EEC173B/ECS152C, Winter 2006

Wireless LANs
- Evolution of Technology & Standards
- IEEE 802.11
  - Design Choices
  - Architecture & Protocols
  - PHY layer
  - MAC layer design

Acknowledgment: Selected slides from Prof. Schiller & Prof. A. Joseph

Wireless LANs: Design Requirements

- Global, seamless operation
  - No special permissions or licenses needed to use the LAN
  - Ad hoc networks, no planning, no wiring
- Simple MAC to support multiple PHY layers
- Mechanism to support multiple overlapping network
  - Provisions to handle interference
  - Mechanisms to handle hidden terminals
- Robust transmission technology
- Easy to use for everyone, simple management
- Low power for battery use
- Security (no one should be able to read my data), privacy (no one should be able to collect user profiles), safety (low radiation)
- Transparency concerning applications and higher layer protocols, but also location awareness if necessary

Design Choices

Q1: Which frequency range to use?

Q2: PHY layers: IR or RF?

Q3: MAC: CSMA (random access) or TDMA?

Q4: Radio Technology: Direct-sequence of frequency-hopping?

Q5: Peer to peer architecture of Base-station approach?

Evolution

- Early experiences (1970-72): IBM, HP, Motorola
  - Abandoned due to limited performance and unavailability of frequency bands
- Early challenges:
  - Complexity and cost
  - Bandwidth
  - Coverage
  - Interference
  - Frequency administration
- Emergence of unlicensed bands
  - Release of Industrial, Scientific and Medical (ISM) bands in 1985
- Applications: military, home and enterprise networks, mobile networks, teethe less access

IEEE 802.11

- Standardization group formed in 1990, first standards completed in 1997
- IEEE 802.11 is the first WLAN standard; only one to secure a market
- IEEE 802.11b
  - Also known as wireless Ethernet and Wi-Fi
  - Operates in an unlicensed radio spectrum at 2.4 GHz
  - Wireless Ethernet access at 11 Mbps
- Other standards: 802.11a, 802.11g, 802.11e, …
- Supports both infrastructure as well as ad hoc modes

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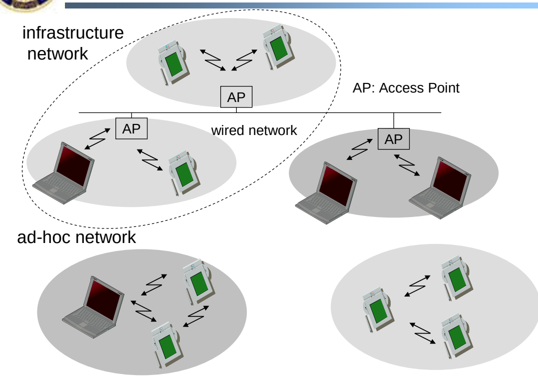
Comparison: infrastructure vs. ad-hoc networks



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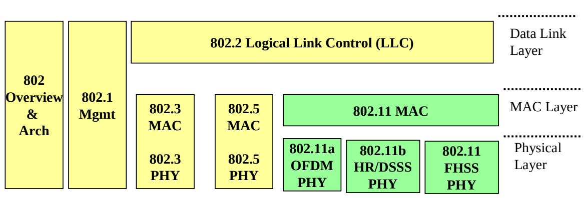
IEEE 802 Standards & OSI Model



- Observe 802.11 MAC is common to all 802.11 Physical Layer (PHY) standards
- 802.11 PHY is split into two sublayers
  - Physical layer convergence procedure (PLCP)
  - Physical Medium Dependent (PMD)

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Related Standards

- Bluetooth
  - Originally intended for interconnecting computing and communication devices
- HIPERLAN
  - European standard for wireless LANs
- IEEE 802.16 Broadband Wireless
  - Addresses needs of fixed broadband wireless access replacing fibers, cables, etc.

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Q1: Which frequency range to use?

802.11 Standards and Spectrum

Key Standards	Max Rate	Spectrum (U.S.)	Year
802.11	2 Mbps	2.4 GHz	1997
802.11a	54 Mbps	5 GHz	1999
802.11b (WiFi)	11 Mbps	2.4 GHz	1999
802.11g	54 Mbps	2.4 GHz	2003

- 2.4-2.5 GHz for all above except 802.11a, referred to as C-Band Industrial, Scientific, and Medical (ISM) Band
  - Microwave ovens and some cordless phones operate in the same band
- 802.11a uses Unlicensed National Information Infrastructure bands
  - 5.15-5.25 GHz, 5.25-5.35 GHz, 5.725-5.825 GHz

ISM Bands Trafeoffs

	915 MHz	2.4 GHz	5.8 GHz
Bandwidth	26 MHz	83.5 MHz	125 MHz
Availability	US/Canada	World-wide	US/Canada
Cost	Low	Medium	High
Usage	High (Very crowded)	Medium (Getting busy)	Low (Empty)

Q2: Physical Layer Alternatives (1)

- Infrared (IR) vs. Radio (RF)
- IR LAN Characteristics
  - Uses IR diodes, infrared light: 850-950 nanometers
  - Range is a function of
    - Xmit power (received optical power varies as $1/r^2$)
    - Background noise (fluorescent lights, sunlight)
    - Type of link: Directed, non-directed, line-of-sight, diffuse
    - Multiple reflections (walls, furniture etc.)
  - No Rayleigh fading (multipath effects)
  - Example Non-directed (15-75 degree capture half angle)
    - IRDA (laptops/cell phones), Rednet (alarm monitoring), ParcTab (Xerox Parc PDA)

Q2: Physical Layer Alternatives (2)

- Radio (RF)
  - Wide area instead of “spot” connectivity
  - More complicated circuitry, regulatory
  - Constraints (ISM bands) in the U.S.,
    - typically using the license free ISM band at 2.4 GHz
  - Very susceptible to Rayleigh fading and Inter-symbol interference

Comparison: Infrared vs. Radio Transmission

Infrared

- Advantages
  - Simple circuitry, cheap, available in many mobile devices
  - No regulatory constraints (no licenses needed)
  - Simple shielding possible
- Disadvantages
  - Interference by sunlight, heat sources etc.
  - Many things shield or absorb IR light
  - Low bandwidth
- Example
  - IrDA (Infrared Data Association) interface available everywhere

Radio

- Advantages
  - Experience from wireless WAN and mobile phones can be used
  - Coverage of larger areas possible (radio can penetrate walls, furniture etc.)
- Disadvantages
  - Very limited license free frequency bands
  - Shielding more difficult, interference with other electrical devices
- Example
  - WaveLAN, HIPERLAN, Bluetooth

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IR vs. RF

	IR	RF
Cost	<$10	<$20
Regulation	None	No Licence (ISM bands)
Interference	Ambient Light	Radiators
Coverage	Spot	Wide Area
Performance	Moderate	Depends on BW
Coexistence	Limited	Possible

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Q3: Media Access

- Why MAC? Same reason as for wired networks
  - Contention/floor control
- Media in wireless networks is shared and is scarce – access must be controlled
- Observations:
  - Contention is at the receiver, not at the sender – makes the carrier sense approach inappropriate
  - Unlike Ethernet, congestion is location-dependent
  - The media access protocol should propagate congestion information explicitly rather than having each device learn about congestion independently
  - Media access protocol should propagate synchronization information about contention periods, so that all devices can contend effectively

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CSMA vs. TDMA

- TDMA (controlled access)
  - Simple remote stations (unless remotes can be both master/slave)
  - High power saving potential thru scheduling
  - Bluetooth approach
- CSMA (random access)
  - Can be implemented on an Ethernet chipset
  - QoS issues (uneven delays)
  - IEEE 802.11 uses a modified version of this

*** *More about this later after we introduce the IEEE 802.11 architecture and protocol stacks*

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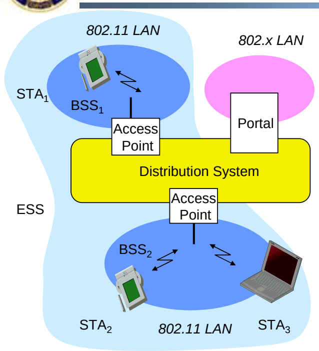
802.11 - Architecture of an Infrastructure Network



- Station (STA)
  - Terminal with access mechanisms to the wireless medium and radio contact to the access point
- Basic Service Set (BSS)
  - Group of stations using the same radio frequency
- Access Point
  - Station integrated into the wireless LAN and the distribution system
- Portal
  - Bridge to other (wired) networks
- Distribution System
  - Interconnection network to form one logical network (EES: Extended Service Set) based on several BSS

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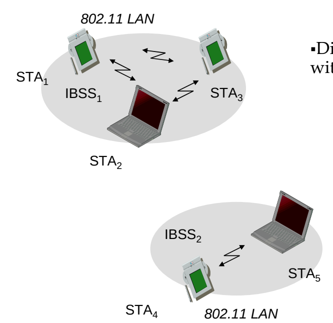
802.11 - Architecture of an Ad-hoc Network



- Direct communication within a limited range
  - Station (STA): terminal with access mechanisms to the wireless medium
  - Independent Basic Service Set (IBSS): group of stations using the same radio frequency

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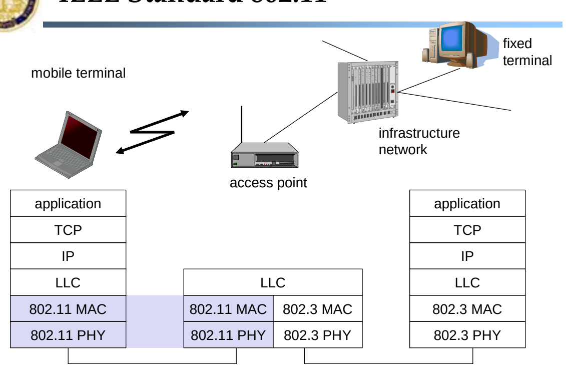
IEEE Standard 802.11



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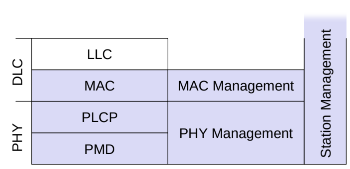
802.11 - Layers and functions

- MAC
  - Access mechanisms, fragmentation, encryption
- MAC Management
  - Synchronization, roaming, MIB, power management
- PLCP (Physical Layer Convergence Protocol)
  - Clear channel assessment signal (carrier sense)
- PMD (Physical Medium Dependent)
  - Modulation, coding
- PHY Management
  - channel selection, MIB (management information base)



- Station Management
  - Coordination of all management functions

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PHY Layer

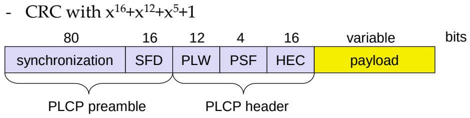
- When the MAC protocol data unit (MPDU) arrive at the PLCP layer, a header is attached that is designed specifically for the PMD
- The PLCP packet is then transmitted by the PMD according to specification of the signaling techniques
- IEEE 802.11 defines three PLCP packet formats: 2 radio (typ. 2.4 GHz), 1 IR
  - FHSS (frequency hopping spread spectrum)
  - DSSS (direct sequence spread spectrum)
  - DFIR (diffused infrared)

FHSS

- PMD hops over 78 channels of 1 MHz each in the center of 2.44 GHz ISM bands
- Spreading, d-espreading, typically, 1 Mbit/s
  - Min. 2.5 frequency hops/s (USA), two-level GFSK modulation
- Each BSS can select one of the three patterns of 26 hops:
  - (0, 3, 6, 9, …, 75)
  - (1, 4, 7, 10, …, 76)
  - (2, 5, 8, 11, …, 77)
- IEEE 802.11 specifies specific random hopping pattern for each of these frequency groups that facilitates multivendor interpretability
- Multiple BSS can co-exist in the same area by up to three APs using different frequency groups

FHSS PHY packet format

- Synchronization
  - Synch with 010101... pattern
- SFD (Start Frame Delimiter)
  - 0000110010111101 start pattern
- PLW (PLCP_PDU Length Word)
  - Length of payload incl. 32 bit CRC of payload, PLW < 4096
- PSF (PLCP Signaling Field)
  - Data of payload (1 or 2 Mbit/s)
- HEC (Header Error Check)
  - CRC with $x^{16}+x^{12}+x^5+1$



DSSS

- DSSS communicates using non-overlapping pulses at 11 Mcps
- The ISM band at 2.4 GHz is divided into 11 overlapping channels spaced at 5 MHz
  - A PHY layer managemnet sublayer of AP covering a BSS can select one of the choices
- Because of wider bandwidth, DSSS provides a better coverage and a more stable signal
- DBPSK modulation for 1 Mbit/s (Differential Binary Phase Shift Keying), DQPSK for 2 Mbit/s (Differential Quadrature PSK)
- Preamble and header of a frame is always transmitted with 1 Mbit/s, rest of transmission 1 or 2 Mbit/s
- Chipping sequence: +1, -1, +1, +1, -1, +1, +1, +1, -1, -1, -1 (Barker code)
- Max. radiated power 1 W (USA), 100 mW (EU), min. 1mW

DSSS PHY packet format

- Synchronization
  - synch., gain setting, energy detection, frequency offset compensation
- SFD (Start Frame Delimiter): 1111001110100000
- Signal
  - Data rate of the payload (0A: 1 Mbit/s DBPSK; 14: 2 Mbit/s DQPSK)
- Service
  - future use, 00: 802.11 compliant
- Length of the payload
- HEC (Header Error Check)
  - protection of signal, service and length, $x^{16}+x^{12}+x^5+1$

128	16	8	8	16	16	variable	bits
synchronization	SFD	signal	service	length	HEC	payload	
PLCP preamble		PLCP header					

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DFIR (diffused infrared)

- Infrared
  - 850-950 nm, diffuse light
  - Typically 10 m range
  - Carrier detection, energy detection, Synchonization

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802.11 - MAC layer

- Functions:
  - Control media access for reliable data delivery
  - Support roaming, authentication, power conservation
- Basic services provided by MAC layer
  - Asynchronous Data Service (mandatory)
    - Exchange of data packets based on "best-effort"
    - Support of broadcast and multicast
  - Time-Bounded Service (optional)
    - implemented using PCF (Point Coordination Function)

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Reliable Data Delivery

- High degree of unreliability and large timers for retransmissions used in higher layers motivates to deal with errors at the MAC layer
- Each transmission is followed by an ACK as an atomic unit. Retransmission is done if the ACK is not received

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DFWMAC

- MAC mechanisms are also called distributed foundation wireless medium access control (DFWMAC)
- Three access methods has been defined
  1. Mandatory basic method based on CSMA/CA
     - Collision avoidance via randomized "back-off" mechanism
     - Minimum distance between consecutive packets
     - ACK packet for acknowledgements (not for broadcasts)
  2. Optional contention-free method w/ RTS/CTS
     - Avoids hidden terminal problem
  3. Optional contention-free method for time-bounded service
     - Access point polls terminals according to a list
- Method 1 + 2: Distributed Coordination Function (DCF)
- Method 3: Point Coordinated Function (PCF) Centralized

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Carrier Sense Multiple Access (CSMA appropriateness?)

- Carrier sense provides information about potential collision at the sender, but not at the receiver
- Since the receiver and sender are not collocated, carrier sense does not provide adequate information for collision avoidance – interference at the sender does not imply interference at the receiver

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Carrier Sensing

- Carrier sensing in IEEE 802.11 is performed physically or virtually
- PHY sensing is through the clear channel assignment (CCA) signal produced by PLCP
- CCA is generated by sensing detected bits or by checking the radio subsystem
- Virtual carrier sensing is done based on a network allocation vector (NAV)
  - Used in combination of RTS/CTS
  - More later …

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MAC: Time Slots & Inter-Frame Spacing

- All access methods use concept of "slots"
  - Slot time is derived from medium propagation delay, transmitter delay, and other PHY dependent paramters
  - 50 μs for FHSS and 20 μs for DSSS
- Medium can be busy or idle (detected by CCA)
- Use different parameters to control the waiting time before medium access, or *Inter-Frame Spacing*
  - i.e., how long should one wait when the medium is "free" before accessing the channel

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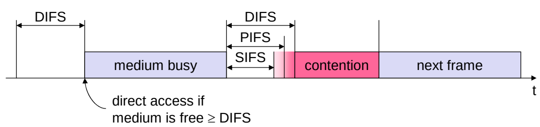
Priorities of Medium Access

- Priorities defined through different inter frame spaces
  - no guaranteed, hard priorities
- SIFS (Short Inter Frame Spacing)
  - Highest priority, for ACK, CTS, polling response
- PIFS (PCF IFS), typically SIFS + 1 slot time
  - Medium priority, for time-bounded service using PCF
- DIFS (DCF IFS), typically SIFS + 2 slot time
  - Lowest priority, for asynchronous data service



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IEEE 802.11 DCF

- DCF sublayer makes use CSMA/CA
  - Contention-based random access
  - Collision detection not possible while a node is transmitting
  - Collision avoidance
    - Nodes stay silent when carrier sensed busy (physical/virtual)
    - Backoff intervals used to reduce collision probability
- Uses RTS-CTS exchange to avoid hidden terminal problem
  - Any node overhearing a CTS cannot transmit for the duration of the transfer
  - Any node receiving the RTS cannot transmit for the duration of the transfer
    - To prevent collision with ACK when it arrives at the sender
- Uses ACK to achieve reliability

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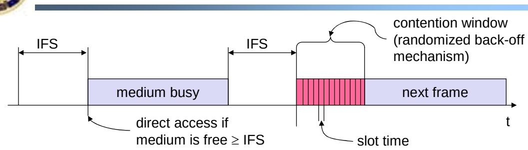
802.11 DCF- CSMA/CA access method (1)



- Station ready to send starts sensing the medium (Carrier Sense based on CCA, Clear Channel Assessment)
- If the medium is free for the duration of an IFS, the station can start sending (IFS depends on service type)
- If the medium is busy, the station has to wait for a free IFS, then the station must additionally wait a random back-off time (collision avoidance, multiple of slot-time)
  - Choose a random backoff interval in the range [0,CW]
  - CW is contention window

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Backoff Timer for Fairness

- Basic CSMA/CA is not fair
  - Independent of the overall time a node has already waited for transmission, each node has to choose a random timer in the next cycle, and has the same chances of transmitting data
- Backoff Timer
  - Choose a random backoff interval between [0,CW]
  - Count down the backoff interval when medium is idle
  - Count-down is suspended if medium becomes busy
  - When channel is idle, continue to count down
  - When backoff interval reaches 0, transmit data

=> Stations waiting longer have advantage over stations that just entered

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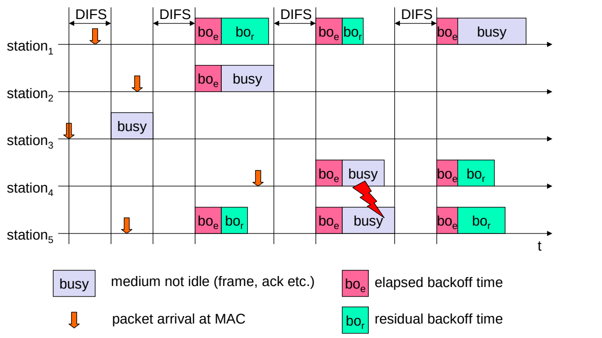
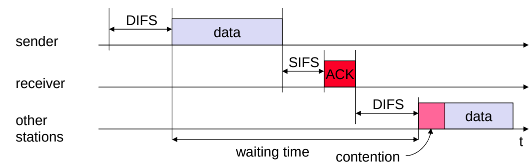
CSMA/CA Example - competing stations



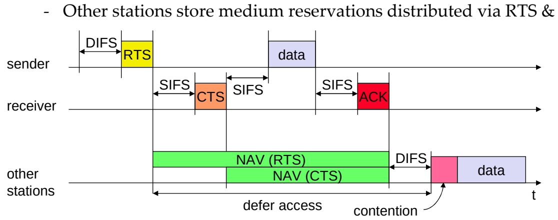
802.11 DCF CSMA/CA: ACK

- Sending unicast packets
  - Station has to wait for DIFS before sending data
  - Receivers acknowledge at once (after waiting for SIFS) if the packet was received correctly (CRC)
  - Automatic retransmission of data packets in case of transmission errors

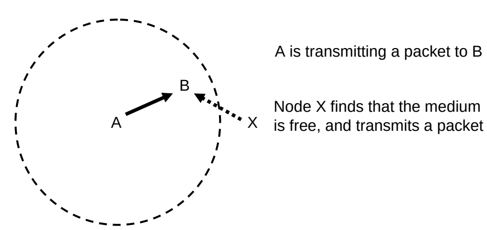


802.11 DCF-RTS/CTS

- Contention-free method
  - Station can send RTS with reservation parameter after waiting for DIFS (reservation determines amount of time the data packet needs the medium)
  - Acknowledgement via CTS after SIFS by receiver (if ready to receive)
  - Sender can now send data at once, acknowledgement via ACK
  - Other stations store medium reservations distributed via RTS & CTS

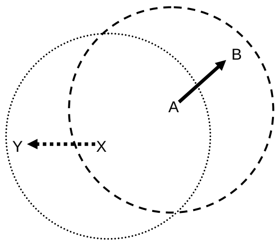


A Case for RTS/CTS: Hidden Terminal Problem



No carrier ≠OK to transmit

Exposed Terminal Problem



A is transmitting a packet to B

X can not transmit to Y, even though it will not interfere at B

Presence of carrier ≠ holds off transmission

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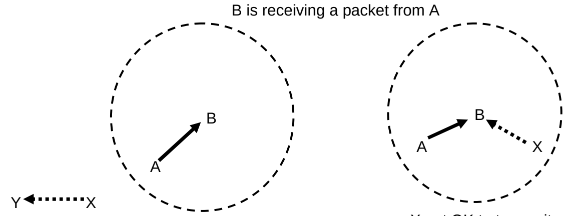
What is needed: Busy Tone

B is receiving a packet from A



X OK to transmit

X not OK to transmit

1. Receiver transmits busy tone when receiving data
2. All nodes hearing busy tone keep silent
3. Requires a separate channel for busy tone

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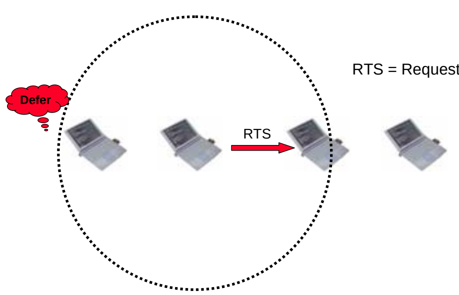
RTS/CTS Dialog (1)



RTS = Request to Send

Any node that hears this RTS will defer medium access.

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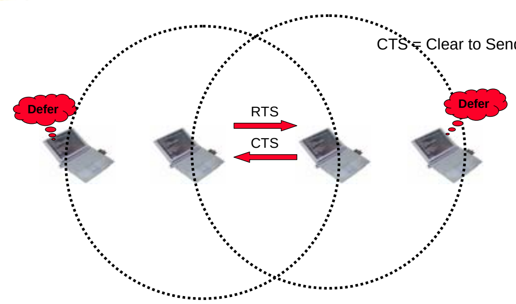
RTS/CTS Dialog (2)

CTS = Clear to Send



Any node that hears this CTS will defer medium access.

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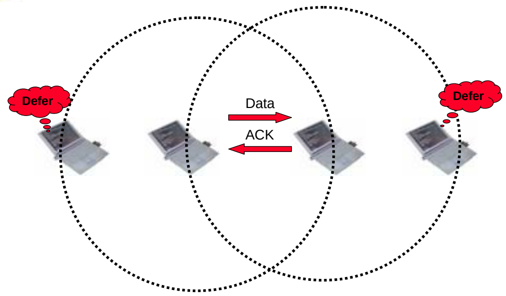
RTS/CTS Dialog (3)



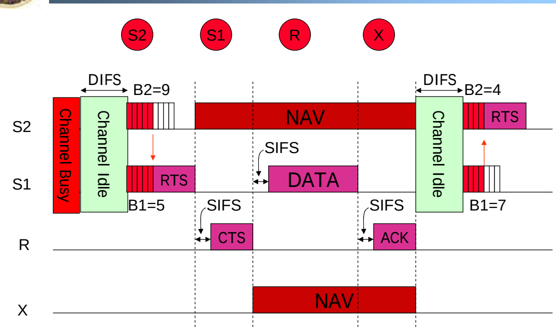
Virtual carrier sense using Network Allocation Vector (NAV)

- NAV is updated based on overheard RTS/CTS packets, each of which specified duration of a pending Data/Ack transmission

Dynamic Contention Window

- Binary Exponential Backoff in 802.11 DCF
  - When a node fails to receive CTS in response to its RTS, it increases the contention window
    - *cw* is doubled (up to an upper bound)
  - When a node successfully completes a data transfer, it restores *cw* to *Cwmin*

802.11 CSMA/CA



cw = 15

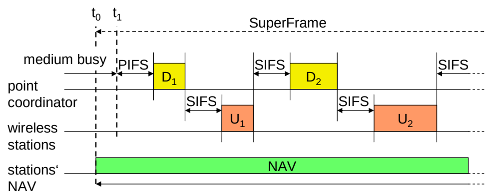
DIFS: DCF Inter-Frame Space

SIFS: Short Inter-Frame Space

802.11 Point Coordination Function (PCF)

- PCF is implemented on top of DCF
- The time sensitive traffic are controlled by the PCF and the remaining traffic contend for access using CSMA/CA
- The centralized polling master (point coordinator) issues polls using PIFS
- The poll responses use SIFS
- The point coordinator could issue polls in a round robin fashion
- Seizing of the medium by the PCF is avoided by using superframes where the point coordinator is allowed to poll for a fixed duration and then idle for the rest of the superframe period to allow the asynchronous traffic to contend for the medium.

802.11 PCF Example (1)



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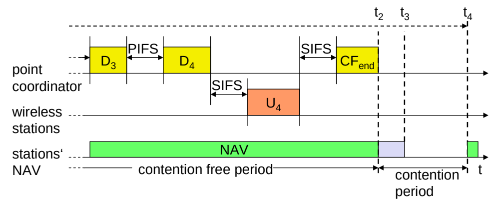
802.11 PCF (2)



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