Wireless LANs (IEEE 802.11)

2025-02-21

Overview

Applications of Wireless LANs

- Key application areas:
  - LAN extension
  - cross-building interconnect
  - nomadic access
  - ad hoc networking

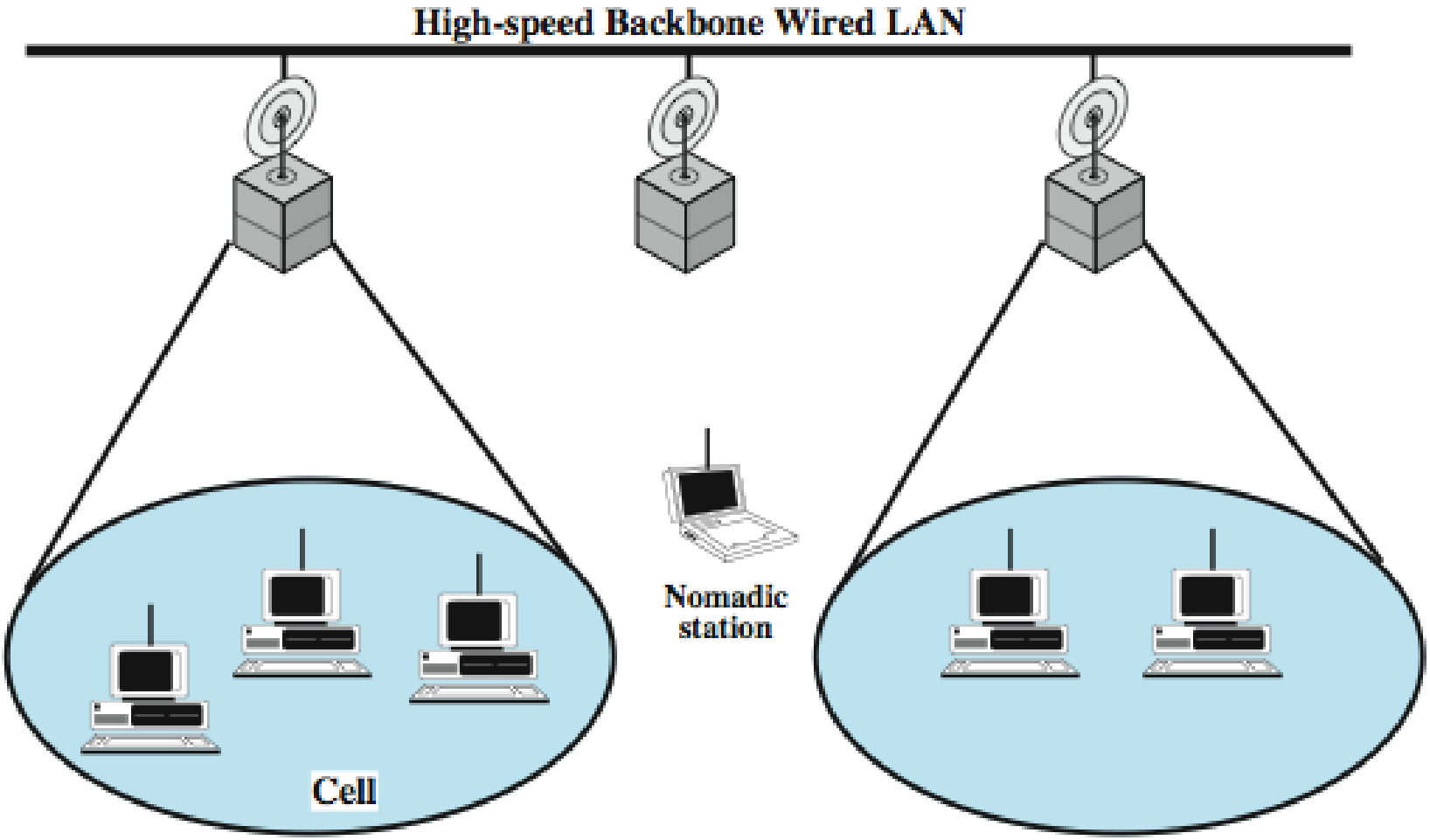
Applications of Wireless LANs

LAN Extension Wireless LAN linked into a wired LAN on same premises
Wired LAN Backbone Support servers and stationary workstations
Wireless LAN Stations in large open areas
Manufacturing plants, stock exchange trading floors, and warehouses
Cross-Building Interconnect Connect LANs in nearby buildings Wired or wireless LANs Point-to-point wireless link is used Devices connected are typically bridges or routers

Applications of Wireless LANs

Nomadic Access Wireless link between LAN hub and mobile data terminal equipped with antenna Laptop computer or notepad computer
Uses: Transfer data from portable computer to office server Extended environment such as campus
Ad Hoc Networking Temporary peer-to-peer network set up to meet immediate need Example: Group of employees with laptops convene for a meeting; employees link computers in a temporary network for duration of meeting

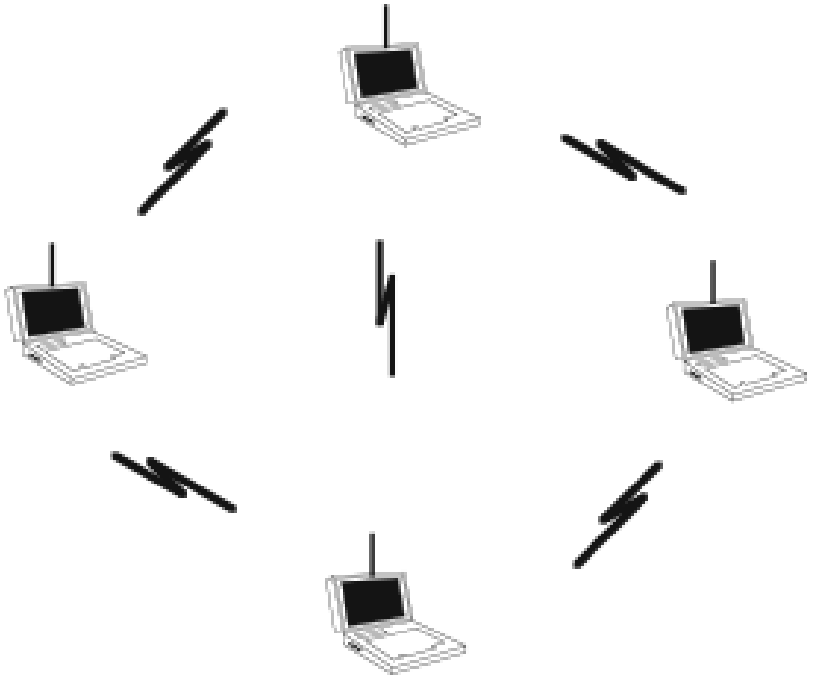
Infrastructure Wireless LAN



(a) Infrastructure Wireless LAN

Ad Hoc Networking

- temporary peer-to-peer network (no infrastructure)



(b) Ad hoc LAN

Wireless LAN Design Requirements

THROUGHPUT – should make efficient use of medium	**NUMBER OF NODES**- hundreds of nodes across multiple cells	**CONNECTION TO BACKBONE LAN** – use of control modules
SERVICE AREA – coverage area of 100 to 300m	**BATTERY POWER CONSUMPTION** – reduce power consumption while not in use	**TRANSMISSION ROBUST AND SECURITY**– reliability and privacy/security
COLLOCATED NETWORK OPERATION – possible interference between LANs	**LICENSE-FREE OPERATION** – not having to secure a license for the frequency band used by the LAN	**HANDOFF/ROAMING** – enable stations to move from one cell to another
DYNAMIC CONFIGURATION- addition, deletion, relocation of end systems without disruption		

IEEE 802.11 Standards

Standard	Scope
IEEE 802.11	Medium access control (MAC): One common MAC for WLAN applications
	Physical layer: Infrared at 1 and 2 Mbps
	Physical layer: 2.4-GHz FHSS at 1 and 2 Mbps
	Physical layer: 2.4-GHz DSSS at 1 and 2 Mbps
IEEE 802.11a	Physical layer: 5-GHz OFDM at rates from 6 to 54 Mbps
IEEE 802.11b	Physical layer: 2.4-GHz DSSS at 5.5 and 11 Mbps
IEEE 802.11c	Bridge operation at 802.11 MAC layer
IEEE 802.11d	Physical layer: Extend operation of 802.11 WLANs to new regulatory domains (countries)
IEEE 802.11e	MAC: Enhance to improve quality of service and enhance security mechanisms
IEEE 802.11f	Recommended practices for multivendor access point interoperability
IEEE 802.11g	Physical layer: Extend 802.11b to data rates >20 Mbps
IEEE 802.11h	Physical/MAC: Enhance IEEE 802.11a to add indoor and outdoor channel selection and to improve spectrum and transmit power management
IEEE 802.11i	MAC: Enhance security and authentication mechanisms
IEEE 802.11j	Physical: Enhance IEEE 802.11a to conform to Japanese requirements
IEEE 802.11k	Radio resource measurement enhancements to provide interface to higher layers for radio and network measurements
IEEE 802.11m	Maintenance of IEEE 802.11-1999 standard with technical and editorial corrections
IEEE 802.11n	Physical/MAC: Enhancements to enable higher throughput
IEEE 802.11p	Physical/MAC: Wireless access in vehicular environments
IEEE 802.11r	Physical/MAC: Fast roaming (fast BSS transition)
IEEE 802.11s	Physical/MAC: ESS mesh networking
IEEE 802.11.2	Recommended practice for the Evaluation of 802.11 wireless performance
IEEE 802.11u	Physical/MAC: Interworking with external networks

IEEE 802.11 version summery

IEEE Standard	802.11a	802.11b	802.11g	802.11n	802.11ac	802.11ax
Year Released	1999	1999	2003	2009	2014	2019
Frequency	5Ghz	2.4GHz	2.4GHz	2.4Ghz & 5GHz	2.4Ghz & 5GHz	2.4Ghz & 5GHz
Maximum Data Rate	54Mbps	11Mbps	54Mbps	600Mbps	3.6Gbps	10-12Gbps

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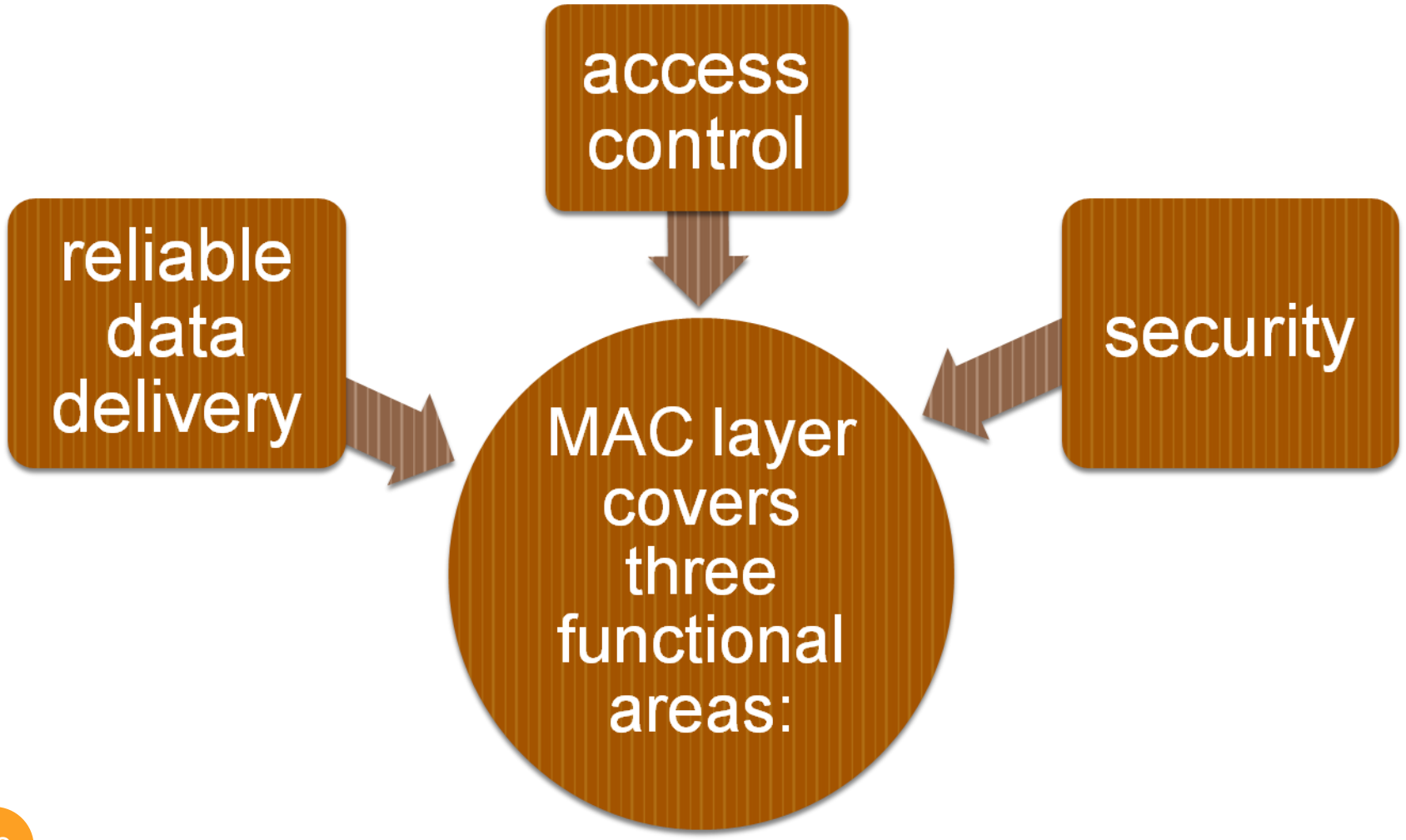
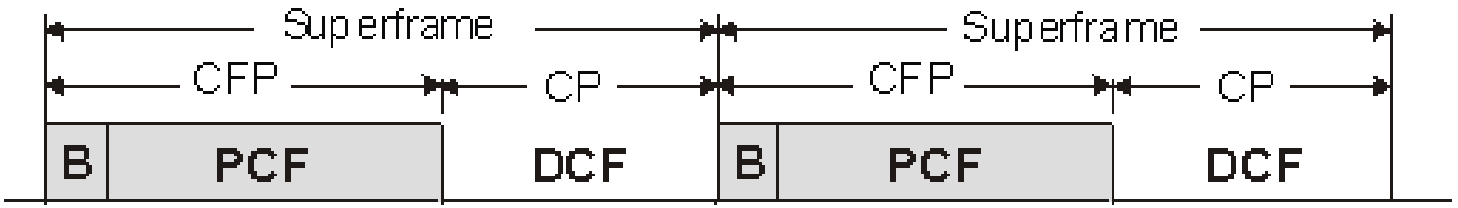
Medium Access Control

Medium Access Control



DCF and PCF

- PCF and DCF operate concurrently within the same BSS.
- The two access methods alternate, with a contention-free period (CFP) followed by a contention period (CP).



- DCF: fundamental access method of IEEE 802.11 MAC, implemented in all STAs.
  - known as CSMA/CA

Distributed Coordination Function (DCF)

DCF MAC Requirements

- To avoid interference among simultaneous transmissions
  - But enable as many non-interfering transmission as possible
  - Maintain fairness among transmissions
- No centralized coordinators: fully distributed operations
- No clock synchronization: asynchronous operations

CSMA/CA

- DCF sub-layer uses CSMA/CA
  - if station has frame to send it listens to medium
  - if medium idle, station may transmit
  - else waits until current transmission completes
- No collision detection since on wireless network, so use collision avoidance (backoff and RTS/CTS)
- DCF includes delays that act as a priority scheme
  - DIFS: DCF inter-frame space
  - SIFS: short inter-frame space (SIFS < DIFS)

Priority IFS Values

- SIFS (short IFS)
  - for all immediate response actions
- PIFS (PCF IFS)
  - used by the centralized controller in PCF scheme when issuing polls
- DIFS (DCF IFS)
  - used as minimum delay for asynchronous frames contending for access

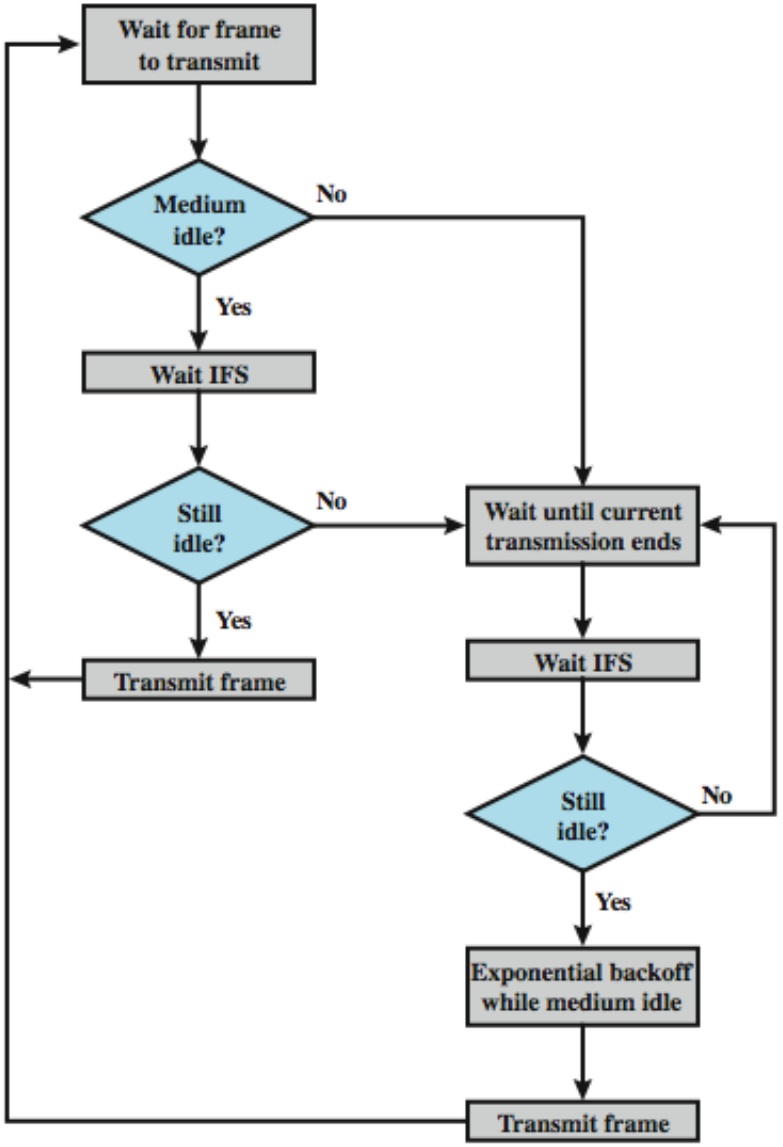
SIFS Use

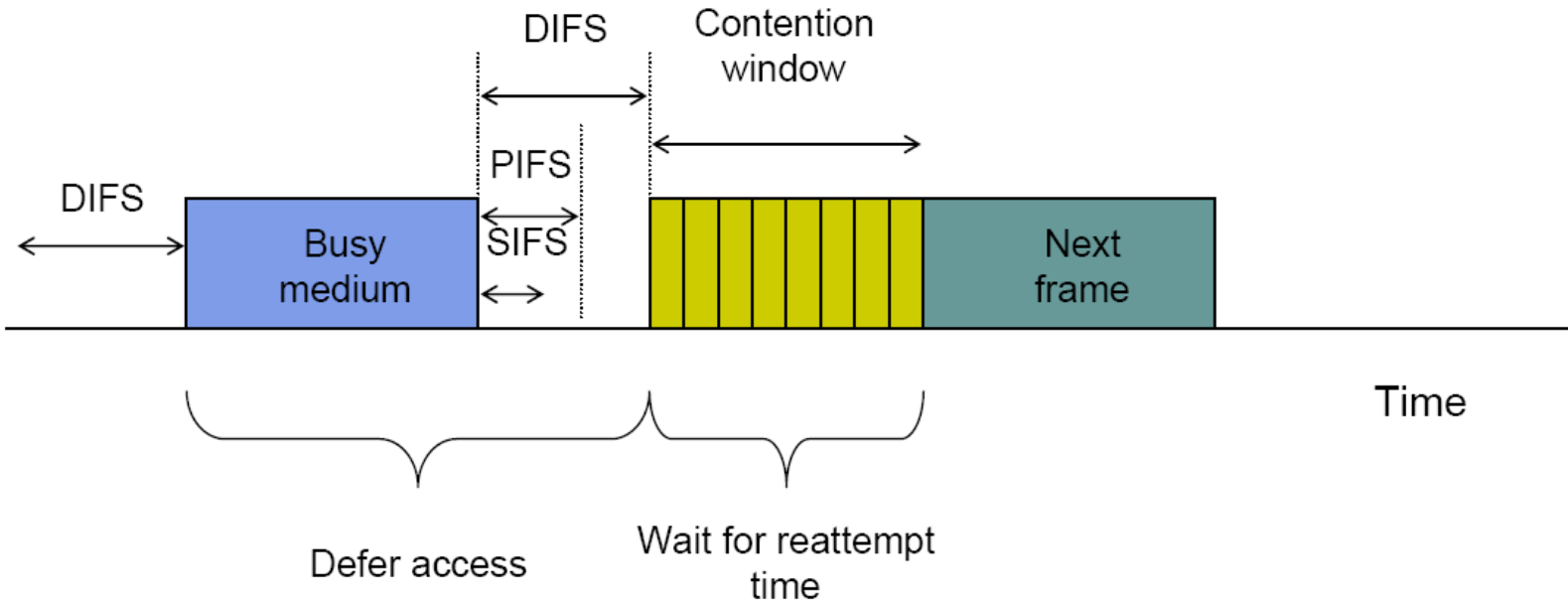
- SIFS gives highest priority
  - over stations waiting PIFS or DIFS time
- SIFS used in following circumstances:
  - Acknowledgment (ACK)
    - station responds with ACK after waiting SIFS gap
    - for efficient collision recovery (there is no collision detection) and multi-frame transmission
  - Clear to Send (CTS)
    - station ensures data frame gets through by issuing RTS
    - and waits for CTS response from destination
  - Poll response
    - see Point Coordination Function (PCF) discussion later

PIFS and DIFS Use

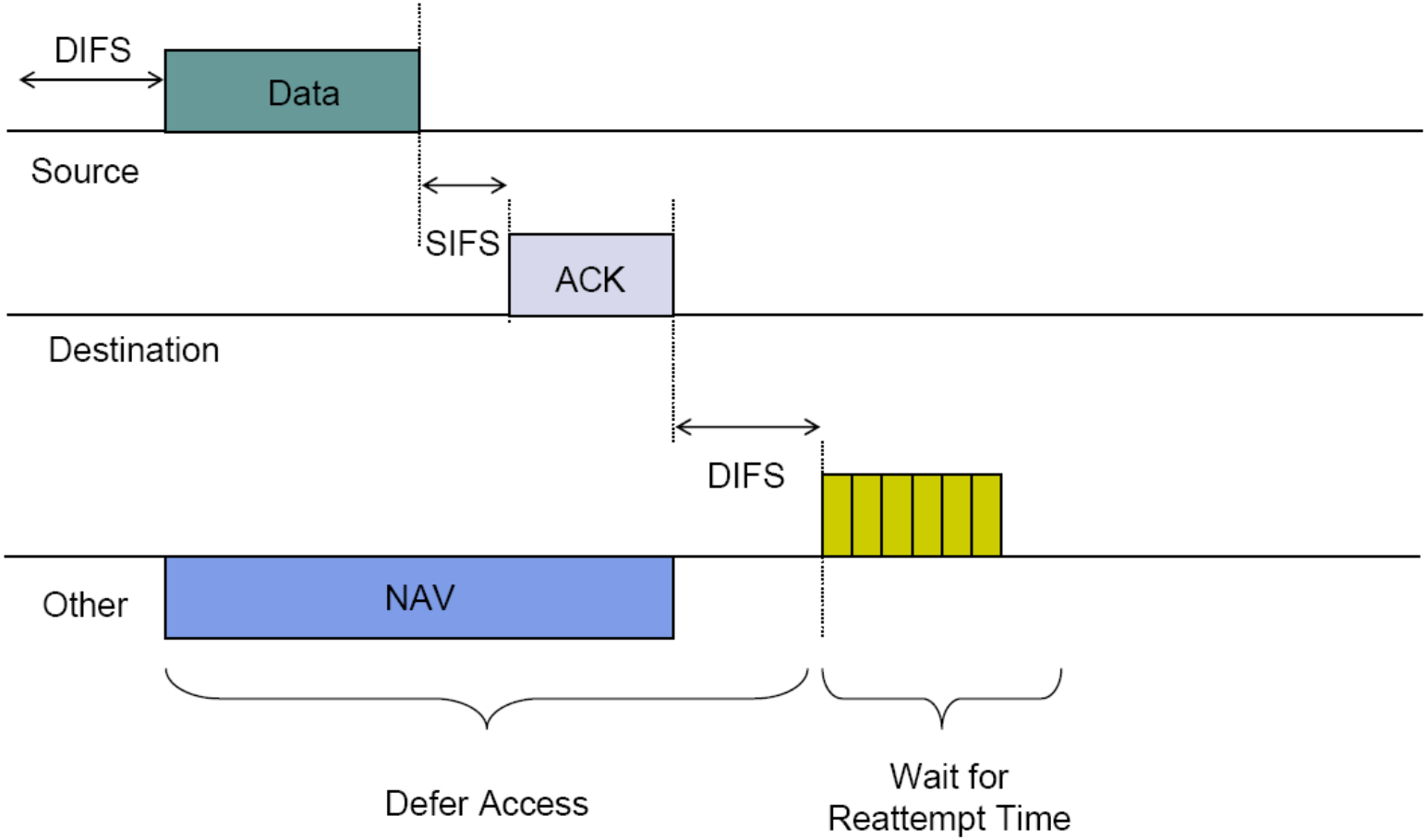
- PIFS used by centralized controller
  - for issuing polls
  - has precedence over normal contention traffic
  - but not SIFS
- DIFS used for all ordinary asynchronous traffic

IEEE 802.11 Medium Access Control Logic





Basic CSMA/CA operations



Transmission without RTS/CTS

Backoff Interval

- When channel is busy, choose a backoff interval in the range [0, *cw*]
- Count down the backoff interval when medium becomes idle.
- Count down is suspended if medium becomes busy again.
- When backoff interval reaches 0, transmit RTS.
- Binary exponential backoff in 802.11 DCF:
  - When a node fails to receive CTS, *cw* is doubled up (up to an upper bound).
  - When a data transfer completes successfully, *cw* is reset to cw_{min}.

- MAC works with a single FIFO 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.
- If the medium becomes busy during backoff, the timer is stopped and a new NAV is set. After NAV, back off continues.

DCF Backoff

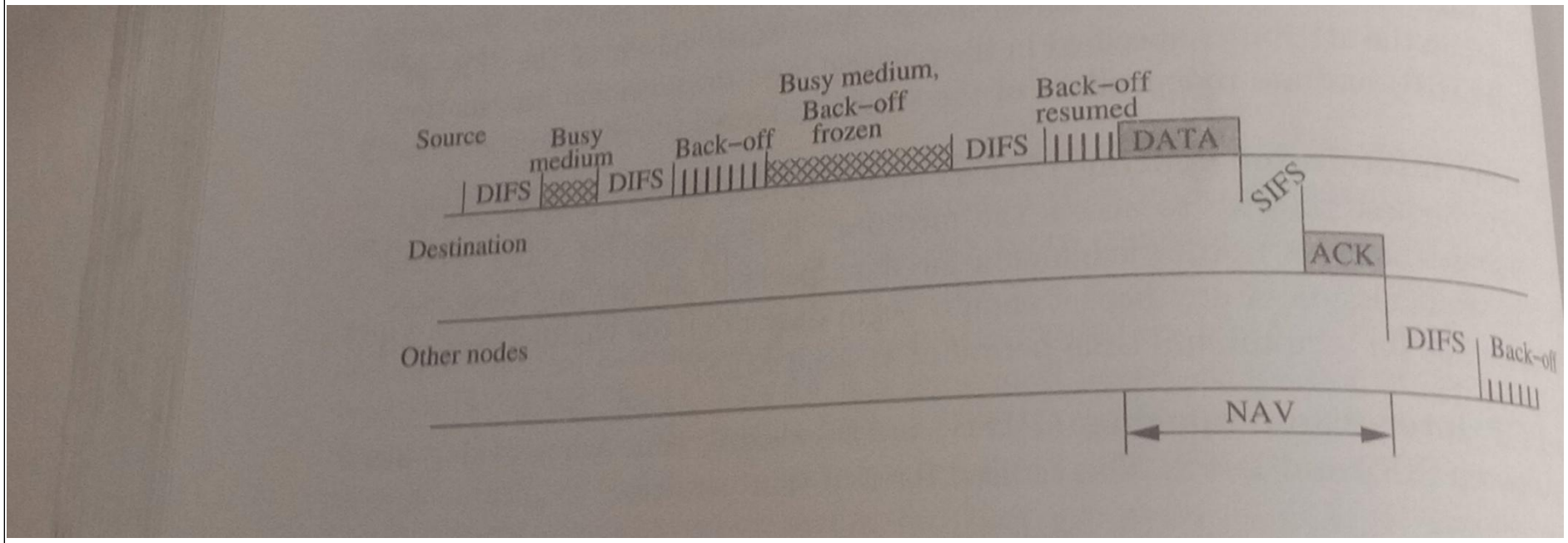
Initially and after each successful transmission,

$CW = CW_{min}$

After each unsuccessful attempt

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

CSMA CA Example

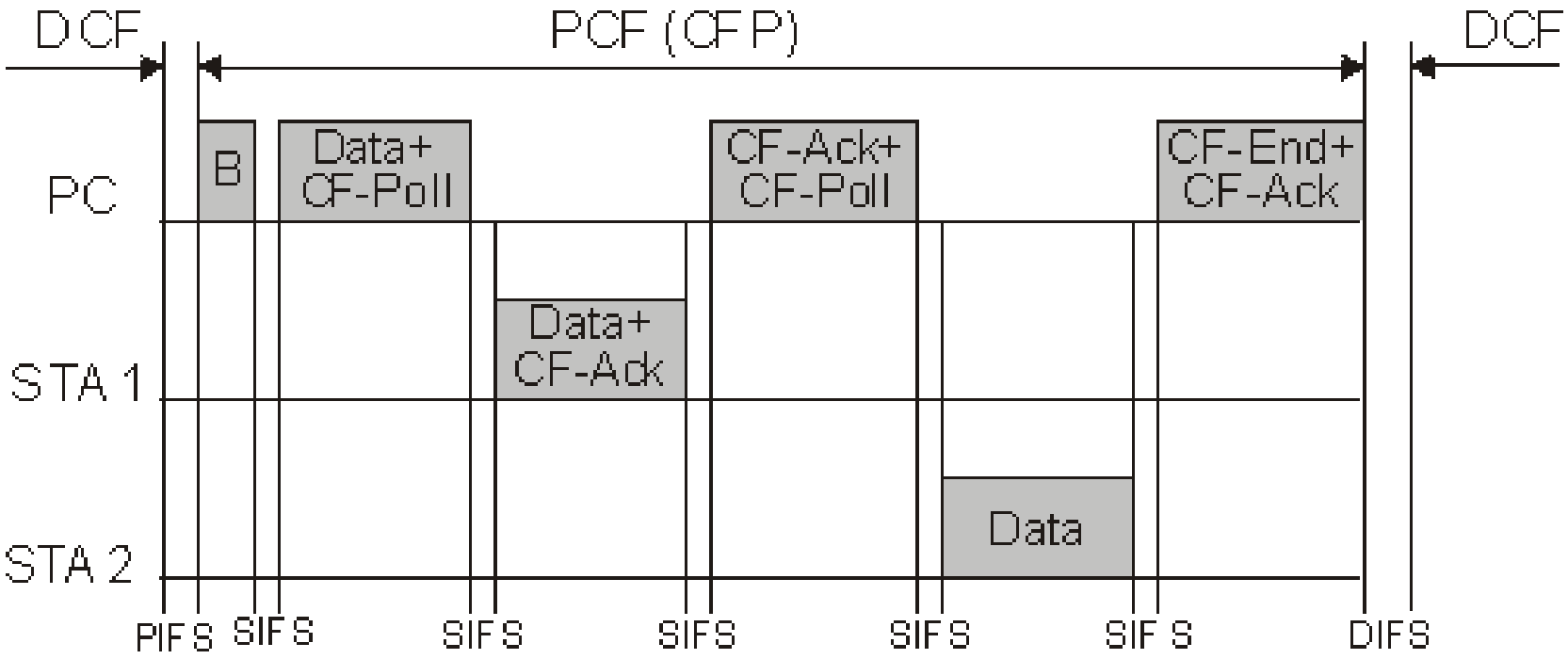


Point Coordination Function (PCF)

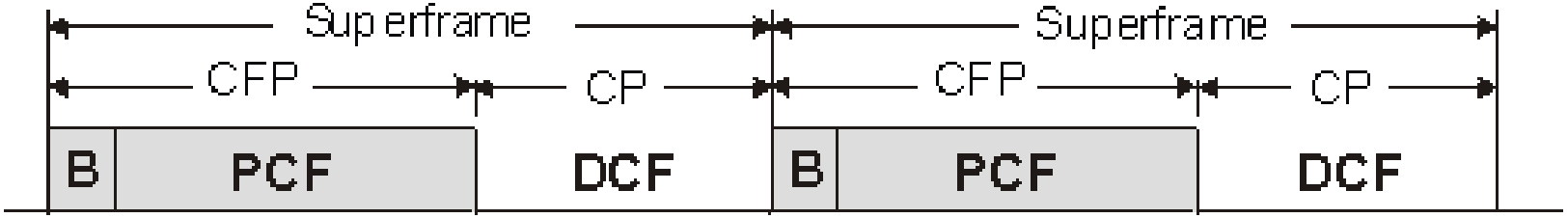
PCF

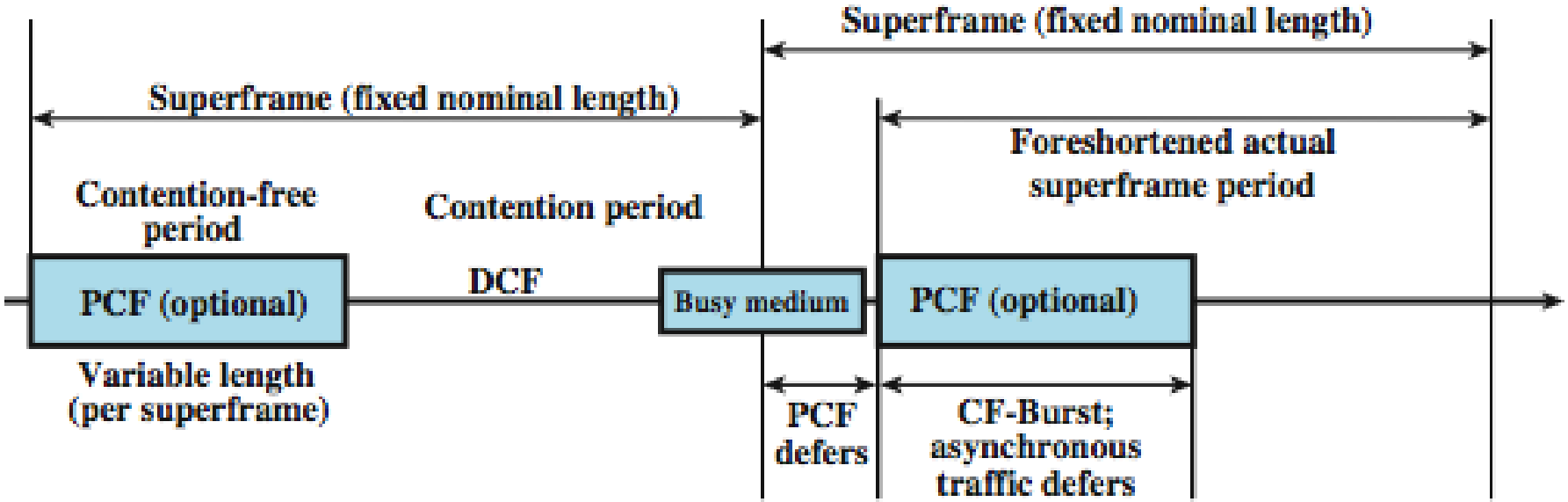
- Supports time-bounded services.
- Lets stations to have priority access to the wireless medium.
- Polling stations one by one (centralized operation)
- Coordinated by Point Coordinator (PC), typically collocated with the AP.
- PCF has higher priority than the DCF.
- Beacon frame is a management frame that maintains the synchronization of the timers in the stations and delivers protocol related parameters.

PCF Examples

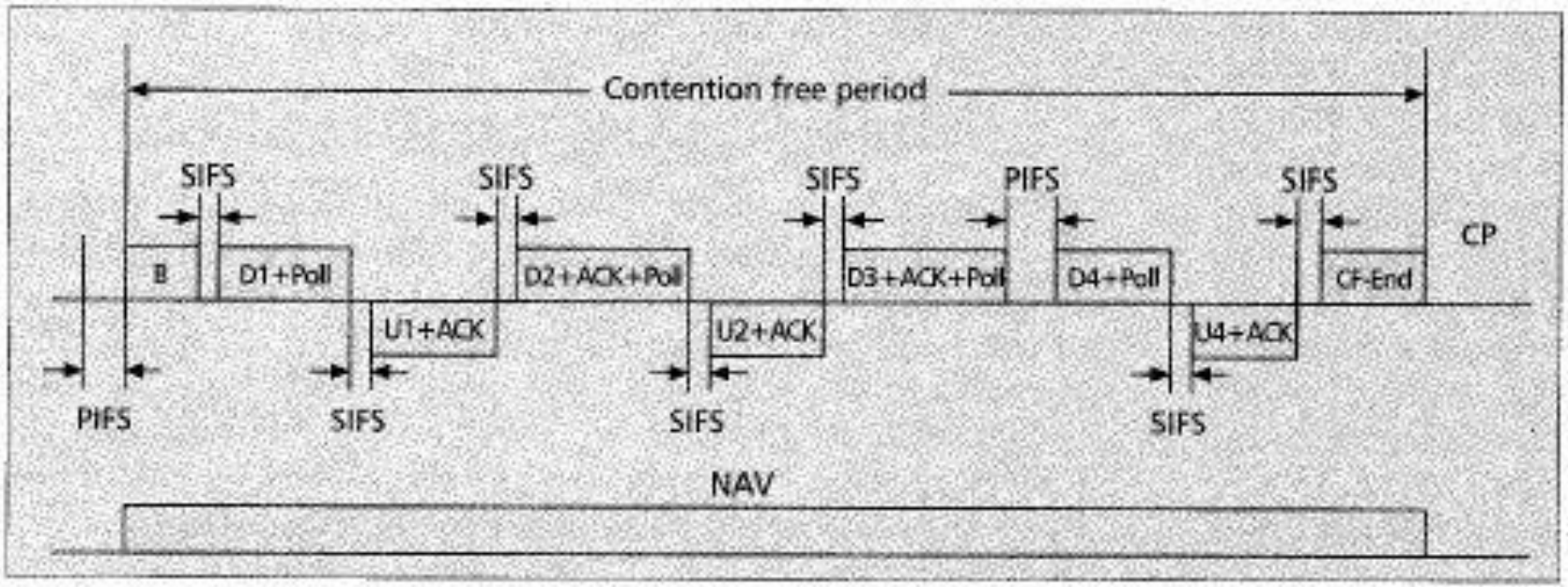


PCF Superframe Timing

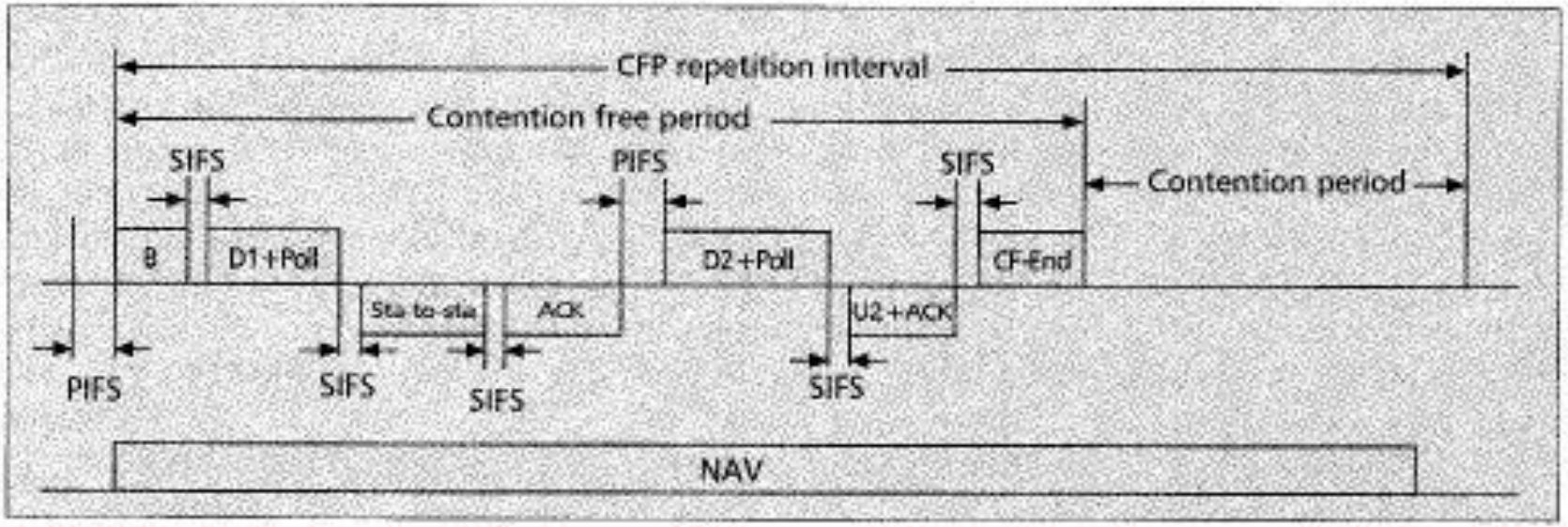




(b) PCF Superframe Construction



■ **Figure 9.** *PC-to-station transmission.*

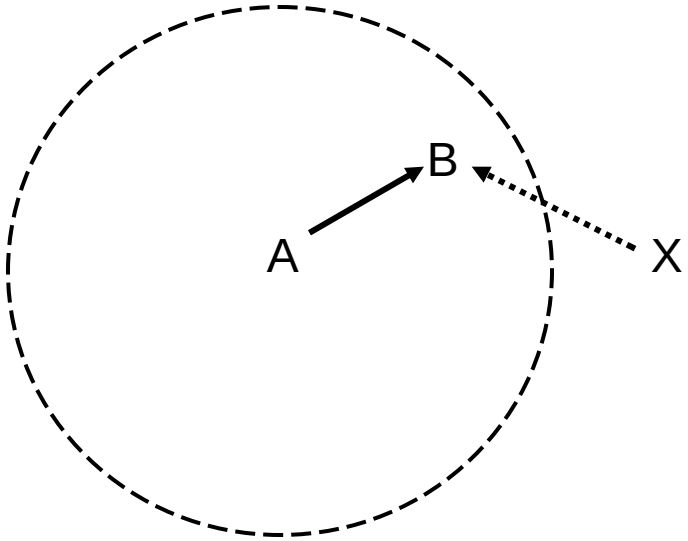


■ **Figure 10.** *Station-to-station transmissions.*

Carrier Sensing

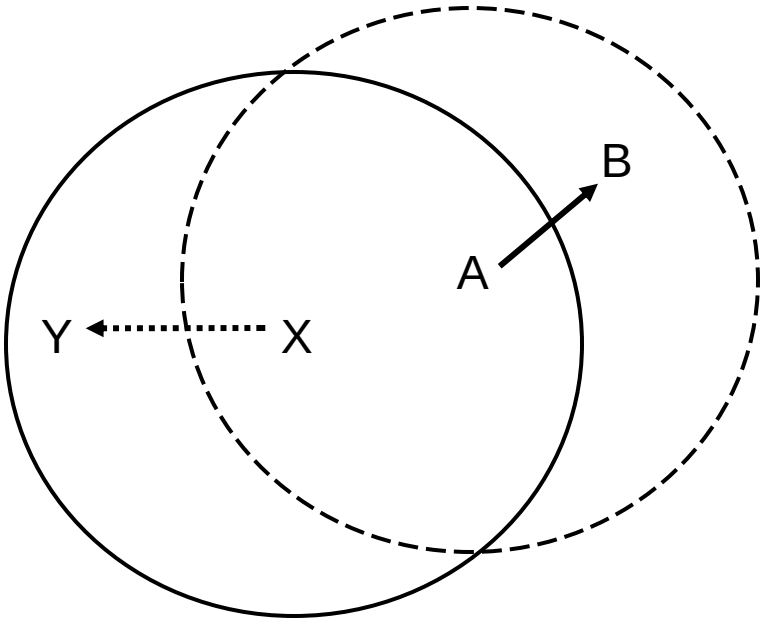
- Problems
  - Hidden terminal problem
  - Exposed terminal problem
- Note: contention matters only at the receiver's terminal

Hidden Terminal Problem



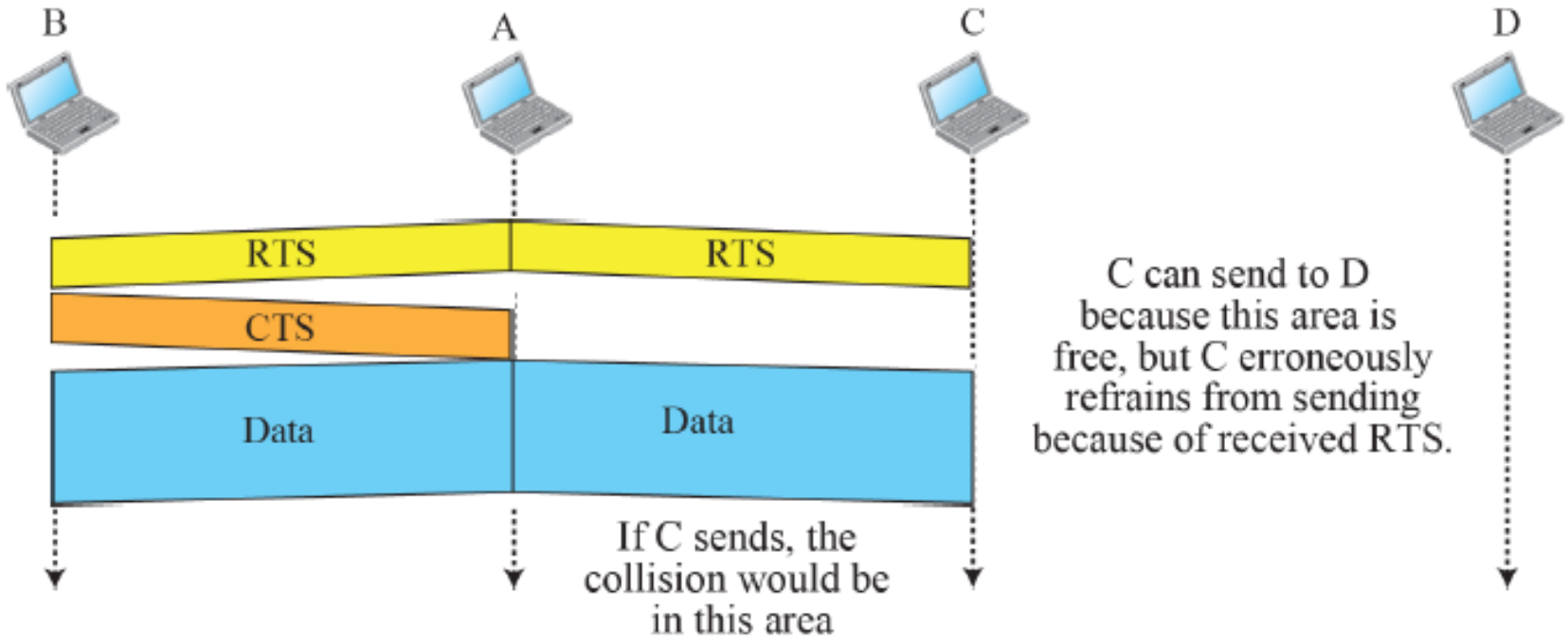
No carrier ≠ OK to transmit

Exposed Terminal Problem



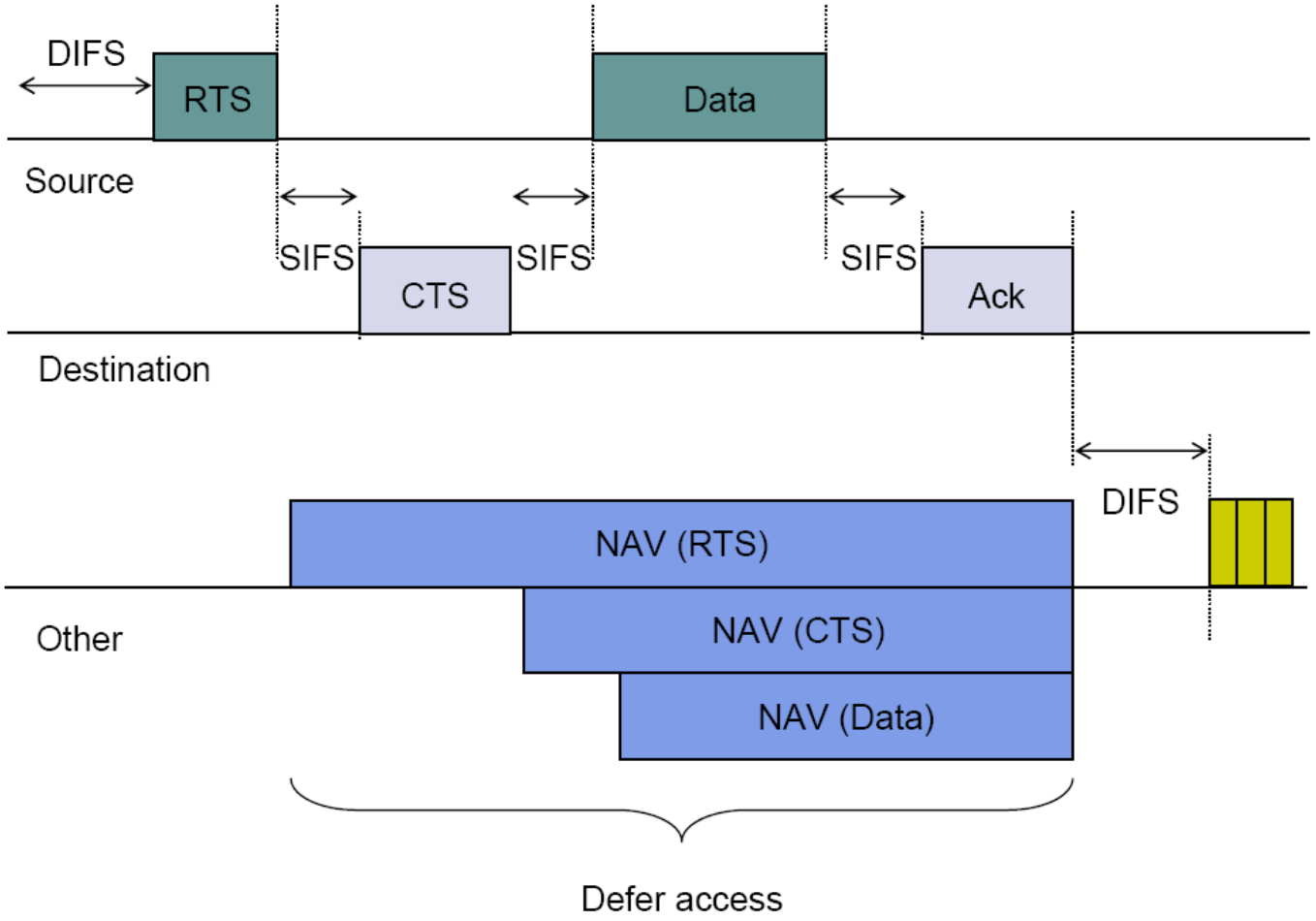
Presence of carrier ≠ holds off transmission

Exposed station problem



Solutions

- MACA [Karn 1990]
  - Proposes to solve the hidden terminal problem by RTS/CTS dialog
- MACAW [Bharghanvan 1994]
  - Increasing reliability by RTS/CTS/DATA/ACK dialog
- IEEE 802.11
  - Distributed Coordination Function (DCF)
  - Also use RTS/CTS/DATA/ACK dialog



Transmission with RTS/CTS

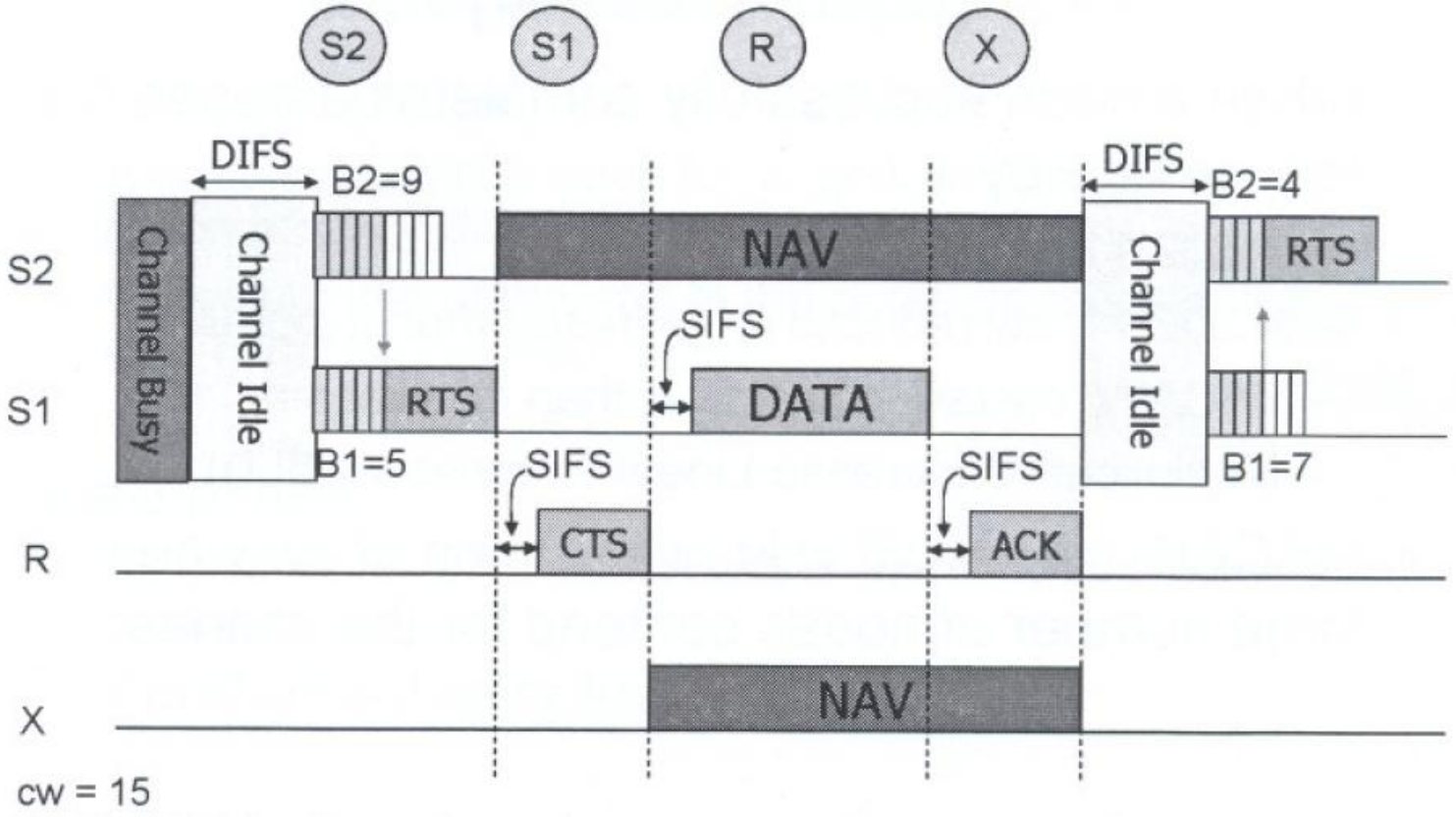
IEEE 802.11 DCF (1)

- CSMA/CA
  - Contention-based random access
  - Collision detection not possible while transmitting
- Uses RTS/CTS exchange to avoid hidden terminal problem
  - Any node overhearing a CTS cannot transmit for the duration of the transfer.
  - Any node overhearing an RTS cannot transmit for the duration of the transfer (to avoid collision with ACK)
- Uses ACK to achieve reliability

IEEE 802.11 DCF (2)

- Carrier sense in 802.11
  - Physical carrier sense
  - Virtual carrier sense using Network Allocation Vector (NAV)
    - RTS/CTS specify duration of subsequent DATA/ACK
    - NAV is updated based on overheard RTS/CTS /DATA
- Collision avoidance
  - Nodes stay silent when carrier sensed busy (physical/virtual)
  - Backoff intervals are used to reduce collision probability

IEEE 802.11 CSMA/CA – Example



DIFS: DCF inter-frame space

SISF: short inter-frame space

Disadvantages of IEEE 802.11 DCF

- High power consumption
- Hidden terminal problem not totally solved (e.g., collision of RTS)
- Exposed terminal problem not solved
- Fairness problem among different transmitting nodes
- Only providing best-effort service

IEEE 802.11 Physical Layer

802.11 Physical Layer

	802.11	802.11a	802.11b	802.11g
Availabl bandwidt	83.5 MHz	300 MHz	83.5 MHz	83.5 MHz
Unlicens frequency operatio	2.4 – 2.483 DSSS, FHS	5.15 – 5.3 OFDM 5.725 – 5. GHz OFDM	2.4 – 2.483 DSSS	2.4 – 2.483 DSSS, OFD
Number of overlapp channel	3 (indoor/out	4 indoor 4 (indoor/out 4 outdoo	3 (indoor/out	3 (indoor/out
Data rate channel	1, 2 Mbps	6, 9, 12, 24, 36, 48 Mbps	1, 2, 5.5, Mbps	1, 2, 5.5, 11, 12, 18 36, 48, 54
Compatibi	802.11	Wi-Fi5	Wi-Fi	Wi-Fi at 11 and below