Institute for the Wireless Internet of Things

at Northeastern University

EECE 5155
Wireless Sensor Networks
(and The Internet of Things)

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February 8, 2021

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Medium Access Control

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Objectives of MAC

➢ Controls how the shared medium (transmission channel) is used by different devices

➢ Controls when to send a packet, and when to listen for a packet

➢ Perhaps the two most important operations in a wireless network

– Idle waiting wastes **huge amounts of energy**

➢ We need schemes for medium access control that are

– Suitable to mobile and wireless networks

– Emphasize energy-efficient operation

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Objectives of MAC?

➢ Collision Avoidance

– Reduce Retransmissions

➢ Energy Efficiency

– Avoid Idle Listening

➢ Scalability

➢ Latency

➢ Fairness

➢ Throughput

➢ Bandwidth Utilization

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Let's assume everybody in the room wants to talk.
How do we achieve this?

Think-Pair-Share!

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February 11, 2021

Classification of MAC Protocols

```
                    ┌─────────────────────────┐
                    │  Wireless Medium Access │
                    └─────────────────────────┘
                       /                    \
          ┌──────────────┐              ┌──────────────┐
          │ Centralized  │              │ Distributed  │
          └──────────────┘              └──────────────┘
            /        \                    /          \
   ┌──────────┐  ┌──────────┐   ┌──────────┐   ┌──────────┐
   │ Schedule-│  │Contention-│   │ Schedule-│   │Contention-│
   │  based   │  │  based    │   │  based   │   │  based    │
   └──────────┘  └──────────┘   └──────────┘   └──────────┘
     /      \                      /      \
┌───────┐ ┌────────┐        ┌───────┐  ┌────────┐
│ Fixed │ │ Demand │        │ Fixed │  │ Demand │
│assign-│ │assign- │        │assign-│  │assign- │
│ ment  │ │ ment   │        │ ment  │  │ ment   │
└───────┘ └────────┘        └───────┘  └────────┘
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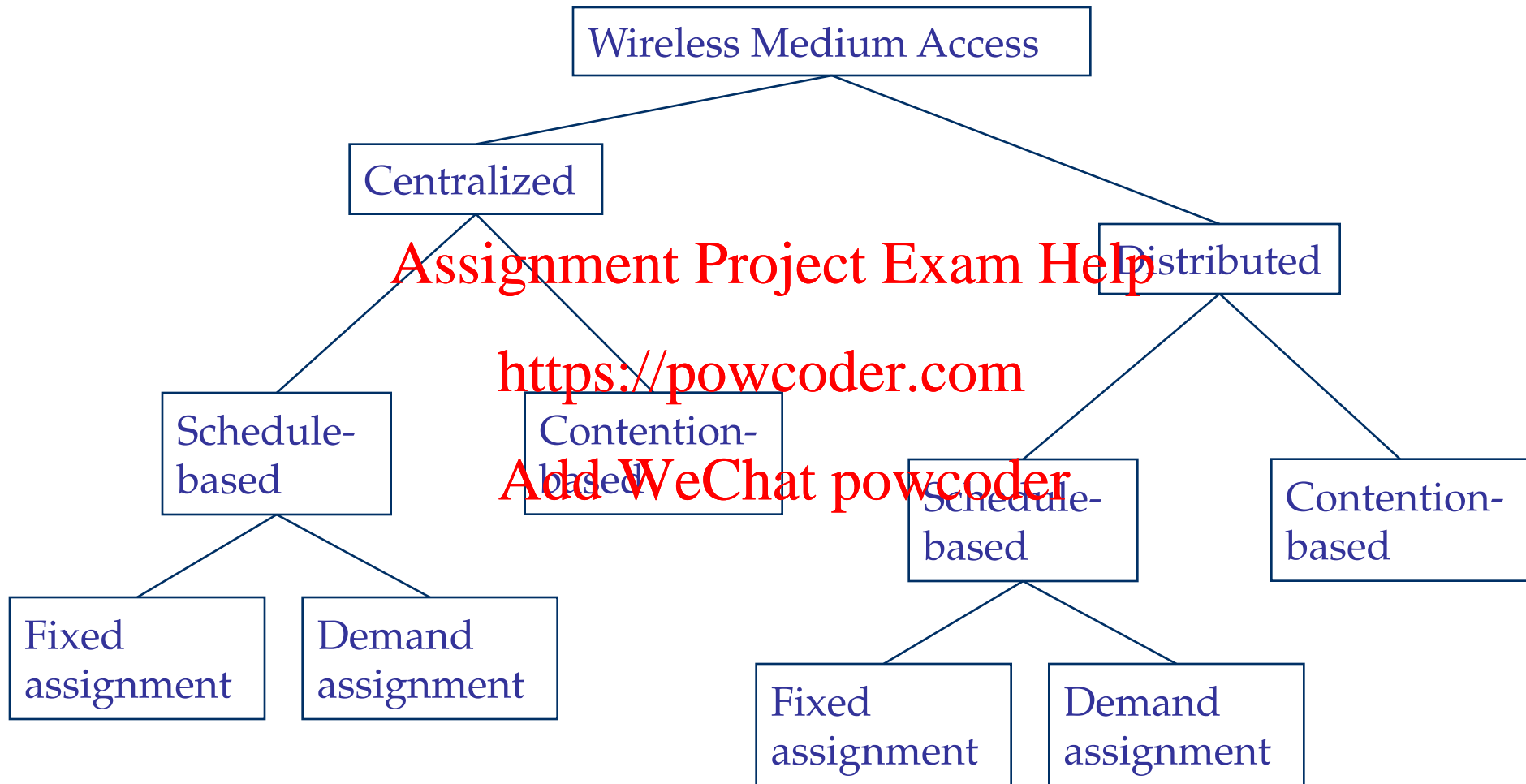
MAC Protocols

➢ Distributed, Contention-Based MAC Protocols

– Typically based on Carrier Sense Multiple Access (CSMA)

– <u>IEEE 802.11</u>, <u>Sleep-MAC</u>, <u>BMAC</u>, T-MAC, <u>CCMAC</u>, IEEE 802.15.4 Assignment Project Exam Help

➢ Schedule-Based MAC Protocols https://powcoder.com

– Based on Time Division Multiple Access (TDMA) and Reservation Add WeChat powcoder

– <u>TRAMA</u>, FLAMA, etc…

➢ HYBRID (CSMA/TDMA) MAC Protocols

– <u>ZMAC</u>, <u>Funneling MAC</u>

Contention-Based Mac Protocols: IEEE 802.11

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Contention-based MAC Protocols

➢ Channel access through **carrier sense** mechanism

➢ Provide robustness and scalability to the network

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➢ Collision probability increases with increasing node density

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IFS

Contention Window
(Randomized Back-off Mechanism)

IFS

Medium Busy

Next Frame

t

Station senses the channel and it is idle

Direct access if medium is free ≥ IFS

Slot Time

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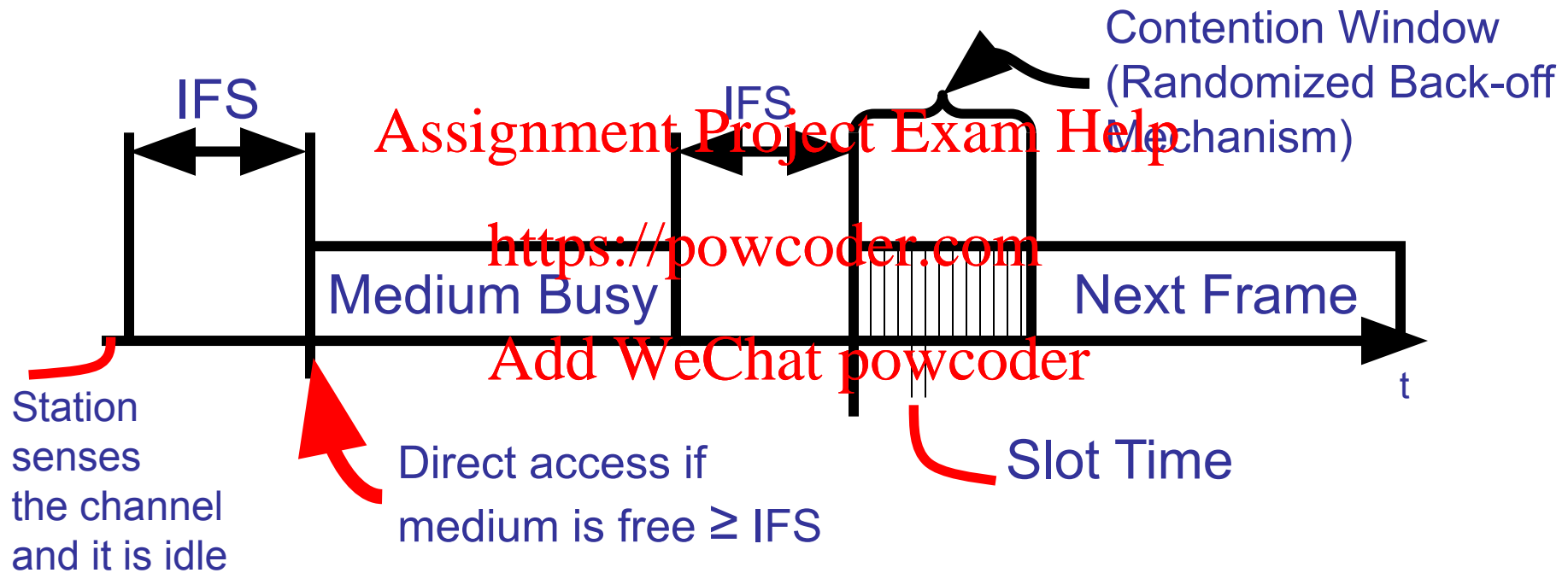
Generic CSMA/CA

➤ A station with a frame to transmit senses the medium (channel)

➤ IF IDLE -> waits to see if the channel remains idle for a time equal to IFS (inter-frame spacing). If so, the station may transmit immediately

➤ IF BUSY -> (either because the station initially finds the channel busy or because the channel becomes busy during the IFS idle time), the station **defers transmission** and continues to monitor the channel until the current transmission is over

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Basic CSMA/CA

➢ Once the current transmission is over, the station delays another IFS

➢ If the medium remains idle for this period, the station backs off using a **binary exponential backoff scheme** and again keeps sensing the medium

➢ The station picks up a random number of slots (the initial value of backoff counter) within a contention window to wait before transmitting its frame

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Backoff

➢ MAC runs a random number generator to set a BACKOFF CLOCK for every contending station

➢ The backoff clock is randomly chosen between [0, CW-1], where CW represents a CONTENTION WINDOW

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➢ During contention, all stations having packets for transmission run down their BACKOFF clocks

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➢ The first station whose clock expires starts transmission

➢ Other terminals sense the new transmission and **freeze their clocks** to be restarted after the completion of the current transmission in the next contention period

CSMA/CA Algorithm

➢ **If Collisions (Control or Data)**

- – Binary exponential increase (doubling) of CW

- – Length of backoff time is exponentially increased as the station goes through successive retransmissions

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How to Handle Priority?

➢ Priorities are defined through different **inter frame spaces**

➢ SIFS (Short Inter Frame Spacing)
  – Highest priority packets such as ACK, CTS, polling response
  – Used for immediate response actions

➢ PIFS (PCF IFS, Point Coordination Function Inter Frame Spacing)
  – Medium priority, for real time service using PCF
  – SIFS + One slot time
  – Used by centralized controller in PCF scheme when using polls

➢ DIFS (DCF, Distributed Coordination Function IFS)
  – Lowest priority, for asynchronous data service
  – SIFS + Two slot times
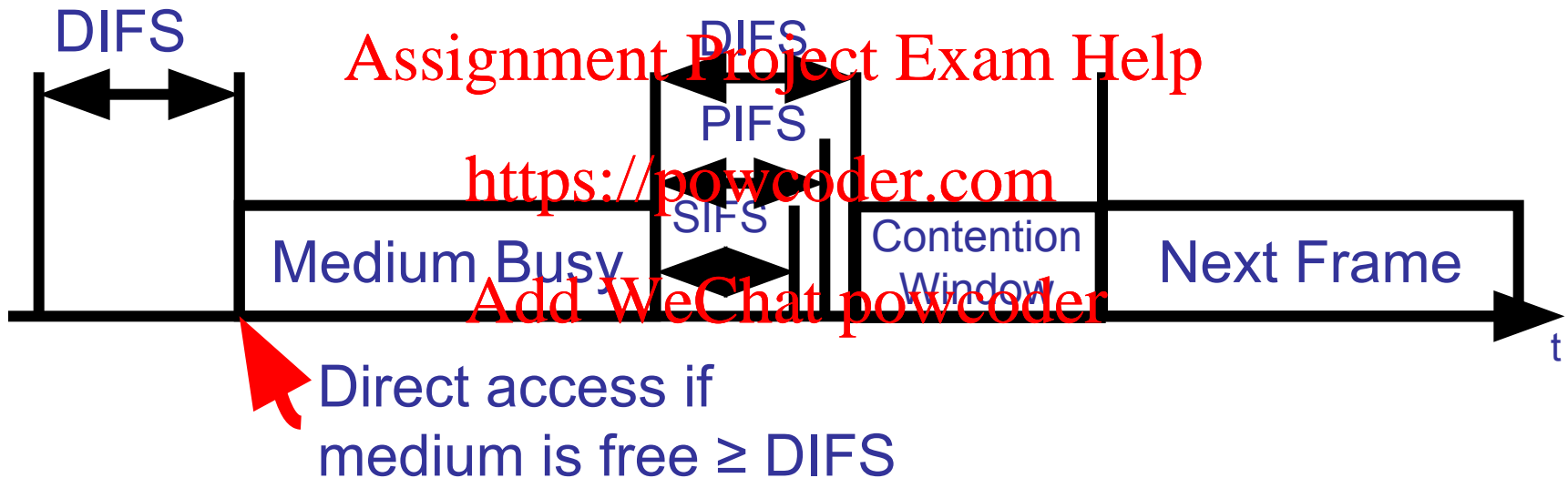 – Used as minimum delay of asynchronous frames contending for access

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DIFS

DIFS

PIFS

SIFS

Medium Busy

Contention Window

Next Frame

t

Direct access if
medium is free ≥ DIFS

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CSMA/CA with ACKs

➢ Station has to wait for DIFS before sending data

➢ Receiver ACKs immediately (after waiting for SIFS < DIFS) if the packet was received correctly (CRC))

➢ Receiver transmits ACK without sensing the medium

➢ If ACK is lost, retransmission done

➢ Also automatic retransmission of data packets in case of transmission errors
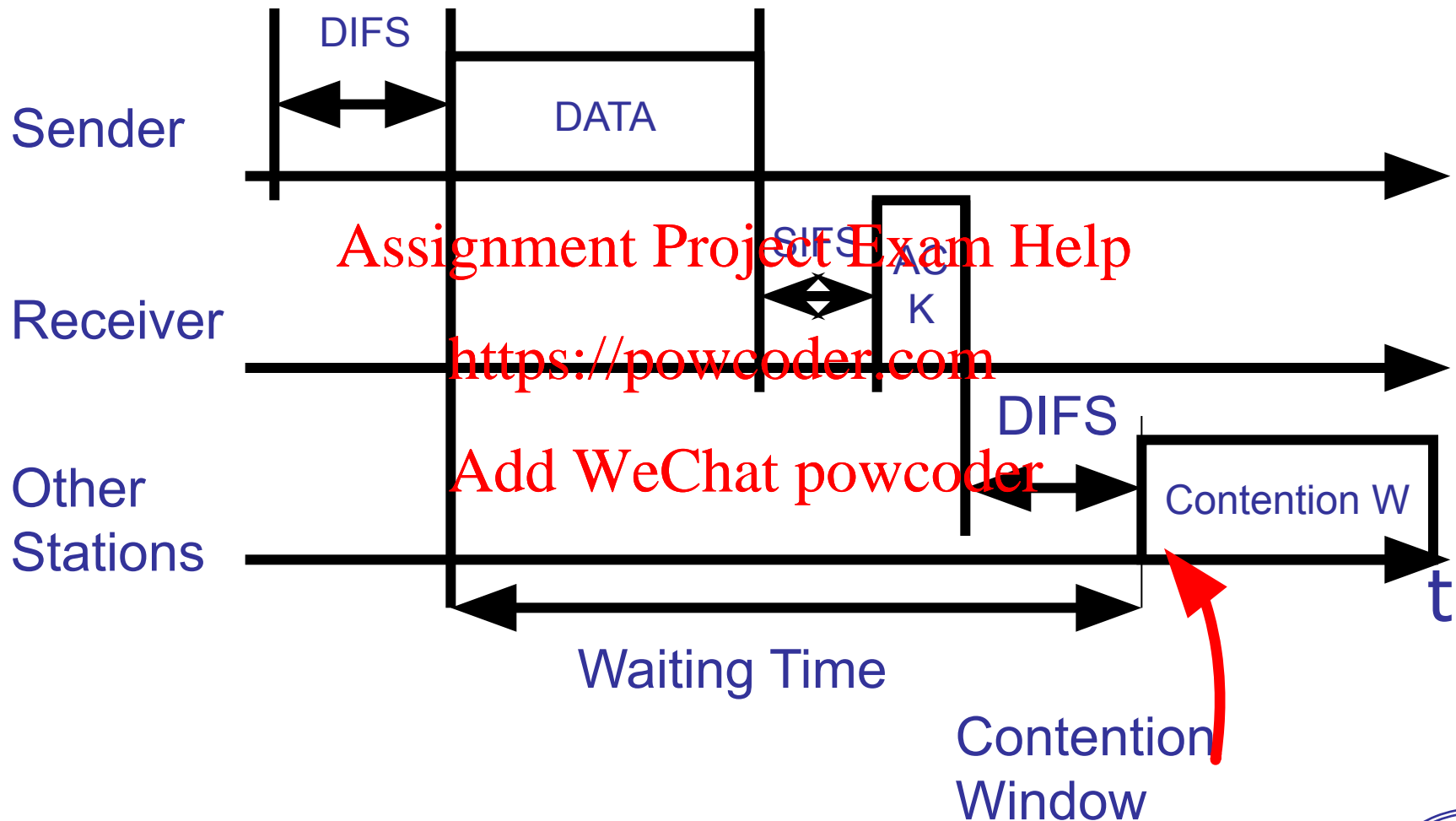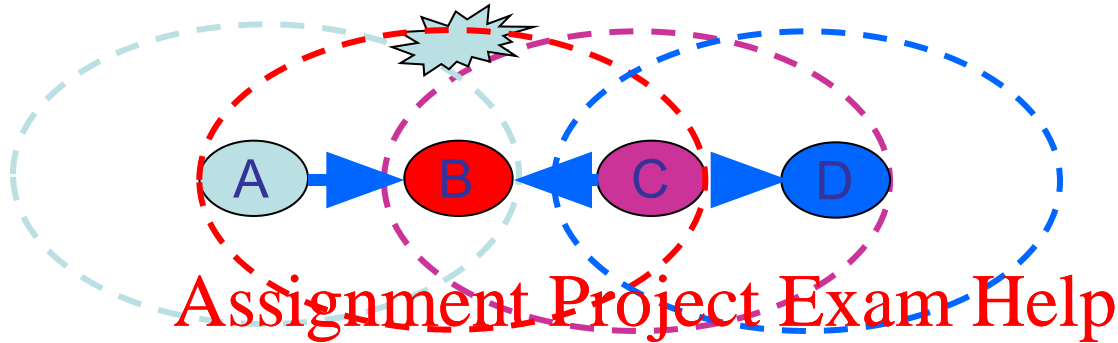
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Sender

DIFS

DATA

Receiver

SIFS

ACK

Other
Stations

DIFS

Contention W

t

Waiting Time

Contention
Window

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Hidden Terminal Problem

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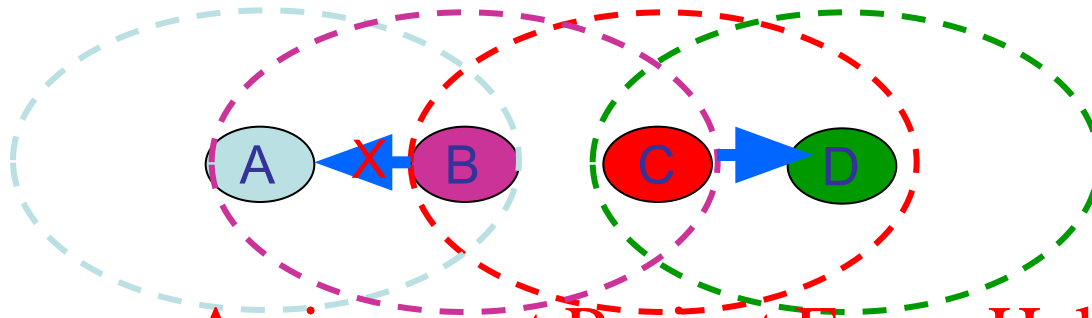
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➢ Node B can communicate with A and C

➢ A and C cannot hear each other

➢ When A transmits to B, C cannot detect the transmission using the carrier sense mechanism

➢ If C transmits to D, collision will occur at B

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Exposed Terminal Problem

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➢ Node C can communicate with B and D

➢ Node B can communicate with A and C

➢ Node A cannot hear C

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➢ Node D cannot hear B

➢ When C transmits to D, B detects the transmission using the *carrier sense* mechanism and postpones transmission to A, even though such transmission would not cause collision

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How do we solve this?

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Think-Pair-Share!

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DCF CSMA/CA with RTS/CTS

➢ Use short signaling packets for Collision Avoidance

➢ RTS (Request To Send) Packet (20 Bytes):
  – A sender requests the right to send from a receiver with a short RTS packet before it sends a data packet

➢ CTS (Clear To Send) Packet (16 Bytes):
  – The receiver grants the right to send as soon as it is ready to receive

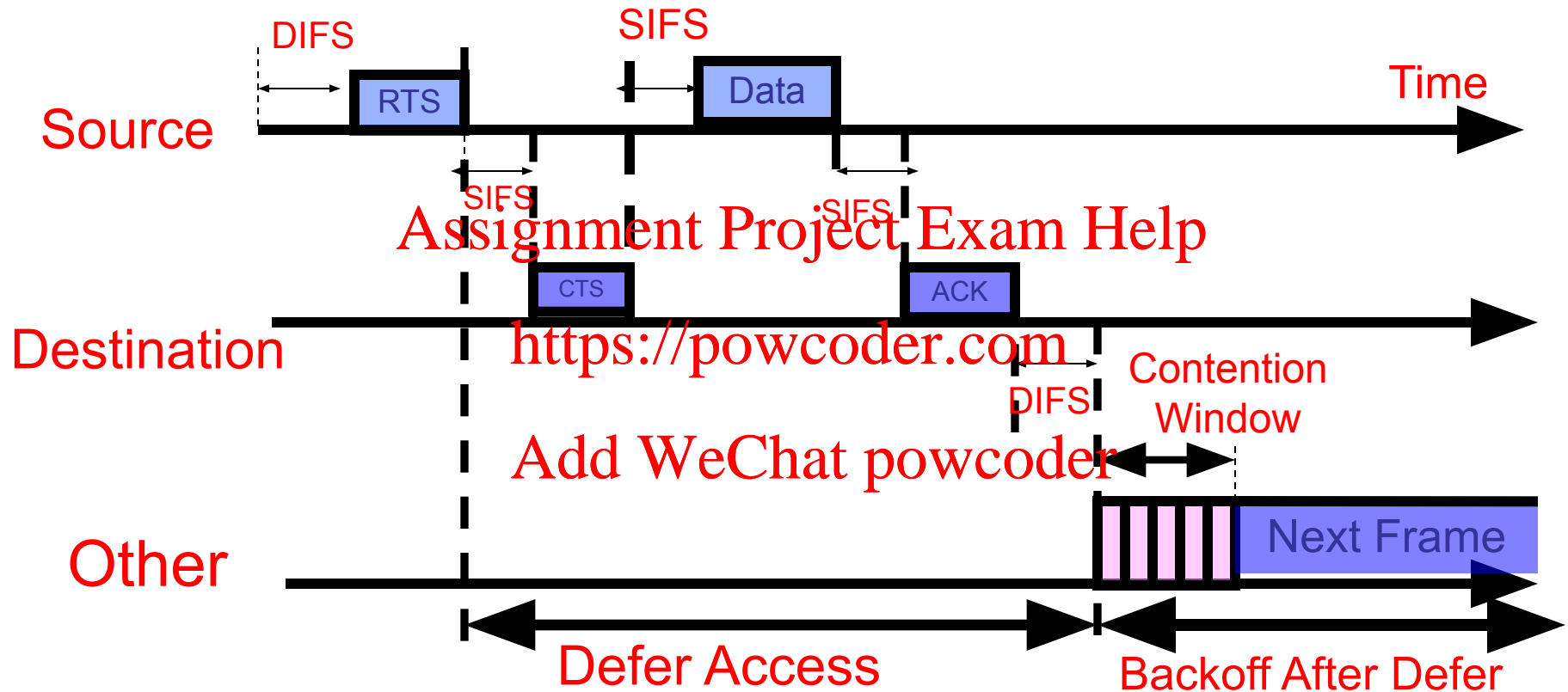➢ They contain: (Sender Address; Receiver Address; Packet Size)

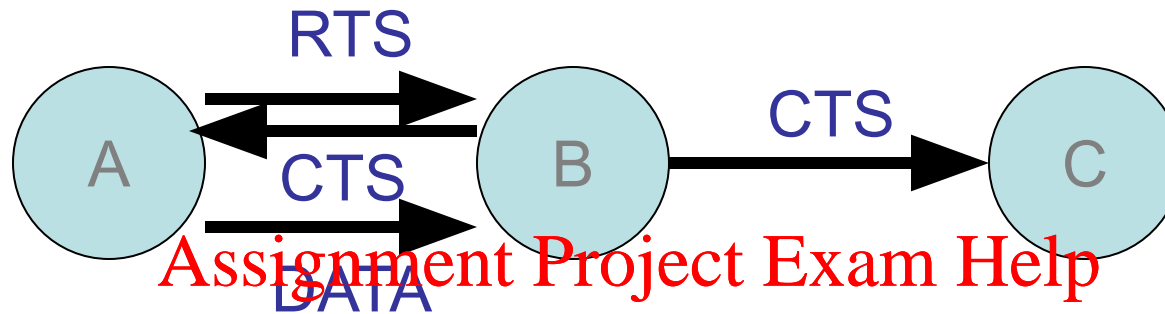Dr. Francesco Restuccia, EECE 5155 Wireless Sensor Networks and the Internet of Things

➢ Transmitter sends an RTS (Request To Send) after medium has been idle for time interval more than DIFS

➢ Receiver responds with CTS (Clear To Send) after medium has been idle for SIFS

➢ Data is transmitted

➢ RTS/CTS is used for reserving channel for data transmission so that the collision can only occur in control message

Source

DIFS

RTS

SIFS

Data
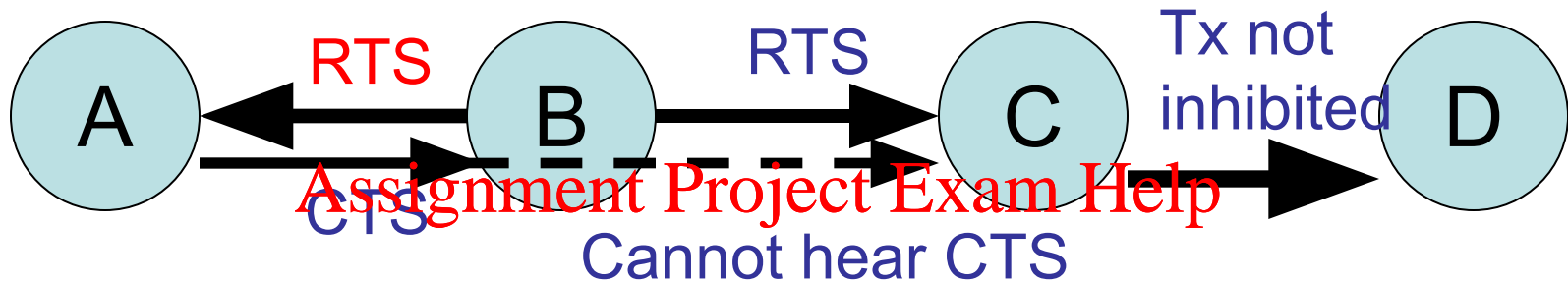
Time

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SIFS

SIFS

CTS

ACK

Destination

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Contention Window

DIFS

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Other

Next Frame

Defer Access

Backoff After Defer

Hidden Terminal Problem Solved

RTS

A → B

CTS

B → C

CTS

A ← B

DATA

➤ A sends RTS

➤ B sends CTS

➤ C overhears CTS

➤ C inhibits its own transmitter

➤ A successfully sends DATA to B

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Exposed Terminal Problem Solved

- B sends RTS to A (overheard by C)
- A sends CTS to B
- C cannot hear A's CTS
- C assumes A is either down or out of range
- C does not inhibit its transmissions to D

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Collisions

➢ Still possible – RTS packets can collide!

➢ Binary exponential backoff performed by stations that experience RTS collisions

➢ RTS collisions not as bad as data collisions in CSMA (since RTS packets are typically much smaller than DATA packets)

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Network Allocation Vector (NAV)

➢ Both Physical Carrier Sensing and Virtual Carrier Sensing used in 802.11

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➢ If either function indicates that the medium is busy, 802.11 treats the channel to be busy
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➢ Virtual Carrier Sensing is provided by the NAV (Network Allocation Vector)

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Network Allocation Vector (NAV)

➢ Most 802.11 frames carry a duration field which is used to reserve the medium for a fixed time period

➢ Tx sets the NAV to the time for which it expects to use the medium

➢ Other stations start counting down from NAV to 0

➢ As long as NAV > 0, the medium is busy

➢ CHANNEL VIRTUALLY BUSY -> a NAV SIGNAL is turned on!

➢ Transmission will be delayed until the NAV signal has disappeared

➢ When the channel is virtually available, then MAC checks for PHY condition of the channel
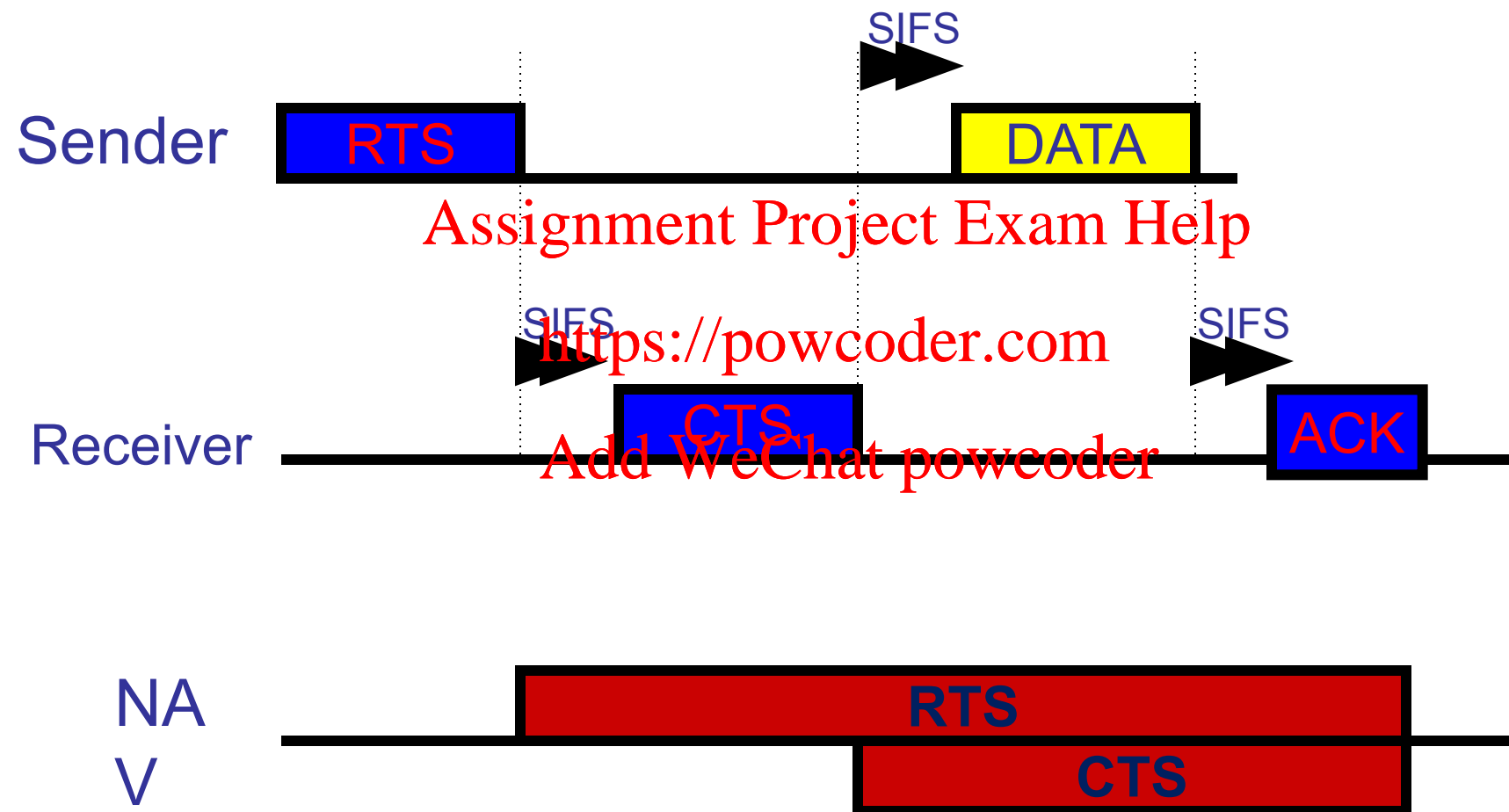
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Illustration

Sender

RTS

SIFS

DATA

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SIFS

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Receiver

CTS

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SIFS

ACK

NAV

RTS

CTS

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CSMA/CA with RTS/CTS (NAV)

➢ If receiver receives RTS, it sends CTS (Clear to Send) after SIFS

➢ CTS again contains duration field and all stations receiving this packet need to adjust their NAV

➢ Sender can now send data after SIFS, acknowledgement via ACK by receiver after SIFS

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CSMA/CA with RTS/CTS (NAV)

➢ Every station receiving the RTS that is not addressed to it, will go to the Virtual Carrier Sensing Mode for the entire period identified in the RTC/CTS communication, by setting their NAV signal on

➢ Network Allocation Vector (NAV) is set in accordance with the duration of the field

➢ NAV specifies the earliest point at which the station can try to access the medium

➢ Thus, the source station sends its packet without contention

➢ After completion of the transmission, the destination terminal sends an ACK and NAV signal is terminated, opening the contention for other users

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CSMA/CA with RTS/CTS (NAV)

Sender
DIFS
RTS
DATA

Receiver
SIFS
CTS
SIFS
SIFS
ACK

Other Stations
NAV (RTS)
NAV (CTS)
DIFS
RTS

defer access

Contention Window

t

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