程序代写代做 CS编程辅导

WiFi Part III

IEEE 802.11 for Niche Applications

802.11af/ah/ad/ay

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Overview

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1. IEEE 802.11a[illegible]
2. IEEE 802.11ah
3. IEEE 802.11ad
4. IEEE 802.11ay

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802.11 Standards

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IEEE 802.11af-2014 (a.k.a. White-Fi)

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802.11af Overview

1. Television Channels
2. Whitespaces
3. Whitespace Database & Protocols
4. Data rates and MCS

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Over-the-Air Television Channels

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

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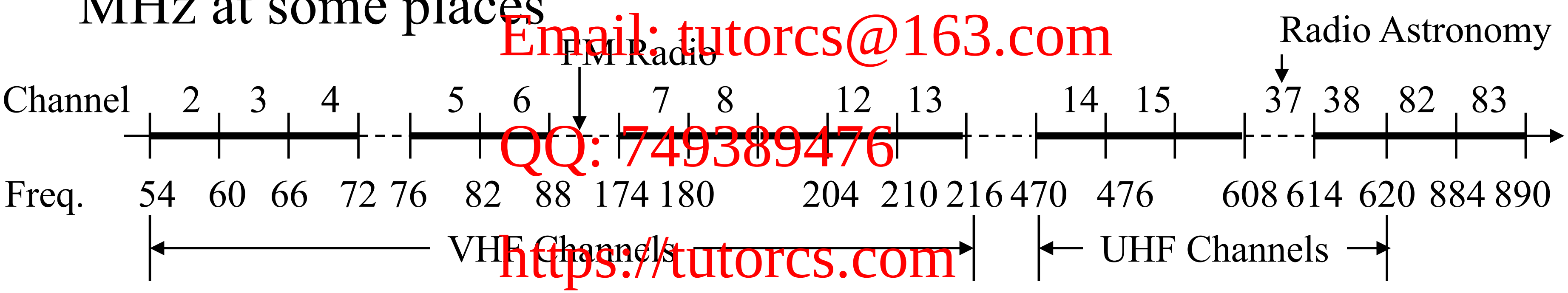

- At least one channel is skipped between two analog stations in neighboring areas to avoid interference

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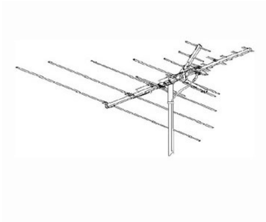

Digital Television

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

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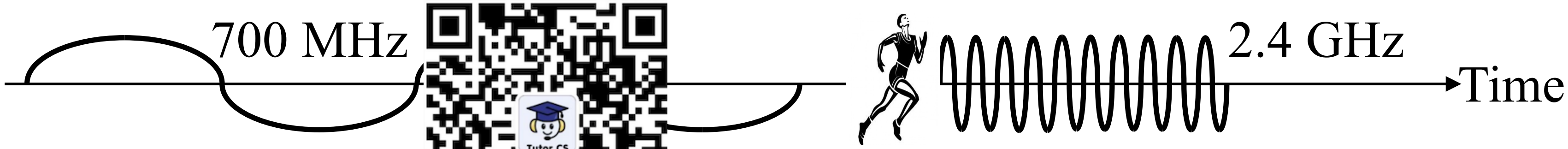
700 MHz Band



- Lower attenuation 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.

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

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Spectral White Spaces

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- Any spectrum at a given area at a given time available for use o[illegible]nterfering basis:
  - Unallocated sp[illegible]
  - Allocated but under-utilized
  - Channels not used to avoid interferences in adjacent cells
  - Digital Dividend

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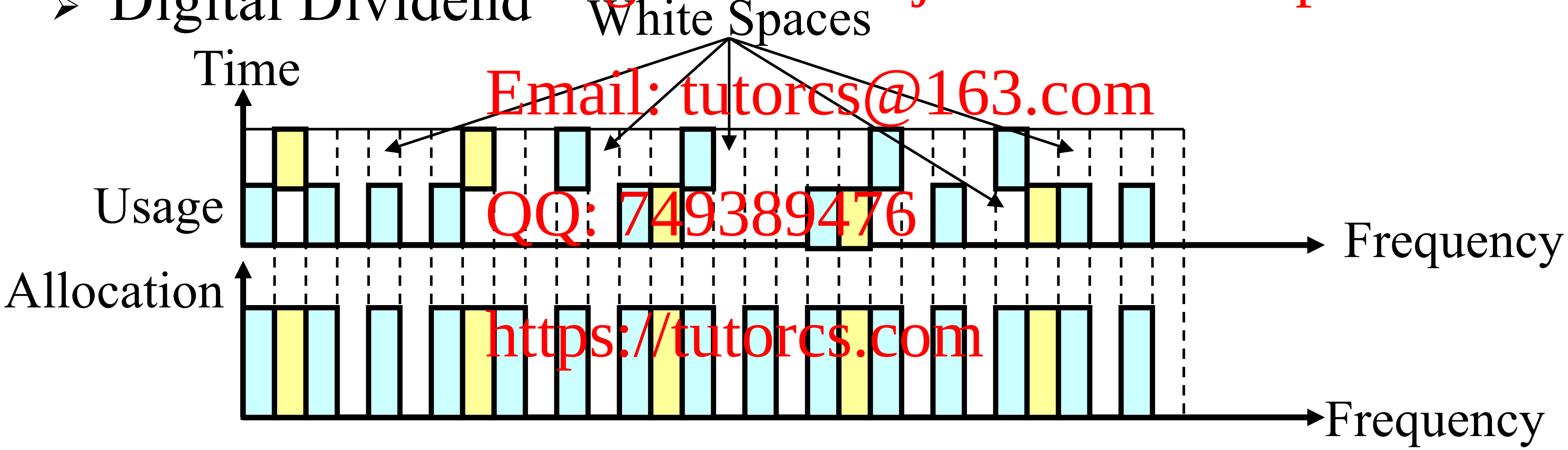

Ref: C. Gomez, "White Spaces for Rural Broadband," April 2013, http://www.itu.int/ITU-D/asp/CMS/Events/2013/PacificForum/ITU-APT-S3_Cristian_Gomez.pdf

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Spectrum Usage Example

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(Test conducted with antenna at a height of 22.1 metres above the groun ector west of Ottawa, Canada)

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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

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TVWS Databases

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- FCC has authorize[illegible]panies to administer TVWS databases.
    - Get info from I[illegible]base
    - Register fixed TVWS devices and wireless microphones
    - Synchronize databases with other companies
    - Provide channel availability lists to TVWS devices
- Europe requires devices to check every two hours

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White Spaces Near WUSTL, St. Louis, USA

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- 17 channels. Zipcode 63130.

Ref: Google Spectrum Database (not available anymore), https://www.google.com/get/spectrumdatabase/channel/

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802.11af Database Operation

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- Geolocation Database (GDB)
- Registered Locati[illegible] Server (RLSS):
  - Provide faster r[illegible]o access points (APs) locally in a campus.
  - May be Internet Service Provider (ISP) owned.
- Geolocation Database Dependent (GDD) entities:
  - GDD Enabling: Access Point
  - GDD Dependent: Other stations

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

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Registered Location Query Protocol (RLQP)

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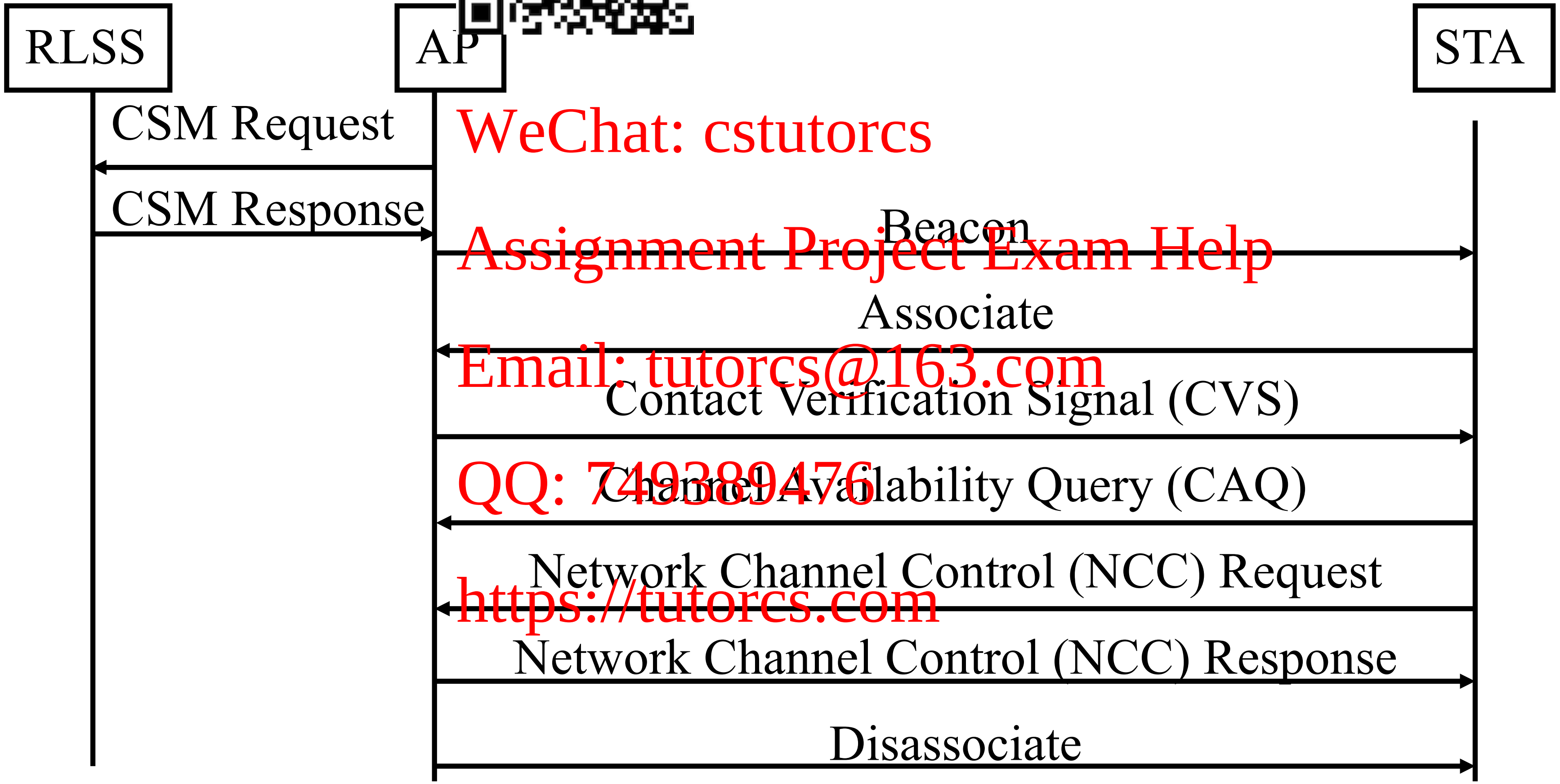
- Protocol for excha… …hite space map (WSM) among RLSS, APs, and st… …a, Channel Schedule Management (CSM)



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RLQP (Cont)

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

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Protocol to Access White-Space (PAWS)

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- IETF working gro[illegible]
- Mechanism to dis[illegible]e space database
- Protocol to commu[illegible]th the database
- Interface Agnostic: [illegible]af, 802.15.4m, 802.22, …
- Spectrum agnostic: 6 MHz, 7 MHz, 8 MHz, …
- Master Device: White-Space Device (WSD) connects to database
- Slave Device: WSD that get info from master devices

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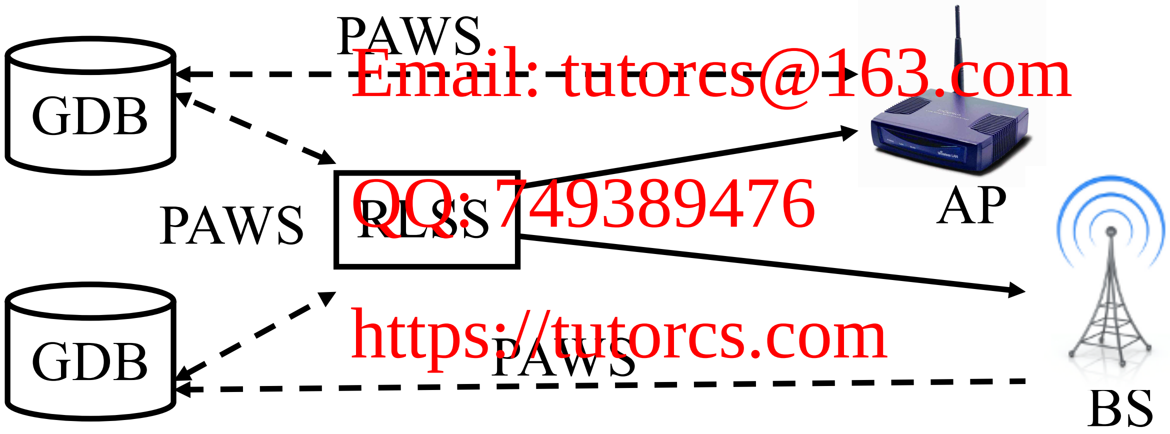

Ref: V. Chen, et al, ed. "Protocol to access White-Space (PAWS) Databases," Feb 2014, http://datatracker.ietf.org/doc/draft-ietf-paws-protocol/

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PAWS (Cont)

- Stations should be [illegible] iscover WS Database, its regulatory domain. May be p[illegible]ed similar to DNS or Certification Authorities.
- Listing Server: W[illegible]sting 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 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

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PAWS (Cont)

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- Allows WSD tc[illegible] geolocation, height, serial number, Certifi[illegible]vice class, radio access technology (RA[illegible]nna 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)

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

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PAWS Messages (Cont)

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

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PAWS Messages

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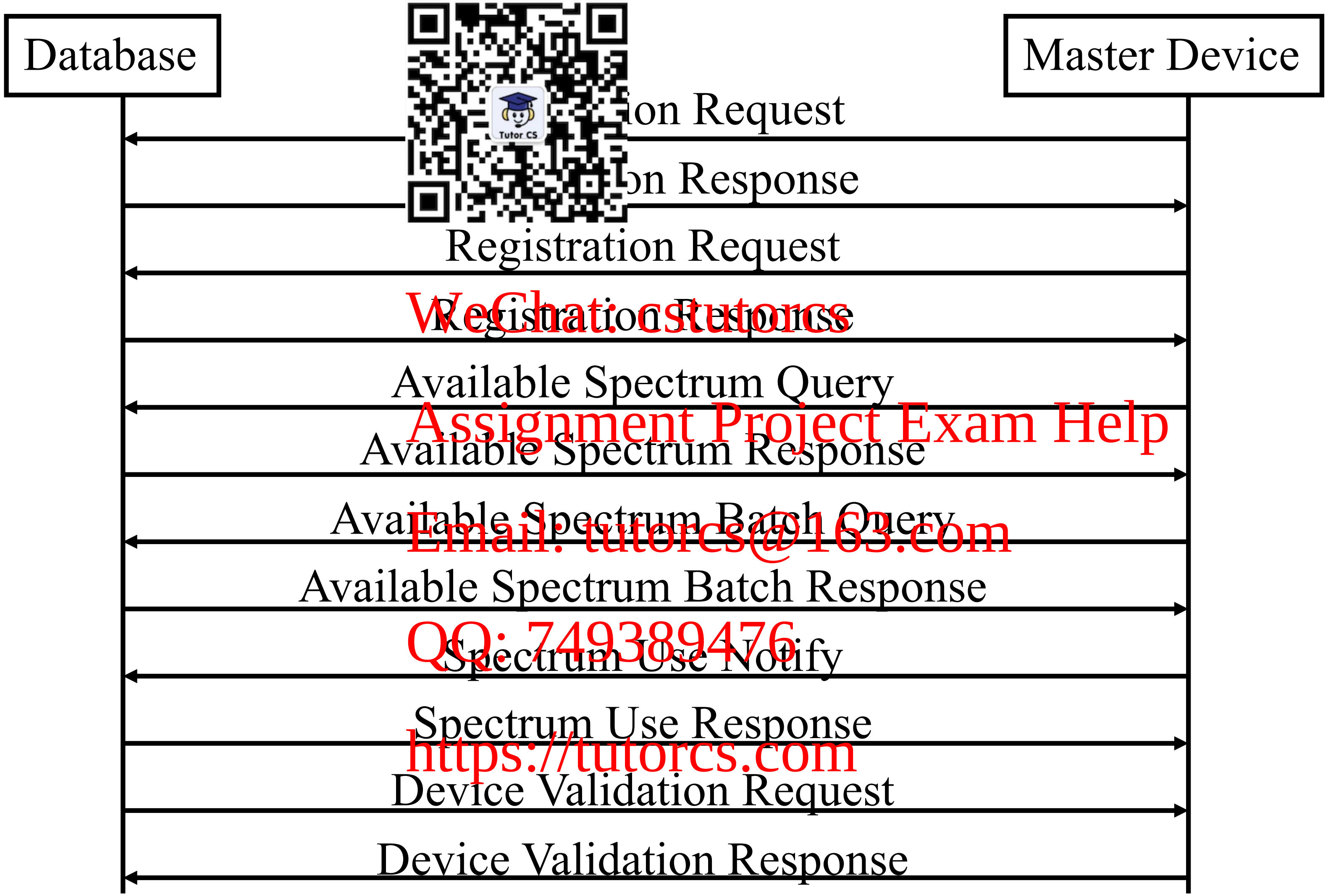

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802.11af Channels

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- Basic Channel Un[illegible]One TV Channel
  W = 6 MHz in US[illegible]
- Channel Bonding:
  - Contiguous: 2W, 4W
  - Non-contiguous: W+W, 2W+2W

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IEEE 802.11af OFDM Data Rates

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- Modulation: 256-QAM highest
- Coding: 5/6 highest
- OFDM similar to 4[illegible]n 802.11n down-clocked by 7.5x
- 6MHz channel: 144 total subcarriers, **108 Data**, 3 DC, 6 pilots, 36 Guard
- 7.5x down clocking
  - 0.4µs GI in 802.11n -→ 3µs in 802.11af (0.4x7.5=3)
  - 3.2µs data interval → 3.2x7.5 = 24µs
  - Total symbol interval = 24+3 = 27µs
- Data rate (single stream, single channel): 26.67 Mbps
- Max. Data rate (4 stream, 4 channel): 26.67x16 = 426.7 Mbps

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IEEE 802.11af Data Rates in Mbps

(Single Stream, Single Unbonded 6MHz Channel)

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MCS	Modulation	Coding	Data Rate
0	BPSK	1/2	2
1	QPSK	1/2	4
2	QPSK	3/4	6
3	16-QAM	1/2	8
4	16-QAM	3/4	12
5	64-QAM	2/3	16
6	64-QAM	3/4	18
7	64-QAM	5/6	20
8	256-QAM	3/4	24
9	256-QAM	5/6	26.7

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IEEE 802.11af: Data Rate Example

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Question: Calculate 8[illegible] rate for MCS=0

Solution:

For MCS=0, Modulation = BPSK and Coding Rate = ½

For BPSK, we have 1 bit per data subcarrier

With 108 data subcarrier: 108 coded bits per symbol

With 27 us symbol interval: 1/27 Mega symbols/s

Coded bits per sec: 108/27 Mbps

With ½ coding rate, effective data rate = 108/(27x2) Mbps = 2 Mbps

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Summary of 802.11af

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1. Analog to Digita[illegible]on of TV channels has freed up spectru[illegible]MHz band ⇒ White Space.
2. 700MHz allows long-distance communication, useful for rural areas
3. FCC has allowed license-exempt use of some of the white space in TV bands. Requires software defined radio.
4. IEEE 802.11af White-Fi spec achieve up to 426.7 Mbps using OFDM, 4-stream MIMO, 256-QAM@5/6.
5. PAWS is the protocol for accessing white space databases.

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IEEE 802.11ah-2017 (a.k.a HaLow)

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Sample Application

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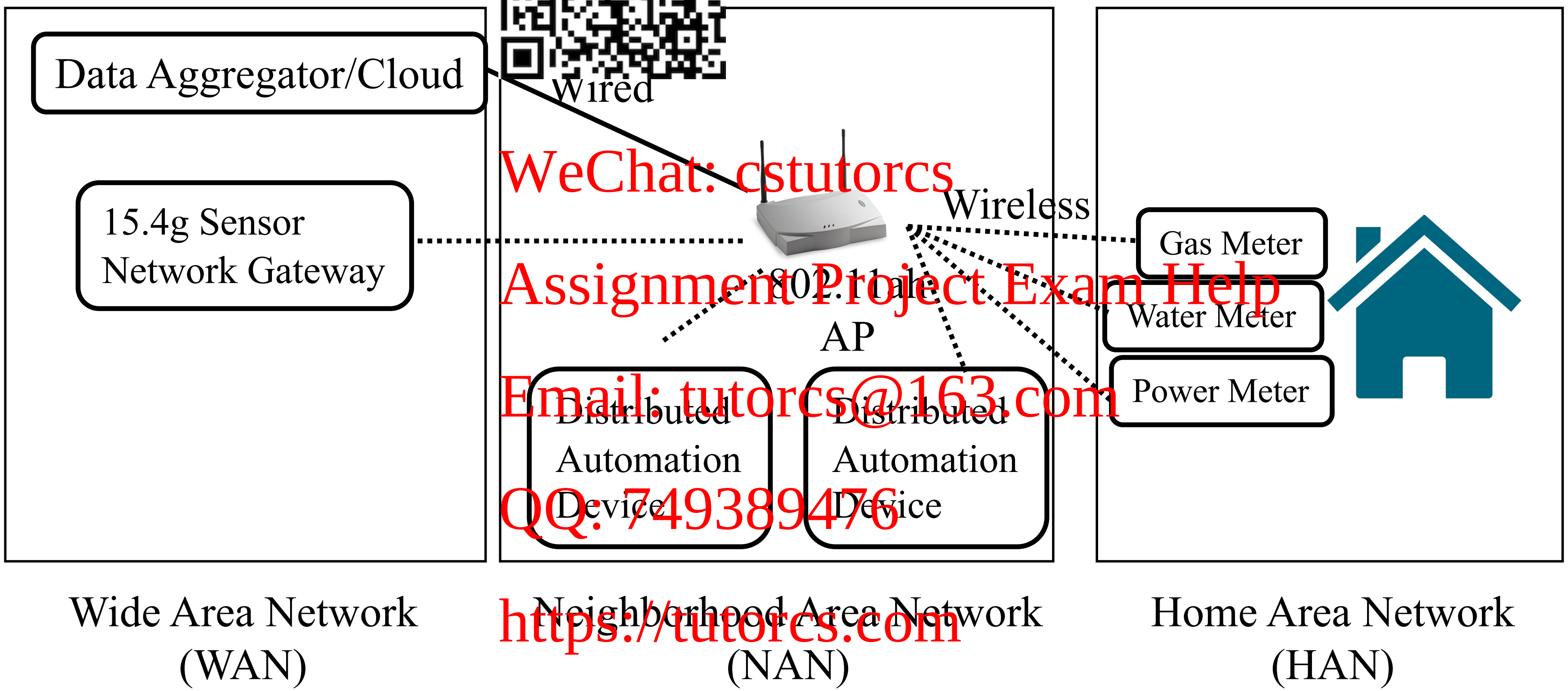

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Ref: H. Wei, "Self-Organizing Energy Efficient M2M Communications," http://cc.ee.ntu.edu.tw/~ykchen/1123-HWei.pdf

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802.11ah PHY

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1. 802.11ac PHY **down** … 10X
   - 2/4/8/16 MHz cha… of 20/40/80/160 MHz in ac
   - 20 MHz 11ac and … both have 64 FFT size and 48 data subcarriers + 4 pilots ⇒ 1/10 … r spacing
     ⇒ 10X longer Symbols ⇒ Allows 10X delay spread
     ⇒ All times (SIFS, ACKs) are 10x longer
   - New 1 MHz PHY with 24 data subcarriers

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2. **Adjacent channel bonding**: 1MHz+1MHz = 2 MHz
3. All stations have to support 1MHz and 2MHz

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4. Up to **4 spatial streams** (compared to 8 in 11ac)
5. 1 MHz also allows a new MCS 10 which is MCS0 with 2x repetition ⇒ Allows 9 times longer reach than 2.4GHz

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6. **Beam forming** to create sectors

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Ref: W. Sun, M. Choi, and S. Choi, "IEEE 802.11ah: A Long Range 802.11 WLAN at Sub 1 GHz," River Journal, 2013, pp. 1-26, http://riverpublishers.com/journal/journal_articles/RP_Journal_2245-800X_115.pdf

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Example

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- If we reduce the cl l of 802.11ac by a factor of 10, what would be the bol rate (symbols/s)?

802.11ac has a symbol duration of 3.6 μs (for 400 ns GI).

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New symbol duration with a 10x slower clock = 36 μs

New symbol rate = $1/(36 \times 10^{-6}) = 27{,}777$ sym/s

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Example

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- In USA, 902-928 I been allocated for 802.11ah. How many different cha be used if 16 MHz channel option is used?

902-928 MHz has a total bandwidth of 26 MHz. There is *only one (non-overlapping)* 16 MHz channel possible out of 26 MHz.

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802.11 MAC

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- **Large number of** [illegible]er Access Point (AP)
  - Hierarchical A[illegible] Identifier (AID)
- **Relays** are used to[illegible]nnectivity outside the coverage area. Limited to 2-hops.

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- **Power Savings Enhancements**:
  - Allows stations to sleep and save energy.
  - AP negotiates a Target Wake Time (TWT) for individual stations

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- **Speed frame exchange** allows stations to exchange a sequence of frames for a TXOP.

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Ref: E. Khorov, et al., "A survey on IEEE 802.11ah: An enabling networking technology for smart cities," Computer Communications, 2014, http://dx.doi.org/10.1016/j.comcom.2014.08.008

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MAC Protocol Versions

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- Protocol Versio[illegible]) is same as that for b/a/g/n/ac
- Protocol versio[illegible]) is optimized for IoT
  - Short headers
  - Null Data packets
  - Speed frame exchange
  - Improved channel access

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Short MAC Header

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- MAC Header shortened by 12-26 Bytes:
  - Removed: Hig[illegible]put control, QoS, Duration field [illegible]al carrier sensing)
  - Optional: 3rd ad[illegible]
  - 2-byte AID in place of some 6-byte addresses
  - Frame Control indicates what protocol version is being used
  - Sequence field indicates if 3rd /4th addresses are present

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Legacy 802.11 (36B)

Frame Control	Duration/ ID	Addr 1	Addr 2	Addr 3	Seq. Control	Addr 4	QoS Control	HT Control
2B	2B	6B	6B	6B	2B	6B	2B	4B

802.11ah Downlink (10-24B)

Frame Control	AID	BSS ID	Seq. Control	Addr 3	Addr 4
2B	2B	6B	0 or 2B	0 or 6B	0 or 6B

802.11ah Uplink (10-24B)

Frame Control	BSS ID	AID	Seq. Control	Addr 3	Addr 4
2B	6B	2B	0 or 2B	0 or 6B	0 or 6B

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Example

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- A garbage bin sensor t ah to upload 10 bytes of bin-fill-level data once every hour. Com acy 802.11 (a/b/g/n/ac), the bin sensor has to upload how many l r day?

Legacy 802.11 MAC header length = 36 byte

Total bytes uploaded with legacy 802.11 = 24x(10+36) = 1104 bytes/day

Total bytes uploaded with 802.11ah = 24x(10+10) = 480 bytes/day (min)

1104 - 480 = 624 less bytes per day

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Null Data Packet (NDP)

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- RTS/CTS/ACK has n[illegible]onsumes too much MAC overhead
- 802.11ah removes the [illegible]C header for these packets and identifies these packets via the *modulation and coding* (MCS) scheme at the PHY
- ACK, Block ACK, CTS, etc. all use different MCS

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Speed Frame Exchange

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- Also called "**Bi Directic** [...] **it** (BDT)"
- Initiator sends a frame w [...] indicator set to "long response"
  - Receiver can send d [...] f ACK within a SIFS
  - Frames are sent unti [...] more frames; block ACK at end

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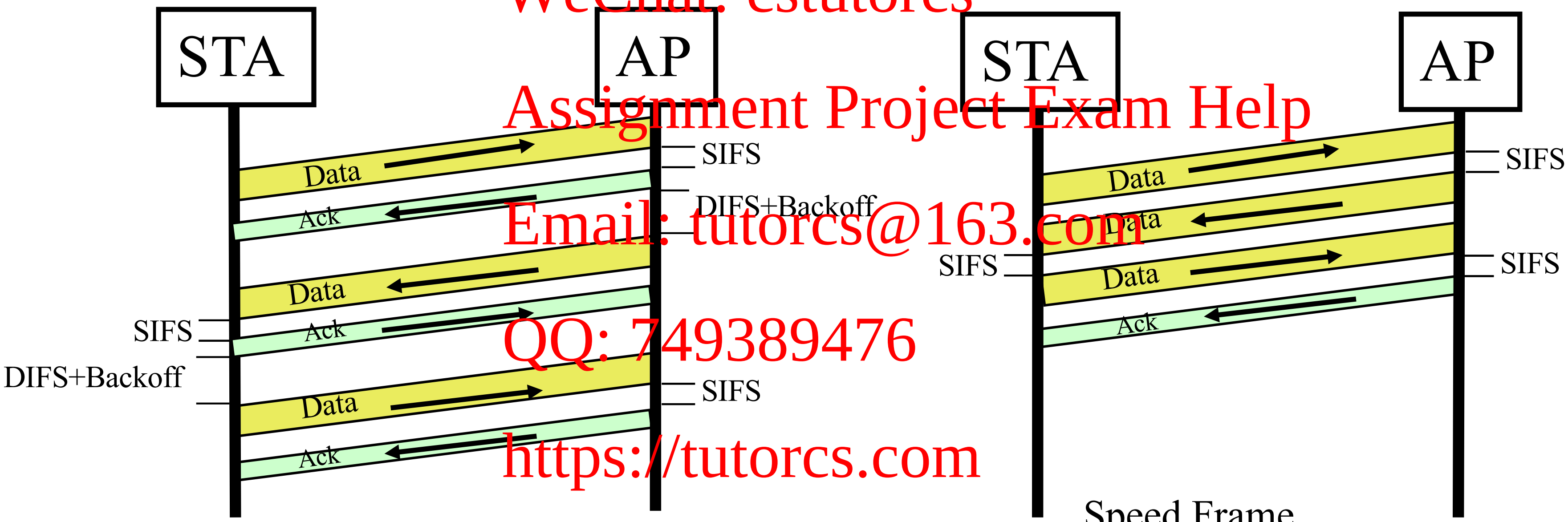

Legacy 802.11

Speed Frame Exchange in 802.11ah

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Types of Stations

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- **High-Traffic**: Lis[illegible]affic Indication Map (TIM) in beacons and transm[illegible]ingly within a restricted access window ⇒ *TIM S[illegible]*
  - *Remain awake all the time to monitor all beacons*

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- **Periodic Low-Traffic**: Negotiate a transmission time allocated in a periodic restricted access windows. Do not listen to beacons ⇒ *Non-TIM Stations*

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- **Very Low-Traffic**: Send a poll to AP and get a transmission opportunity in response ⇒ *Unscheduled Stations*

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Page Segmentation

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- Announcing all bu[illegible]mes in each beacon
  $\Rightarrow$ 8096 bits woul[illegible]ed per beacon interval
- AP segments the T[illegible]ns in segments and announces only one segment at a time.
- Every Delivery TIM (DTIM) interval, AP announces which segments have pending data and downlink, uplink periods.

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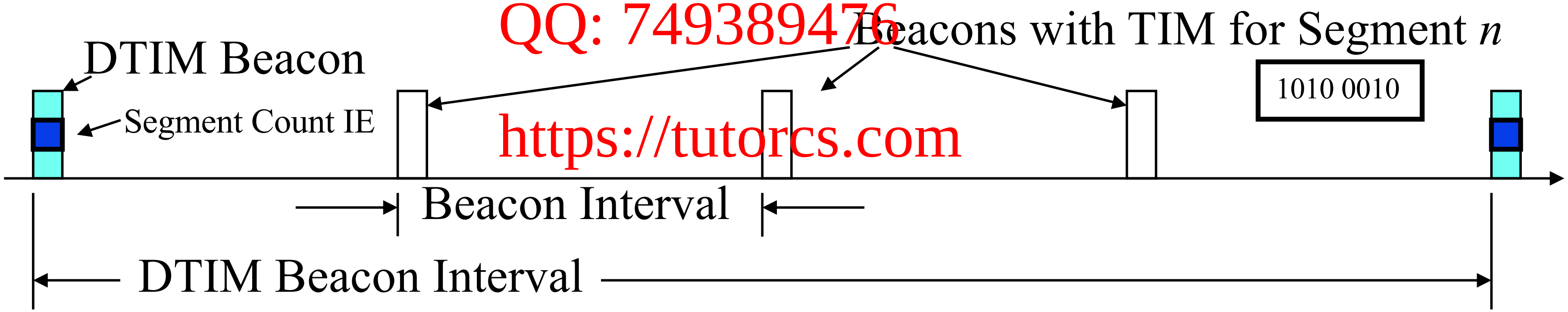

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Channel Access for TIM

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- Each station knows which segments they belong to.
- Stations wake up every "*TIM*" interval and find out which beacon they should listen. The beacon has detailed map indicating which station has pending traffic and when stations can contend for access
- If the map indicates, AP has buffered packets for a station, the station uses DCF (distributed coordination function) to send a PS-poll to get the packet
- If a station has a packet to send, it listens to the map and uses DCF to send RTS in the allocated slot (two or more stations may be allocated to the same slot → collision is possible)
- Small number of stations per slot reduces chances of collisions
- Under low load, it becomes TDMA

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Response Indication Deferral (RID)

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- New virtual carrier se[illegible]ism replacing NAV (Network Allocation Vector)
- Can not use NAV sin[illegible]o duration field
- RID is also a time cou[illegible]echanism similar to NAV
  - NAV is MAC-based, RID is PHY-based
- RID is set after reception of PHY header
  NAV is set after reception of complete MAC frame
- RID is set based on the 2-bit response indication field in the PHY header (2 bits → 4 combinations)
  - Normal Response: RID ← SIFS + Ack or Block Ack time
  - NDP Response: RID ← SIFS + NDP Frame time
  - No Response (Broadcast frames): RID ← 0
  - Long Response: RID ← SIFS + Longest transmission time (Used with Speed Frame Exchange)

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Power Enhancements

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- Page Segmentat
- Restricted Acce ow
- Target Wake Time

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Association Identifier

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- 802.11 b/g/n/ac use 11 [illegible] er ⇒ 2007 stations
  - 2000+ bits require [illegible] c Indication Map (TIM)”
- 802.11ah uses 16-bit i [illegible] 8X stations
  - 8 pages of $\sim 2^{11}$ sta [illegible] Actually 2007 stations.
    Currently only page 0 is allowed. Page 1-7 are reserved.
    First 2 bits should be 11 to distinguish AID from duration and others.

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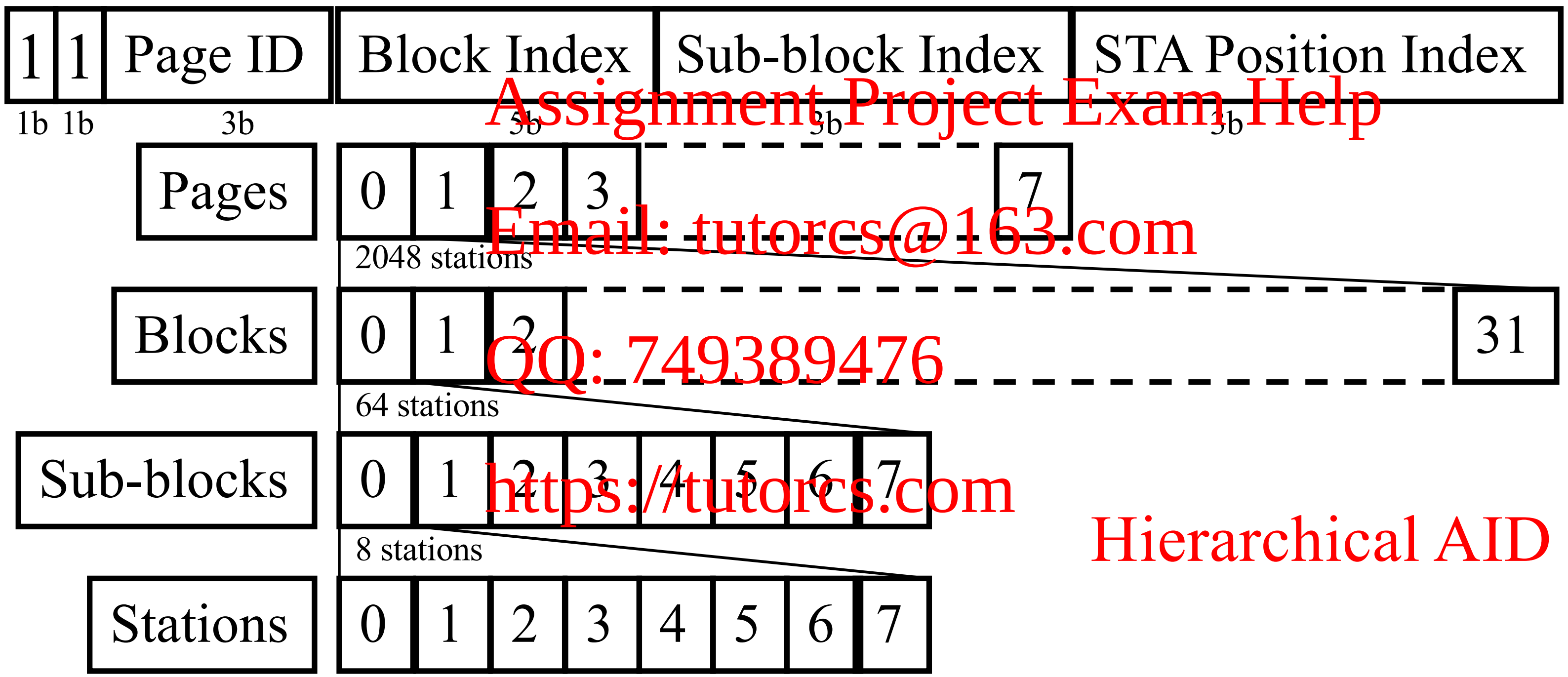

Hierarchical AID

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Restricted Access Window (RAW)

- Allows a set of slot to … d to a group of stations (pages/blocks/subbloc…
  $\Rightarrow$ Reduces contentio…
- A TIM station can be … ots during restricted access window (RAW) to transmit/re… s
- RAW is a part of "Contention Free Period"
- Access may granted for transmission, reception, polling, etc for one or a group of stations
- A RAW schedule is transmitted at the beginning of RAW interval
- A station can tell AP that it has a frame to transmit using a Uplink Data Indication (UDI) bit
  - Helps AP to workout which stations need access in the next round
- Dividing stations into groups and dividing time into slots for each group increases the efficiency under heavy load.
  - At 100% load: RAW gives close to 100%. Regular EDCF gives 0%.

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Other RAWs

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- **Periodic RAW**: P duration of PRAW are announced by AP for *periodic*
- **Sounding RAW**: ector sounding
- **AP Power Management RAW**: used by AP to announce the time when it will be sleeping

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- **Non-TIM RAW**: Protects transmission of non-TIM stations
  - Prevents TIM stations from hogging the channel

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- **Triggering Frame RAW**: Used to allow stations to send PS-poll frames indicating their need to transmit

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Target Wake Time (TWT)

- Non-TIM stations may sleep for a long time → waste for AP to include their buffer information in every beacon
- Non-TIM stations can provide a Target Wake Time (TWT), so the AP does not worry about these stations during their l[illegible]
- Because sleeps can be very [illegible]cult to precisely provide waking tie in ms and sec. -→ three parameters: Target[illegible] Minimum-Wake-Duration, and Wake Interval mantissa.
- AP sends a "Null Data Pac[illegible] a station at its target wake up time containing buffering status. A station can then send a PS-poll and get its frames.
- AP can also sleep if all stations are sleeping

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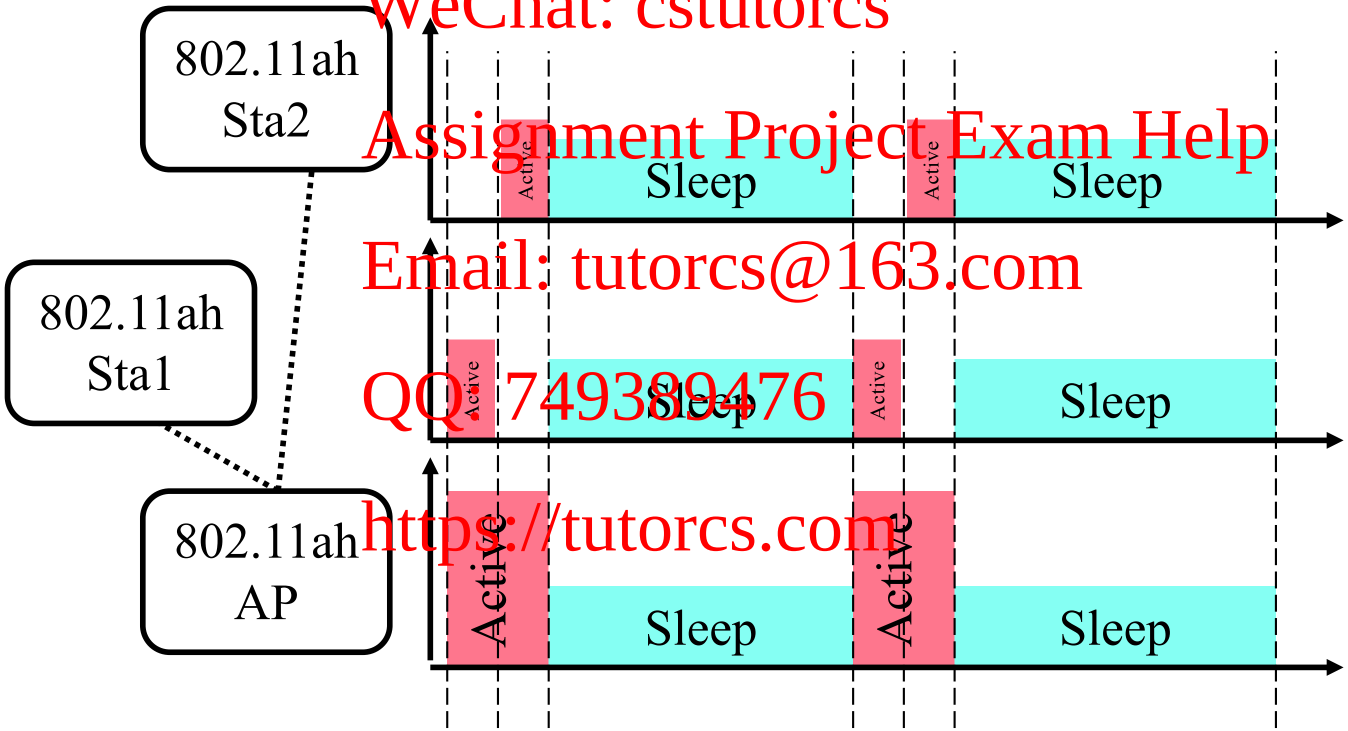

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Sectorization

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- AP can divide the … ectors
  Each station is tol… ector it belongs to.
- Beacon announces … ctors can transmit in this sector interval
- Some sector intervals may be for omni-directional transmissions
  Some may be for only some sectors
- Allows spatial reuse and increase throughput

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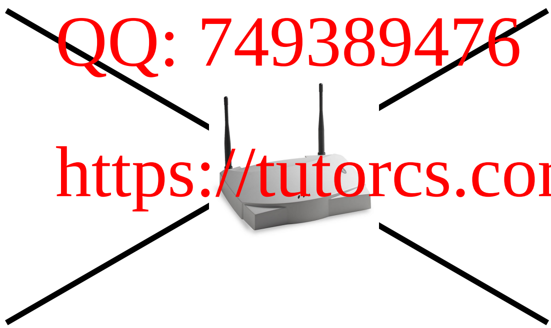

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802.11ah: Summary

1. 802.11ah runs ... MHz band ⇒ Longer distance
2. 802.11ah is 80... down by 10x.
   It uses OFDM with 1/2/4/8/16 MHz channels.
   Longer symbols ⇒ Can handle longer multi-path
3. MAC is more efficient by reducing header, aggregating acks, null data packets, speed frame exchanges → good for short M2M communications
4. Saves energy by allowing stations and AP to sleep longer using Target Wakeup Time, Restricted Access Window

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IEEE 802.11ad-2012 (a.k.a WiGig) 60 GHz WLAN

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Overview

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1. 60 GHz Frequen[illegible]ons and characteristics
2. IEEE 802.11ad
   - PHY data rate
   - Network topology and MAC
   - Beamforming
   - Spatial Frequency Sharing

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60 GHz Frequency Allocations

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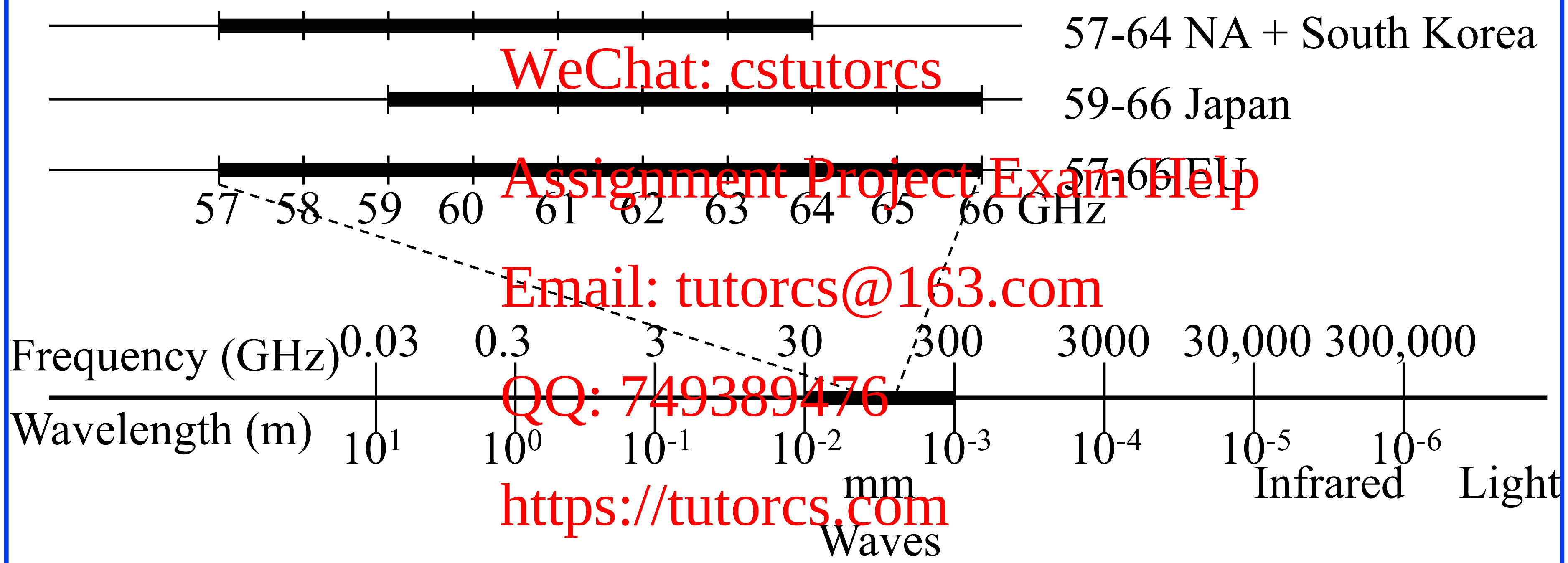
- 7-9 GHz in 57-66 GH … eter waves 30GHz-300GHz)
- 4 Channels of ~ 2 GH
- Significant activity aft … de 57-64 GHz license-exempt



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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

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Advantages of 60 GHz Band

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1. **Large spectrum**: 7 GH
   - 7 Gbps requi b/Hz (BPSK ok).
   - Complex 256 ot needed
2. **Small Antenna Separation**:
   5 mm wavelength/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 transmissions**: Spatial reuse is easy
6. **Inherent security**: Difficult to intercept

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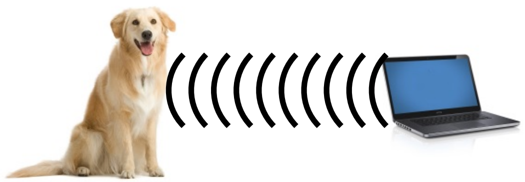
Disadvantages of 60 GHz Band

1. **Large Attenuati**[illegible]**uation / frequency^2**
   - Strong absor[illegible]xygen
   - Need larger t[illegible]ower
   - Need high antenna gain ⇒ directional antennas
   - Short Distance ~ 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



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Multi-Gigabit Wireless Applications

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

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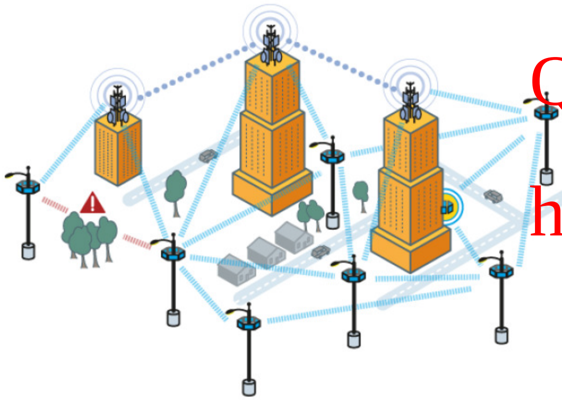

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802.11ad OFDM PHY

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- Total 355 subcarri… r-carrier spacing of 5.15626MHz
  ➔ 1830.47MHz c… ndwidth
- 336 data subcarrie… ots, 3 DC)
- Guard interval = ¼ of the data symbol interval
  - GI = 1/5 of the total symbol interval

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- Symbol interval = ~242ns (=336/1386)

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- Guard interval = ~48.4ns

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- Modulation: QPSK, 16-QAM, 64-QAM

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- Coding rates: ½, ¾, 5/8, 13/16
- Only single stream allowed

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802.11ad OFDM Data Rates (Mbps)

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MCS.	Modulation	Coding	Data Rate
13	SQPSK	1/2	693.00
14	SQPSK	5/8	866.25
15	QPSK	1/2	1386.00
16	QPSK	5/8	1732.50
17	QPSK	3/4	2079.00
18	16-QAM	1/2	2772.00
19	16-QAM	5/8	3465.00
20	16-QAM	3/4	4158.00
21	16-QAM	13/16	4504.50
22	64-QAM	5/8	5197.50
23	64-QAM	3/4	6237.00
24	64-QAM	13/16	6756.75

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802.11ad Data Rate Example

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Question: What is the 8[illegible]DM data rate for 64-QAM with 5/8 coding rate?

Solution:

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802.11ad symbol rate = 1386/336 Msym/s
# of data subcarriers = 336
Data rate = modulation-rate x symbol-rate x #data-carriers x coding-rate
Data rate = $\log_2(64)$ x (1386/336) x 336 x (5/8) = 5197.5Mbps

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MAC Challenges for 60 GHz

- High path loss at 60 G[illegible]
  - 28 dB higher than 2[illegible]N, 22 dB higher than 5 GHz WLAN
- Stations must have hi[illegible]gain to overcome high path loss → directional antenna/be[illegible]g
  - The narrower the beam, the higher the antenna gains
- Directional communication complicates MAC design
  - AP can talk to a STA only if their beams point to each other
  - Similarly, two STAs must point their beams to each other before they can exchange data
- MAC must always facilitate all stations to find the right beam directions
  - Different beam directions for different destinations
  - Beam directions change with mobility
  - Becomes challenging with many stations in a network

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IEEE 802.11ad Network Topology

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- **Personal Basic Service Set (PBSS):**
  Group of stations that … te
- **PBSS Central Point (** … ides scheduling and timing using beacons
  - Dedicated AP not ne… unction can be assumed by any 802.11ad device, such as a TV in the room can be PCP/AP
- **1 PCP/AP per PBSS, 1-254 non-PCP stations (STA)**

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802.11ad MAC – Beacon Interval

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- Each super-frame called "Beacon **Interval**" is divided into 4 *access periods*: Beacon Time (**BT**), Associating Beamforming Training (**A-BFT**), Announcement Time (**AT**), and Data Transfer Time (**DTT**)

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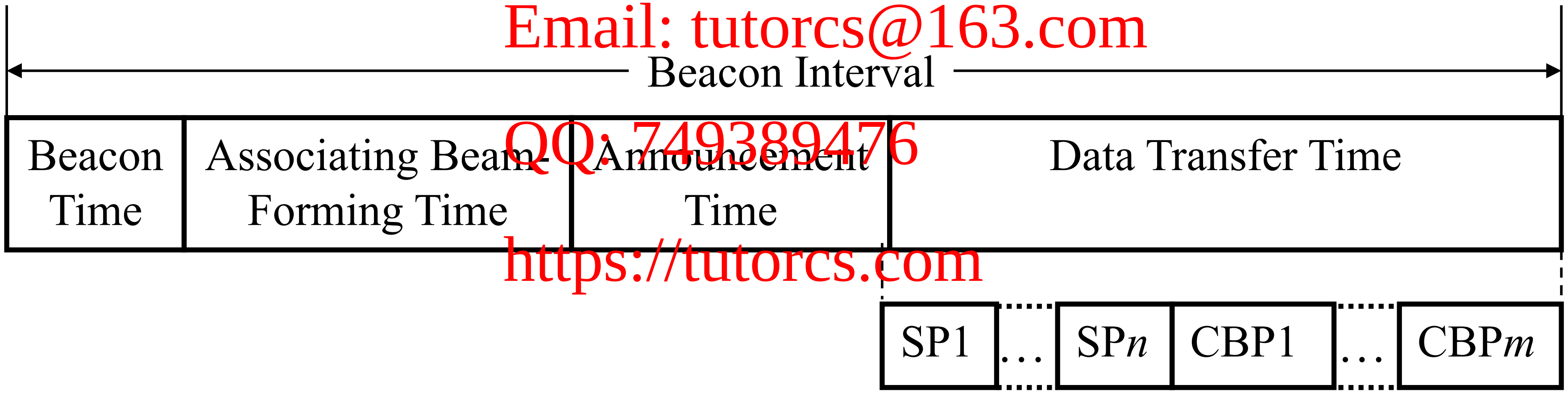

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Access Periods in 802.11ad Beacon Interval

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- BT: Only PCP can se[illegible] during beacon time; PCP starts beamforming training [illegible] ending training frames; STAs cannot transmit
- A-BFT: PCP performs antenna training with its members (STAs)
- AT: PCP polls members and receives non-data responses (STAs can request *service periods or SPs* to be scheduled during DTT)
- DTT: STA-to-STA exchange happens. All stations exchange data frames in a dedicated **service period (SP)** or by **contention in contention-based period (CBP)**
  - CBP uses Distributed Coordination Function (DCF); SP uses Hybrid Coordination Function (HCF)

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IEEE 802.11ad Beacon

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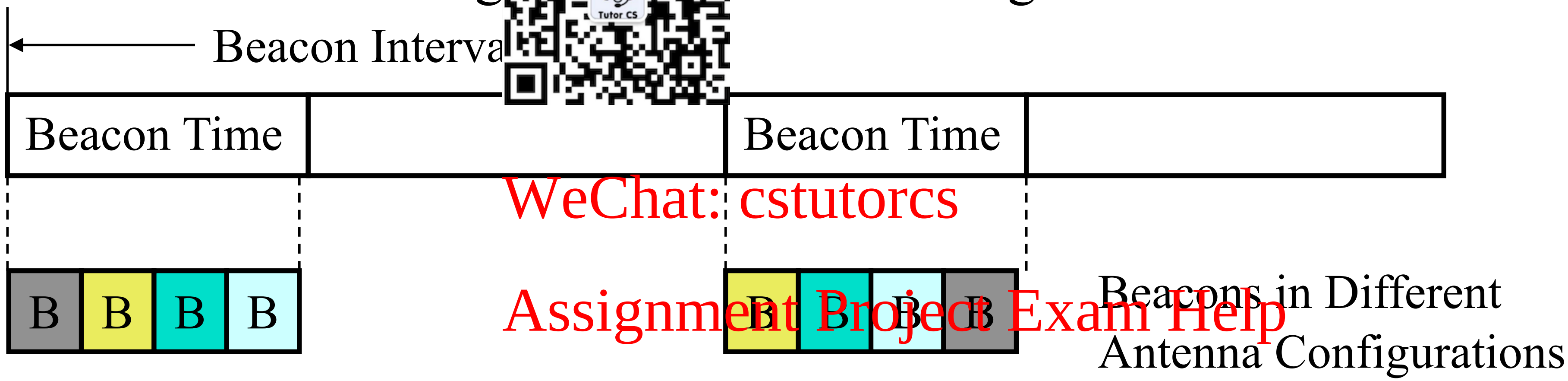
- Beacon transmissi[illegible]nni-directional ⇒ One beacon is transmitted throug[illegible]ntenna configuration/sectors



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Example 1

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- A 802.11ad PC[illegible] a four-sector antenna with every sector co[illegible] degrees. During a Beacon Time (BT), how [illegible]eacons the AP should transmit?

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Beacons must be transmitted in omni-direction, so all STAs receive it. 360-degree coverage is achieved by four sectors (each sector covers 90 degrees). The AP therefore will send four beacons, one per sector.

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Beamforming Options

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- The goal of beamf[illegible] to choose the best beam direction pair that gives the [illegible]ain
- **Exhaustive searc[illegible]**[illegible]tively examine all beam pairs
  - E.g., 64 pairs for 8x8, 1024 pairs for 32x32 → O(B1xB2)
  - Time and energy consuming

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- **Semi-exhaustive search**

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  - Transmitter transmits on all beam directions (B1 transmissions)
  - Receiver uses omni-directional antenna to record RSS for all beam directions of the transmitter

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  - Receiver selects the highest RSS as the best beam for the transmitter

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  - The pair takes turn to find each others best beam direction (B2 transmissions) → O(B1+B2)

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Exhaustive vs. Semi-exhaustive Sector Search

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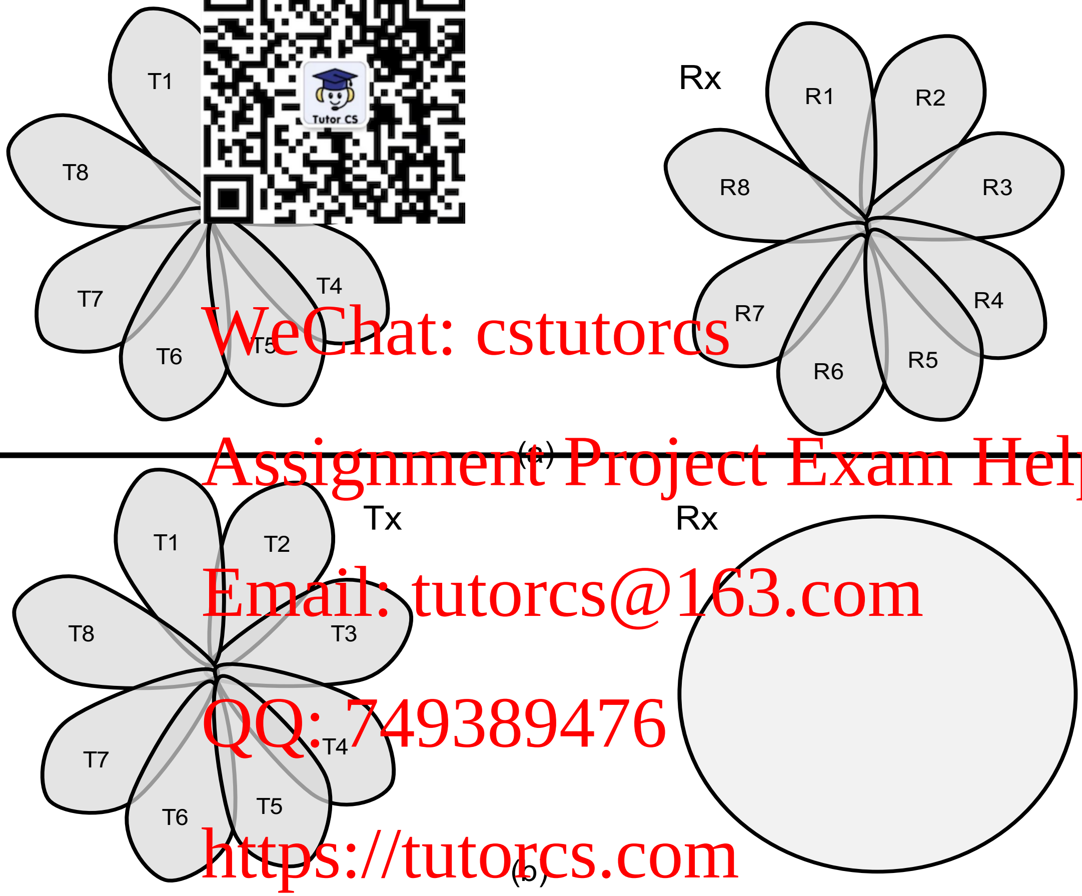
Exhaustive

Semi-exhaustive



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Example 2

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- Two 802.11ad device[illegible] STA2, want to beamform. STA1 has 32 different antenna conf[illegible]i.e., capable of steering the beam to 32 different directions). S[illegible]ly 4 beam directions. For Exhaustive Search, how many tra[illegible]s are transmitted in total by these two devices before they discover the optimum beam pairs for communication?

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Total combinations of antenna configurations between the two stations is 32x4 = 128. Therefore, 128 training frames are transmitted, one per specific pair of antenna configurations, before the best combination (pair) is finally selected.

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Example 3

程序代写代做 CS编程辅导

- Two 802.11ad device[illegible] STA2, want to beamform. STA1 has 16 different antenna conf[illegible].e., capable of steering the beam to 16 different directions). S[illegible]ly 4 beam directions. For Omni-direction Antenna approach, ho[illegible]ning frames are transmitted in total by these two devices before they discover the optimum beam pairs for communication?

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STA1 first transmits 16 training frames while STA2 is listening in omni-direction. Then STA2 transmits 4 frames while STA2 is listening. Total frames transmitted = 16+4 = 20.

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IEEE 802.11ad Beamforming Training

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- Each station finds the optimal antenna configuration with its recipient using a two-stage search --- SLS followed by BRP
- **Sector Level Sweep (SL…** … all sectors and finds the optimal *sector pair*
  - Sector → coarse dir… can be several sharper beams within a sector)
  - Low data rate with s… eamforming
- **Beam Refinement Prot…** Searches through the optimal sector to find the optimal parameters in th… ntify a narrower beam)
  - Higher data rate (multi-gigabit) with beam refinement

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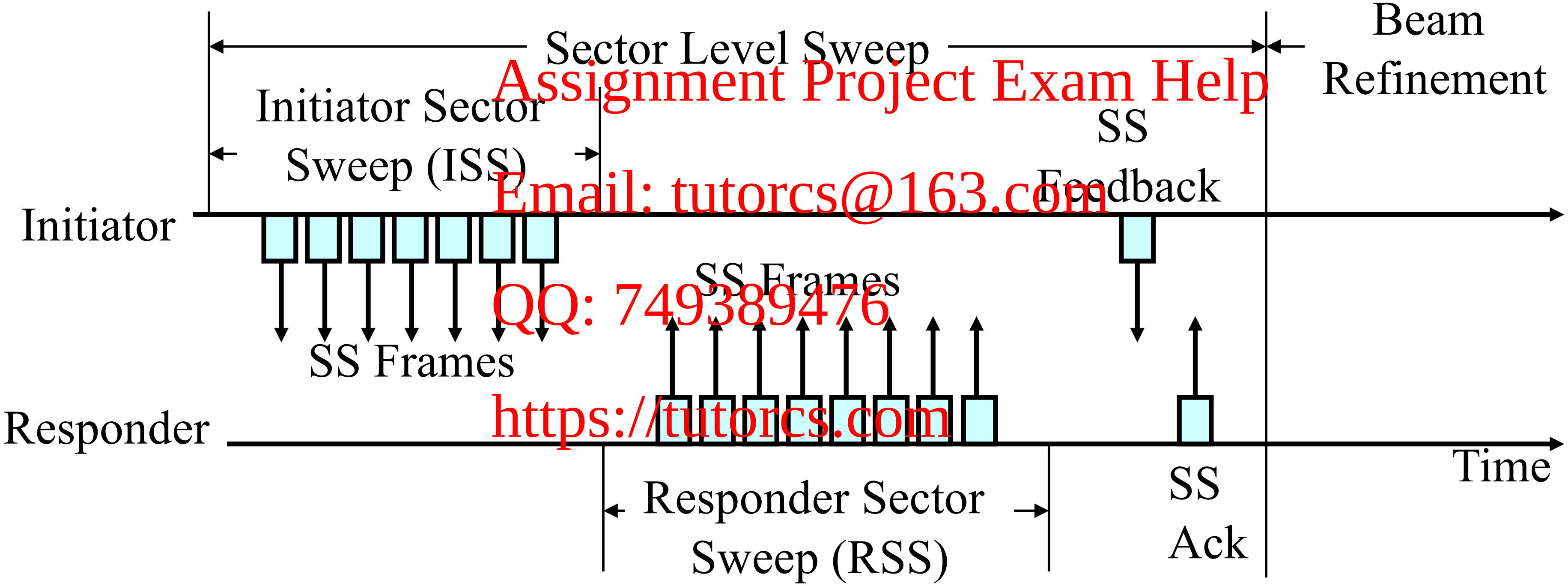

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AP-STA Beamforming

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- Takes place during BT and A-BFT durations
- During BT, AP transmits training frames on all its sectors; all STAs listen in omni-direction mode
- A-BFT duration is slotted; each STA selects a slot randomly and transmits training frames on all its sectors; AP listens in omni-direction mode
- Random slot selection may lead to collision. No feedback from AP to the STA if collision; STA tries in next beacon interval
- Only SLS is completed in BT and A-BFT; BFP is optional and may take place in DT duration

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Example 4

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- The table shows the rece[illegible]trength (RSS) at the responder f[illegible]mitted training frame from the [illegible]g initiator during SLS. Th[illegible]ectors for both initiator and responder, and the number after the station letter denotes the sector number. For example, row 1 shows the frame transmitted by station A on its sector 1. What is the optimum beam (sector) pair discovered after the SLS?

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Transmitted Training Frame	RSS at Responder
A.1	-70 dBm
A.2	-62 dBm
A.3	-50 dBm
A.4	-64 dBm
B.1	-49 dBm
B.2	-71 dBm
B.3	-75 dBm
B.4	-80 dBm

The sector that produces the strongest signal is selected as the best sector. For A, the strongest sector is 3 (-50 dBm). For B, sector 1 produces the strongest signal at A (-49 dBm). The optimum beam pair for (A,B) therefore is (3,1).

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SLS vs. Beam Refinement

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- SLS uses “coarse” (w
  - Quick, but low ga e low data rate
- Beam refinement find beams within the same sector
  - Increases gain and data rate, but takes additional time before communication can begin

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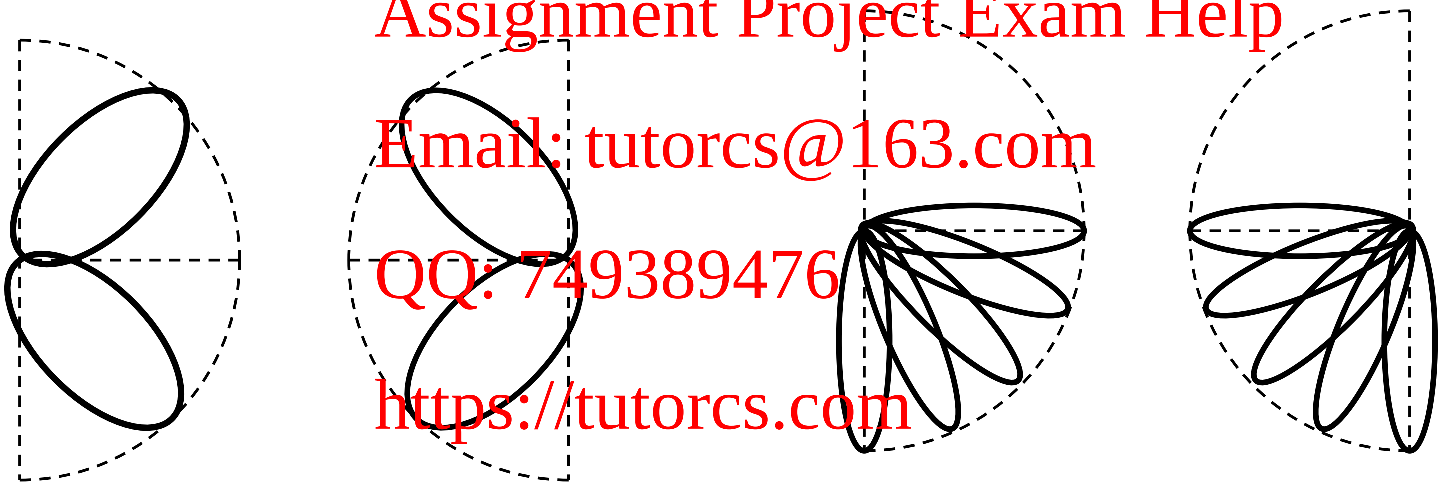

Sector-Level Sweep Beam Refinement

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Spatial Frequency Sharing (SFS)

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- Multiple transmiss[illegible] be scheduled on the same frequency at the sa[illegible]f they don't interfere
- PCP asks stations [illegible]sults of any STA-STA beamforming training outcomes. PCP then has the complete knowledge of beam pairing among the stations within its PBSS. PCP then can work out which station pairs can share the same slot (will not interfere).

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Example 6

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- In a given PBSS, all stations have 12 antenna sectors with 30 degree transmission a[illegible]le shows the beam pairs learned from beam [illegible]ng 6 stations, A to F. For example, the first [illegible]ble shows that A would use its beam #1 to [illegible]e with B while B would use its beam #7 to communicate with A. If a communication, SP1, between A and B has already been scheduled, can SP2, a new communication between E and F, be spatially shared with SP1, i.e., be allocated during the same time slots without interference?

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No. During SP1, B will transmit on its beam #7, which is the same beam number found to be optimum to communicate with E (Row 3 in the table). Therefore B's transmissions to A during SP1 will affect E. SP2 therefore cannot be spatially shared with SP1 without interference.

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STA Pair	Beam Pair
(A,B)	(1,7)
(A,E)	(4,12)
(B,E)	(7,2)
(B,F)	(9,10)
(C,D)	(10,4)
(A,F)	(2,7)
(E,F)	(3,7)

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Summary of 802.11ad

程序代写代做 CS编程辅导

1. 60 GHz, a.k.a. mm wa[illegible] bandwidth, small antenna separation allows easy beamforming an[illegible]ds but short distance due to large attenuation
2. Tri-band Wireless LA[illegible]th 2.4 GHz, 5.8GHz, and 60GHz are coming
3. 802.11ad LAN uses a [illegible] control point (PCP)
4. In all cases antenna alignment and tracking is required.
5. **Centralized** scheduling. Only **PCP** can send beacons. It sends beacons in all sectors.
6. Superframe (**Beacon Interval**) consists of Beacon Time, Associating Beamforming Training, Announcement Time, and Data Transfer Time
7. Announcement time is used for collecting requests from STAs
8. Data transfer can be pre-allocated or by contention
9. **Antenna training** is a 2-phase process. Sector selection and beam refinement.
10. Multiple transmission can take place on the same frequency at the same time (**Spatial Frequency Sharing**).

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程序代写代做 CS编程辅导

IEEE 802.11ay-2020 (expected) Faster 60 GHz WLAN

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802.11ay

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- 60GHz like 802.11ad, ... han 802.11ad
  - 802.11ad is single ... cannot bond channels (channel = 2.16GHz)
  - Single channel, si... max speed: ~7Gbps
- 802.11ay expects to support 4 streams and bond multiple channels
  - 4 channels = 8.64GHz bandwidth
  - Max speed (4 channel, 4 stream) 170+ Gbps
- 802.11ay also offers longer range: up to 500m
- Expected in 2020

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802.11ay projected use cases

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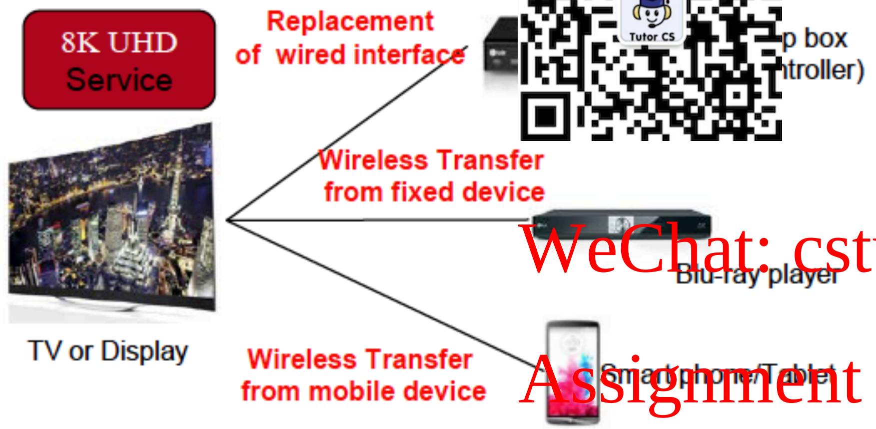
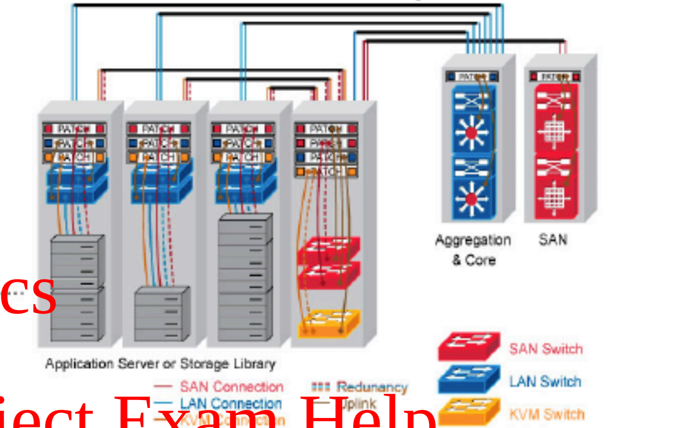
Wireless Video

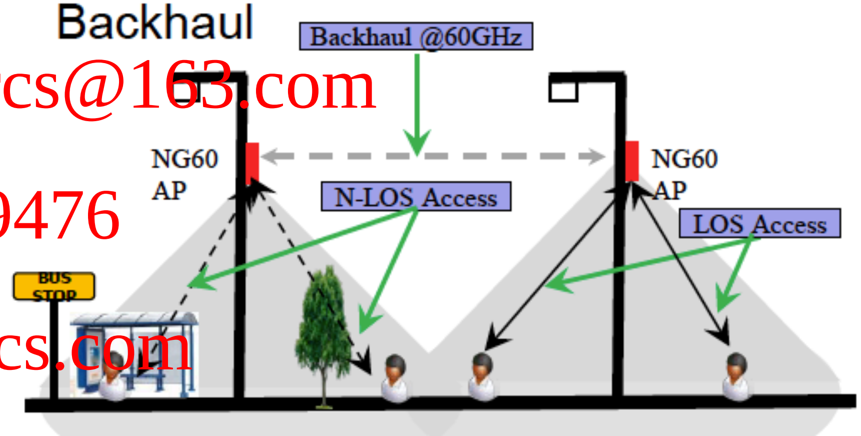


Data Center backup connection



VR/AR

Backhaul



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Source: KEYSIGHT Technologies

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Summary: Niche WiFi

程序代写代做CS编程辅导

- Mainstream WiFi ope[illegible]5GHz band: hugely popular and used in many consumer produ[illegible]phone, tablets, laptops, …
  - IEEE 802.11a/b/g[illegible]n=WiFi4, 11ac=WiFi5, 11ax=WiFi6)
- Niche WiFi: both sub-GHz and 60GHz
- Sub-GHz: 802.11af (700 MHz TV Whitespace: long-distance) and 802.11ah (900 MHz: IoT, sensors networks, home automation, large number of connections)
- 60GHz: 802.11ad (7Gbps; already penetrated some niche products) and 802.11ay (upcoming; 100+Gbps cable replacement, backhaul, …)

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