Institute for the Wireless Internet of Things at Northeastern University

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

Prof. Francesco Restuccia
Email: f.restuccia@northeastern.edu

Medium Access Control

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

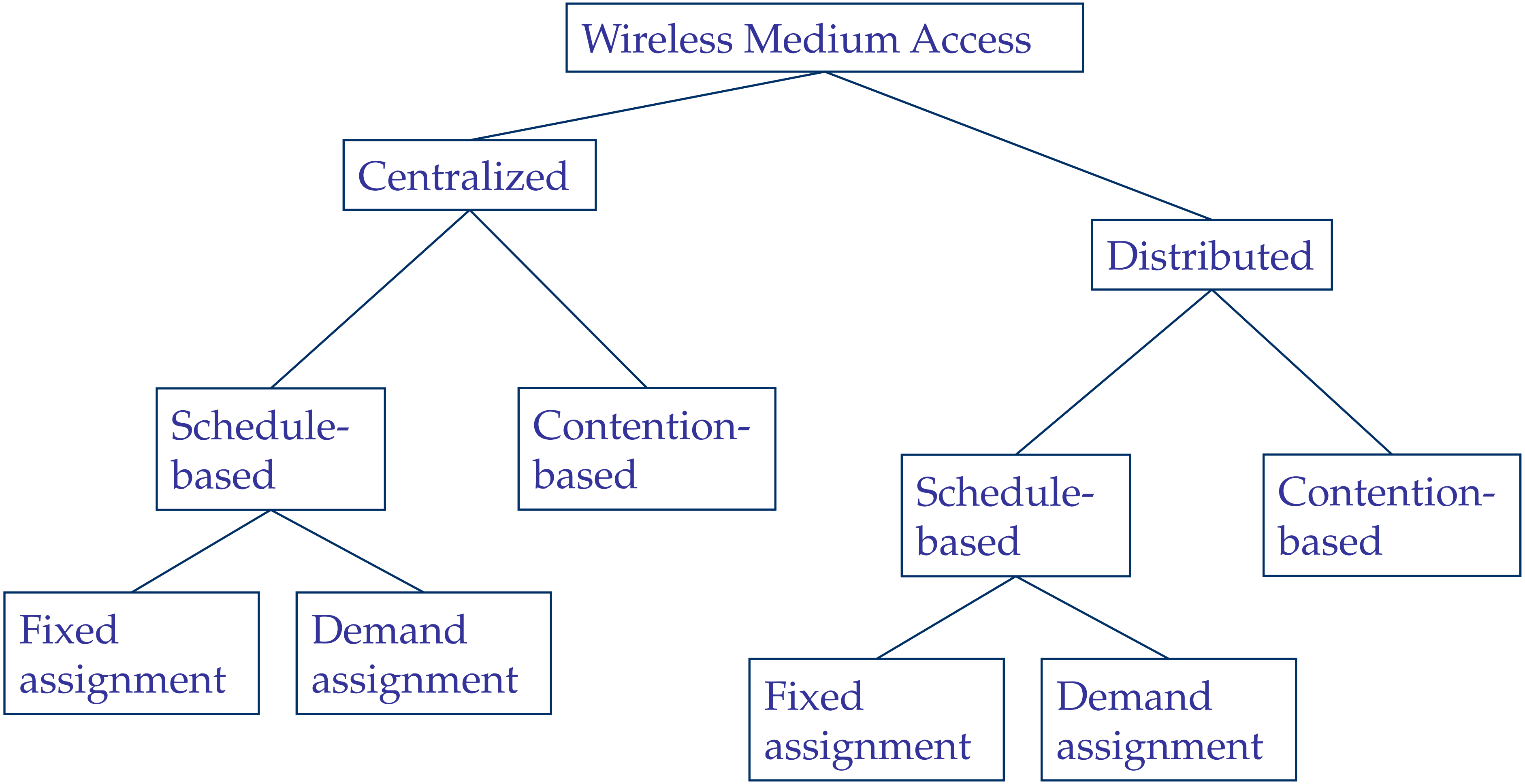
Objectives of MAC?

- Collision Avoidance
  - Reduce Retransmissions
- Energy Efficiency
  - Avoid Idle Listening
- Scalability
- Latency
- Fairness
- Throughput
- Bandwidth Utilization

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

Think-Share!

Classification of MAC Protocols



MAC Protocols

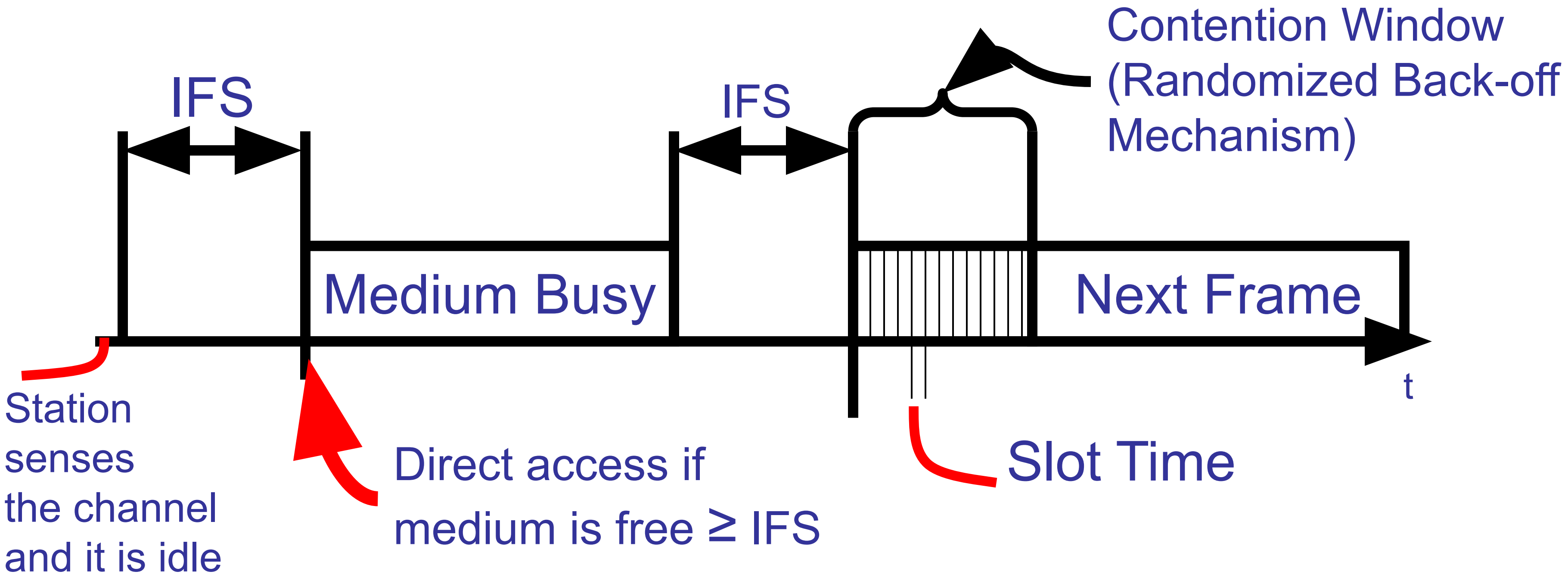
- Distributed, Contention-Based MAC Protocols
  - Typically based on Carrier Sense Multiple Access (CSMA)
  - IEEE 802.11, Sleep-MAC, BMAC, T-MAC, CCMAC, IEEE 802.15.4
- Schedule-Based MAC Protocols
  - Based on Time Division Multiple Access (TDMA) and Reservation
  - TRAMA, FLAMA, etc…
- HYBRID (CSMA/TDMA) MAC Protocols
  - ZMAC, Funneling MAC

Contention-Based Mac Protocols: IEEE 802.11

Contention-based MAC Protocols

- Channel access through **carrier sense** mechanism
- Provide robustness and scalability to the network
- Collision probability increases with increasing node density

Generic CSMA/CA



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

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

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

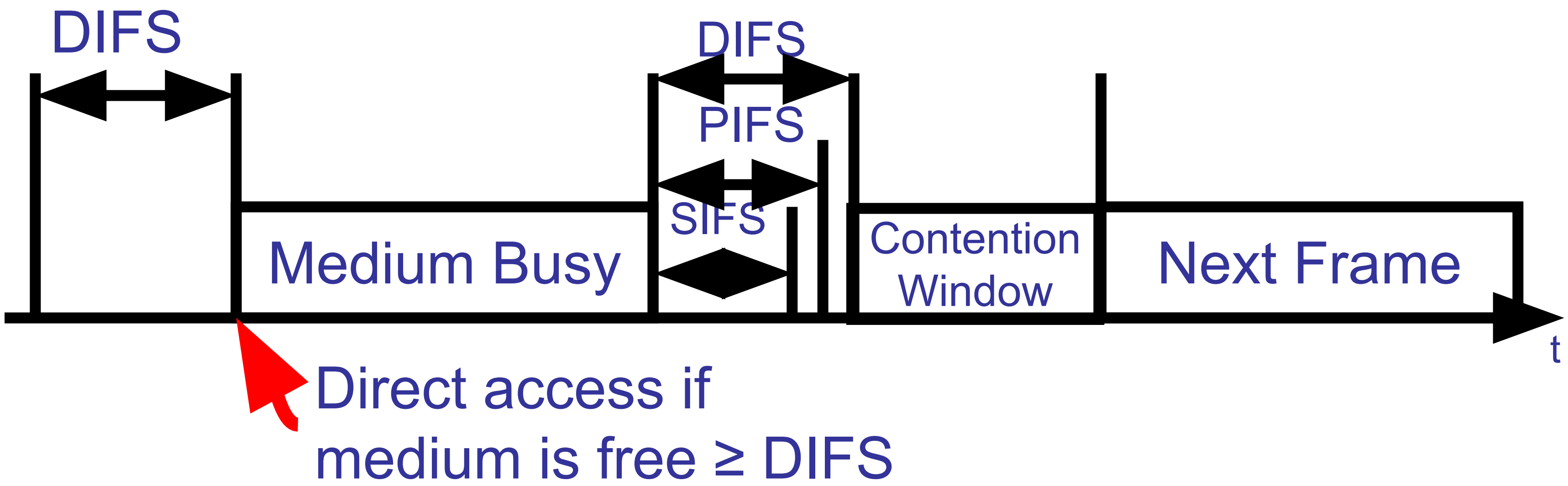
CSMA/CA Algorithm

- 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

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

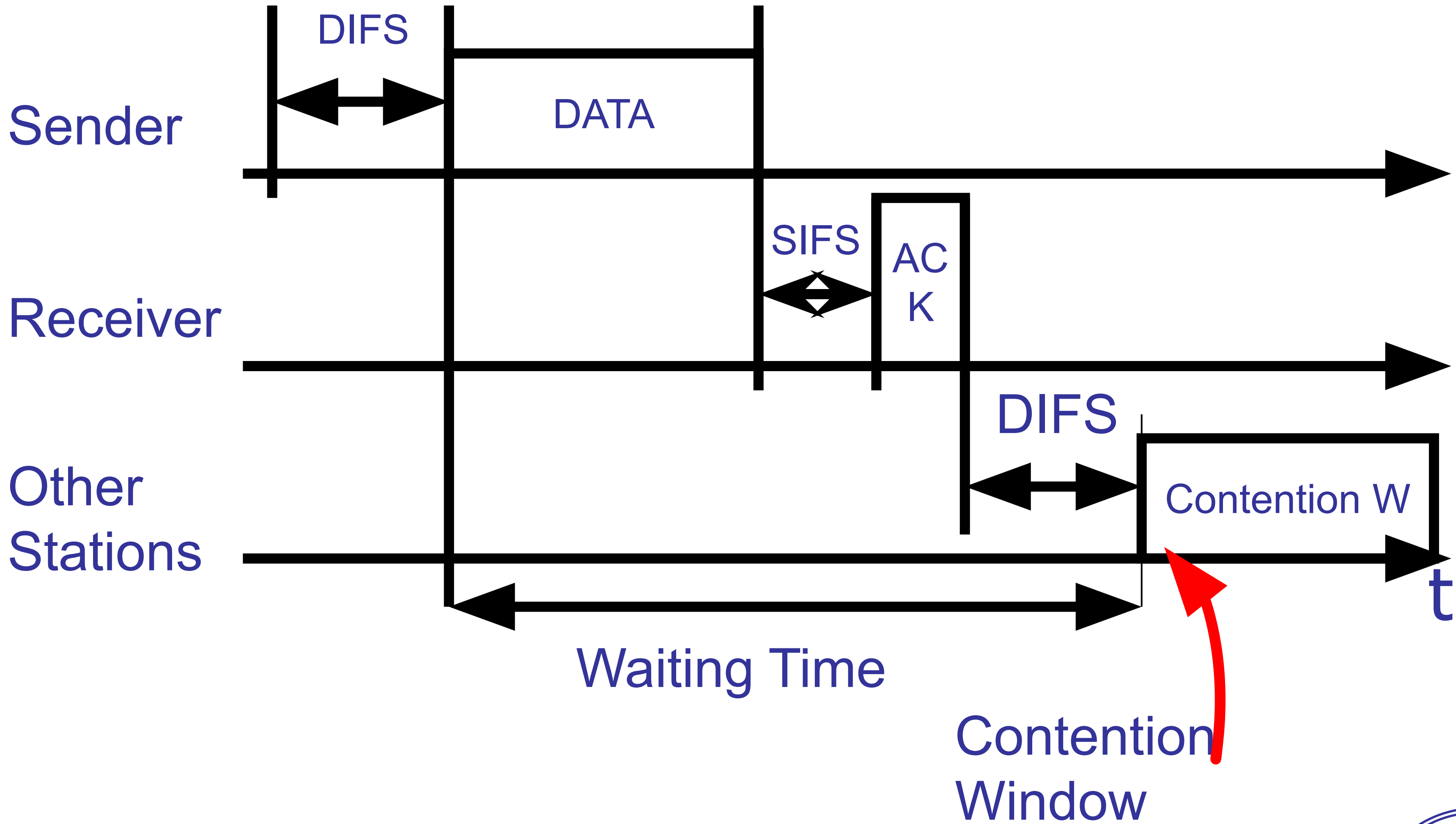
Inter-frame Spaces (IFS)



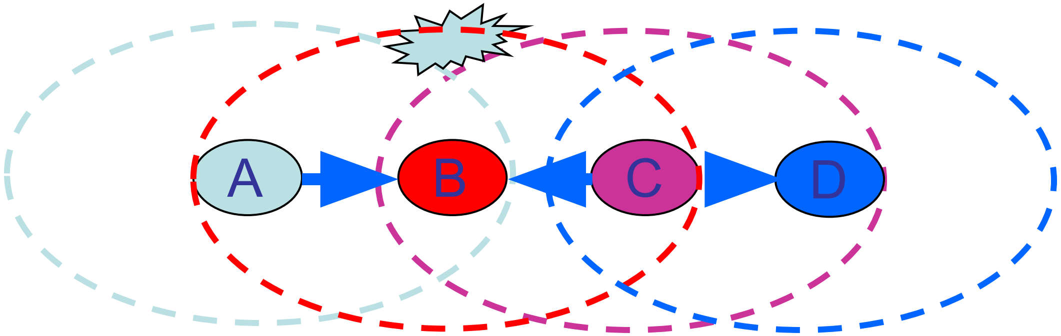
CSMA/CA with ACKs

- 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

CSMA/CA with ACKs (2)

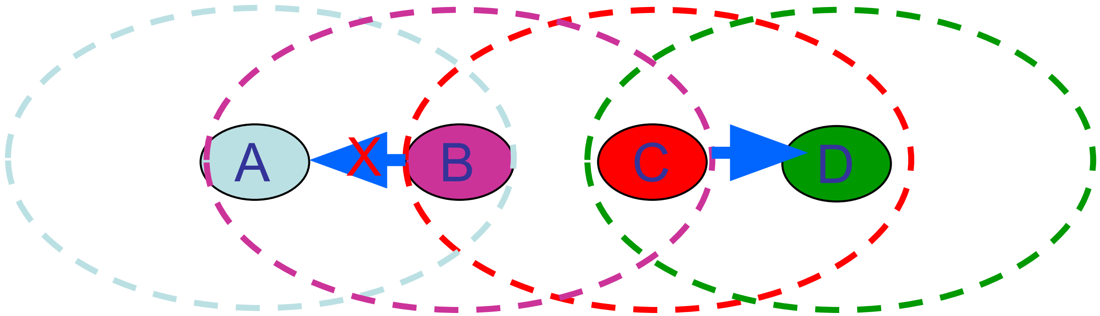


Hidden Terminal Problem



- 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

Exposed Terminal Problem



- Node C can communicate with B and D
- Node B can communicate with A and C
- Node A cannot hear C
- 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

How do we solve this?

Think-Share!

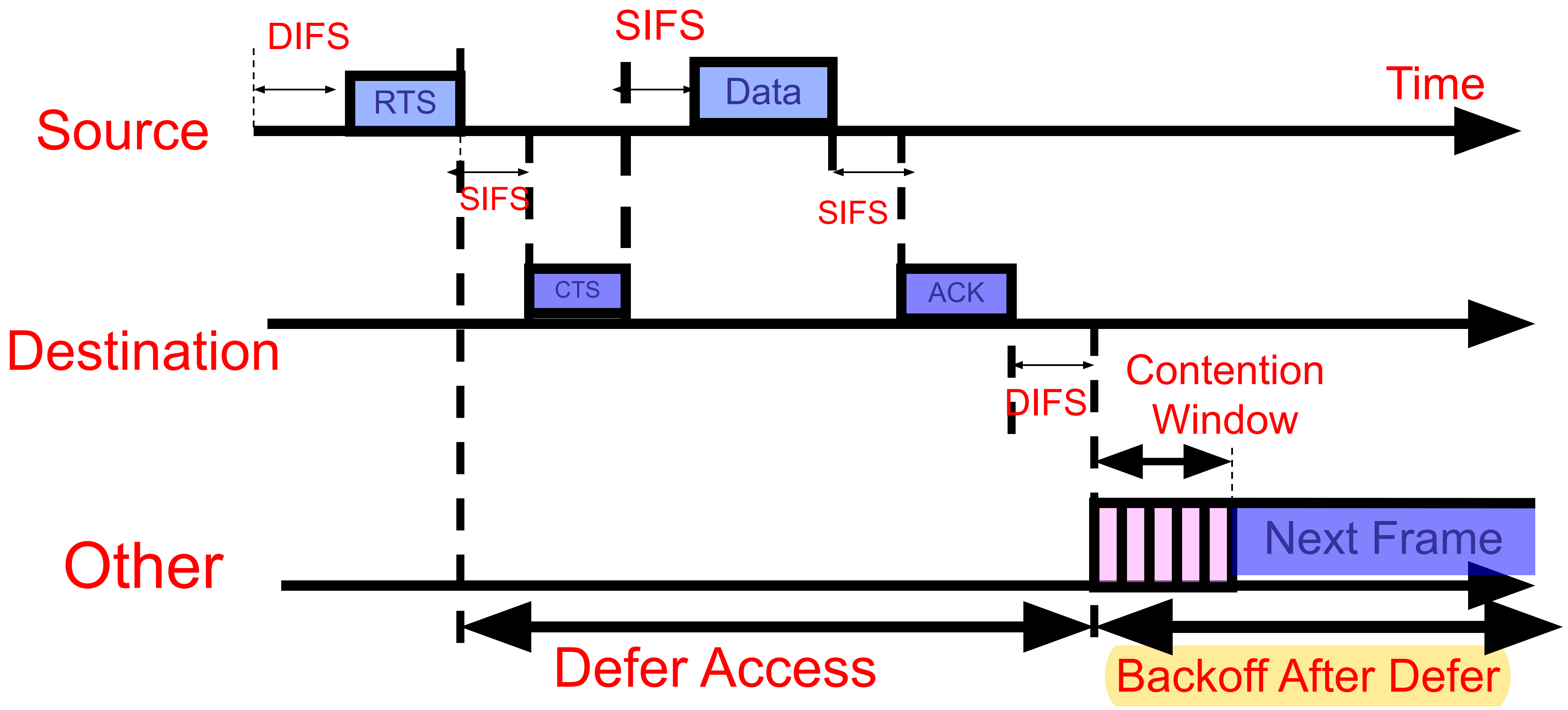
DCF CSMA/CA with RTS/CTS

- 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)

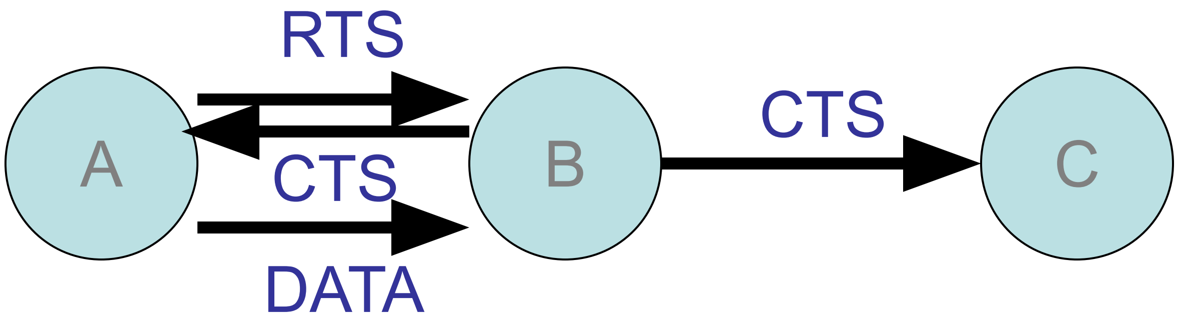
CSMA/CA with RTS/CTS (2)

- 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

DCF CSMA/CA with RTS/CTS (3)

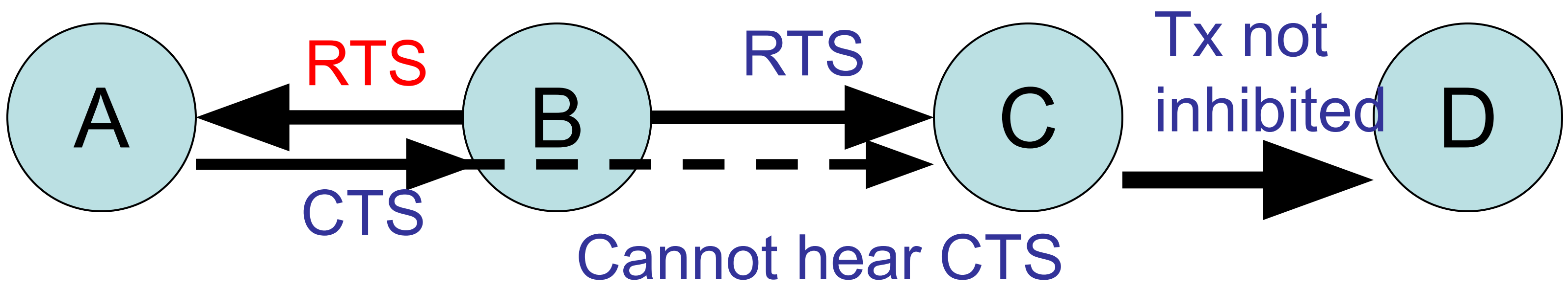


Hidden Terminal Problem Solved



- A sends RTS
- B sends CTS
- C overhears CTS
- C inhibits its own transmitter
- A successfully sends DATA to B

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

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)

Network Allocation Vector (NAV)

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

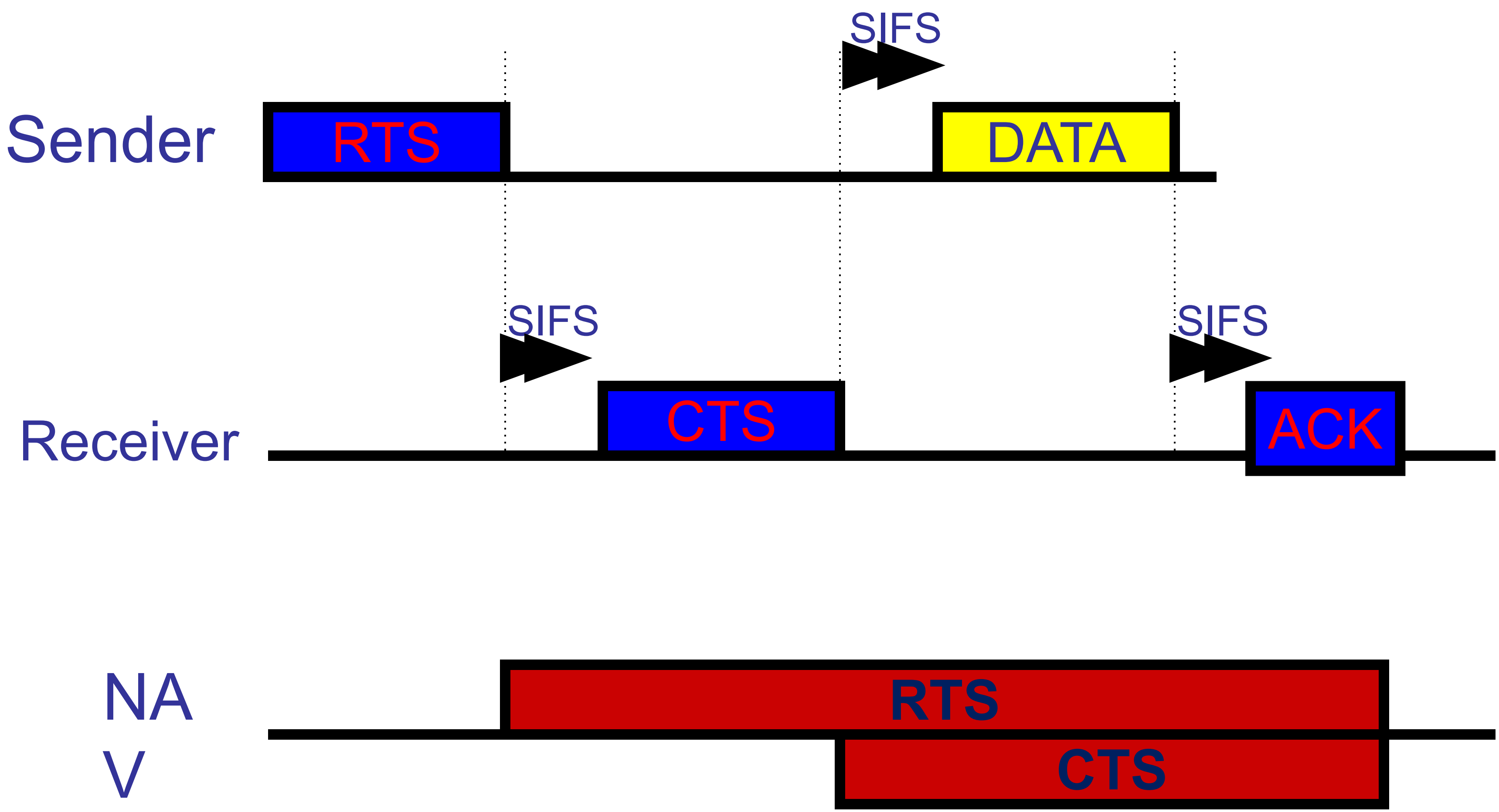
- If either function indicates that the medium is busy, 802.11 treats the channel to be busy

- Virtual Carrier Sensing is provided by the NAV (Network Allocation Vector)

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

Illustration



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

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

CSMA/CA with RTS/CTS (NAV)