Wireless LAN I

IEEE 802.11 Basics

Overview

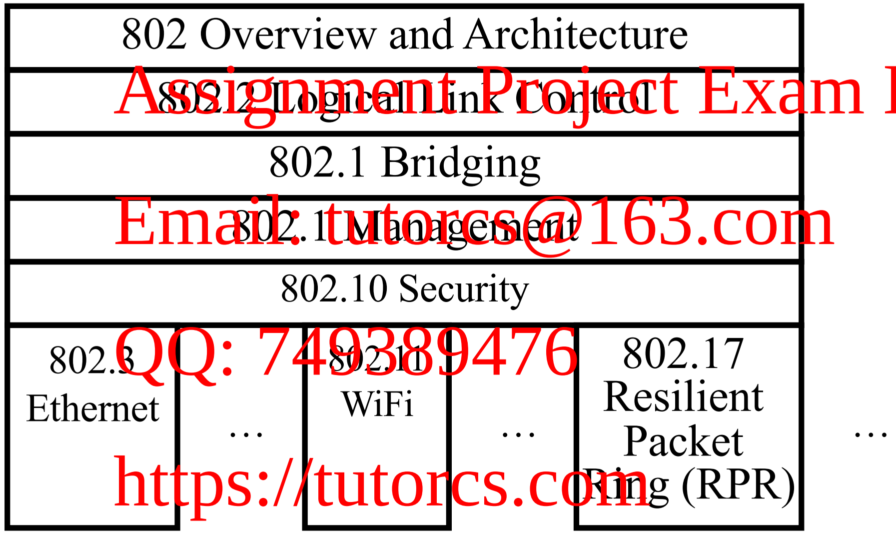
1. IEEE 802.11 vs. [illegible]
2. IEEE Standards [illegible]ng System
3. Key features of 802.11
4. 802.11 Bands and Channels
5. Hidden Node Problem and 4-Way Handshake RTS/CTS)
6. 802.11 MAC (inter-frame space, PCF, DCF)
7. 802.11 Architecture and Addressing
8. 802.11 Frame Format
9. 802.11 Power Management

IEEE 802.11 vs. WiFi

- IEEE 802.11 is a standard
- WiFi = "Wireless Fidelity" is a trademark
- Fidelity = **Compatibility** between wireless equipment from different manufacturers
- WiFi Alliance is a non-profit organization that does the compatibility testing (WiFi.org)
- 802.11 has many options and it is possible for two equipment based on 802.11 to be *incompatible*.
- All equipment with "WiFi" logo have selected options such that they will **interoperate**.

IEEE Standards Numbering System

- IEEE 802.* and IE[illegible] 1* standards (e.g., IEEE 802.1Q-201[illegible] o all IEEE 802 technologies:
  - IEEE 802.3 Et[illegible]
  - IEEE 802.11 W[illegible]
  - IEEE 802.16 WiMAX



Lettered vs. Numerical Versions

- IEEE 802.11 us[illegible]s to name the versions
  - E.g., 802.11a/b (1999), 802.11g (2003), 802.11n (2009), 802.11ac (2013), and so on

- WiFi Alliance proposes numbers to simplify
  - E.g., WiFi 4 (802.11n), WiFi 5 (802.11ac), WiFi 6 (802.11ax) …

IEEE 802.11 Features

- Data rate (a.k.a. *sp*[illegible]
  - Original IEEE 802[illegible]as at 1 and 2 Mbps.
  - Newer versions at [illegible]4 Mbps, 108 Mbps, 1.2 Gbps, …
- Spectrum licensing
  - All versions use *license-exempt* spectrum
- PHYs:
  - Spread spectrum (in old versions)
  - OFDM (in new versions)
- Supports multiple priorities (time-critical and data traffic)
- Power management allows a node to `doze off'
  - Longer battery life

IEEE 802.11 Physical Layers

- Issued in several s[illegible]
- First version in 19[illegible]y IEEE 802.11 (no longer used)
  - 3 physical laye[illegible]ations (2 in 2.4-GHz, 1 in infrared)
  - All operating at 1 and 2 Mbps
- Amendments in 1999:
  - IEEE 802.11a-1999: 5-GHz band, 54 Mbps/20 MHz, **OFDM**
  - IEEE 802.11b-1999: 2.4 GHz band, 11 Mbps/22 MHz (spread spectrum)
- Amendment in 2003:
  - IEEE 802.11g-2003: 2.4 GHz band, 54 Mbps/20 MHz, **OFDM**

ISM Bands

- **I**ndustrial, **S**cienti[illegible]edical bands. **License exempt**

From	[illegible]	**[illegible]width**	**Availability**
6.765 MHz	6.795 [illegible]	[illegible] kHz	
13.553 MHz	13.567 MHz	14 kHz	Worldwide
26.957 MHz	27.283 MHz	326 kHz	Worldwide
40.660 MHz	40.700 MHz	40 kHz	Worldwide
433.050 MHz	434.790 MHz	1.74 MHz	Europe, Africa, Middle east, Former Soviet Union
902.000 MHz	928.000 MHz	26 MHz	America, Greenland
2.400 GHz	**2.500 GHz**	**100 MHz**	**Worldwide**
5.725 GHz	**5.875 GHz**	**150 MHz**	**Worldwide**
24.000 GHz	24.250 GHz	250 MHz	Worldwide
61.000 GHz	61.500 GHz	500 MHz	
122.000 GHz	123.000 GHz	1 GHz	
244 GHz	246 GHz	2 GHz	

Ref: http://en.wikipedia.org/wiki/ISM_band

WLAN/WiFi Bands

WLAN/WiFi Standard	Frequency Band
802.11b/g/n	2.4 GHz
802.11a/n/ac/ax	5 GHz
802.11be	6 GHz (not confirmed yet)
802.11p (car-to-car)	5.9 GHz (licensed band)
802.11ah (IoT)	900 MHz
802.11af (Rural)	700 MHz (unused TV channels)
802.11ad/ay (Multi Gbps wireless applications: e.g., cable replacement, VR, …)	60 GHz

WiFi Channels

- The entire *band* is nto several individual *channels*
- An AP operates ov e **channel** at any given time
- Different nearby A erate over different channels of the same band
  - Avoid congestion and interference
- Each channel is usually 20 or 22 MHz wide
- With newer WiFi versions, it is possible to combine two or more channels to get a wider channel
  - More bandwidth for higher data rates

2.4 GHz WiFi Channel Frequencies

- A total of 14 channels (not all channels available in all countries)
- Centre frequencies are 5 MHz apart (except channel 14)
- Each channel is 22 MHz

CHANNEL NUMBER	L[illegible]	CENTER FREQUENCY MHZ	UPPER FREQUENCY MHZ
1	[illegible]	2412	2423
2	2406	2417	2428
3	2411	2422	2433
4	2416	2427	2438
5	2421	2432	2443
6	2426	2437	2448
7	2431	2442	2453
8	2436	2447	2458
9	2441	2452	2463
10	2446	2457	2468
11	2451	2462	2473
12	2456	2467	2478
13	2461	2472	2483
14	2473	2484	2495

From http://www.radio-electronics.com/info/wireless/wi-fi/80211-channels-number-frequencies-bandwidth.php

2.4 GHz Channel Overlaps

- Most channels in 2.4 GH[illegible]ap
- Maximum of three non-[illegible]hannels are possible
- 1-6-11 are most widely [illegible]rlapping channels (6 is usually default)
  - E.g., if three are thr[illegible]s in an enterprise, they are usually set to 1-6-11

From http://boundless.aerohive.com/experts/WLAN-Channels-Explained.html

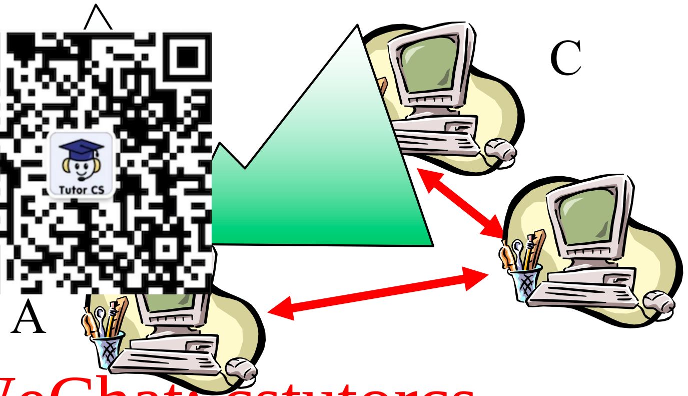
Channels in 5 GHz Band

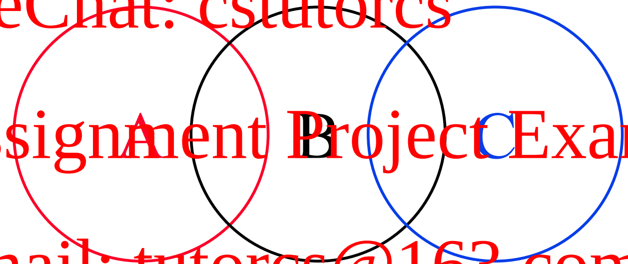
- 20 MHz channels [illegible]Hz in 2.4 GHz band)
- Non-overlapping (c.f., mostly overlapping in 2.4 GHz)
- Two types of channels
  - Always available
  - Channels used by **radar** (requires DFS)
- Dynamic Frequency Selection (DFS): WiFi AP monitors radar channels and vacate them (switch to another channel) if radar is detected
  - May cause connection drop for clients

5GHz Channel Structure

Source: https://www.ekahau.com/blog/channel-planning-best-practices-for-better-wi-fi/ (accessed 15 June 2020): this structure is probably for the US; radar channels may vary with countries

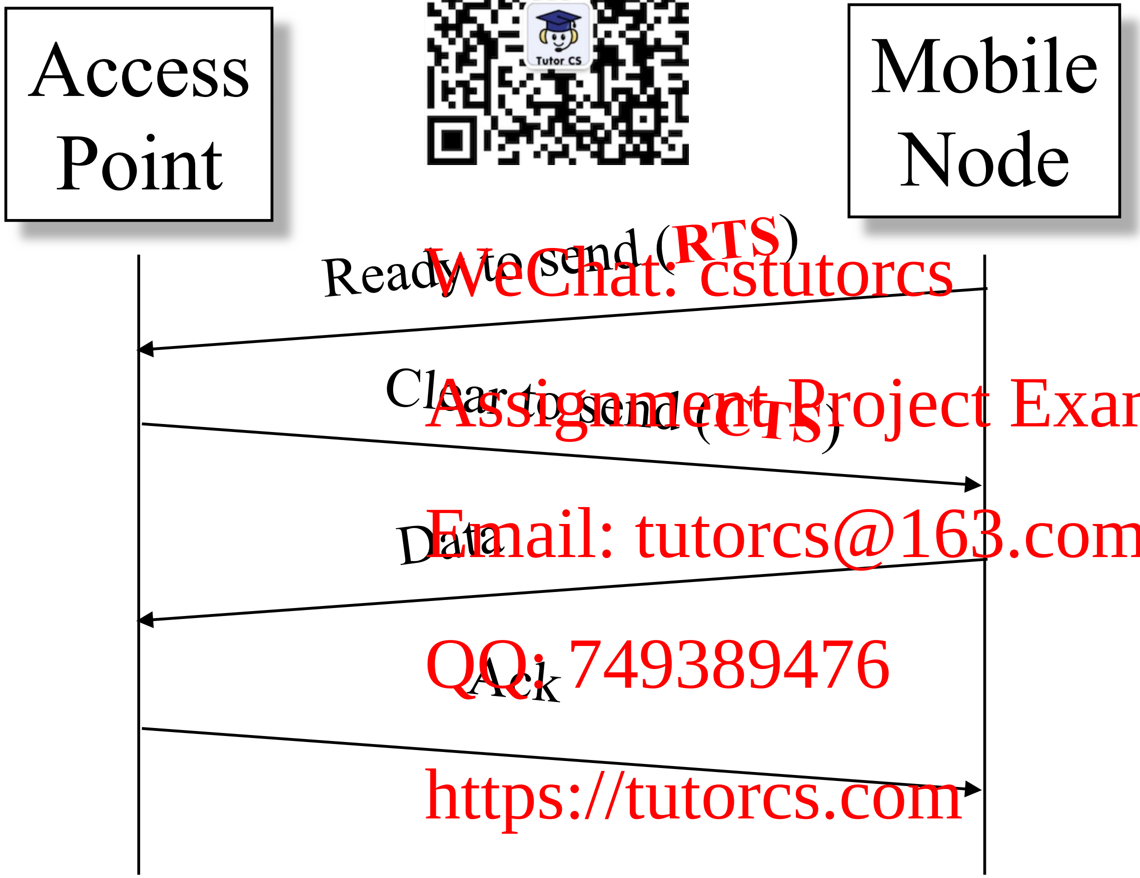
Hidden Node Problem





- A can hear B, B can hear C, but C cannot hear A (C and A are *hidden* from each other)
- C may start transmitting while A is also transmitting → collision at B!
  - A and C (wireless transmitters) can't detect collision (why?).
- CSMA/CD is not possible (CD = collision detection; CD used in Ethernet) → in WLAN, only the receiver can help *avoid* collisions
- 4-way handshake needed to implement CA (*collision avoidance*) in WLAN

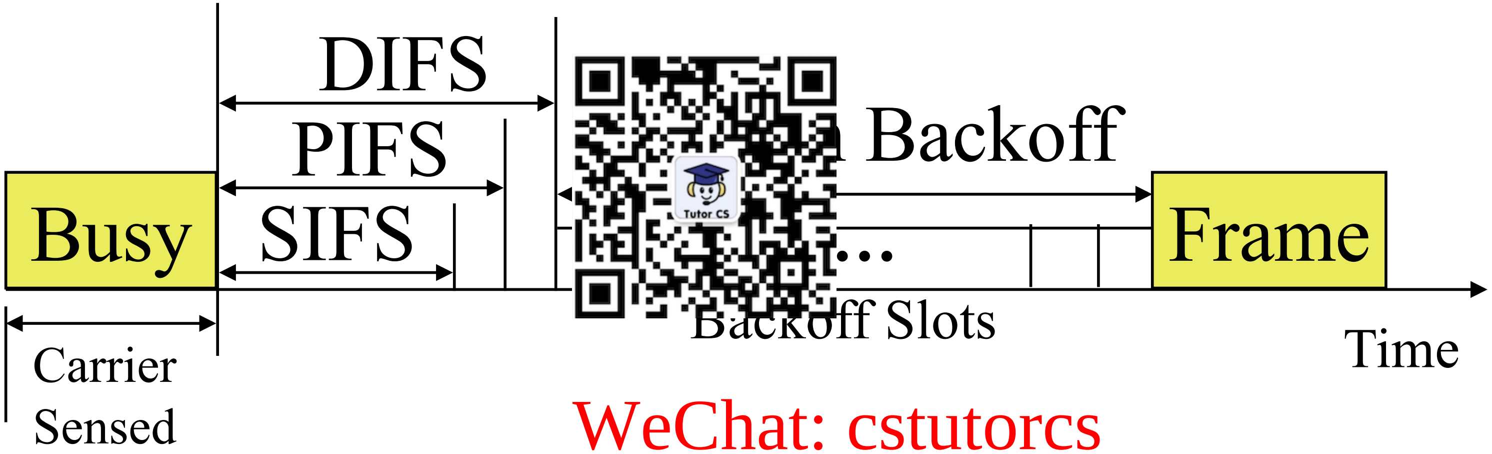
4-Way Handshake



IEEE 802.11 MAC

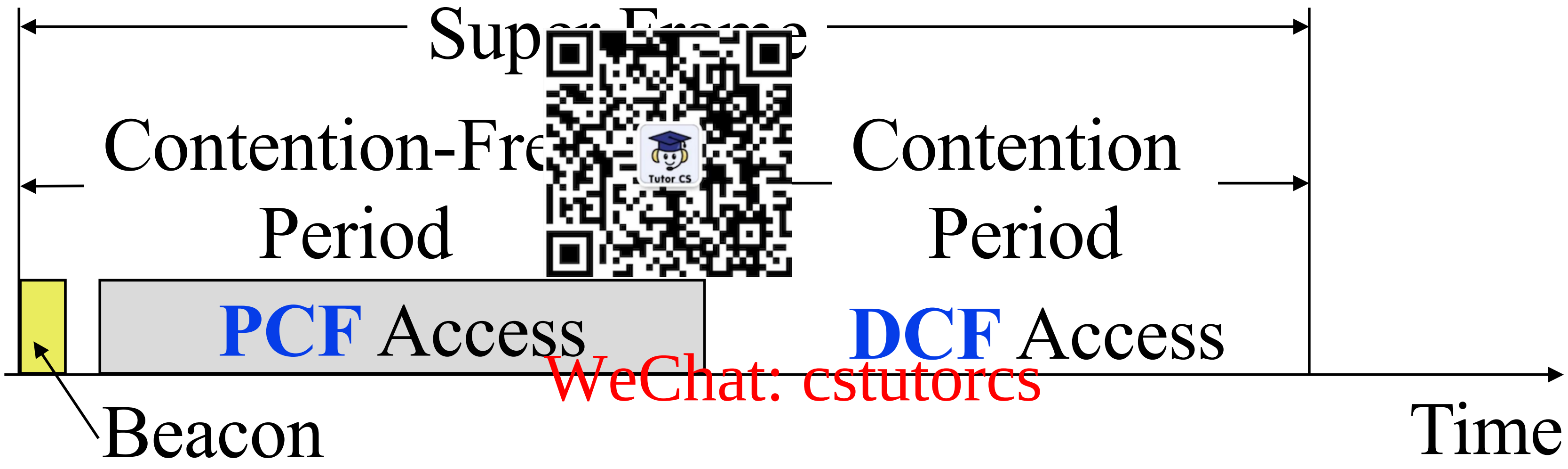
- Carrier Sense Multiple Access with Collision Avoidance (**CSMA/CA**)
- Listen before you talk. If the medium is busy, the transmitter backs off for a random period.
- Avoids collision by sending a short message: Ready to send (**RTS**)
  RTS contains dest. address and duration of message.
  Tells everyone to backoff for the duration.
- Destination sends: Clear to send (**CTS**)
  Other stations set their network allocation vector (**NAV**) and wait for that duration
- Cannot detect collision, hence each packet is acked.
- MAC-level retransmission if not acked.

IEEE 802.11 Priorities with Inter-frame space



- 802.11 has different priorities for **control**, **data**, and **time-critical** packets
- Achieve priorities by using different amounts of interframe space (IFS)
- Highest priority frames, e.g., Acks, use short IFS (**SIFS**)
- Medium priority time-critical frames use "Point Coordination Function IFS" (**PIFS**)
- Asynchronous data frames use "Distributed coordination function IFS" (**DIFS**)

Time Critical Services



- Timer critical services use **Point Coordination Function**
- The point coordinator allows only one station to access
- Coordinator sends a beacon frame to all stations. Then uses a polling frame to allow a particular station to have contention-free access
- Contention Free Period (CFP) varies with the load.

IEEE 802.11 DCF Backoff

- MAC works with a si[illegible]Queue
  - Focuses on transm[illegible]acket at the head of the queue
- Three variables:
  - Contention Window (CW)
  - Backoff count (BO)
  - Network Allocation Vector (NAV)
- If a frame (RTS, CTS, Data, Ack) is heard, NAV is set to the duration in that frame. Stations sense the media after NAV expires.
- If the medium is idle for DIFS, and backoff (BO) is not already active, the station draws a random BO in [0, CW] and sets the backoff timer.
  - CW is in units of *slot time* (slot time varies with 802.11 standards)
- If the medium becomes busy during backoff, the timer is paused and a new NAV is set. After NAV, back off continues.

IEEE 802.11 DCF Backoff (Cont)

- BO = *random*(0
- Initially and after each *successful* transmission:

$$CW = CW_{min}$$

- After each *unsuccessful* attempt

$$CW = \min\{2CW + 1, CW_{max}\}$$

Example

- Assume that we ha[illegible]in=3 and CWmax=127 configured for a given WLAN[illegible]ould be the values of CW if there were 8 successive [illegible]sful attempts after initalizing the network?

After initialization, CW = CWmin = 3

After 1st unsuccessful attempt, CW = min(7,127) = 7

After 2nd unsuccessful attempt, CW = min(15,127) = 15

Then on, 31, 63, 127, 127, 127, …

Parameter Values: interframe space and contention window

WLAN	Slot-time (µs)	SIFS (µs)	CWmin	CWmax
11a	9	16	15	1023
11b	20	10	31	1023
11g	9 or 20	10	15 or 31	1023
11n (2.4 GHz)	9 or 20	10	15	1023
11n (5 GHz)	9	16	15	1023
11ac	9	16	15	1023

- PIFS = SIFS + 1 slot time
- DIFS = SIFS + 2 slot times = PIFS + 1 slot time

Slot time: basic unit of backoff algorithm

Example

- What is the dur PIFS and DIFS for IEEE 802.11b?

Slot time = 20 μs

SIFS = 10 μs

PIFS = SIFS + slot time = 10+20 = 30 μs

DIFS = SIFS + 2 x slot time = 10 + 40 = 50 μs

Virtual Carrier Sense

- Every frame has a h ID” which indicates how long the medium will be bu
  - RTS has duration IF + CTS + SIF + Frame + SIF + Ack
  - CTS has duration of CTS + SIF + Frame + SIF + Ack
  - Frame has a duration of Frame + SIF + ACK
  - ACK has a duration of ACK
  - A station has to estimate the durations of RTS/CTS/ACK
- All stations keep a “**Network Allocation Vector (NAV)**” timer in which they record the duration of each frame they hear.
- Stations do not need to sense the channel until NAV becomes zero (conserve power)

Example

- Consider an 802.1[illegible]N. A station estimates the transmission times [illegible] CTS, and ACK as 10 μs, 10 μs, and 25 μs, respectively [illegible] ould be the value of the Duration field in the RTS header if the station wants to send a 250 μs long data frame ?

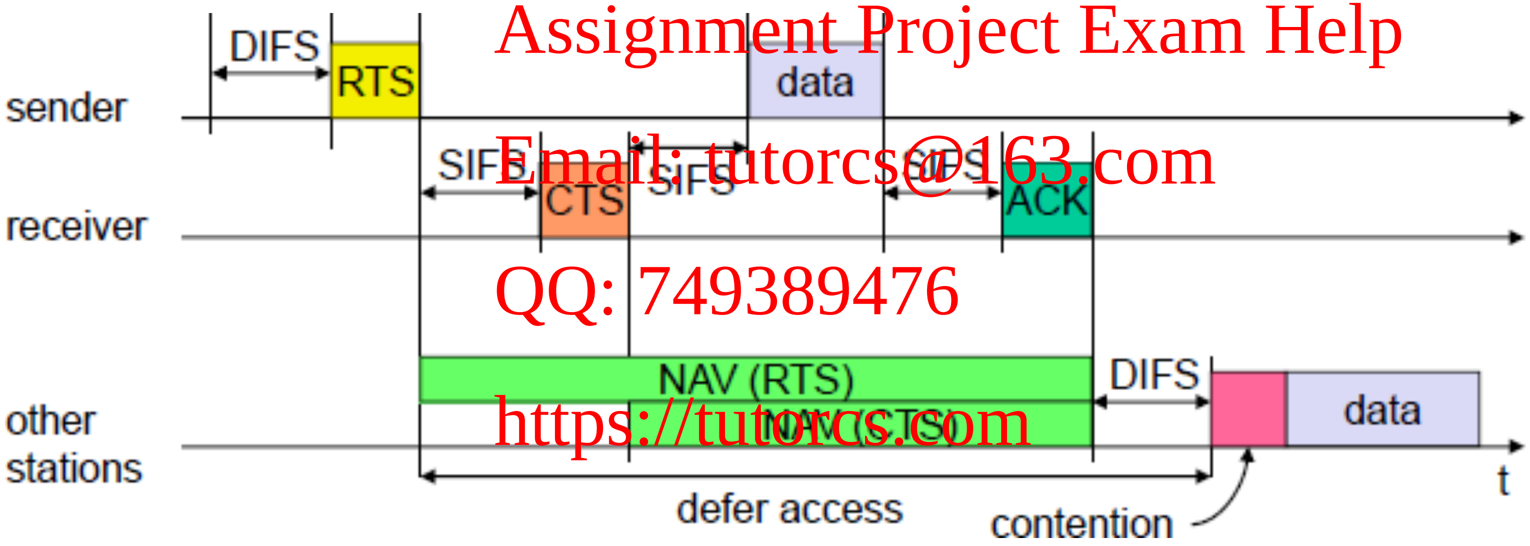
802.11b has a SIFS duration of 10 μs.

Duration field in RTS = RTS_time + CTS_time + ACK_time + data_time + 3xSIFS

= 10+10+25+250+3x10 = 325 μs

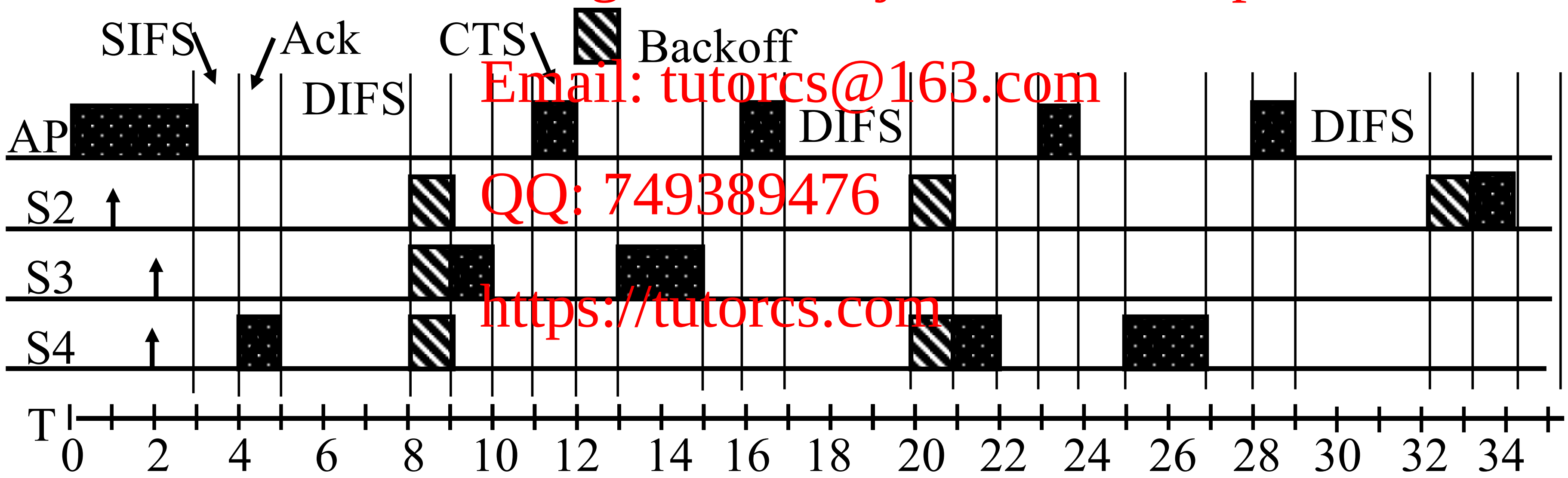
802.11 with RTS/CTS

When a node is sensing … l, it must be free for DIFS period. SIFS is used as the wai … een the RTS, CTS, DATA and ACK frames. SIFS < DIFS r … nother node cannot incorrectly determine that the channel is idle during the 4-way handshake between two other nodes.



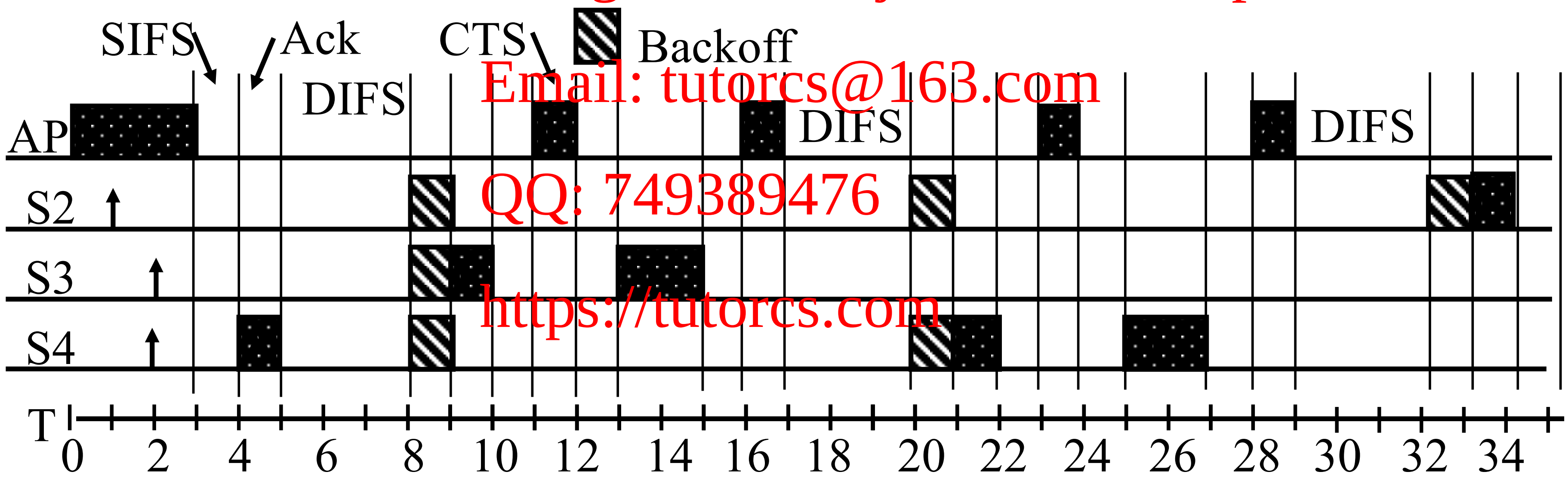
DCF Example

- Example: Slot Time = 1, CWmin = 5, DIFS=3, PIFS=2, SIFS=1
- T=1 Station 2 wants t[illegible]ut the media is busy
- T=2 Stations 3 and 4 [illegible]smit but the media is busy
- T=3 Station 1 finishes[illegible]on.
- T=4 Station 1 receive[illegible] transmission (SIFS=1)
  Stations 2, 3, 4 s[illegible]V to 1.
- T=5 Medium becomes free
- T=8 DIFS expires. Stations 2, 3, 4 draw backoff count between 0 and 5.
  The counts are 3, 1, 2

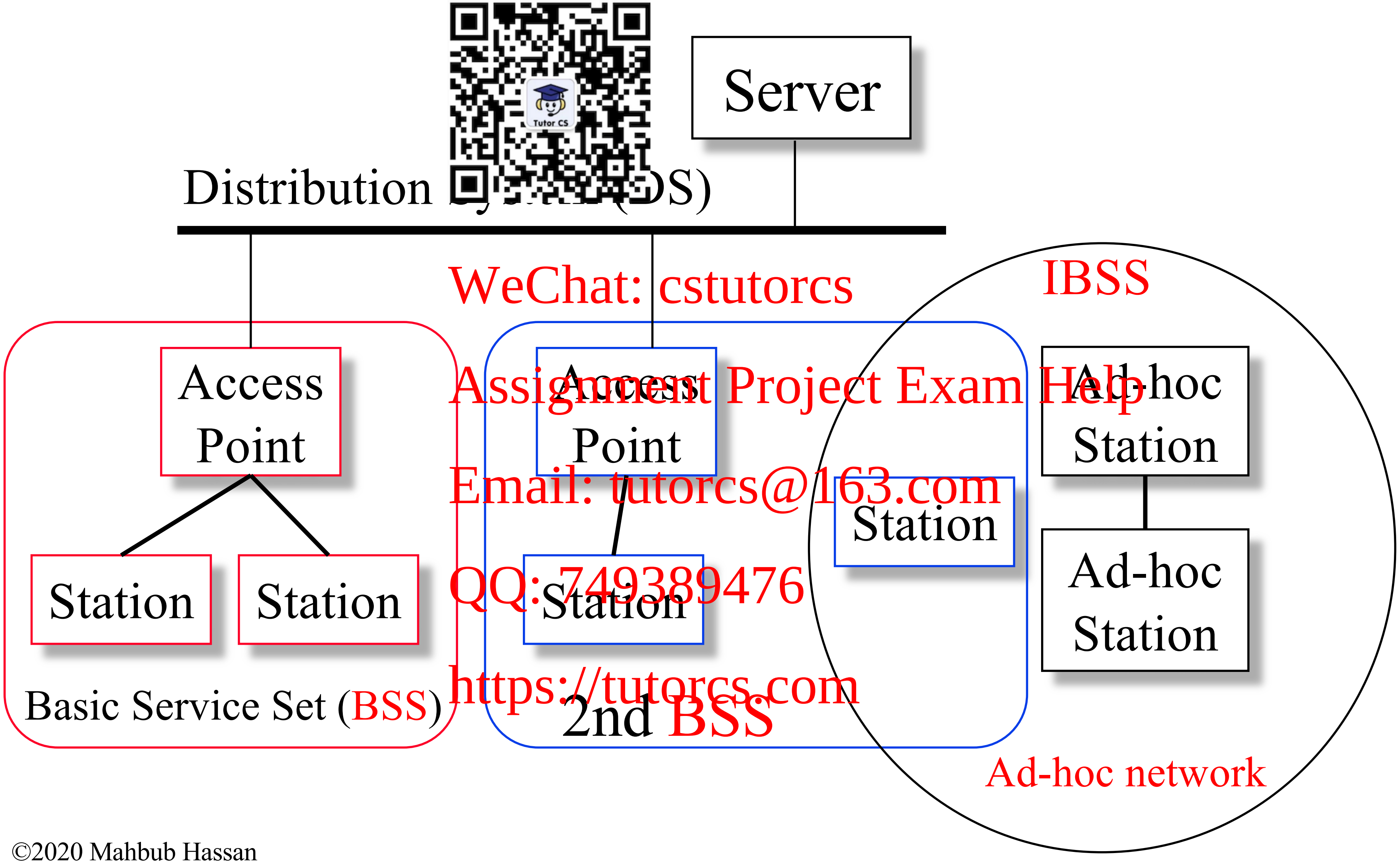


DCF Example (Cont)

- T=9 Station 3 starts transmitting. Announces a duration of 8 (RTS + SIFS + CTS + SIFS + DATA + SIFS + ACK). Station 2 and 4 pause backoff counter at 2 and 1 resp. and wait till T=17
- T=15 Station 3 finishes [illegible]sion
- T=16 Station 3 receives [illegible]
- T=17 Medium becomes [illegible]
- T=20 DIFS expires. Station 2 and 4 notice that there was no transmission for DIFS. Stations 2 and 4 start their backoff counter from 2 and 1, respectively.
- T=21 Station 4 starts transmitting RTS



IEEE 802.11 Architecture



IEEE 802.11 Architecture (Cont)

- **Basic Service Set** [illegible]
  = Set of stations as[illegible] with one AP
- **Distribution Syst**[illegible] - wired backbone
- **Independent Basic Service Set (IBSS)**: Set of computers in **ad-hoc mode**. May not be connected to wired backbone.

- Ad-hoc networks coexist and interoperate with infrastructure-based networks

- BSSID: 48-bit MAC address of the AP

- IBSSID: randomly generated address
  - 2 bits are fixed, 46 bits are generated randomly

- All-1s BSSID/IBSSID is used for broadcast

Frame Format

Frame Control	Duration/ ID	Adr 1	Adr 2	Adr 3	Seq Control	Adr 4	Info	CRC
16b	16b	48b	48b	48b	16b	48b		32b

Prot. Ver.	Type	Sub type	To DS	DS	More Frag.	Retry	Power mgt	More Data	WEP	Order
2b	2b	4b	1b	1b	1b	1b	1b	1b	1b	1b

- Type: Control, management, or data
- Sub-Type: Association, disassociation, re-association, probe, authentication, de-authentication, CTS, RTS, Ack, Power-Save Poll (PS-POLL) …
- Retry/retransmission
- Power mgt: Going to Power Save mode
- More Data: More buffered data at AP for a station in power save mode
- WEP: Wireless Equivalent Privacy (Security) info in this frame
- Order: Strict ordering

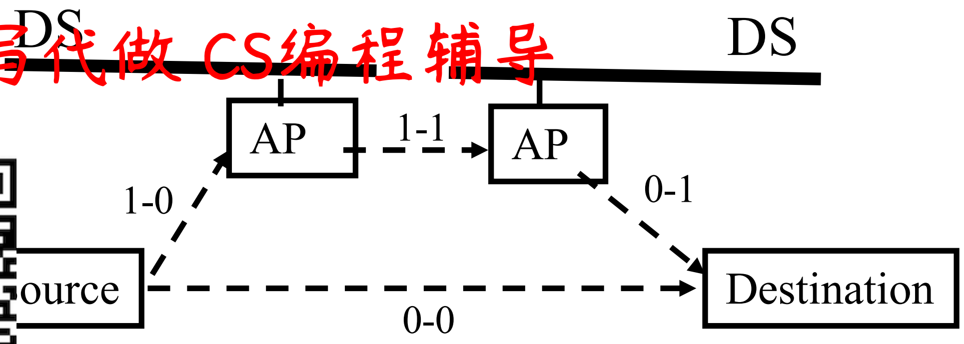
MAC Frame Fields

- **Duration/Connec**[illegible]
  - If used as durat[illegible] indicates time (in μs) channel will be allocated fo[illegible]ul transmission of MAC frame. Includes time until the end of Ack
  - In some control frames, contains association or connection identifier

- **Sequence Control**:
  - 4-bit fragment number subfield
    - For fragmentation and reassembly
  - 12-bit sequence number
  - Number frames between given transmitter and receiver

802.11 Frame Address Fields – data frames

- Source/Destination: ultimate network devices that prepare and decode the frame for network layer
- Transmitter(Tx)/Receiver(R… be the source/destination, o… intermediate radio devices, … access point (AP)
- 4 address fields; defined by 2 DS bits



Purpose	ToDS	FromDS	ADR1 (Rx)	ADR2 (Tx)	ADR3	ADR4
IBSS	0	0	DA	SA	IBSSID	N/A
From AP (from infra.)	0	1	DA	BSSID	SA	N/A
To AP (to infra.)	1	0	BSSID	SA	DA	N/A
AP-to-AP (W'less Brdg)	1	1	RxA	TxA	DA	SA

Example 802.11 Addressing: Wireless Client to Server

Addresses in frames transmitted by the client radio

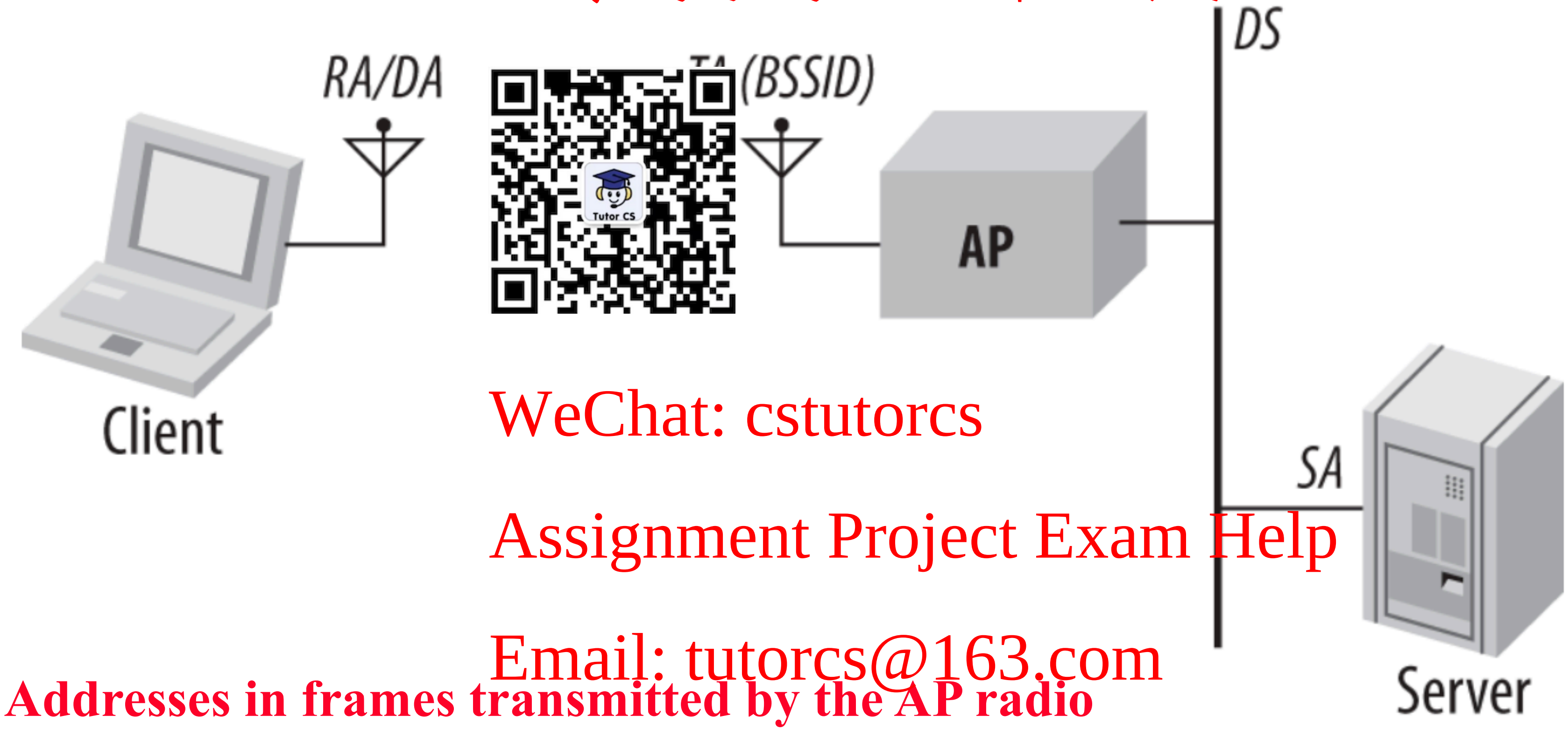
ADR1: AP MAC address (BSSID)

ADR2: Client MAC address (source address)

ADR3: Server MAC address (destination address)

ADR4: Not applicable

Example 802.11 Addressing: Server to Wireless Client



Addresses in frames transmitted by the AP radio

ADR1: Client MAC address (destination address)

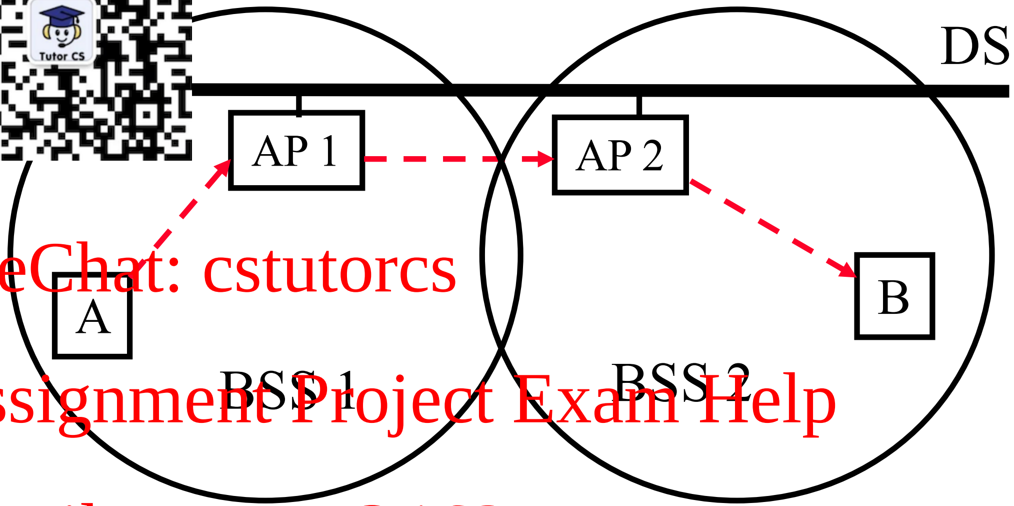
ADR2: AP MAC address (BSSID)

ADR3: Server MAC address (source address)

ADR4: Not applicable

Example 802.11 addressing

- Consider the example WLAN in the figure where two BSSs are connected via a distribution system. What is the content of the Address 3 field when Station A wants to send a packet to Station B via AP 1?



- In this case (To DS=1, From DS=0), Address 3 field should contain the address of the destination station. Therefore, it should be the address of B.

Power Saving

- Extending the battery [illegible]ble devices is one of the main challenges of wireless networks.
- Mechanisms must be devised to let the device sleep as much as possible and wake up only when it needs to transmit or receive.
- If there are no packets to be received, a receiver could go to sleep and save battery power.
- To facilitate this kind of power saving, IEEE 802.11 has a power management function.

802.11 Power Management

- Station tells the base s[illegible]ode: Power saving (PS) or [illegible]
  - Mode changed by Power Mgmt bit in the frame control header.
- All packets destined to stations in PS mode are buffered (at AP)
- AP broadcasts list of stations with buffered packets in its beacon frames: Traffic Indication Map (TIM)
- When a station wakes up, it waits for the beacon; sends a PS-Poll message to AP if its bit is turned on in TIM; AP then sends one frame with buffered data and sets the More Data bit in the header if more data in the buffer (station does not go back to sleep after receiving one frame if More is set).

Traffic Indication Map (TIM)

- A bit map insid[illegible]on
- 2008 bits; each [illegible]sents an Association ID (one associated client)
- If packets are buffered in the AP for a given Association ID, its corresponding bit is set to ‘1’, ‘0’ otherwise

Summary

1. 802.11 PHYs: Spread spectrum in earlier versions, but OFDM in new versions
2. 2.4 GHz channels (22 MHz) are mostly overlapped, but 5 GHz channels (20 MHz) are non-overlapped, but some are shared with the radar service

3. High speed applications can be supported by combining multiple adjacent channels into single channel with higher bandwidth

4. 802.11 uses SIFS, PIFS, DIFS for priority
5. WLAN frames have *four* address fields

6. 802.11 supports power saving mode

Acronyms

Ack	Acknow[illegible]
AP	Access [illegible]
APSD	Automa[illegible] Save Delivery
BO	Backof[illegible]
BSA	Basic Service Area
BSS	Basic Service Set
BSSID	Basic Service Set Identifier
CA	Collision Avoidance
CD	Collision Detection
CDMA	Code Division Multiple Access
CFP	Contention Free Period
CRC	Cyclic Redundancy Check
CSMA	Carrier Sense Multiple Access
CTS	Clear to Send
CW	Congestion Window
CWmax	Maximum Congestion Window

Acronyms (Cont)

CWmin	Minimu[illegible]ion Window
DA	Destina[illegible]s
DCF	Distribu[illegible]nation Function
DIFS	DCF In[illegible]pacing
DS	Direct Sequence
ESA	Extended Service Area
ESS	Extended Service Set
FH	Frequency Hopping
FIFO	First In First Out
GHz	Giga Hertz
IBSS	Independent Basic Service Set
ID	Identifier
IEEE	Institution of Electrical and Electronics Engineers
IFS	Inter-frame spacing
ISM	Instrumentation, Scientific and Medical
LAN	Local Area Network

Acronyms (Cont)

MAC	Media Access Control
MHz	Mega Hertz
MIMO	Multiple Input Multiple Output
NAV	Network Allocation Vector
OFDM	Orthogonal Frequency Division Multiplexing
PCF	Point Coordination Function
PHY	Physical Layer
PIFS	PCF inter-frame spacing
PS	Power saving
QoS	Quality of Service
RA	Receiver Address
RTS	Ready to Send
SA	Source Address
SIFS	Short Inter-frame Spacing

Acronyms (Cont)

- SS — Subscri Stati
- TA — Transm ess
- TIM — Traffic Map
- WiFi — Wireles
- WLAN — Wireless Local Area Network