Part I Syllabus

Lecture	Date	Subject
1	10/08/2016	Introduction
2	10/08/2016	Layered network architecture & Physical resilience
3	17/08/2016	Data link layer – flow control
4	17/08/2016	Data link layer – error control
5	24/08/2016	Data link layer – HDLC
6	24/08/2016	Local area network – introduction
7	31/08/2016	Local area network – MAC
8	31/08/2016	Local area network – Ethernet
9	**07/09/2016**	**Local area network – WLAN**
10	07/09/2016	Packet switch network - Introduction
11	14/09/2016	Packet switch network – queue analysis
12	14/09/2016	Review and examples

What is the problem with the guy?

Lecture 9
Wireless LAN: IEEE 802.11

Contents

- **WLAN Overview**
  - WLAN Standard
  - WLAN Architecture
  - WLAN Protocol Stack
- **802.11 Physical Layer**
- **802.11 MAC Layer**
  - Hidden and Exposed Station Problems
  - CSMA/CA Protocol
  - MAC Management
- **Multi-Access Reservation Protocol**
  - Scheme
  - Throughput Calculation

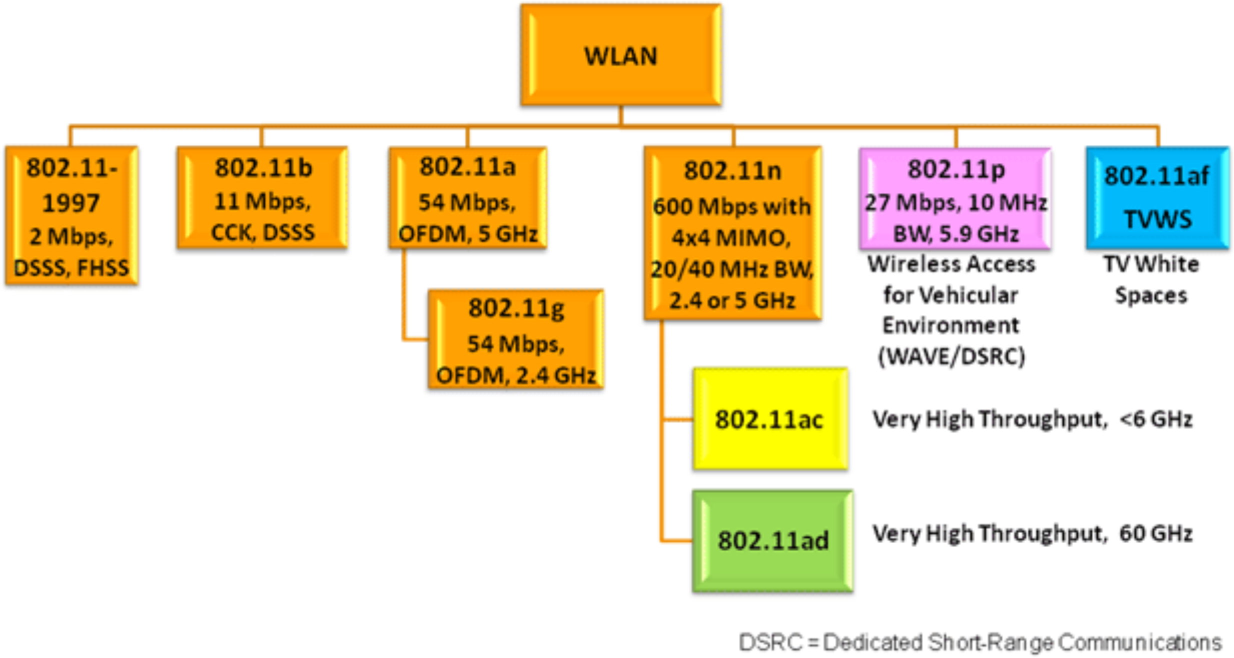
WLAN Overview

LAN/WLAN World

- **LANs provide connectivity for interconnecting computing resources at local levels of an organization**
- **Wired LANs**
  - Limitations because of physical, hard-wired infrastructure
- **Wireless LANs**
  - Flexibility
  - Portability
  - Mobility
  - Ease of Installation

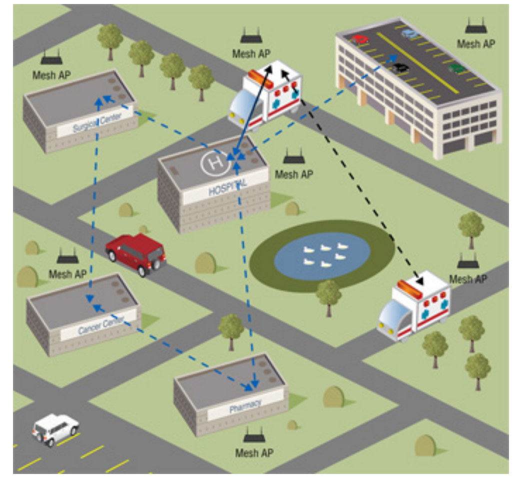
IEEE 802.11 WLAN Standard

- In response to lacking standards, IEEE developed the first internationally recognized wireless LAN standard – IEEE 802.11
- IEEE published 802.11 in 1997, after seven years of work
- Most prominent specification for WLANs
- Scope of IEEE 802.11 is limited to Physical and Data Link Layers



Wireless LANs: Characteristics

- Advantages
  - Flexible deployment
  - Minimal wiring difficulties
  - More robust against disasters (earthquake etc)
  - Historic buildings, conferences, trade shows,…

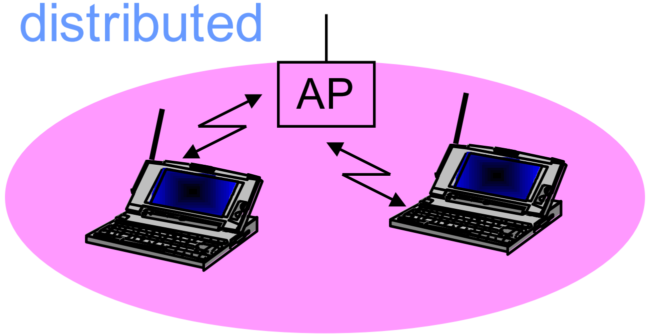


- Disadvantages
  - Low bandwidth compared to wired networks (1-10 Mbit/s)
  - Proprietary solutions
  - Need to follow wireless spectrum regulations

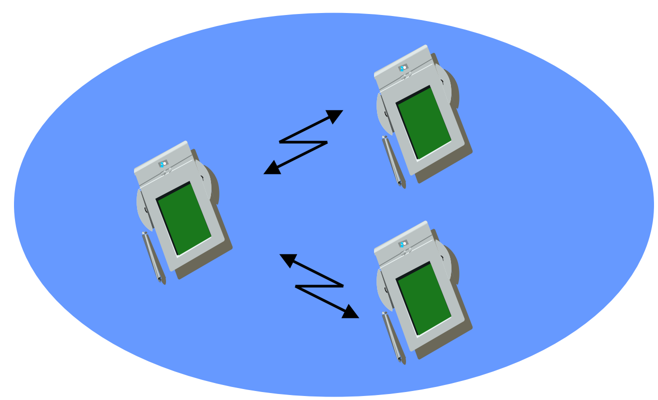
WLAN Architecture

- **Building Modules**
  - Station (STA)
    - Mobile node
    - Smartphone, pad, laptop
  - Access Point (AP)
    - Stations are connected to access points.

- **Two Architectural Modes**
  - Infrastructure: centralized
  - Ad Hoc: distributed



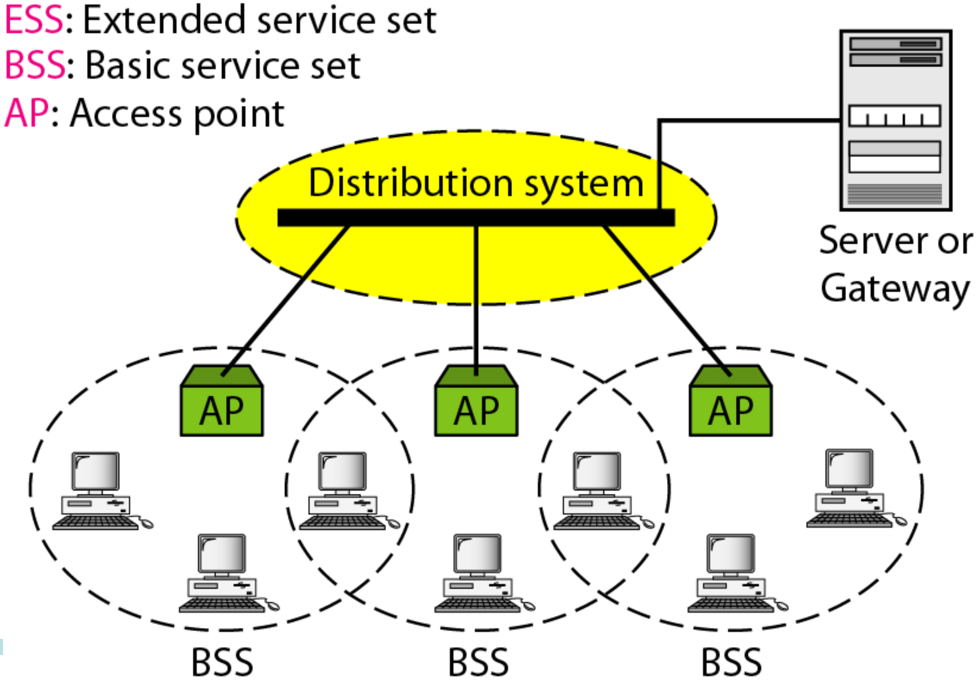
Infrastructure



Ad Hoc

(Extended) Service Set

- **Basic Service Set (BSS)**
  - Stations and the AP within the same radio coverage form a BSS.
- **Extended Service Set (ESS)**
  - Several BSSs connected through APs form an ESS.



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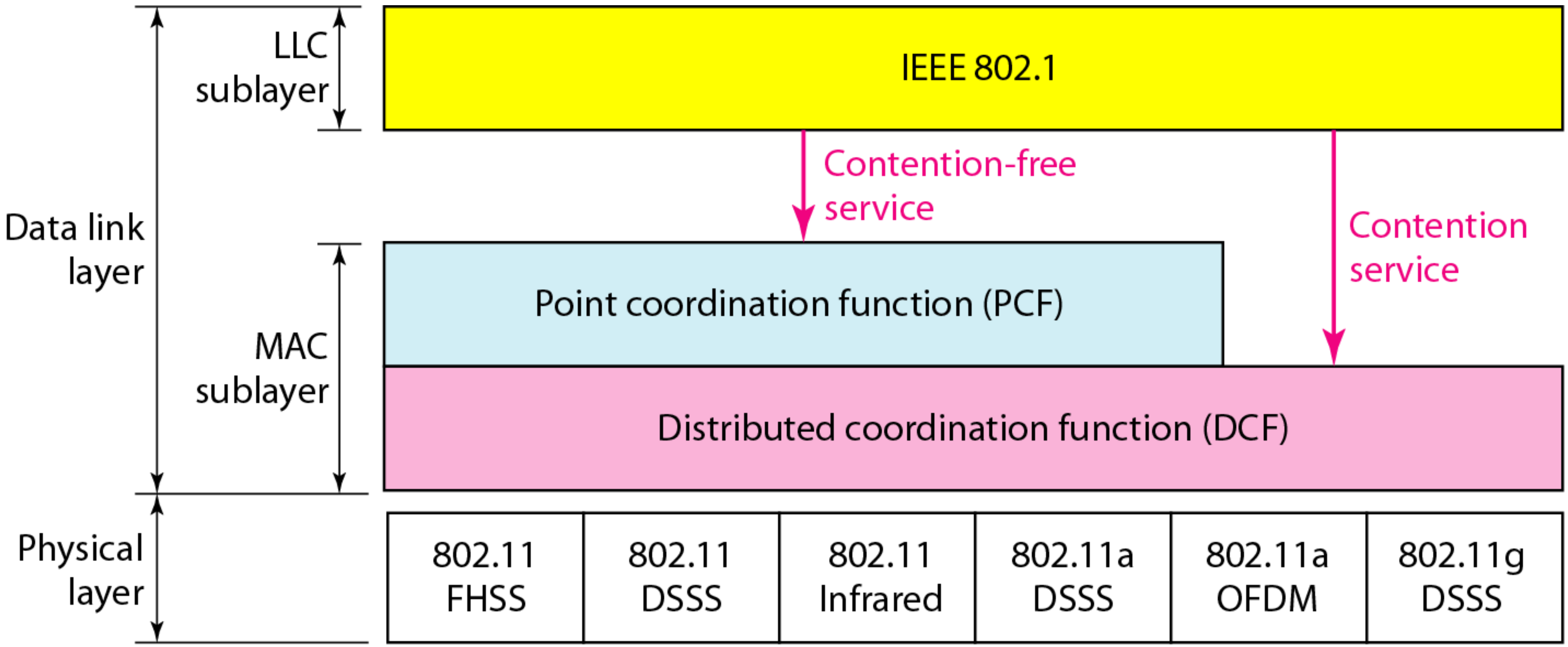
802.11 Protocol Stack



Wireless Physical Layer

IEEE 802.11 Physical Layer

	802.11b	802.11g	802.11a	802.11n	
Frequency Band	2.4GHz	5GHz	2.4GHz	2.4	5
Non-overlapping Channels	3	3	12	3	12
Baseline BW Per Channel	11Mbps	54Mbps	54Mbps	65	65
Max BW Per Channel	11Mbps	54Mbps	54Mbps	**130**	**270**
MIMO	1	1	1	4	4
Modulation	DSSS	DSSS/OFDM	OFDM	OFDM	

802.11 MAC

802.11 MAC Sublayer

- **In 802.11 wireless LANs, “seizing channel” does not exist as in 802.3 wired Ethernet.**
- **Three functional areas**
  - Reliable data delivery
  - Access control
  - Security
- **Two additional problems:**
  - Hidden Terminal Problem
  - Exposed Station Problem

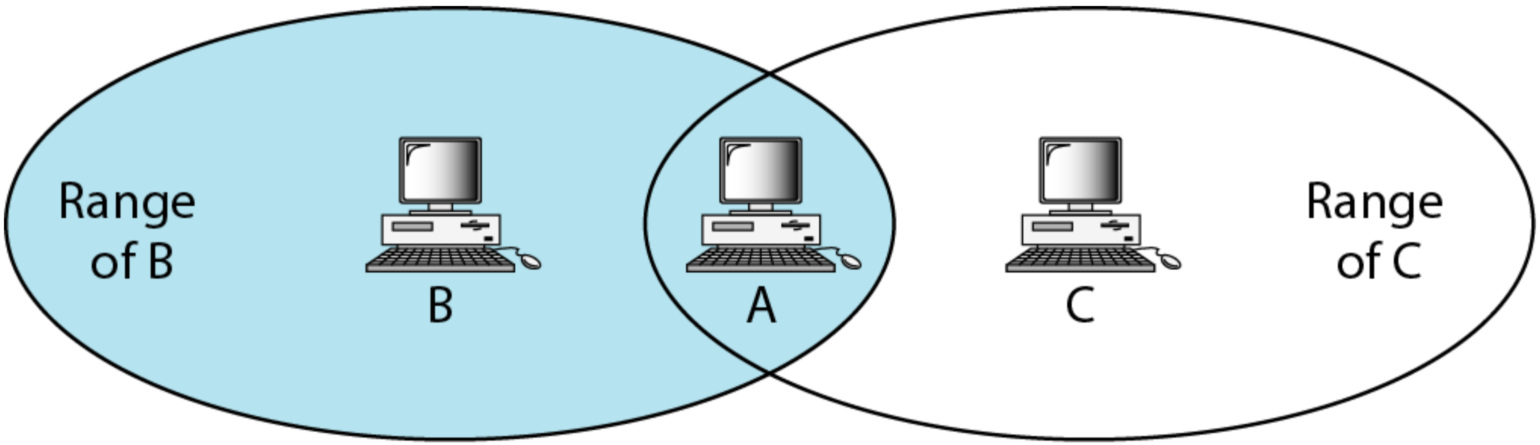
Reliable Data Delivery

- **Loss of frames due to noise, interference and propagation effects**
- **Frame exchange protocol**
  - Source station transmits data
  - Destination responds with acknowledge (ACK)
  - If source does not receive ACK, it retransmits frame
- **Four frame exchange for enhanced reliability**
  - Source issues request to send (RTS)
  - Destination responds with clear to send (CTS)
  - Source transmits data
  - Destination responds with ACK

Access Control

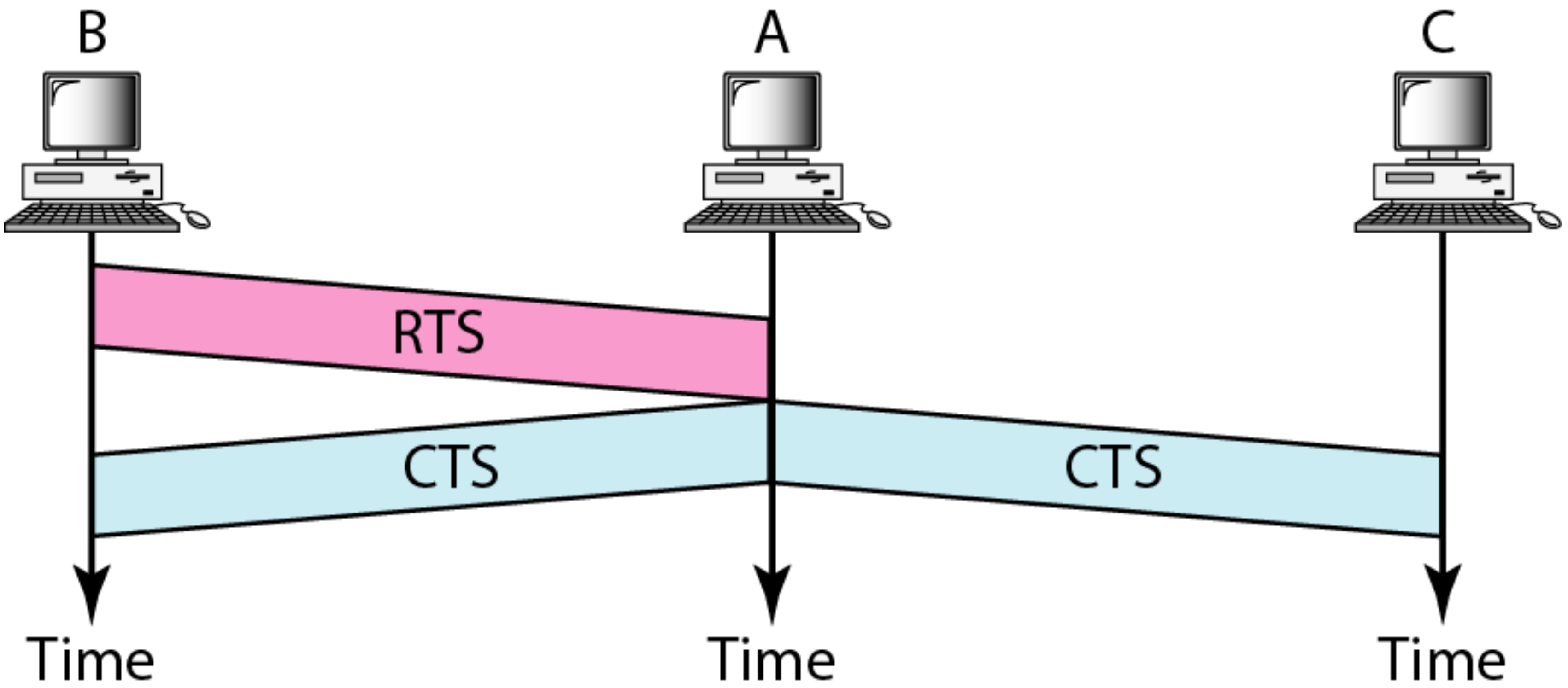
- **Distributed Coordination Function (DCF)**
  - Distributed access protocol
  - Contention-based
  - Makes use of CSMA/CA
  - Suited for ad-hoc network and asynchronous traffic
- **Point Coordination Function (PCF)**
  - Alternative access method on top of DCF
  - Centralized access protocol
  - Contention-free, and Works like polling
  - Suited for time-bound services like voice and multimedia

Hidden Station Problem

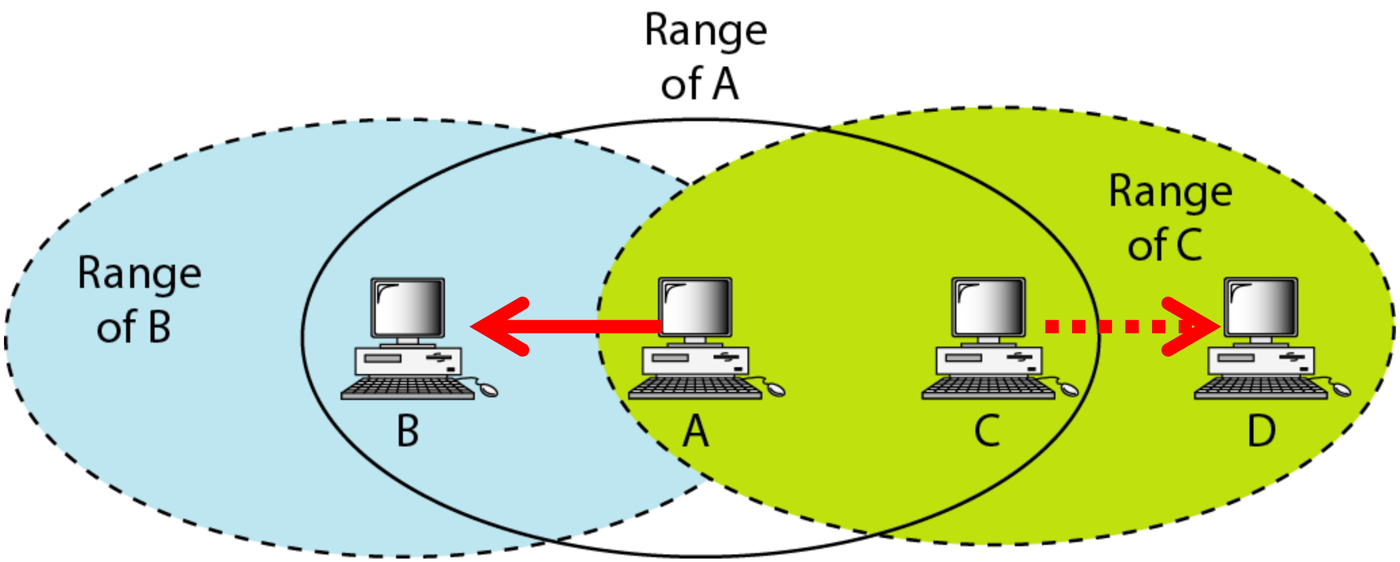


B and C are hidden from each other with respect to A.

Handshaking for Hidden Station Problem

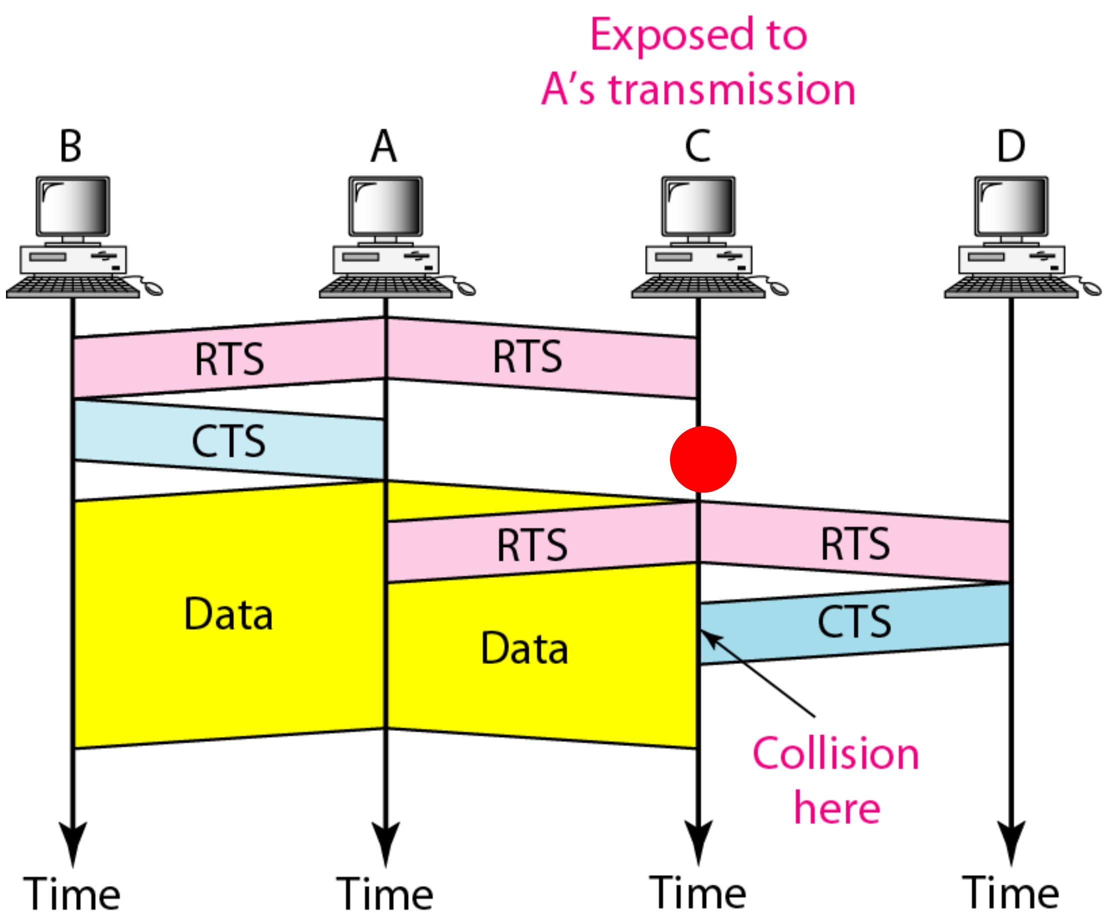


Exposed Station Problem



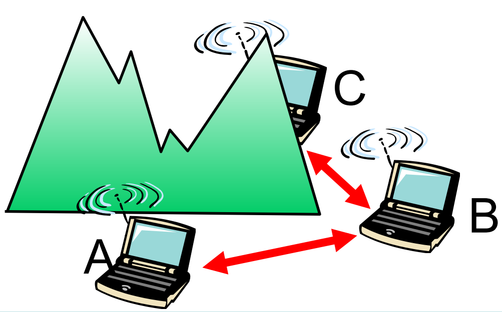
C is exposed to transmission from A to B.

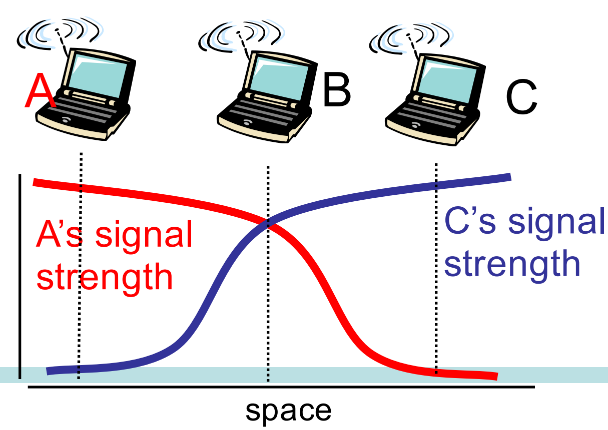
Handshaking in Exposed Station Problem



802.11 Multi-Access

- **Avoid collisions**
  - 2^+ nodes transmitting at same time
- **802.11: CSMA - sense before transmitting**
  - don't collide with ongoing transmission by other node
- **802.11: *no* collision detection!**
  - difficult to receive (sense collisions) when transmitting due to weak received signals (fading)
  - can't sense all collisions in any case: hidden terminal, fading
  - goal: *avoid collisions:* CSMA/C(ollision)A(voidance)





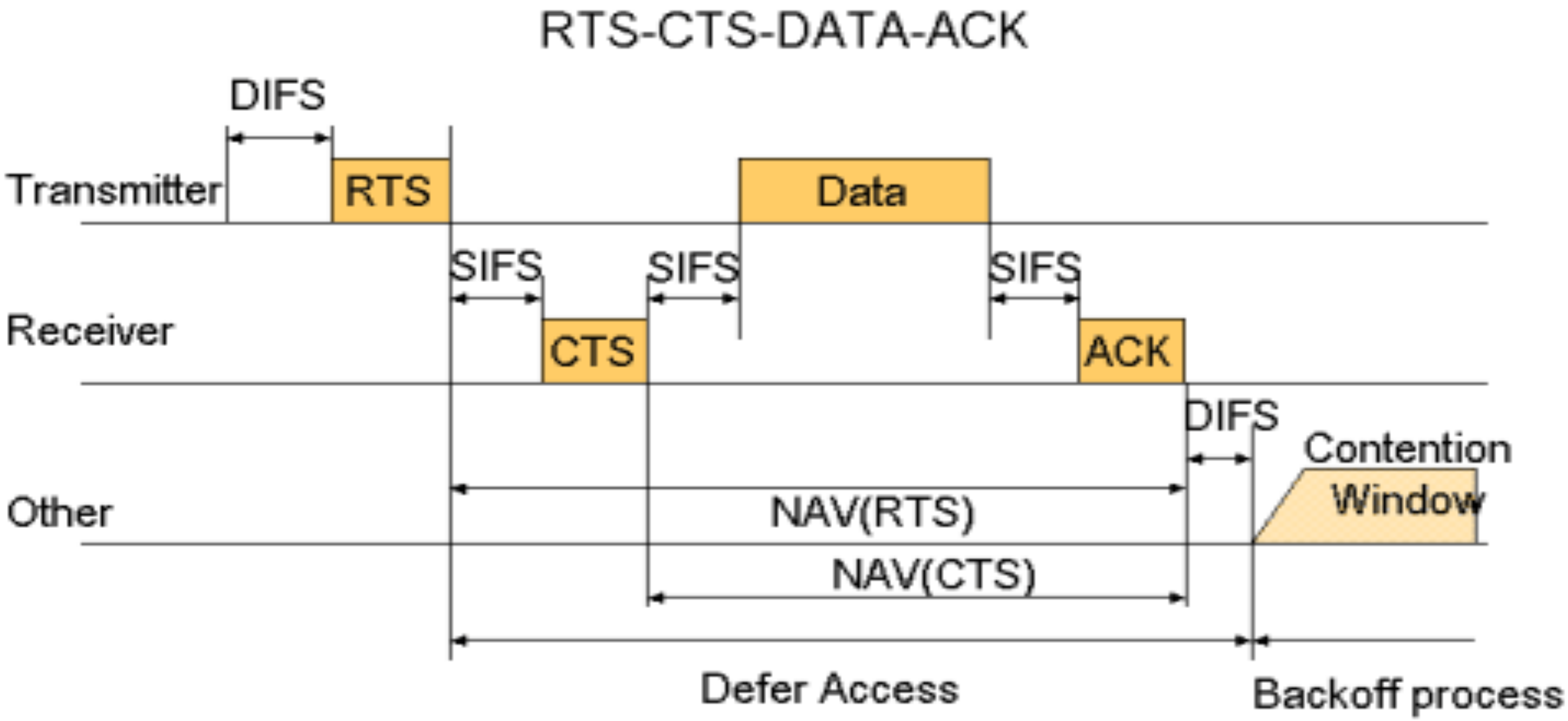
Collision Avoiding

idea: **to allow sender to "reserve" channel rather than random access of data frames: avoid collisions of long data frames**

- **sender first transmits *small* request-to-send (RTS) packets to base station using CSMA**
  - RTSs may still collide with each other (but they're short)
- **BS broadcasts clear-to-send CTS in response to RTS**
- **RTS heard by all nodes**
  - Sender transmits data frame
  - Other stations defer transmissions

Avoid data frame collisions completely using small reservation packets!

RTS-CTS-DATA-ACK



DIFS: Distributed IFS (Interframe Space)
RTS: Request To Send
SIFS: Short IFS
CTS: Clear To Send
ACK: Acknowledgement
NAV: Network Allocation Vector
DCF: Distributed Coordination Function

IEEE 802.11 MAC: CSMA/CA

802.11 Sender

1 if sense channel idle for **DIFS** then

transmit entire frame (no CD)

2 if sense channel busy then

start random backoff time

timer counts down while channel idle

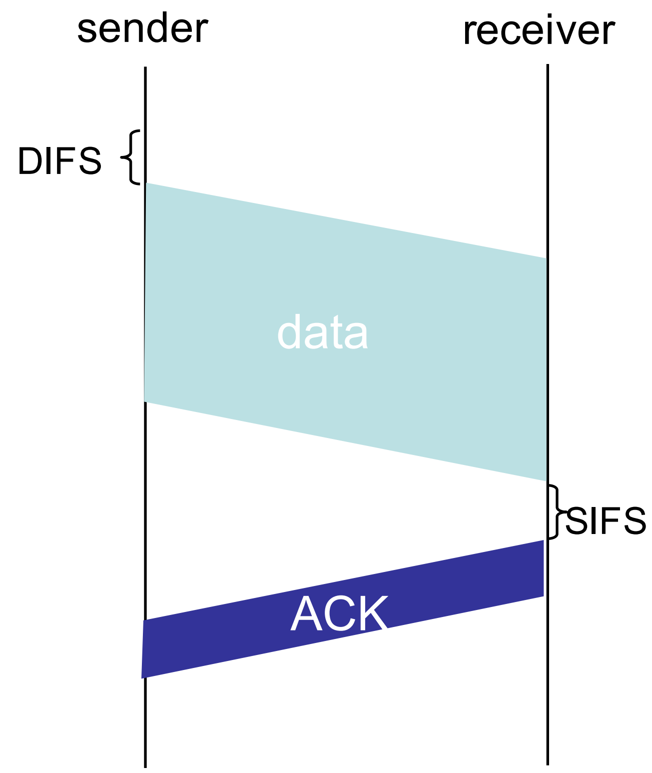
transmit when timer expires

3 if no ACK, increase random backoff interval, repeat 2

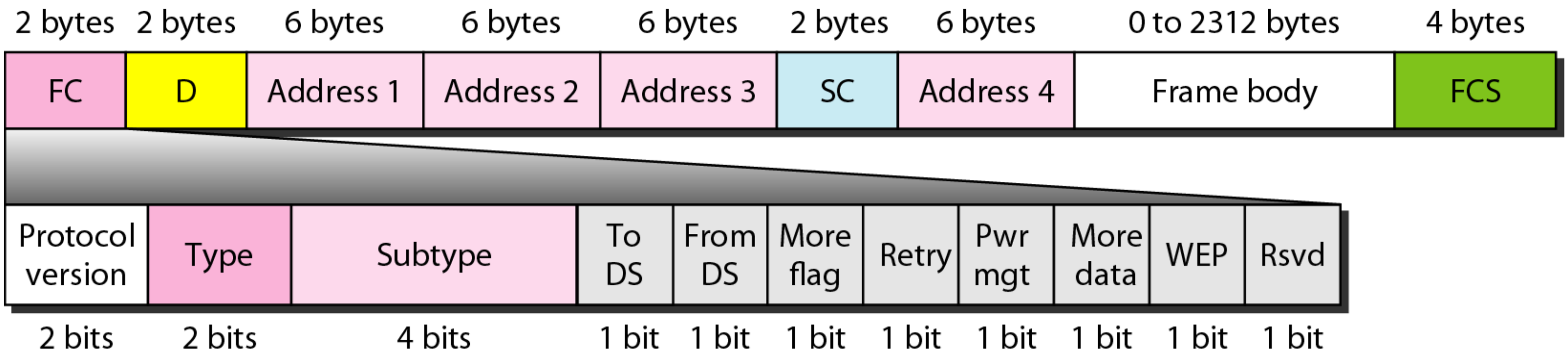
802.11 Receiver

- if frame received OK

return ACK after **SIFS** (ACK needed due to hidden terminal problem)



802.11 Frame Format



Field	*Explanation*
Version	Current version is 0
Type	Type of information: management (00), control (01), or data (10)
Subtype	Subtype of each type (see Table 14.2)
To DS	Defined later
From DS	Defined later
More flag	When set to 1, means more fragments
Retry	When set to 1, means retransmitted frame
Pwr mgt	When set to 1, means station is in power management mode
More data	When set to 1, means station has more data to send
WEP	Wired equivalent privacy (encryption implemented)
Rsvd	Reserved

To DS	*From DS*	*Address 1*	*Address 2*	*Address 3*	*Address 4*
0	0	Destination	Source	BSS ID	N/A
0	1	Destination	Sending AP	Source	N/A
1	0	Receiving AP	Source	Destination	N/A
1	1	Receiving AP	Sending AP	Destination	Source

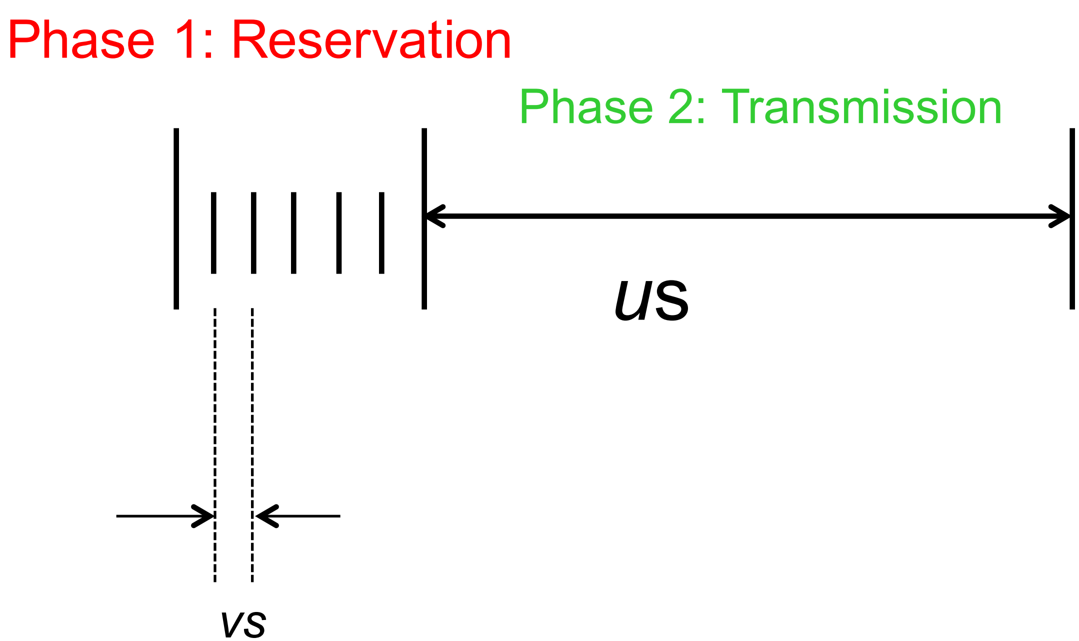
802.11 Advanced Capabilities

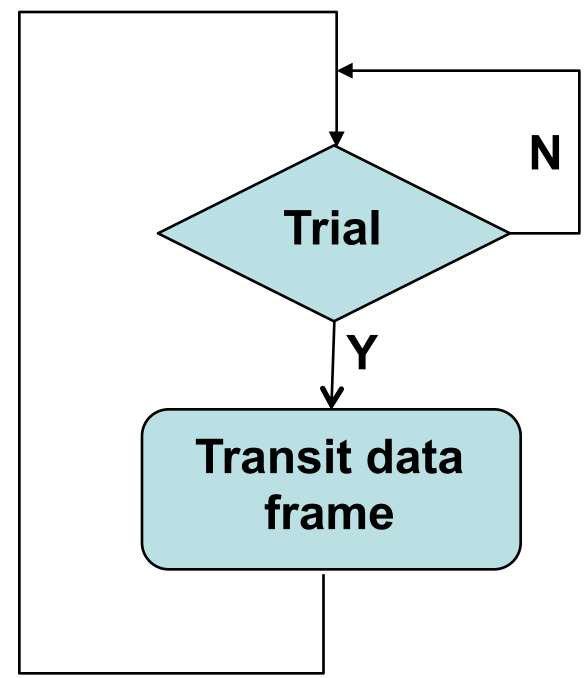
- **Synchronization**
  - finding and staying with a WLAN
  - synchronization functions
- **Power Management**
  - sleeping without missing any messages
  - power management functions
- **Roaming**
  - functions for joining a network
  - changing access points
  - scanning for access points
- **Management information base**

Multi-Access Reservation Protocol (MARP)

Multi-Access Reservation Protocol

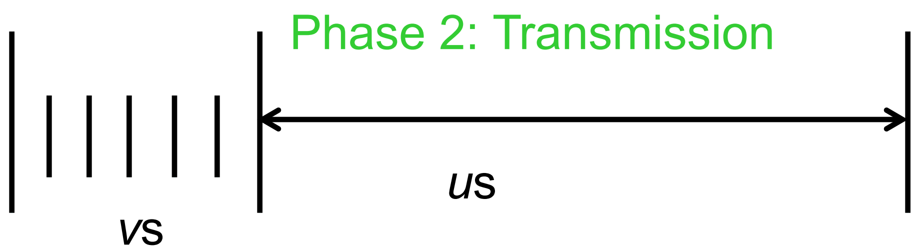
- **Two-Phase Protocol**
  - Phase 1: Channel Reservation
  - Phase 2: Data Transmission



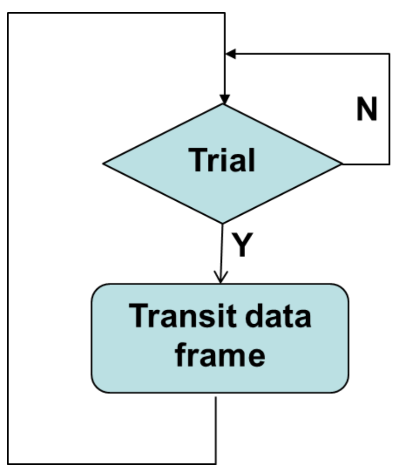


MARP: Reservation Phase

Phase 1: Reservation



- Assume that the channel utilization in reservation phase: S_r
- Number of reservation trial frames to reserve the channel: ***X***
  - If the first trial succeeds, **X = 1** with probability of S_r
  - If the first trial fails, the process resumes from the beginning, **X= X+1** with probability of **1-**S_r



$$E\{X\} = 1 \cdot S_r + (E\{X\}+1) \cdot (1-S_r)$$

$$E\{X\} = 1/S_r$$

MARP Throughput

$$S = \frac{\text{Time for message transmission}}{\text{Total transmission window}}$$

Case	Message Length	Reservation Phase Length	Throughput
Reservation frame used for control information	u	v/S_r	$S = \frac{u}{u + {}^{v}/_{S_r}}$
Reservation frame used for message information	$u + v$	v/S_r	$S = \frac{u + v}{u + {}^{v}/_{S_r}}$

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MARP Example

Consider an experimental local area network using a multi-access reservation protocol for data transmission. The protocol consists of two phases. In phase 1, it adopts some MAC protocol for transmission stations to reserve the channel. In phase 2, when one station reserves the channel, it transmits one frame. The length of reservation frame is 5ms, and the length of the data frame is 1s. No information bit is carried in the reservation frame. If the MAC protocol used in phase 1 has a utilization of 0.5, what is the throughput of the multi-access reservation protocol?

CRACK Framework:

Context:	It is a MARP problem
fRamwork:	the throughput of MARP is S=1/(1+v/S_r)
Apply:	*v*=5ms, *S*_r=0.5
Calculation:	S = 1/(1+0.005/0.5)=1/1.01=0.99
checK:	S<=1

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Local Area Network Summary

<table>
<tr><th colspan="2" rowspan="2">MAC Protocols</th><th colspan="3">Transmission Protocol</th><th rowspan="2">Throughput/ Utilization</th><th rowspan="2">Note</th></tr>
<tr><th>Carrier Sensing</th><th>Frame Transmission</th><th>Collision Detection</th></tr>
<tr><td rowspan="2">Aloha</td><td>Slotted</td><td rowspan="2">• None</td><td>• Each transmits in a slot immediately with probability p</td><td rowspan="5">• When a collision is detected, the colliding frames are transmitted up to their last bits.</td><td>$S = Np(1-p)^{(N-1)}$
$= Ge^{-G}$</td><td rowspan="2">Number of Stations: N
Probability of Attempt: p
Attempt Rate: $G = Np$</td></tr>
<tr><td>Pure</td><td>• Each transmits immediately with probability p</td><td>$S = Np(1-p)^{2(N-1)}$
$= Ge^{-2G}$</td></tr>
<tr><td rowspan="3">CSMA</td><td>Non-Persistent</td><td rowspan="3">• Must sense channel before transmission</td><td>• When a busy channel is sensed, a station defers for a random period of time before next sense</td><td rowspan="3"></td><td rowspan="3"></td></tr>
<tr><td>P-Persistent</td><td>• When a busy channel is sensed, a station continues to sense until the channel turns idle. Then, with probability p, it transmits, and with probability $1-p$, it defers to next time slot.</td></tr>
<tr><td>1-Persistent</td><td>• A special case of P-Persistent where $p = 1$</td></tr>
<tr><td colspan="2">CSMA/CD (Ethernet)</td><td>• Must sense channel before transmission</td><td>• The same as CSMA</td><td>• When a collision is detected, transmissions are aborted to reduce the channel wastage.</td><td>$S = \frac{1}{1 + 6.44a}$
$a = \frac{T_{Prop}}{T_{frame}}$</td><td>Minimum Frame Size
• $T_{frame} \geq 2\tau$
Binary Exponential Backoff
• In i-th retransmission, the slot is chosen from a uniformly distributed random variable R, in the range of $[0, 2^K - 1]$, where $K = \min(i, 10)$.</td></tr>
<tr><td colspan="2">CSMA/CA (802.11)</td><td>• Must sense channel before transmission</td><td>Sender:
• If sense channel idle for DIFS, then transmit entire frame (no CD).
• If sense channel busy, then start random backoff time. Transmits when timer expires.
• If no ACK, increase random backoff interval
Receiver:
• If frame received OK, return ACK after SIFS</td><td>• No collision detection due to hidden terminal</td><td colspan="2">Multi-Access Reservation
• Use random-access with mini-frame (v unit of time) to reserve the channel
• If reservation successful, transmit u unit of data frame
<table><tr><th></th><th>$\frac{u}{u + v/S_r}$</th><th>$\frac{u}{(u-v) + \frac{v}{S_r}}$</th><th>$\frac{u+v}{u + v/S_r}$</th></tr><tr><td>Total data length</td><td>u</td><td>u</td><td>$u + v$</td></tr><tr><td>Data bit in mini-frame</td><td>No</td><td>Yes</td><td>Yes</td></tr></table></td></tr>
</table>

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Learning Objectives

- **WLAN Overview**
  - Understand two alternative WLAN architectures
- **802.11 Physical Layer**
  - Understand different transmission schemes
- **802.11 MAC Layer**
  - Understand hidden and exposed station problems
  - Understand CSMA/CA protocol
- **Multi-Access Reservation Protocol (MARP)**
  - Understand the scheme of MARP
  - Calculate and Maximize throughput for MARP

Reading Material

Wireless Physical Layer (I)

- **Physical layer conforms to OSI (five options)**
  - 1997: **802.11** infrared, FHSS, DHSS
  - 1999: **802.11a** OFDM and **802.11b** HR-DSSS
  - 2001: **802.11g** OFDM
- **802.11 *Infrared***
  - Two capacities 1 Mbps or 2 Mbps.
  - Range is 10 to 20 meters and cannot penetrate walls.
  - Does not work outdoors.
- **802.11 *FHSS* (*Frequency Hopping Spread Spectrum*)**
  - **The main issue is multipath fading.**
  - 79 non-overlapping channels, each 1 Mhz wide at low end of 2.4 GHz ISM band.
  - Same pseudo-random number generator used by all stations.
  - Dwell time: min. time on channel before hopping (400msec).

Wireless Physical Layer (II)

- **802.11 *DSSS* (*Direct Sequence Spread Spectrum*)**
  - Spreads signal over entire spectrum using pseudo-random sequence (similar to CDMA see Tanenbaum sec. 2.6.2).
  - Each bit transmitted using an 11 chips Barker sequence, PSK at 1Mbaud.
  - 1 or 2 Mbps.
- **802.11a *OFDM* (Orthogonal Frequency Divisional Multiplexing)**
  - Compatible with European HiperLan2.
  - 54Mbps in wider 5.5 GHz band ➔ transmission range is limited.
  - Uses 52 FDM channels (48 for data; 4 for synchronization).
  - Encoding is complex (PSM up to 18 Mbps and QAM above this capacity).
  - E.g., at 54Mbps 216 data bits encoded into 288-bit symbols.
  - More difficulty penetrating walls.

Wireless Physical Layer (III)

- **802.11b** ***HR-DSSS*** **(*High Rate Direct Sequence Spread Spectrum*)**
  - **11a and 11b** *shows a split in the standards committee.*
  - **11b** approved and hit the market before **11a.**
  - Up to 11 Mbps in 2.4 GHz band using 11 million chips/sec.
  - Note in this bandwidth all these protocols have to deal with interference from microwave ovens, cordless phones and garage door openers.
  - Range is 7 times greater than **11a.**
  - **11b and 11a are incompatible!!**
- **802.11g** ***OFDM*****(*Orthogonal Frequency Division Multiplexing*)**
  - **An attempt to combine the best of both 802.11a and 802.11b.**
  - Supports bandwidths up to 54 Mbps.
  - Uses 2.4 GHz frequency for greater range.
  - Is backward compatible with 802.11b.