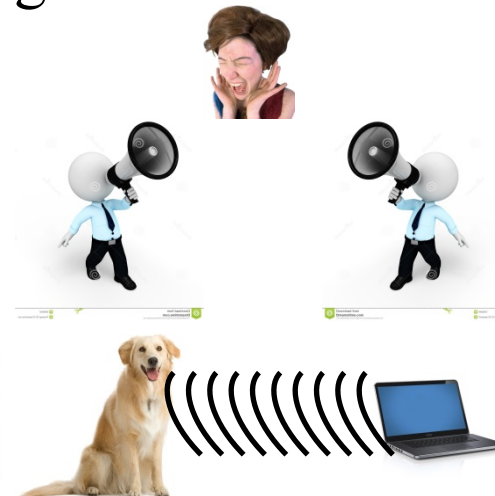
## 1. **Large Attenuation:** Attenuation $\propto$ frequency<sup>2</sup>

- Strong absorption by Oxygen
- Need larger transmit power: 10W allowed in 60GHz
- Need high antenna gain  $\Rightarrow$  directional antennas
- Short Distance  $\sim$  10m

## 2. **Directional Deafness:** Can't hear unless aligned

- Carrier sense not possible
- RTS/CTS does not work
- Multicast Difficult

## 3. **Easily Blocked:** By a human/dog Need a relay



## Student Questions

- ❑ Does 60 GHz band require a significantly greater amount of antennas? If so, what are the implications in terms of chip size & cost?

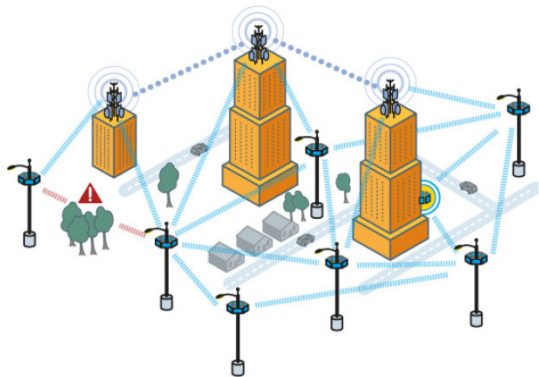
*Higher power and directionality is achieved by using many antennas. The cost is negligible.*

- ❑ Would some of these issues be solved with a mesh network similar to google home?

*Mesh networks are simply multiple access points connected via a wireless backhaul.*

# Multi-Gigabit Wireless Applications

- ❑ **Cable Replacement:** High-Definition Uncompressed streaming video
- ❑ Interactive **gaming**
- ❑ High-speed file transfer
- ❑ Wireless Mesh **Backhaul** (200-400m)



## Student Questions

- ❑ To what degree does the wireless mesh backhaul mitigate the signal being easily blocked? Can the signal still be blocked?

*Yes, the signal will be blocked for some locations. Some places could still be in the shadow.*

# 60 GHz Wireless Standards

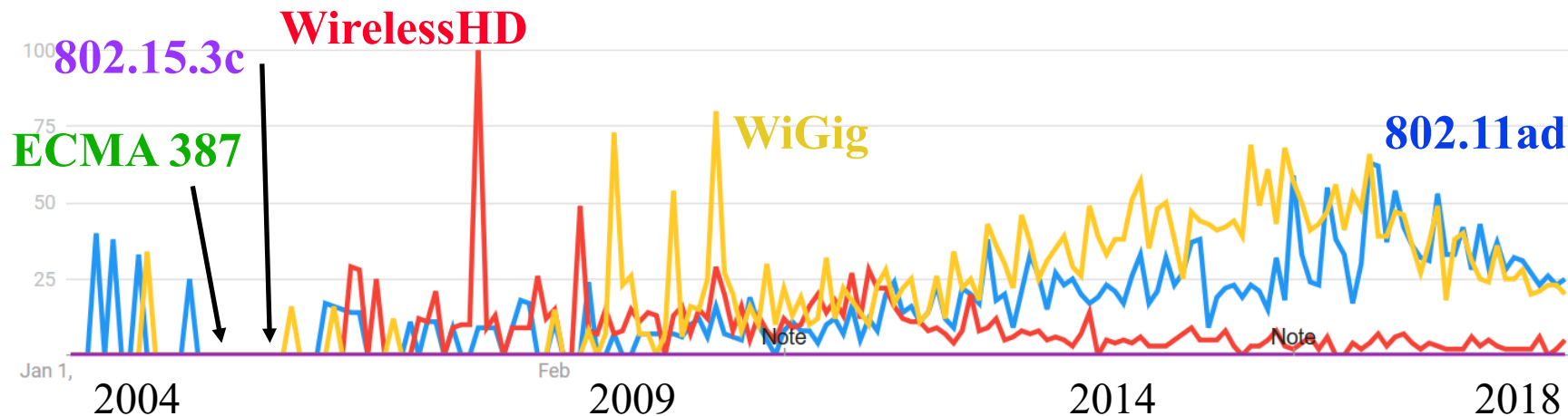
1. **IEEE 802.11ad-2014**
2. **ECMA-387-2009** (European Computer Manufacturers Association). Second Edition 2010.
3. **IEEE 802.15.3c-2009**
4. **WirelessHD 2010**
5. **WiMAX 802.16-2001** used 10-66 GHz **licensed** bands for fixed broadband wireless access (WirelessMAN-SC) but was not widely deployed.
6. **ARIB STD-T69** (2005): Millimeter Wave Video Transmission Equipment for Specified Low Power Radio Stations. Association of Radio Industries and Business (ARIB), Japan
7. **ARIB STD-T74** (2005): Millimeter Wave Data Transmission Equipment for Specified Low Power Radio Stations (Ultra High-Speed Wireless LAN System)

## Student Questions



# Google Trends

- ❑ Google trends shows number of searches over time
  - No one is interested in ECMA 387 or 802.15.3c
  - WirelessHD was hot in 2008-2009 but now being taken over by 802.11ad
- ❑ Amazon Search:
  - 4 pages of products on WirelessHD on Amazon
  - 9 pages of products on WiGig on Amazon



## Student Questions

# Sample WiGiG Products



Netgear 11ac/ad Router



Dell Triband Dock



WiGig USB3 Dongle



Dell Laptop with WiGig



Dell 11 a/b/g/n/ad+Bluetooth  
Mini-PCI express card

- ❑ Mostly computer industry
- ❑ 802.11AD added to other datalinks

Source: All product photos are from Amazon.  
Washington University in St. Louis

<http://www.cse.wustl.edu/~jain/cse574-20/>

©2020 Raj Jain

## Student Questions

# Sample WirelessHD Products



IOGEAR Wireless 3D Kit



J-Tech Wireless HDMI Extender



Actiontec Wireless HDMI



Nyrius ARIES Wireless HDMI

- ❑ Mostly Wireless HDMI  $\Rightarrow$  Video Industry
- ❑ All come with both ends

Source: All product photos are from Amazon.  
Washington University in St. Louis

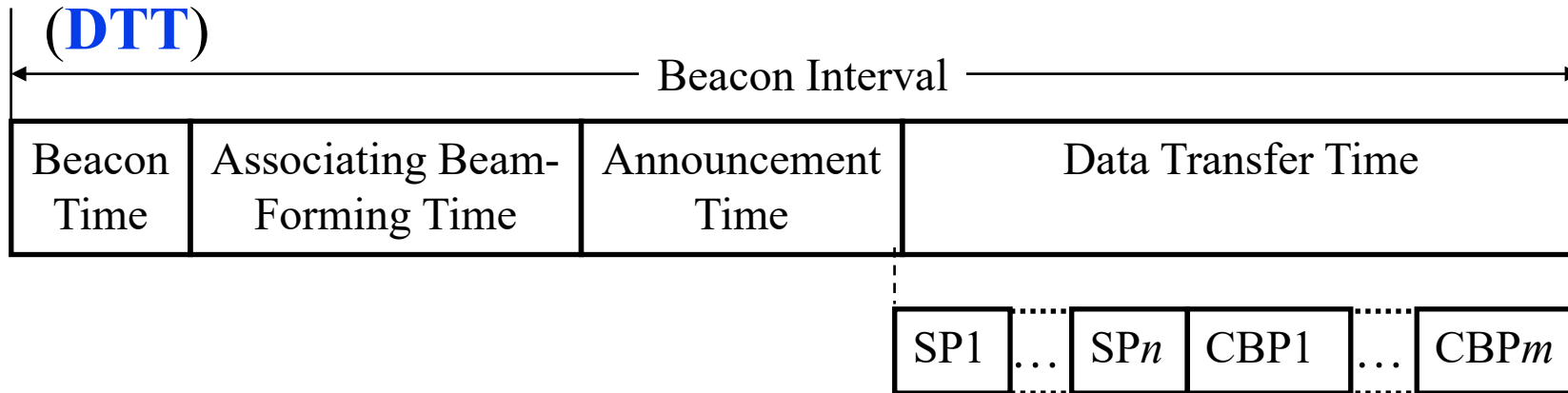
<http://www.cse.wustl.edu/~jain/cse574-20/>

©2020 Raj Jain

## Student Questions

# IEEE 802.11ad

- ❑ **Personal Basic Service Set (PBSS):**  
Group of stations that communicate
- ❑ **PBSS Central Point (PCP)** provides scheduling and timing using beacons
- ❑ Each super-frame called “**Beacon Interval**” is divided in to: Beacon Time (**BT**), Associating Beamforming Training (**A-BFT**), Announcement Time (**AT**), and Data Transfer Time (**DTT**)



## Student Questions

# IEEE 802.11ad (Cont)

- ❑ Only PCP can send a beacon during beacon time
- ❑ In A-BFT, PCP performs antenna training with its members
- ❑ In AT, PCP polls members and receives non-data responses
- ❑ In DTT, all stations exchange data frames in a dedicated **service period (SP)** or by **contention in contention-based period (CBP)**
- ❑ During DTT, stations use either Distributed Coordination Function (DCF) or Hybrid Coordination Function (HCF)

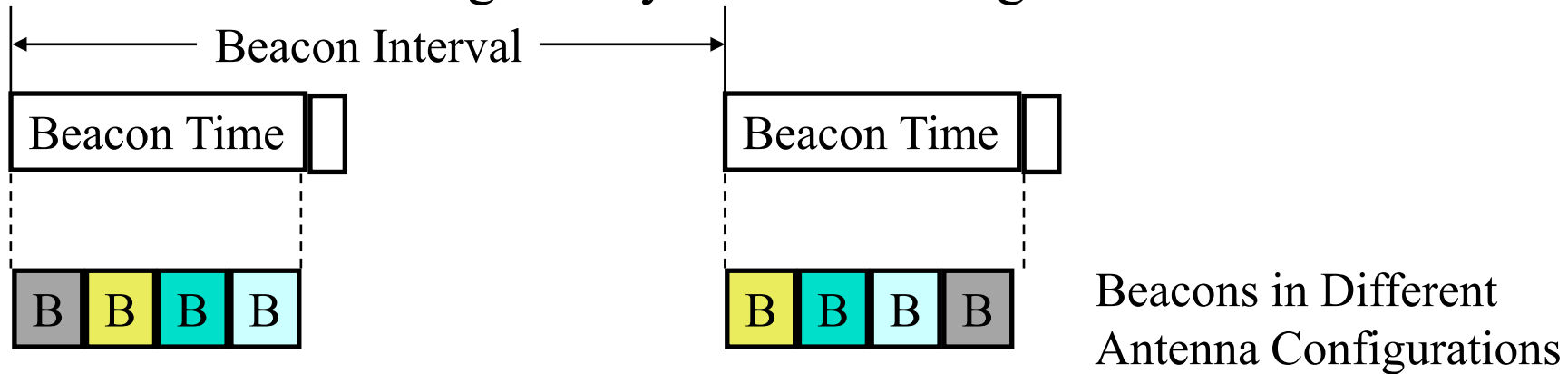
## Student Questions

- ❑ Could you please repeat the difference between SP and CBP?

*SP is contention free pre-allocated period. CBP is contention based.*

# IEEE 802.11ad Beacon

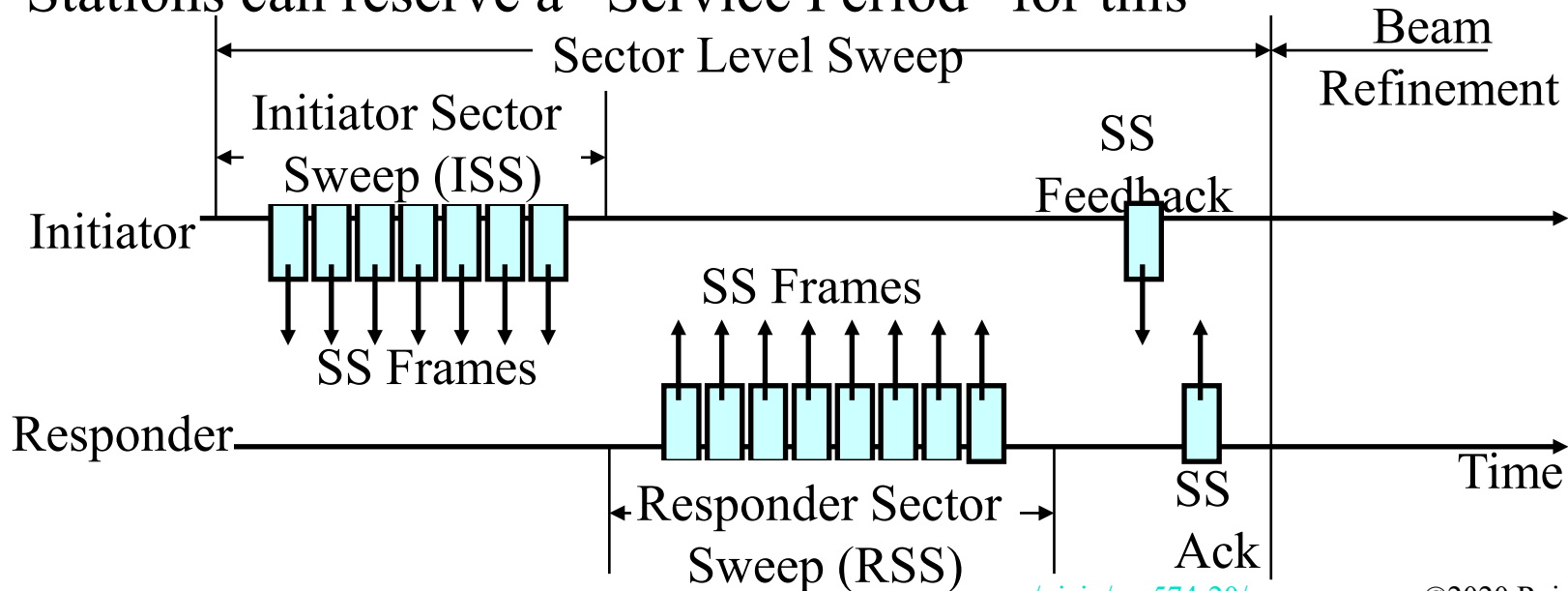
- Beacon transmissions are omni-directional  $\Rightarrow$  One beacon is transmitted through every antenna configuration



## Student Questions

# IEEE 802.11ad Antenna Training

- ❑ Each station finds the optimal antenna configuration with its recipient using a two-stage search
- ❑ **Sector Level Sweep (SLS)**: First it sends in all sectors and finds the optimal sector
- ❑ **Beam Refinement Procedure (BRP)**: It searches through the optimal sector to find the optimal parameters in that sector
- ❑ Stations can reserve a “Service Period” for this

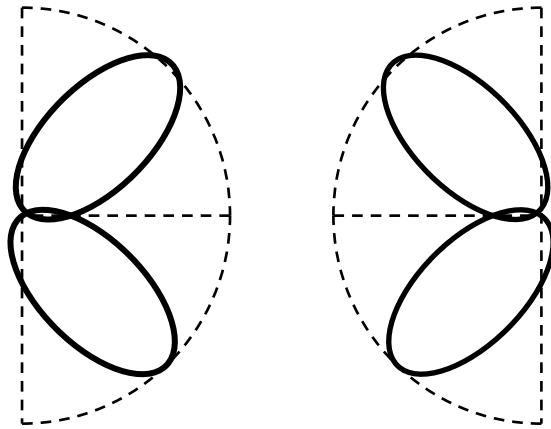


## Student Questions

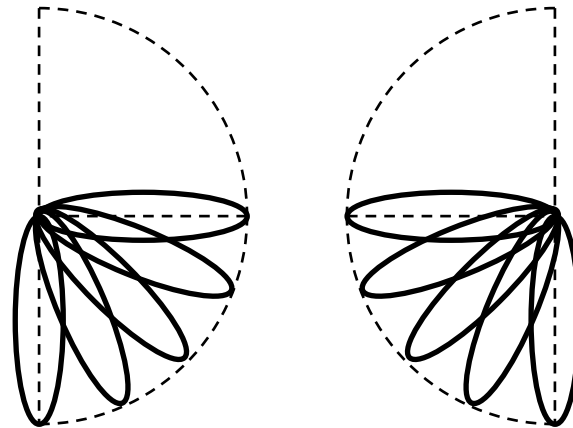
- ❑ What is sector? Is it physical location?  
*See next slide*

# Antenna Alignment

- ❑ **Beam Search:** Binary search through sectors using beam steering
- ❑ **Beam Tracking:** Some bits are appended to each frame to ensure that the beams are still aligned.



Sector-Level Sweep



Beam Refinement

## Student Questions

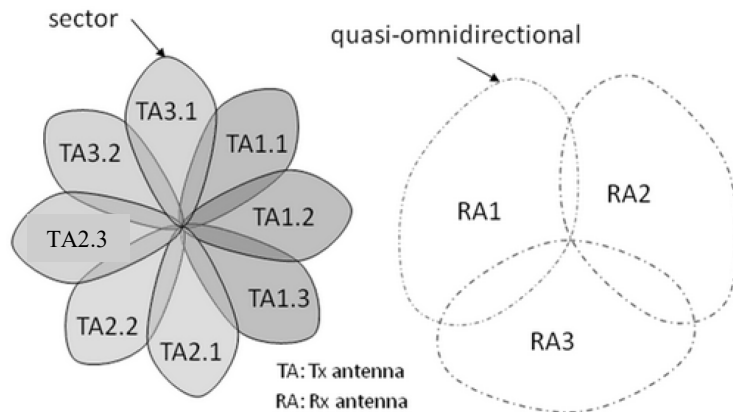
- ❑ Does this relate to the signal waves being in phase? Is directional deafness caused from out of phase signals?

*Directional deafness is when the receiver is not in the transmit lobe. For example, receivers on the left of the antenna in the left-most picture here.*



# Antenna Training Example

- ❑ Initiator (left) has 3 antennas with 3, 3, 2 sectors.  
Responder (right) has 3 antennas with 1 sector each
- ❑ Initiator performs 3 sweeps with 8 frames each using a different sector. Responder sends feedbacks.
- ❑ They find the best receive antenna and the best transmit antenna.



Ref: A. Suarez Sarmiento and E. M. Lopez, "Multimedia Services and Streaming for Mobile Devices," IGI Global, Sep 2011, ISBN:1613501447

## Student Questions

# IEEE 802.11ad PCP Cluster

- ❑ Overlapping PBSS avoid interference by electing a “**Synchronization PCP**” (**S-PCP**) for the PCP cluster
- ❑ All PCP’s select the beacon interval to be an integral multiple of that selected by S-PCP
  - ⇒ Non-overlapping beacon transmit intervals
- ❑ All PCP allocate Service Periods in their schedule for BT of all other PCP’s
  - ⇒ All PCP’s hear all allocations
  - ⇒ Avoid overlapping scheduling

## Student Questions

# Spatial Frequency Sharing (SFS)

- ❑ Multiple transmissions may be scheduled on the same frequency at the same time if they don't interfere
- ❑ PCP asks stations to send results of “Directional Channel Quality” during an overlapping SP. The stations measure the channel quality and send to PCP.  
PCP then knows which station pairs can share the same slot.

## Student Questions

# IEEE 802.11ad Relays

- ❑ **Link Switch Relays:** MAC relays like a switch. Receive complete frames from the source and send to destination.
- ❑ **Link Cooperation Relays:** Phy relays like a hub.  
Amplify and forward (AF) or decode and forward (DF)  
⇒ Destination may receive direct signal and relayed signal  
⇒ Spatial diversity

## Student Questions

# 802.11ad Summary

1. **Centralized** scheduling. Only **PCP** can send beacons. It sends beacons in all sectors.
2. Superframe (**Beacon Interval**) consists of Beacon Time, Associating Beamforming Training, Announcement Time, and Data Transfer Time
3. Announcement time is used for collecting requests
4. Data transfer can be pre-allocated or by contention
5. **Antenna training** is a 2-phase process. Sector selection and beam refinement.
6. Multiple transmission can take place on the same frequency at the same time (**Spatial Frequency Sharing**).
7. **Relays** can be used if LoS blocked.

## Student Questions

- Can you re-explain the superframe components briefly?

*See Slide 7-12*

# WirelessHD

- ❑ 60 GHz wireless standard to connect television, displays to laptops, blu-ray players, DVRs, ...
- ❑ Designed for high-quality uncompressed video e.g., 2560×1440p, 60Hz, 36b color = 8.0 Gbps
- ❑ Lossless, 3D, 48b color, 240 Hz refresh, 4k (4048p) resolution video streaming from smart phones and tablets
- ❑ **Wireless Video Area Network (WVAN):** 10m - 30m
- ❑ 4 Channels of 1.76 GHz each
- ❑ Very-high data rates (28 Gbps+) using spatial multiplexing (4 concurrent streams)
- ❑ Non-line of sight operation

Ref: WirelessHD.org, “WirelessHD Specification Overview,”

<http://www.wirelesshd.org/pdfs/WirelessHD-Specification-Overview-v1.1May2010.pdf>

<http://www.cse.wustl.edu/~jain/cse574-20/>

## Student Questions

# WirelessHD PHYs

- ❑ Three PHYs:
  1. **High-Rate PHY (HRP):** 1-7 Gbps for high-quality video
  2. **Medium-Rate PHY (MRP):** 0.5-2 Gbps for lower power mobile applications
  3. **Low-Rate PHY (LRP):** 2.5-40 Mbps for omni-directional control and discovery, multicast, acks for HRP/MRP, antenna beam forming, capability exchange
- ❑ HRP/MRP (**HMRP**) and LRP use the same band: Use TDMA
- ❑ Peer-to-Peer  $\Rightarrow$  No access point (but need one coordinator)
- ❑ A device may have coordinator capability. |  
Generally displays and storage devices have this capability

## Student Questions

# WirelessHD HRP OFDM Parameters

- Similar tables for LRP and MRP

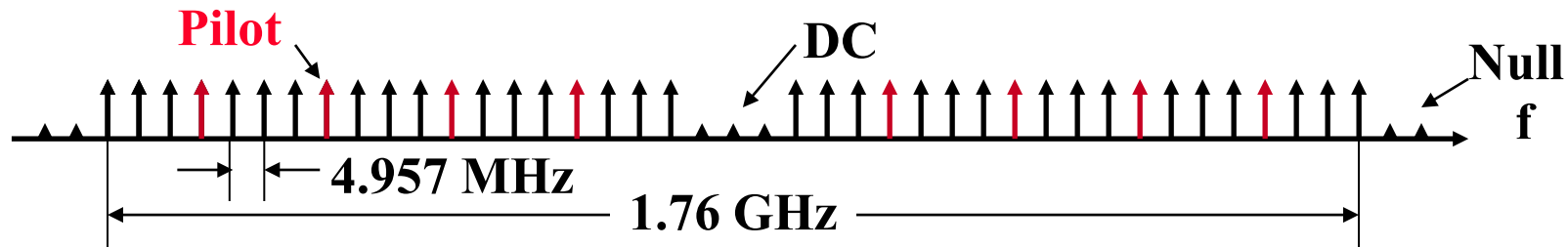
Parameter	Value	Symbol	
Occupied Bandwidth	1.76 GHz	$B$	} Frequency Domain
Subcarrier Spacing	4.957 MHz	$\Delta f_{sc}$	
Number of subcarriers	$355 = 1.76/4.957$	$B/\Delta f_{sc}$	
FFT Size	512	$F = \text{Round up to a power of 2}$	
Number of Data Subcarriers	336	$N_{dsc}$	
Number of DC Subcarriers	3	$N_{dc}$	} 355
Number of Pilots	16	$N_p$	
Number of Null subcarriers	157	$F - N_{dsc} - N_{dc} - N_p$	
FFT Period	$1/\Delta f_{sc} = 201.73 \text{ ns}$	$T_{FFT}$	} Time Domain
Guard Interval	$T_{FFT}/8 = 25.22 \text{ ns}$	$T_{GI}$	
Symbol Duration	$T_{FFT} + T_{GI} = 226.95 \text{ ns}$	$T_S \Rightarrow \text{Symbols/s}$	
Modulation	QPSK, 16-QAM, 64-QAM	$\Rightarrow \text{bits/Symbol}$	} Coding
Outer block code	RS(224, 216)	$\Rightarrow 224 - 216 = 8 \text{ check bits}$	
Inner Code	1/3, 1/2, 2/3, 5/6 (EEP) 2/5, 1/2, 4/7, 2/3, 4/5 (UEP)	$x/y \Rightarrow x \text{ info bits}$ $\text{in } y \text{ total bits}$	

## Student Questions

- I'm confused by the numbers for EEP/UEP  
 *$x/y \Rightarrow$  for every  $y$  bits, only  $x$  are data bits.  $y-x$  are check bits. The numbers are in the standard.*
- I don't understand how the numbers of data subcarriers, DC subcarriers, and pilots are chosen/calculated.  
*All formulas have been added on the left. **Please practice.***  
**Example:** PHY bit rate with 64-QAM, 2/5 UEP  
 $= (1/(226.95 \times 10^{-9})) \times 6 \times (216/224) \times (2/5)$   
 $= 10.2 \text{ Mbps per data subcarrier}$   
 $= 10.2 * 336 = 3.4272 \text{ Gbps}$   
**Exam Question:** What would the data rate with 5/6 EEP and 16-QAM?



# HRP OFDM Frequency Parameters



Parameter	Value	Symbol
Occupied Bandwidth	1.76 GHz	
Subcarrier Spacing	4.957 MHz	$D_{f_{sc}}$
Number of subcarriers	355	
FFT Size	512	
Number of Data Subcarriers	336	$N_{dsc}$
Number of DC Subcarriers	3	
Number of Pilots	16	
Number of Null subcarriers	157	

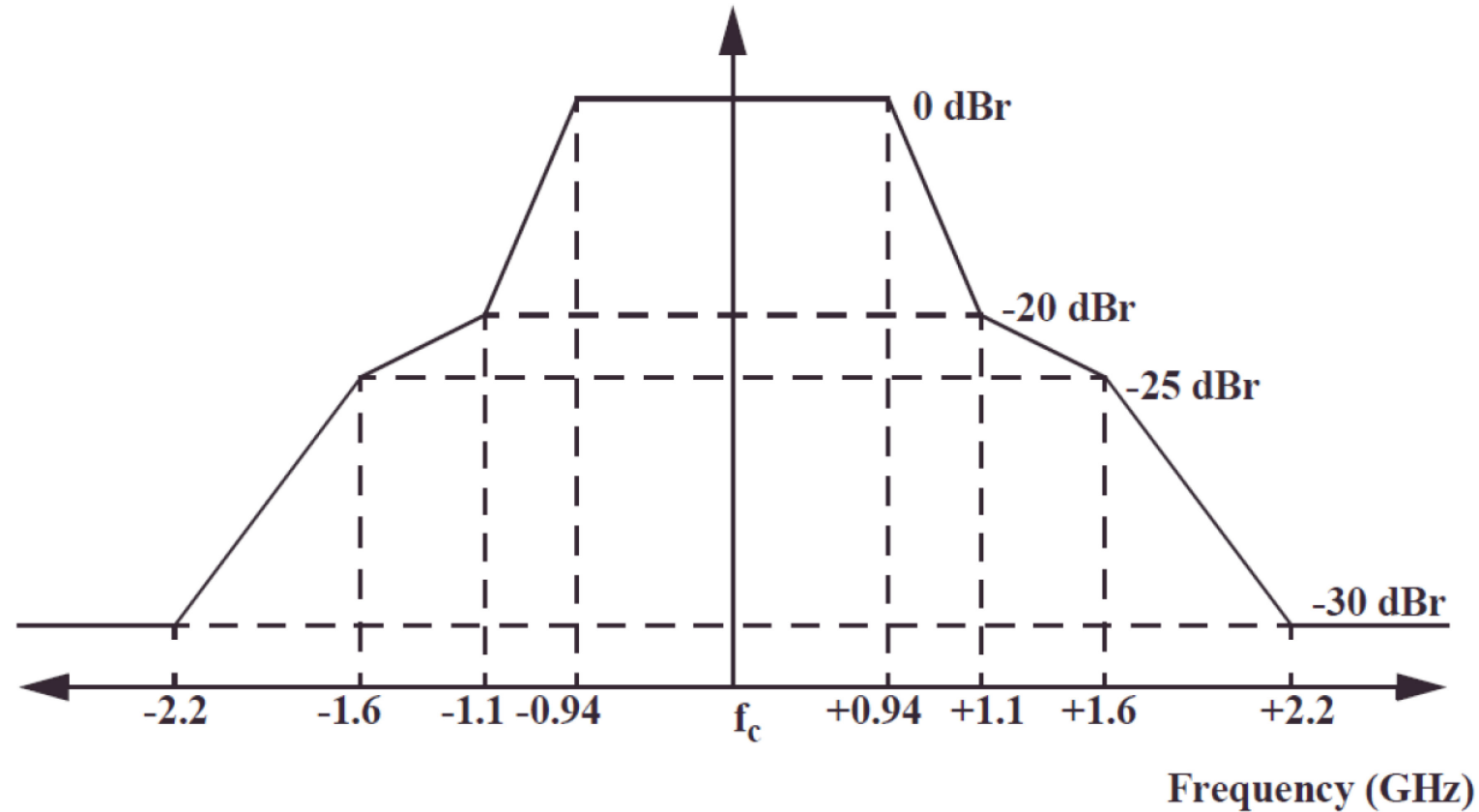
- Similar tables for MRP and LRP

## Student Questions

- Are DC subcarriers always in the middle?  
*Yes, as much as I have seen.*

# HRP Transmit Mask

- ❑ Similar masks exist for LRP and MRP
- ❑ dBr = deci-Bel relative



Ref: WirelessHD.org, "WirelessHD Specification Overview,"

<http://www.wirelesshd.org/pdfs/WirelessHD-Specification-Overview-v1.1May2010.pdf>

Washington University in St. Louis

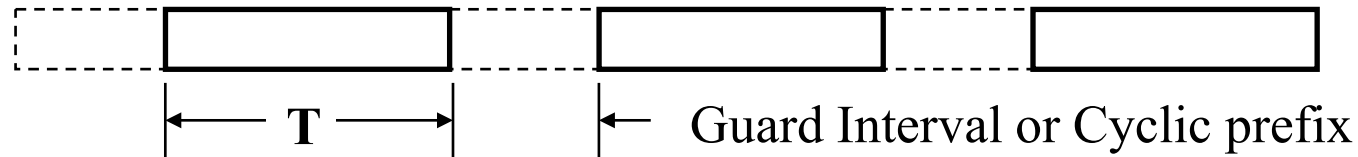
<http://www.cse.wustl.edu/~jain/cse574-20/>

©2020 Raj Jain

## Student Questions

# HRP OFDM Time Parameters

- Symbol time = 1/subcarrier spacing =  $1/\Delta f_{sc}$



Parameter	Value	Symbol
FFT Period	$1/\Delta f_{sc} = 201.73 \text{ ns}$	$T_{\text{FFT}}$
Guard Interval	$T_{\text{FFT}}/8 = 25.22 \text{ ns}$	$T_{\text{GI}}$
Symbol Duration	$T_{\text{FFT}} + T_{\text{GI}} = 226.95 \text{ ns}$	$T_{\text{S}}$

## Student Questions

# HRP OFDM Coding Parameters

- ❑ Reed-Solomon Coding:  $RS(n,k) \Rightarrow$  Send  $n$  bits for  $k$  bits
- ❑ Equal Error Protection (EEP): All data bits and ECC bits are equally protected
- ❑ Unequal Error Protection (UEP): Bits are divided in subgroups. Each subgroup has a different protection level

Parameter	Value	Symbol
Modulation	QPSK, 16-QAM, 64-QAM	
Outer block code	RS(224, 216)	
Inner Code	1/3, 1/2, 2/3, 5/6 (EEP) 2/5, 1/2, 4/7, 2/3, 4/5 (UEP)	

## Student Questions

# WirelessHD MAC

- ❑ Two MAC capabilities:
  1. **Coordinator**: Controls timing and keeps track of members of WVAN
  2. Other stations
- ❑ Everyone can transmit and receive LRP
- ❑ Some may be able to receive HMRP but may/may not be able to transmit HMRP
- ❑ Shutdown and sleep modes
- ❑ Channel estimation
- ❑ Higher Layer: Video format selection, video coding/encoding, service discovery, ...

## Student Questions

# WirelessHD Summary

1. Designed for uncompressed video. Video Cable replacement.
2. **Three PHYs**: High-Rate (1-7 Gbps), Medium-Rate (0.5-2 Gbps), and Low-Rate(2.5-40 Mbps)
3. LRP is used for discovery, multicast
4. Centralized Access. Coordinator issues beacons and allocates reserved transmission slots
5. No access points. But some devices need **coordinator capabilities**.
6. Random Access Time Blocks (**RATBs**) are used for unallocated transfers
7. Channel Time Blocks (**CTBs**) are used for pre-allocated transfers
8. Power save mode and device control commands in MAC

## Student Questions

# Summary



1. 60 GHz, a.k.a. mm wave, has large bandwidth, small antenna separation allows easy beamforming and gigabit speeds but short distance due to large attenuation
2. Tri-band Wireless LAN devices with 2.4 GHz, 5.8GHz, and 60GHz are coming
3. 802.11ad LAN uses a PBSS central control point (PCP)
4. WirelessHD was designed for HD video.
5. In all cases antenna alignment and tracking is required.

## Student Questions

# Homework 7

- ❑ A. What is the EIRP of a system that transmits 1 Watt using a 10 dBi antenna?
  
- ❑ B. An OFDM system has to be designed using 1GHz band with 5 MHz spacing. What is the number of:
  - Used Subcarriers
  - Size of FFT
  - FFT duration
  - Symbol duration assuming  $1/4^{\text{th}}$  cyclic prefix
  - Data bit rate using QPSK with RS(224, 216) coding with  $3/4$  rate inner code. Assume  $7/8^{\text{th}}$  of the subcarriers are used for data transmission.

## Student Questions

- ❑ FFT duration and period are the same, right?



# Reading List

- ❑ S. Yong, P. Xia, A. Valdes-Garcia, “60 GHz Technology for Gbps WLAN and WPAN: From Theory to Practice,” Wiley, Aug. 2011, 296 pp., ISBN:0470747706, Safari Book
- ❑ WirelessHD.org, "WirelessHD Specification Overview," <http://www.wirelesshd.org/pdfs/WirelessHD-Specification-Overview-v1.1May2010.pdf>

## Student Questions

# Wikipedia Links

- ❑ [http://en.wikipedia.org/wiki/Wireless\\_Gigabit\\_Alliance](http://en.wikipedia.org/wiki/Wireless_Gigabit_Alliance)
- ❑ <http://en.wikipedia.org/wiki/WirelessHD>
- ❑ [https://en.wikipedia.org/wiki/Effective\\_radiated\\_power](https://en.wikipedia.org/wiki/Effective_radiated_power)
- ❑ [http://en.wikipedia.org/wiki/Extremely\\_high\\_frequency](http://en.wikipedia.org/wiki/Extremely_high_frequency)
- ❑ [http://en.wikipedia.org/wiki/Frame\\_aggregation](http://en.wikipedia.org/wiki/Frame_aggregation)
- ❑ <http://en.wikipedia.org/wiki/Beamforming>
- ❑ [http://en.wikipedia.org/wiki/Phased\\_array](http://en.wikipedia.org/wiki/Phased_array)
- ❑ [http://en.wikipedia.org/wiki/Antenna\\_array\\_\(electromagnetic\)](http://en.wikipedia.org/wiki/Antenna_array_(electromagnetic))
- ❑ [http://en.wikipedia.org/wiki/Wireless\\_USB](http://en.wikipedia.org/wiki/Wireless_USB)
- ❑ [http://en.wikipedia.org/wiki/MAC\\_service\\_data\\_unit](http://en.wikipedia.org/wiki/MAC_service_data_unit)
- ❑ [http://en.wikipedia.org/wiki/Protocol\\_data\\_unit](http://en.wikipedia.org/wiki/Protocol_data_unit)
- ❑ [http://en.wikipedia.org/wiki/Block\\_acknowledgement](http://en.wikipedia.org/wiki/Block_acknowledgement)

## Student Questions

# References

- ❑ IEEE 802.11ad-2012, “IEEE Standard for Information Technology – Telecommunications and Information Exchange Between Systems – Local and Metropolitan Area Networks – Specific Requirements – Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specification, Amendment 3: Enhancements for Very High Throughput in the 60 GHz Band,” 28 December 2012, 628 pp.
- ❑ FCC, “Part 15 Rules for Unlicensed Operation in the 57-64 GHz Band,” FCC13-112, August 2013, [http://hraunfoss.fcc.gov/edocs\\_public/attachmatch/FCC-13-112A1.pdf](http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-13-112A1.pdf)
- ❑ IEEE 802.15.3c-2009, “IEEE Standard for Information Technology – Telecommunications and Information Exchange Between Systems – Local and Metropolitan Area Networks – Specific Requirements, Part 15.3: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for High Rate Wireless Personal Area Networks (WPANs), Amendment 2: Millimeter-Wave-Based Alternative Physical Layer Extension,” 12 October 2009, 203 pp.
- ❑ ECMA, "High Rate 60 GHz PHY, MAC and PALs," 2nd Edition, December 2010, 302pp. <http://www.ecma-international.org/publications/files/ECMA-ST/ECMA-387.pdf>

## Student Questions

# References (Cont)

- A. Suarez Sarmiento and E. M. Lopez, "Multimedia Services and Streaming for Mobile Devices," IGI Global, Sep 2011, ISBN:1613501447.

## Student Questions

# Acronyms

- ❑ A-BFT      Associating Beamforming Time
- ❑ AF          Amplify and forward
- ❑ ARIB        Association of Radio Industries and Business
- ❑ AT          Announcement Time
- ❑ AV          Audio Video
- ❑ BFT         Beamforming Time
- ❑ BP          Beacon Period
- ❑ BPSK        Binary Phase Shift Keying
- ❑ BRP         Beam Refinement Procedure
- ❑ BT          Beacon Time
- ❑ CAP         Contention Access Period
- ❑ CBP         Contention-based period
- ❑ CMS         Common mode signaling
- ❑ CRC         Cyclic Redundancy Check
- ❑ CTA         Channel Time Allocation

## Student Questions

# Acronyms (Cont)

- ❑ CTS Clear to Send
- ❑ dBi Deci-Bel Isotropic
- ❑ dBm Deci-Bel milliwatt
- ❑ DBS Discovery Block Set
- ❑ DCF Distributed Coordination Function
- ❑ DF Decode and forward
- ❑ DI Discovery Interval
- ❑ DTP Data Transfer Period
- ❑ DTT Data Transfer Time
- ❑ DTV Digital Television
- ❑ DVDO Name of a company
- ❑ DVR Digital Video Recorder
- ❑ ECMA European Computer Manufacturers Association
- ❑ EEP Equal Error Protection
- ❑ EIRP Equivalent Isotropically Radiated Power
- ❑ EM Expectation Maximization

## Student Questions

# Acronyms (Cont)

- ❑ EU Europe
- ❑ EURASIP Name of a Publisher
- ❑ FCC Federal Communications Commission
- ❑ FFT Fast Fourier Transform
- ❑ GHz Giga Hertz
- ❑ HCF Hybrid Coordination Function
- ❑ HCS Header Check Sequence
- ❑ HD High Definition
- ❑ HMRP HRP/MRP
- ❑ HRP High Rate Protocol
- ❑ HSI High Speed Interface
- ❑ IEEE Institution of Electrical and Electronics Engineers
- ❑ LAN Local Area Network
- ❑ LoS Line of Sight
- ❑ LRP Low Rate Protocol
- ❑ MAC Media Access Control

## Student Questions

# Acronyms (Cont)

- ❑ MCS Modulation and Coding Scheme
- ❑ MHz Mega Hertz
- ❑ MRP Medium Rate Protocol
- ❑ MSDU MAC Service Data Unit
- ❑ NA North America
- ❑ OFDM Orthogonal Frequency Division Multiplexing
- ❑ OSD On-Screen Display
- ❑ PAL Protocol Adaptation Layer
- ❑ PAN Personal Area Network
- ❑ PBSS Personal Basic Service Set
- ❑ PCI Peripheral Component Interconnect
- ❑ PCIE PCI Express
- ❑ PCP PBSS Control Point
- ❑ PHY Physical Layer
- ❑ PNC Piconet Coordinator

## Student Questions



## Acronyms (Cont)

- ❑ QAM            Quadrature Amplitude Modulation
- ❑ QPSK        Quadrature Phase Shift Keying
- ❑ RATB        Random Access Time Block
- ❑ RTS         Ready to Send
- ❑ S-CAP       Sub-Contention Access Period
- ❑ SC          Single Carrier
- ❑ SFS         Spatial Frequency Sharing
- ❑ SH          Subframe Header
- ❑ SLS         Sector Level Sweep
- ❑ SP          Service Period
- ❑ SS          Sector Sweep
- ❑ STB         Set-Top Box
- ❑ STD         Standard
- ❑ TA          Transmit Antenna
- ❑ TDMA       Time Division Multiple Access

## Student Questions

# Acronyms (Cont)

- ❑ UEP Unequal Error Protection
- ❑ USB Universal Serial Bus
- ❑ WiGig Wireless Gigabit Alliance
- ❑ WiMAX Worldwide Interoperability for Microwave Access
- ❑ WLAN Wireless Local Area Network
- ❑ WPAN Wireless Personal Area Network
- ❑ WVAN Wireless Video Area Network

## Student Questions

**Scan This to Download These Slides**



Raj Jain

<http://rajjain.com>

**Student Questions**

[http://www.cse.wustl.edu/~jain/cse574-20/j\\_07sgl.htm](http://www.cse.wustl.edu/~jain/cse574-20/j_07sgl.htm)

# Related Modules



CSE567M: Computer Systems Analysis (Spring 2013),  
[https://www.youtube.com/playlist?list=PLjGG94etKypJEKjNAa1n\\_1X0bWWNyZcof](https://www.youtube.com/playlist?list=PLjGG94etKypJEKjNAa1n_1X0bWWNyZcof)

CSE473S: Introduction to Computer Networks (Fall 2011),  
[https://www.youtube.com/playlist?list=PLjGG94etKypJWOSPMh8Azcg5e\\_10TiDw](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