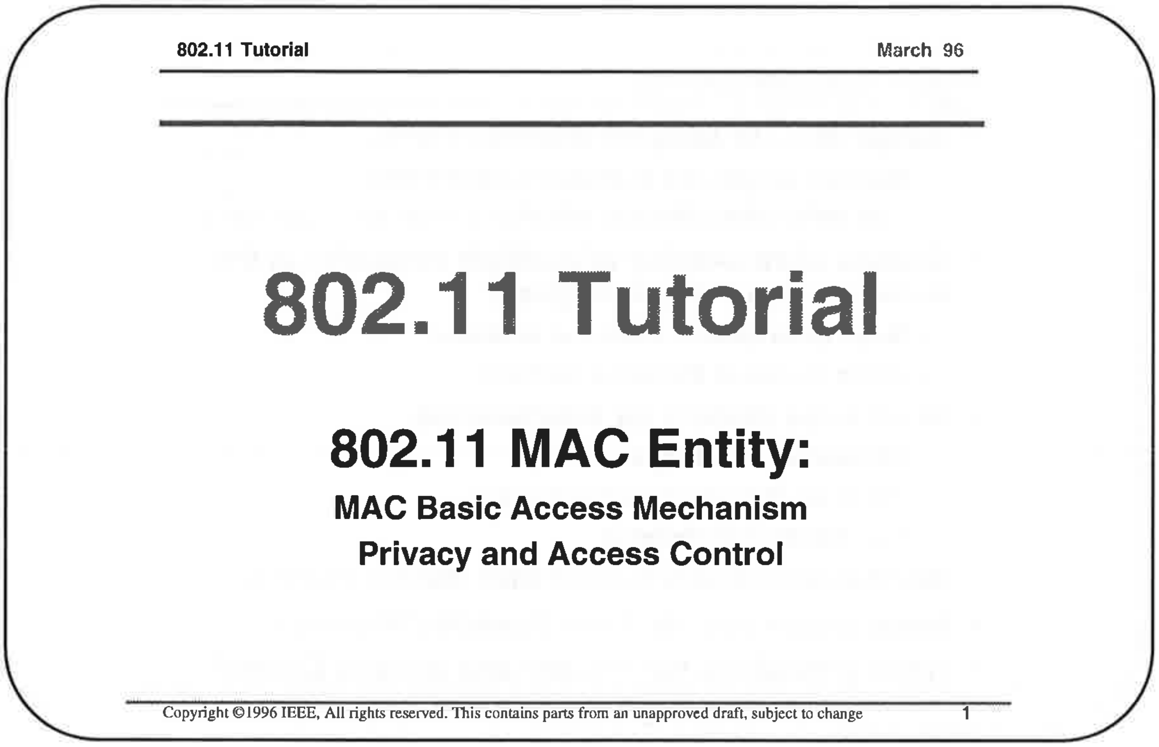

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802.11 Tutorial

802.11 MAC Entity:

MAC Basic Access Mechanism
Privacy and Access Control

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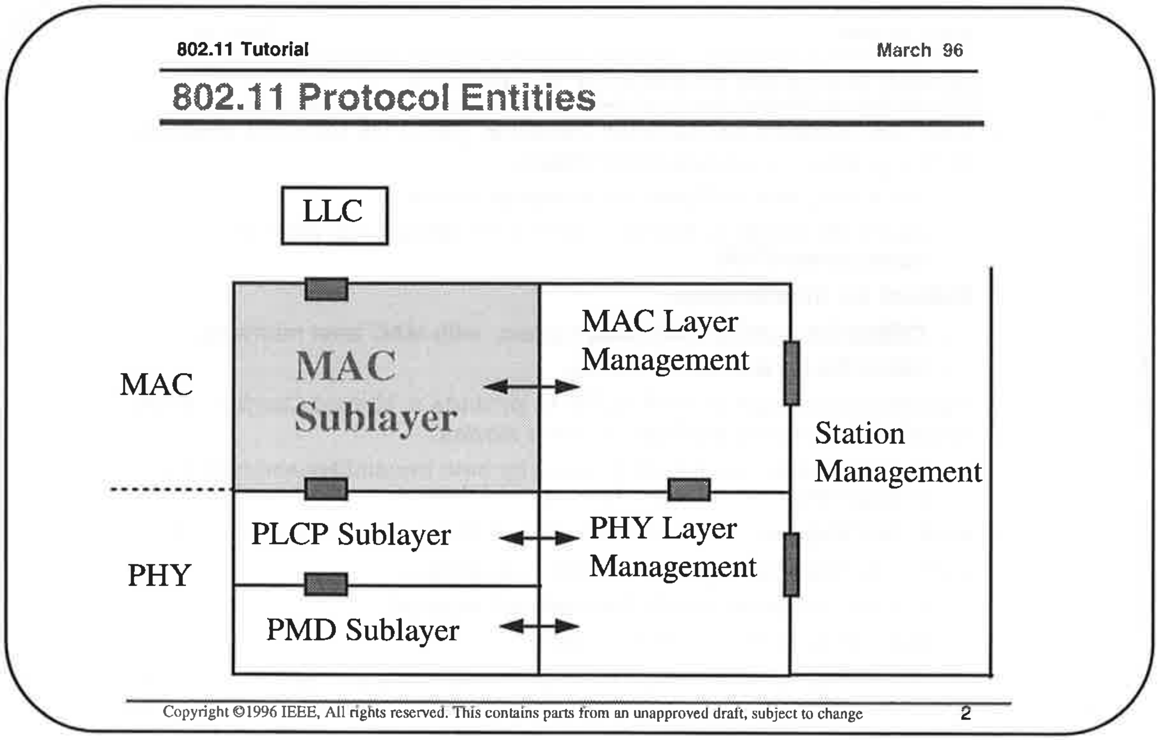

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802.11 Protocol Entities

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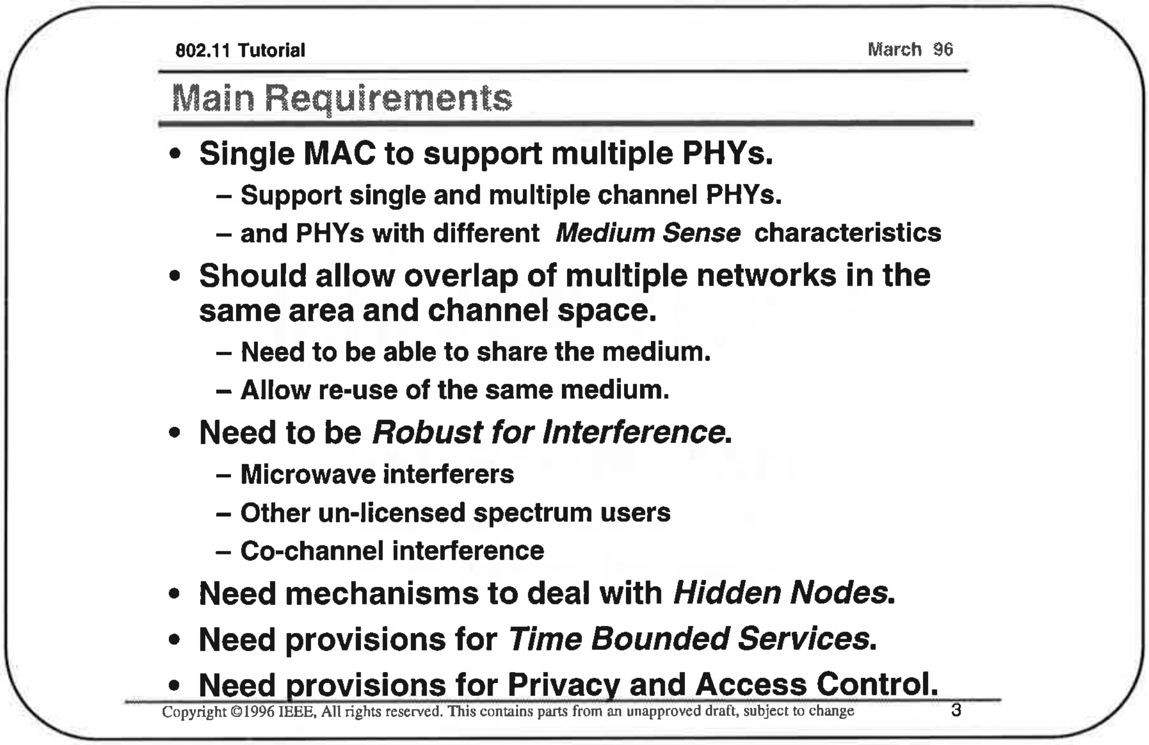

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Main Requirements

- **Single MAC to support multiple PHYs.**
  - **Support single and multiple channel PHYs.**
  - **and PHYs with different *Medium Sense* characteristics**
- **Should allow overlap of multiple networks in the same area and channel space.**
  - **Need to be able to share the medium.**
  - **Allow re-use of the same medium.**
- **Need to be *Robust for Interference*.**
  - **Microwave interferers**
  - **Other un-licensed spectrum users**
  - **Co-channel interference**
- **Need mechanisms to deal with *Hidden Nodes*.**
- **Need provisions for *Time Bounded Services*.**
- **Need provisions for Privacy and Access Control.**

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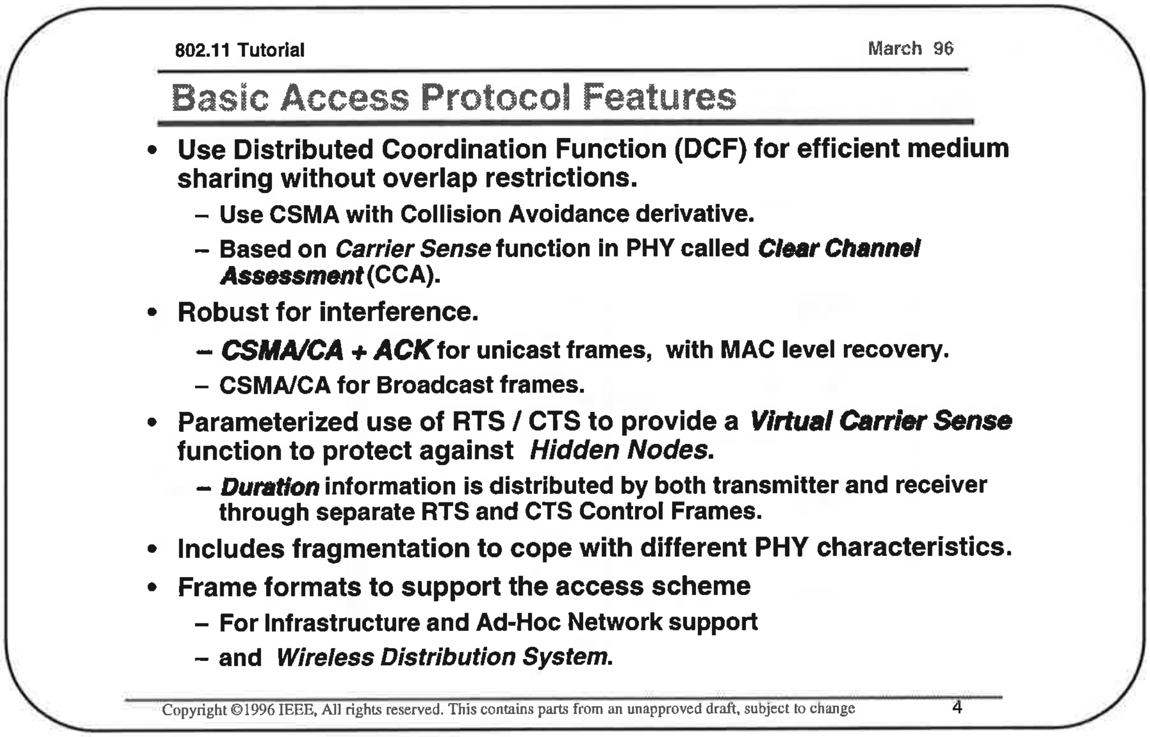

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Basic Access Protocol Features

- **Use Distributed Coordination Function (DCF) for efficient medium sharing without overlap restrictions.**
  - **Use CSMA with Collision Avoidance derivative.**
  - **Based on *Carrier Sense* function in PHY called *Clear Channel Assessment* (CCA).**
- **Robust for interference.**
  - ***CSMA/CA + ACK* for unicast frames, with MAC level recovery.**
  - **CSMA/CA for Broadcast frames.**
- **Parameterized use of RTS / CTS to provide a *Virtual Carrier Sense* function to protect against *Hidden Nodes*.**
  - ***Duration* information is distributed by both transmitter and receiver through separate RTS and CTS Control Frames.**
- **Includes fragmentation to cope with different PHY characteristics.**
- **Frame formats to support the access scheme**
  - **For Infrastructure and Ad-Hoc Network support**
  - **and *Wireless Distribution System*.**

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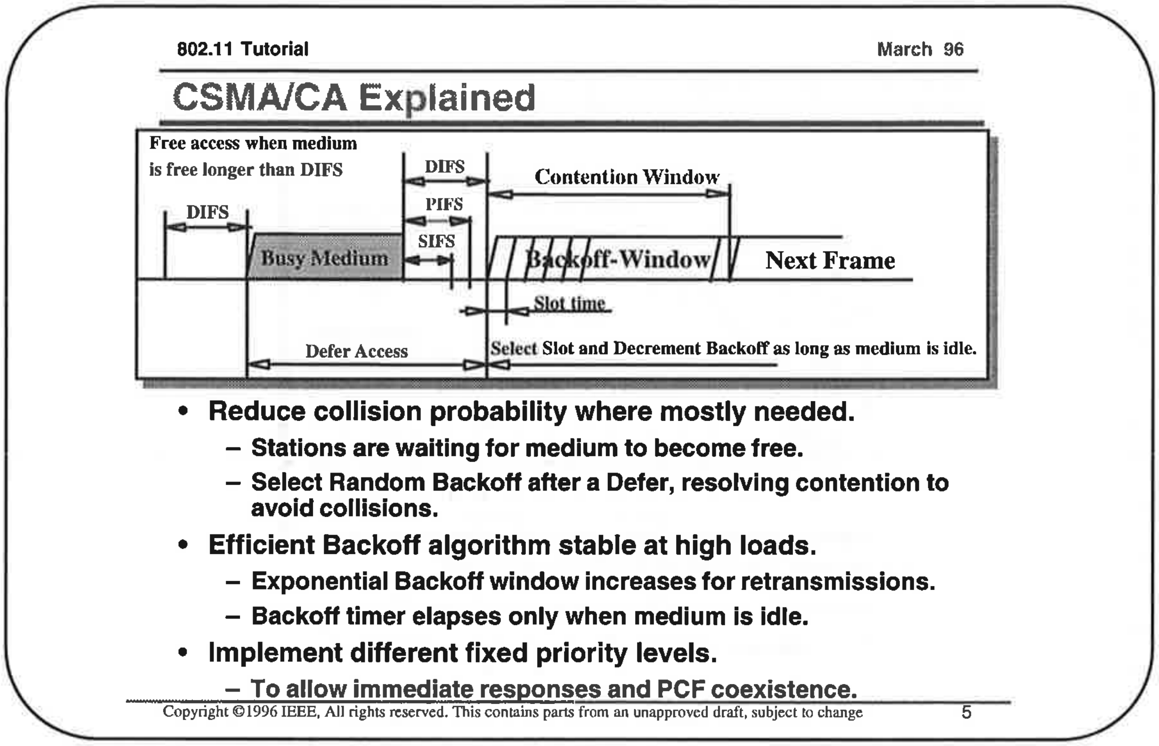

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CSMA/CA Explained

Free access when medium is free longer than DIFS
DIFS
DIFS
PIFS
SIFS
Contention Window
Busy Medium
Backoff-Window
Next Frame
Slot time
Defer Access
Select Slot and Decrement Backoff as long as medium is idle.

- Reduce collision probability where mostly needed.
  - Stations are waiting for medium to become free.
  - Select Random Backoff after a Defer, resolving contention to avoid collisions.
- Efficient Backoff algorithm stable at high loads.
  - Exponential Backoff window increases for retransmissions.
  - Backoff timer elapses only when medium is idle.
- Implement different fixed priority levels.
  - To allow immediate responses and PCF coexistence.

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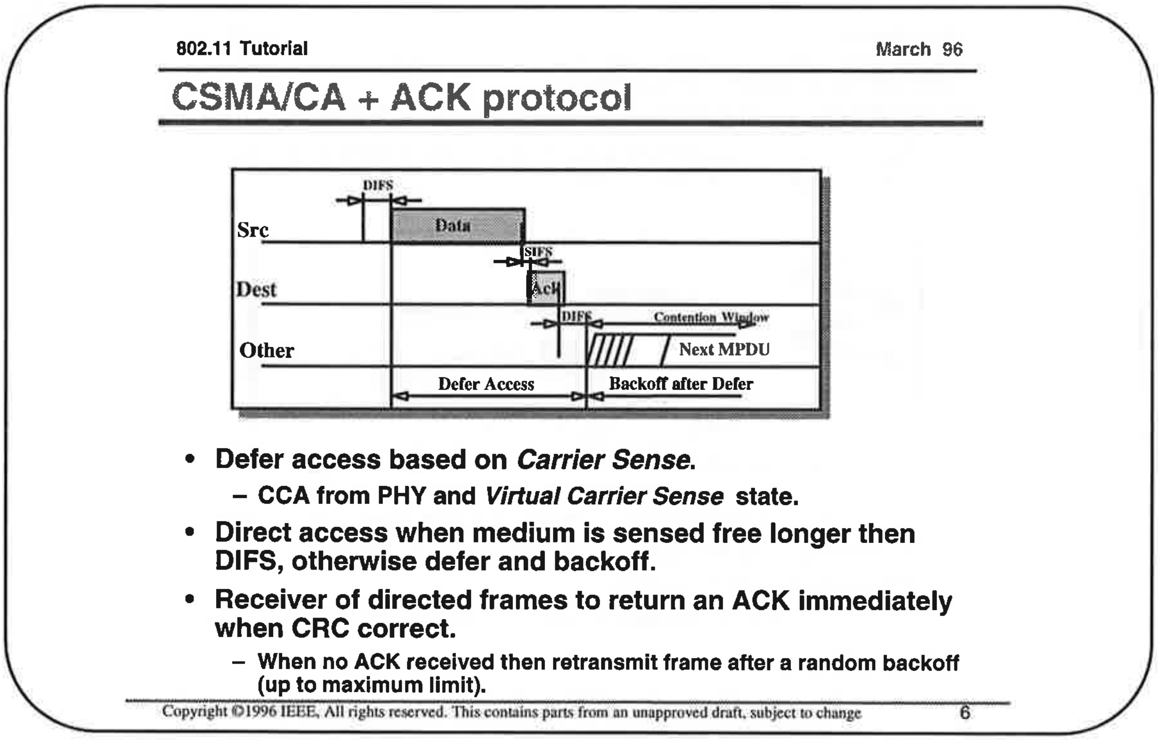

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CSMA/CA + ACK protocol

- Defer access based on *Carrier Sense*.
  - CCA from PHY and *Virtual Carrier Sense* state.
- Direct access when medium is sensed free longer then DIFS, otherwise defer and backoff.
- Receiver of directed frames to return an ACK immediately when CRC correct.
  - When no ACK received then retransmit frame after a random backoff (up to maximum limit).

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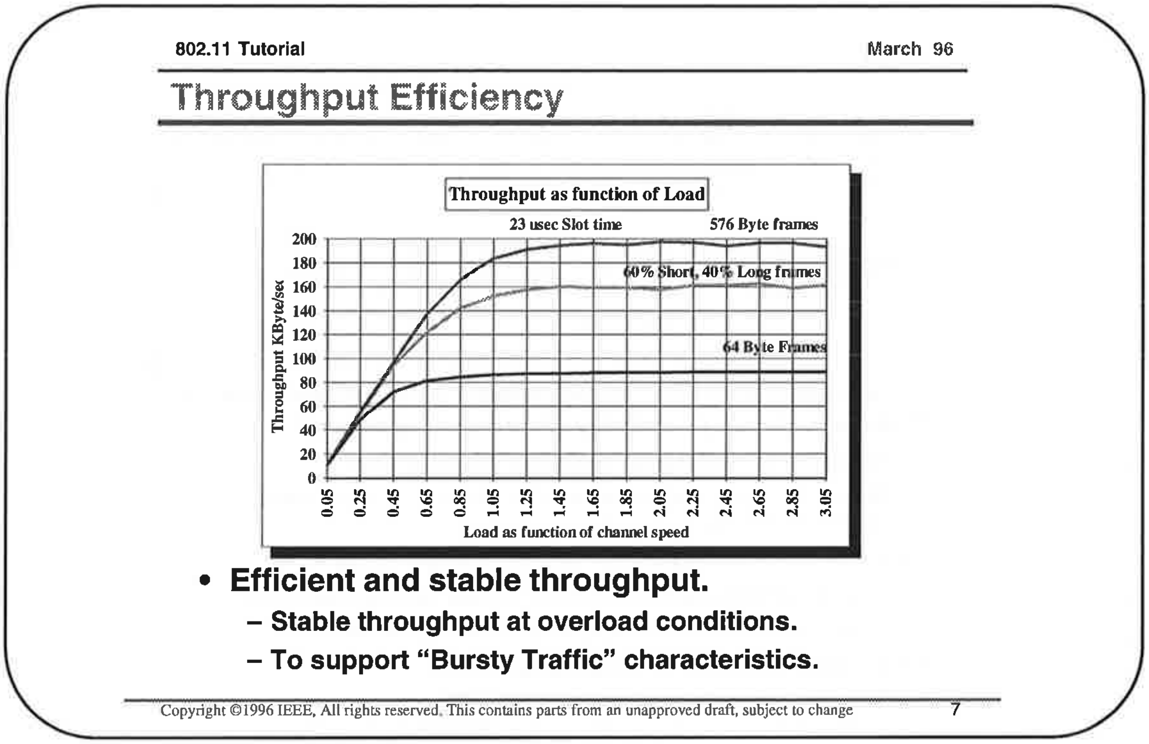

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Throughput Efficiency

- **Efficient and stable throughput.**
  - **Stable throughput at overload conditions.**
  - **To support "Bursty Traffic" characteristics.**

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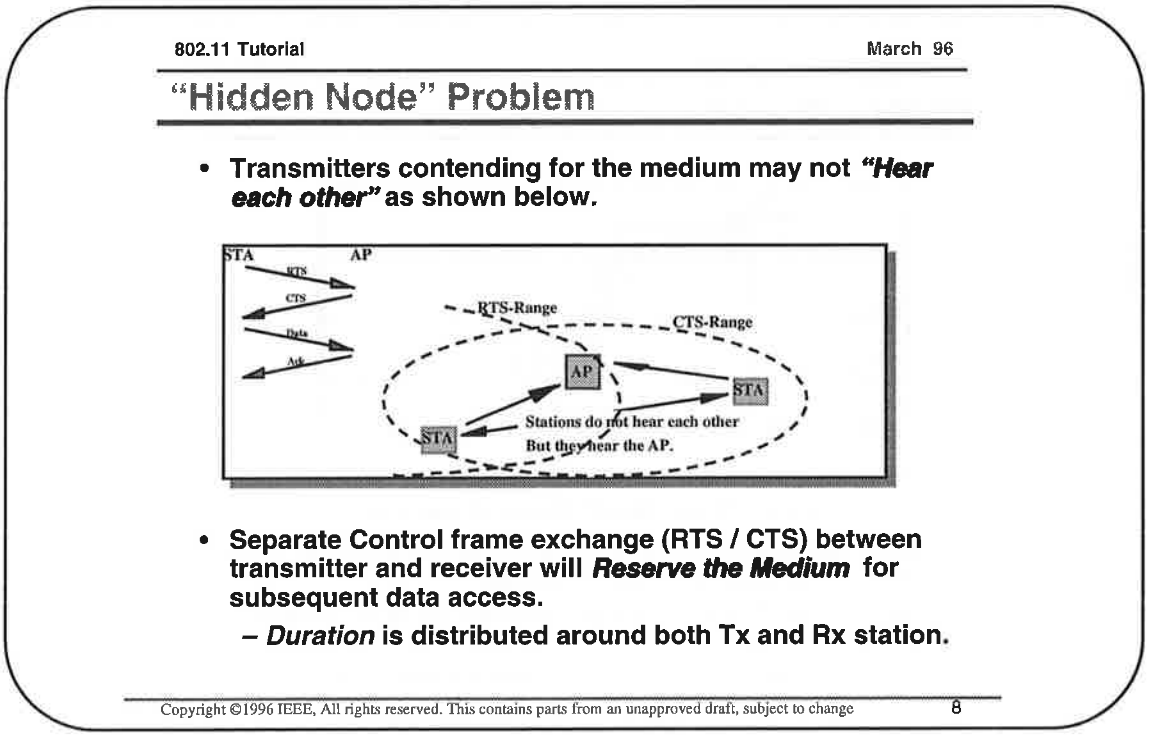

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"Hidden Node" Problem

- **Transmitters contending for the medium may not *"Hear each other"* as shown below.**

- **Separate Control frame exchange (RTS / CTS) between transmitter and receiver will *Reserve the Medium* for subsequent data access.**
  - ***Duration* is distributed around both Tx and Rx station.**

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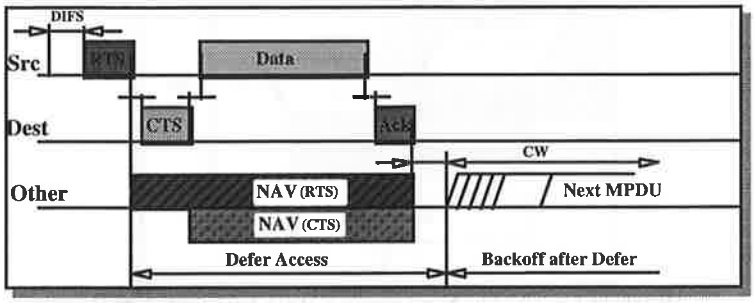
"Hidden Node" Provisions



- ***Duration*** **field in RTS and CTS frames distribute** ***Medium Reservation*** **information which is stored in a** ***Net Allocation Vector (NAV).***
- **Defer on either NAV or "CCA" indicating** ***Medium Busy.***
- **Use of RTS / CTS is optional but must be implemented.**
- **Use is controlled by a** ***RTS_Threshold*** **parameter per station.**
  - **To limit overhead for short frames.**

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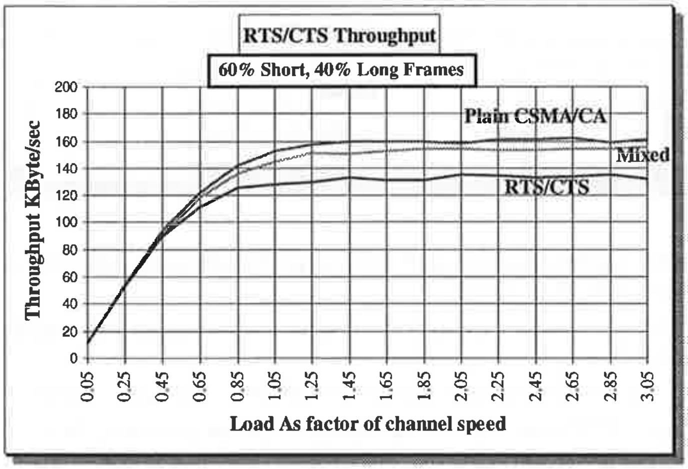
RTS/CTS Overhead Impact



Good mixed Throughput (long inbound frames) efficiency.

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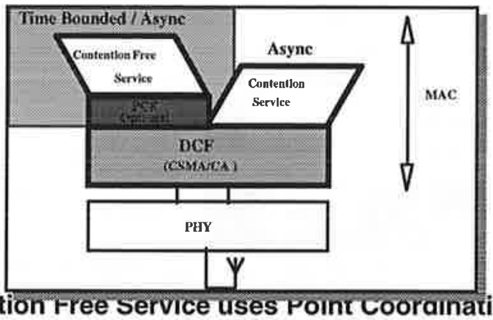
Optional Point Coordination Function (PCF)



- Contention Free Service uses Point Coordination Function (PCF) on a DCF Foundation.
  - PCF can provide lower *transfer delay* variations to support ***Time Bounded Services***.
  - Async Data, Voice or mixed implementations possible.
  - Point Coordinator resides in AP.
- Coexistence between Contention and optional Contention Free does not burden the implementation.

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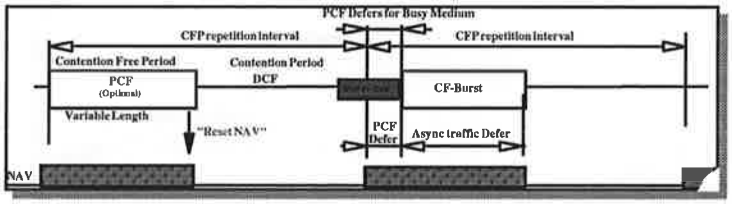
Contention Free operation



- Alternating ***Contention Free*** and ***Contention*** operation under PCF control.
- NAV prevents *Contention* traffic until reset by the last PCF transfer.
  - So variable length *Contention Free* period per interval.
- Both PCF and DCF defer to each other causing PCF Burst start variations.

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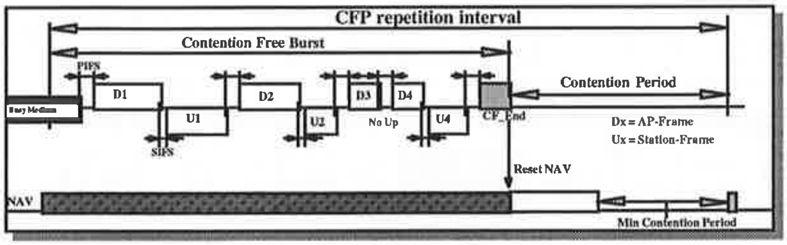
PCF Burst



- CF-Burst by Polling bit in CF-Down frame.
- Immediate response by Station on a CF_Poll.
- Stations to maintain NAV to protect CF-traffic.
- Responses can be variable length.
- “Reset NAV” by last (CF_End) frame from AP.
- "ACK Previous Frame" bit in Header.

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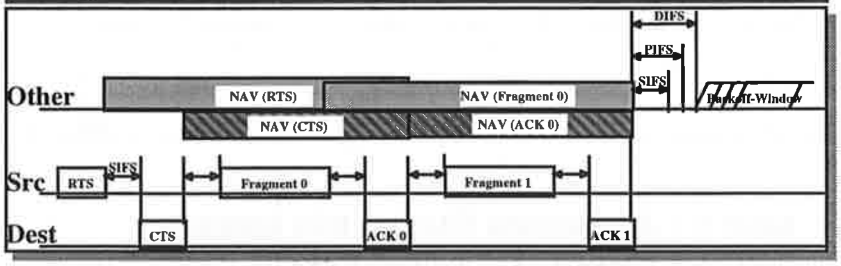
Fragmentation



- Burst of Fragments which are individually acknowledged.
  - For Unicast frames only.
- Random backoff and retransmission of failing fragment when no ACK is returned.
- *Duration* information in data fragments and Ack frames causes NAV to be set, for medium reservation mechanism.

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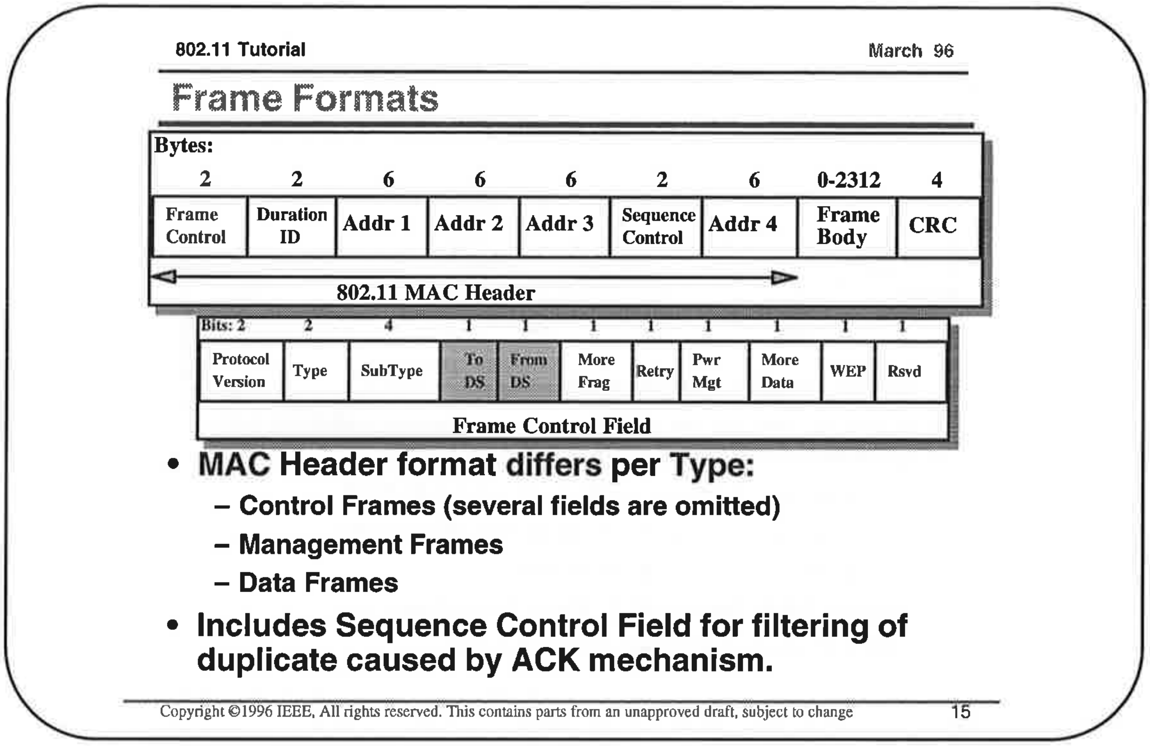

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Frame Formats

Bytes:

2	2	6	6	6	2	6	0-2312	4
Frame Control	Duration ID	Addr 1	Addr 2	Addr 3	Sequence Control	Addr 4	Frame Body	CRC

802.11 MAC Header

Bits: 2	2	4	1	1	1	1	1	1	1	1
Protocol Version	Type	SubType	To DS	From DS	More Frag	Retry	Pwr Mgt	More Data	WEP	Rsvd

Frame Control Field

- **MAC Header format differs per Type:**
  - **Control Frames (several fields are omitted)**
  - **Management Frames**
  - **Data Frames**
- **Includes Sequence Control Field for filtering of duplicate caused by ACK mechanism.**

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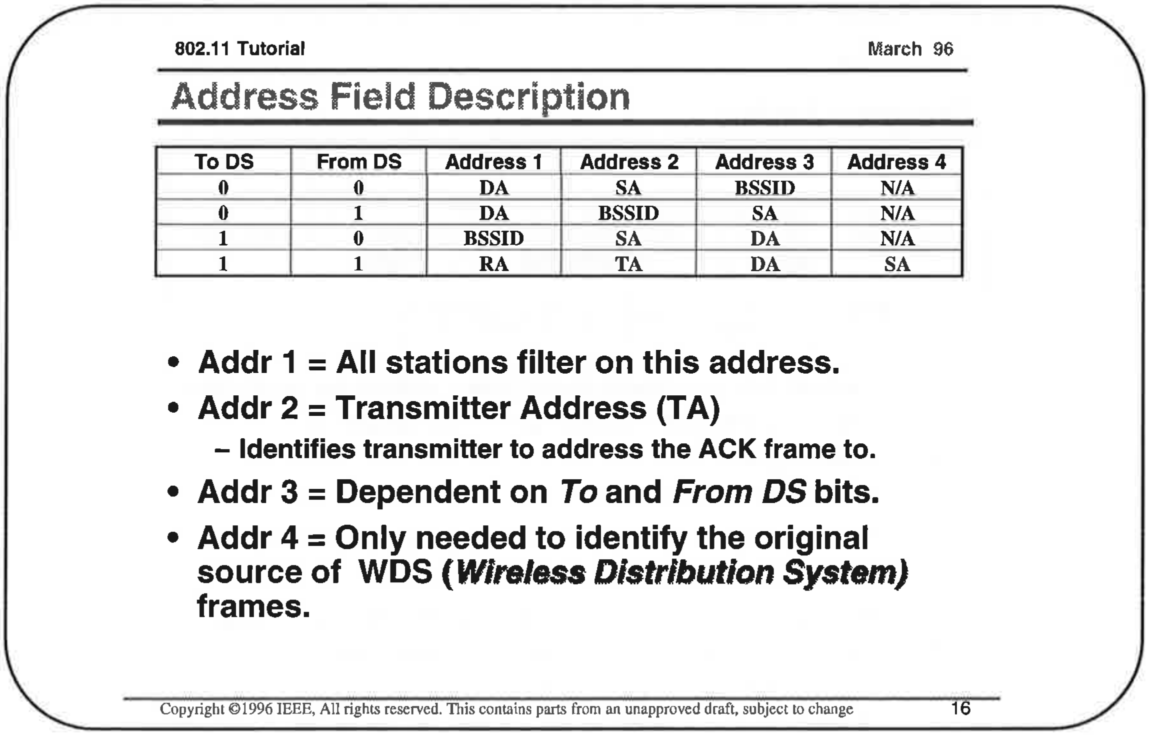

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Address Field Description

To DS	From DS	Address 1	Address 2	Address 3	Address 4
0	0	DA	SA	BSSID	N/A
0	1	DA	BSSID	SA	N/A
1	0	BSSID	SA	DA	N/A
1	1	RA	TA	DA	SA

- **Addr 1 = All stations filter on this address.**
- **Addr 2 = Transmitter Address (TA)**
  - **Identifies transmitter to address the ACK frame to.**
- **Addr 3 = Dependent on *To* and *From DS* bits.**
- **Addr 4 = Only needed to identify the original source of WDS (*Wireless Distribution System)* frames.**

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Privacy and Access Control

- Goal of 802.11 is to provide "Wired Equivalent Privacy" (WEP)
  - Usable worldwide
- 802.11 provides for an Authentication mechanism
  - To aid in access control.
  - Has provisions for "OPEN", "Shared Key" or proprietary authentication extensions.
- Optional (WEP) Privacy mechanism defined by 802.11.
  - Limited for Station-to-Station traffic, so not "end to end".
    - » Embedded in the MAC entity.
  - Only implements "Confidentiality" function.
  - Uses RC4 PRNG algorithm based on:
    - » a 40 bit secret key (No Key distribution standardized)
    - » and a 24 bit IV that is send with the data.
    - » includes an ICV to allow integrity check.
  - Only payload of Data frames are encrypted.
    - » Encryption on per MPDU basis.

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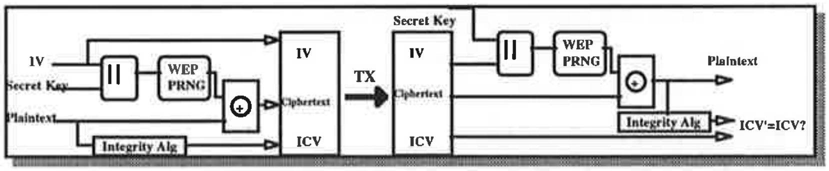
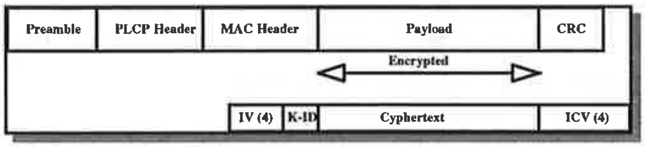
Privacy Mechanism





- WEP bit in Frame Control Field indicates WEP used.
  - Each frame can have a new IV, or IV can be reused for a limited time.
  - If integrity check fails then frame is ACKed but discarded.

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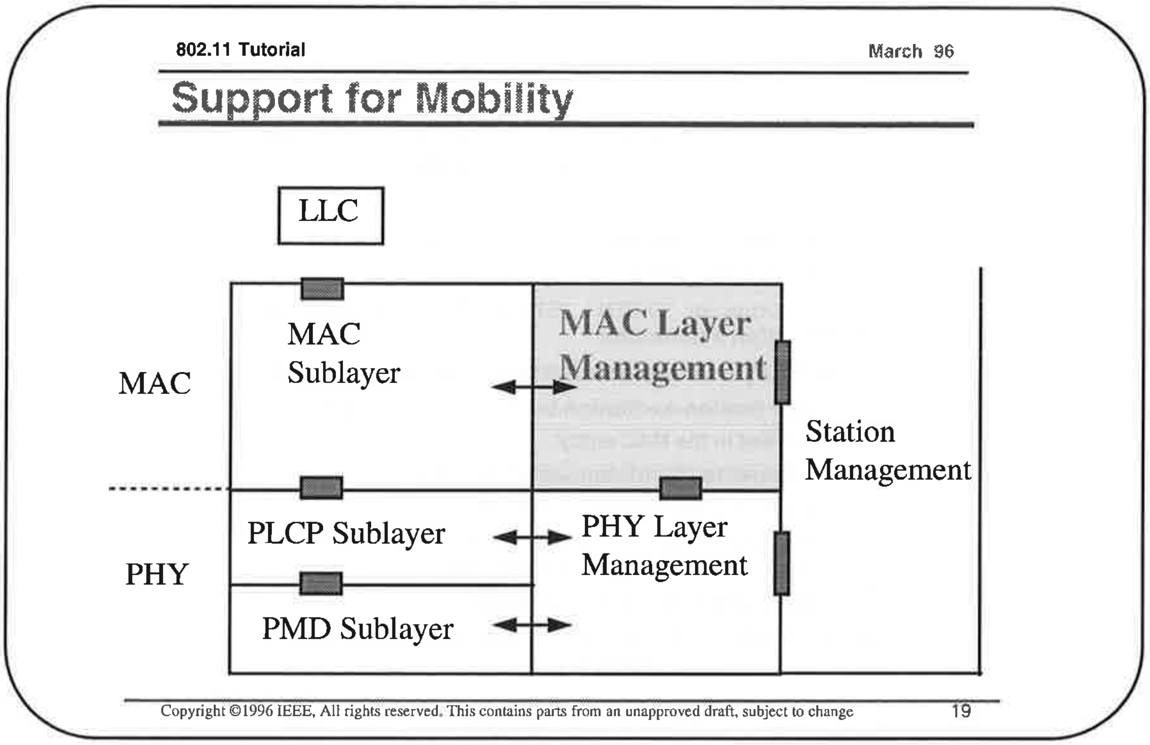

Support for Mobility

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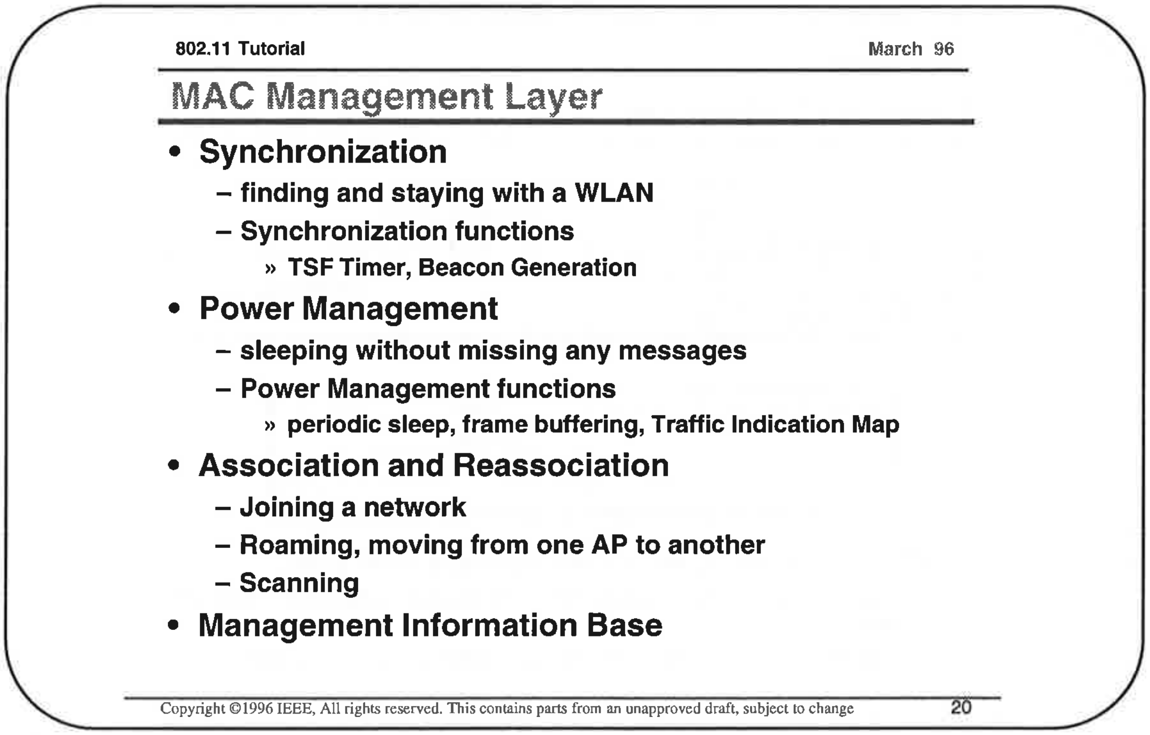

MAC Management Layer

- **Synchronization**
  - finding and staying with a WLAN
  - Synchronization functions
    - » TSF Timer, Beacon Generation
- **Power Management**
  - sleeping without missing any messages
  - Power Management functions
    - » periodic sleep, frame buffering, Traffic Indication Map
- **Association and Reassociation**
  - Joining a network
  - Roaming, moving from one AP to another
  - Scanning
- **Management Information Base**

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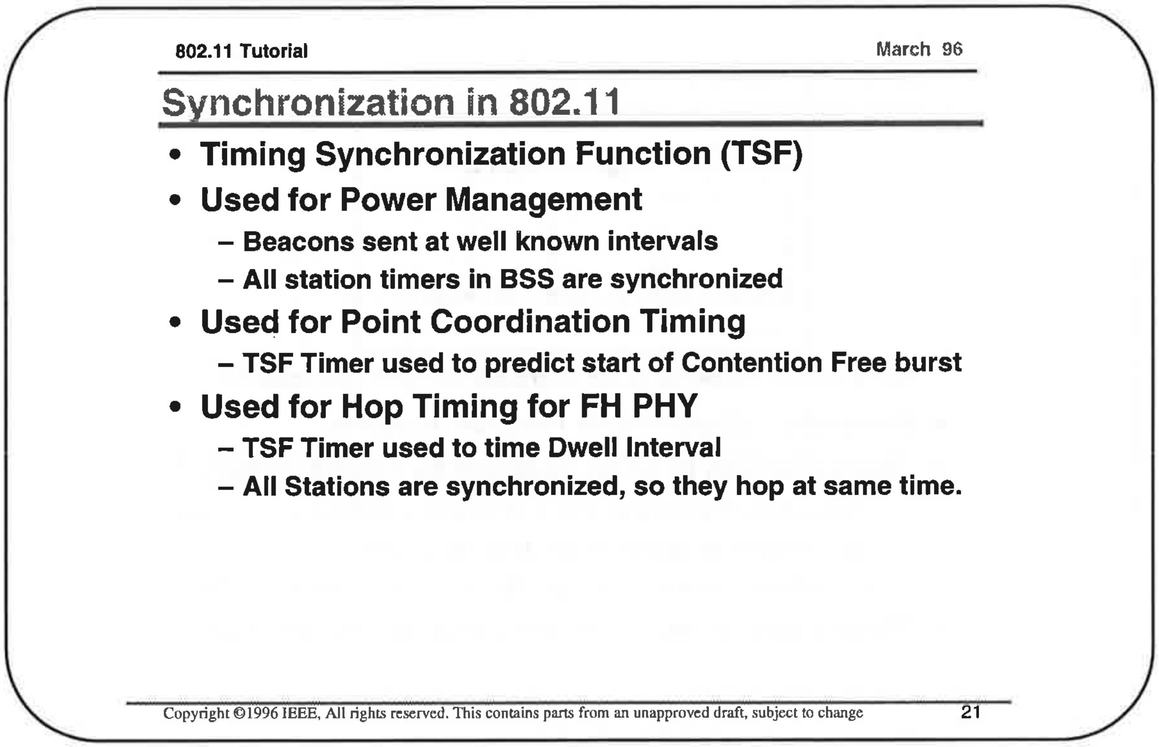

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Synchronization in 802.11

- Timing Synchronization Function (TSF)
- Used for Power Management
  - Beacons sent at well known intervals
  - All station timers in BSS are synchronized
- Used for Point Coordination Timing
  - TSF Timer used to predict start of Contention Free burst
- Used for Hop Timing for FH PHY
  - TSF Timer used to time Dwell Interval
  - All Stations are synchronized, so they hop at same time.

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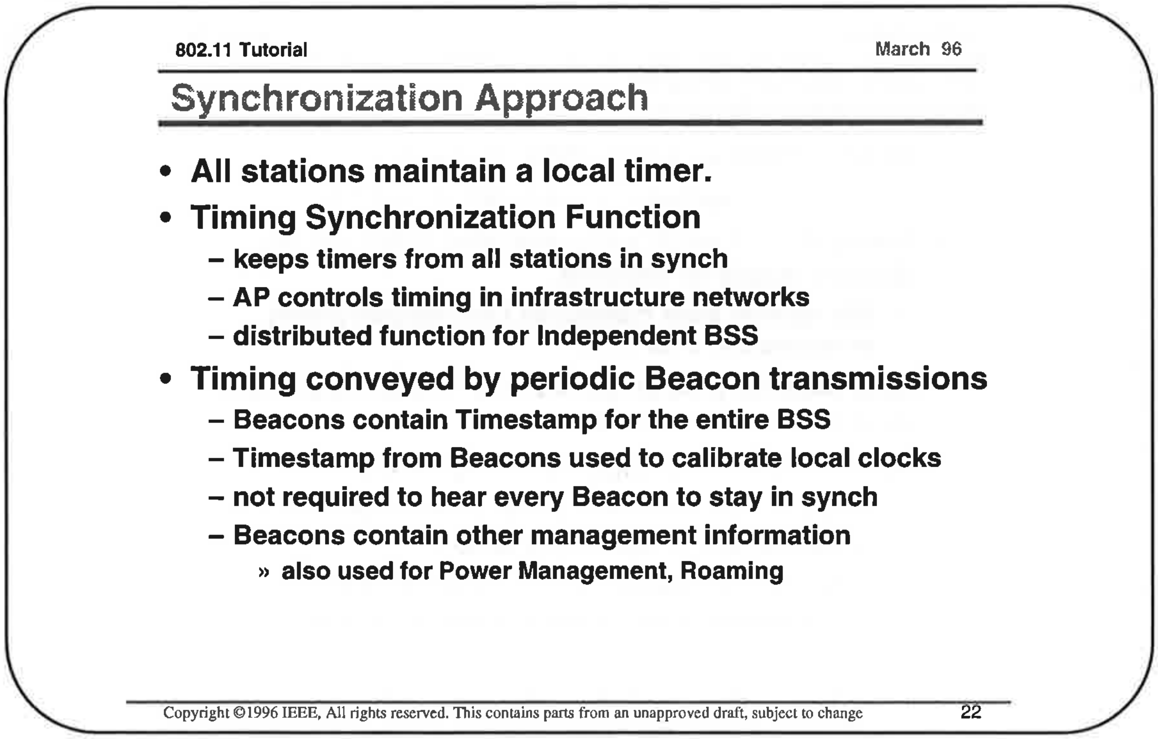

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Synchronization Approach

- All stations maintain a local timer.
- Timing Synchronization Function
  - keeps timers from all stations in synch
  - AP controls timing in infrastructure networks
  - distributed function for Independent BSS
- Timing conveyed by periodic Beacon transmissions
  - Beacons contain Timestamp for the entire BSS
  - Timestamp from Beacons used to calibrate local clocks
  - not required to hear every Beacon to stay in synch
  - Beacons contain other management information
    - » also used for Power Management, Roaming

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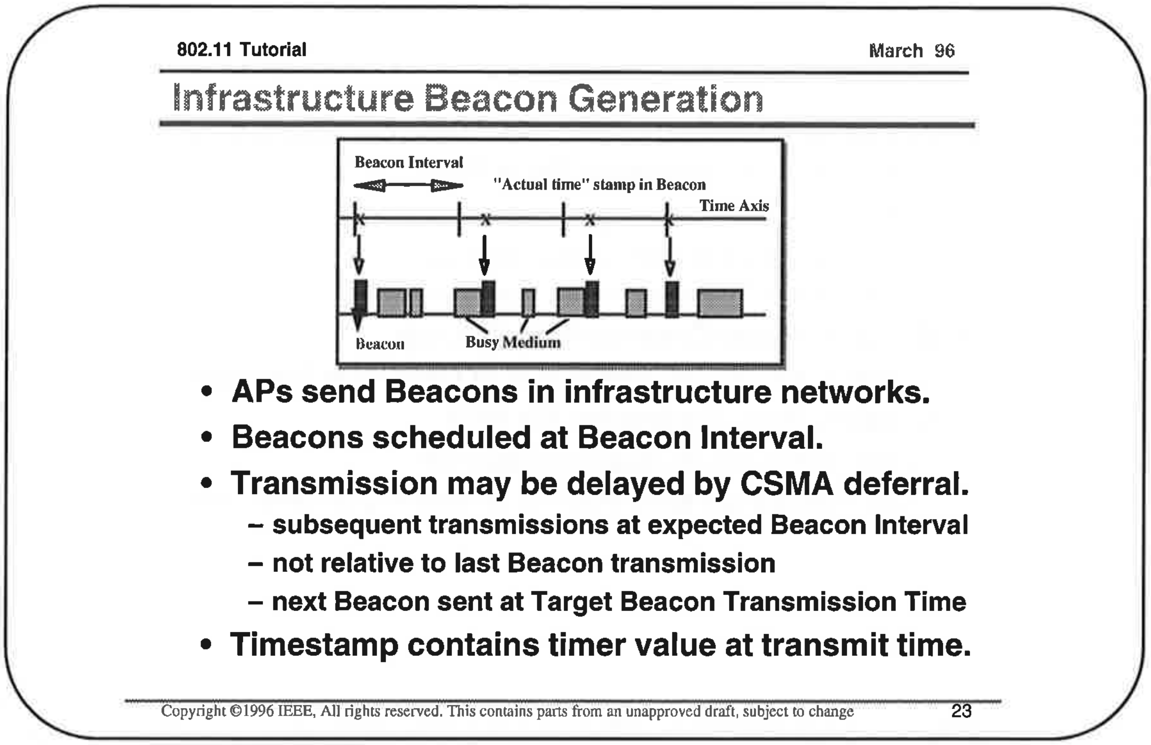

Infrastructure Beacon Generation

Beacon Interval
"Actual time" stamp in Beacon
Time Axis
Beacon
Busy Medium

- **APs send Beacons in infrastructure networks.**
- **Beacons scheduled at Beacon Interval.**
- **Transmission may be delayed by CSMA deferral.**
  - **subsequent transmissions at expected Beacon Interval**
  - **not relative to last Beacon transmission**
  - **next Beacon sent at Target Beacon Transmission Time**
- **Timestamp contains timer value at transmit time.**

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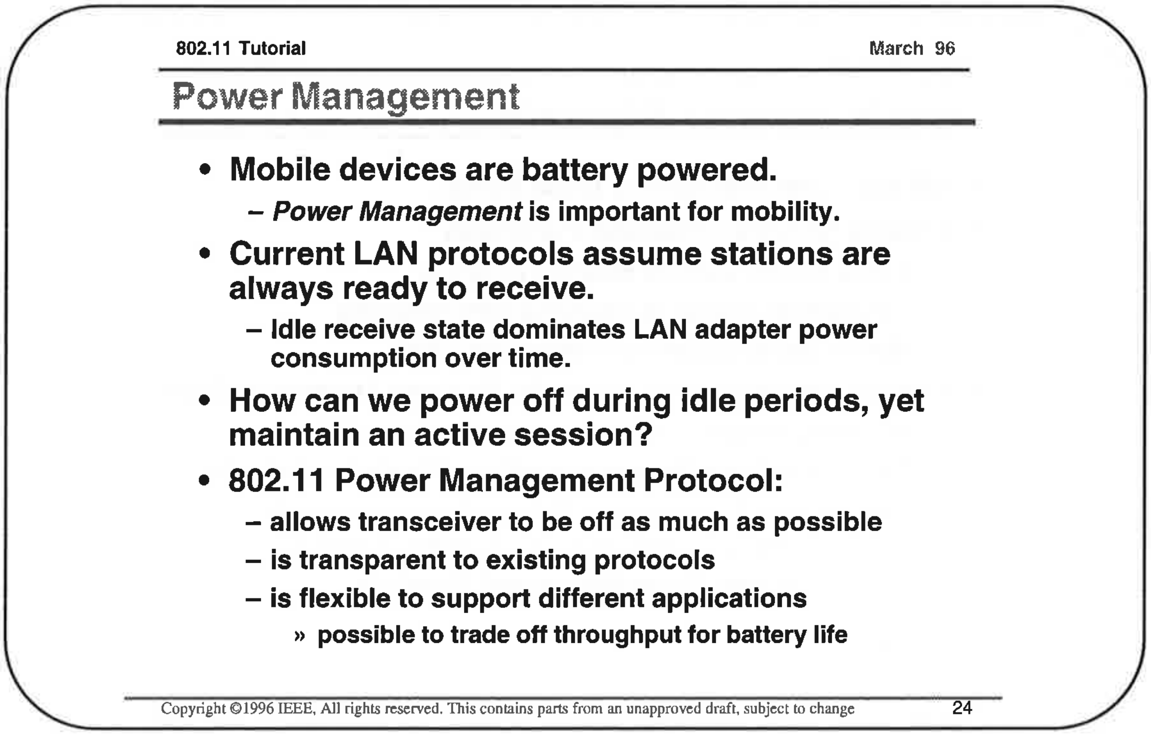

Power Management

- **Mobile devices are battery powered.**
  - ***Power Management* is important for mobility.**
- **Current LAN protocols assume stations are always ready to receive.**
  - **Idle receive state dominates LAN adapter power consumption over time.**
- **How can we power off during idle periods, yet maintain an active session?**
- **802.11 Power Management Protocol:**
  - **allows transceiver to be off as much as possible**
  - **is transparent to existing protocols**
  - **is flexible to support different applications**
    - **» possible to trade off throughput for battery life**

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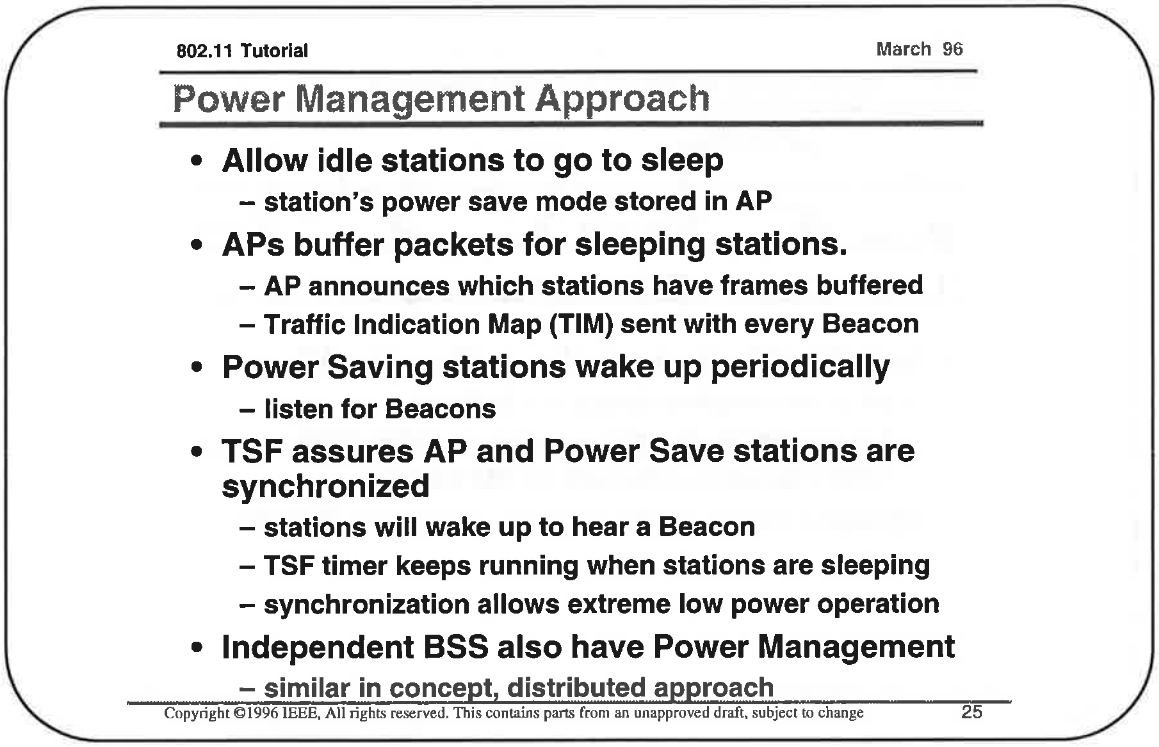

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Power Management Approach

- Allow idle stations to go to sleep
  - station's power save mode stored in AP
- APs buffer packets for sleeping stations.
  - AP announces which stations have frames buffered
  - Traffic Indication Map (TIM) sent with every Beacon
- Power Saving stations wake up periodically
  - listen for Beacons
- TSF assures AP and Power Save stations are synchronized
  - stations will wake up to hear a Beacon
  - TSF timer keeps running when stations are sleeping
  - synchronization allows extreme low power operation
- Independent BSS also have Power Management
  - similar in concept, distributed approach

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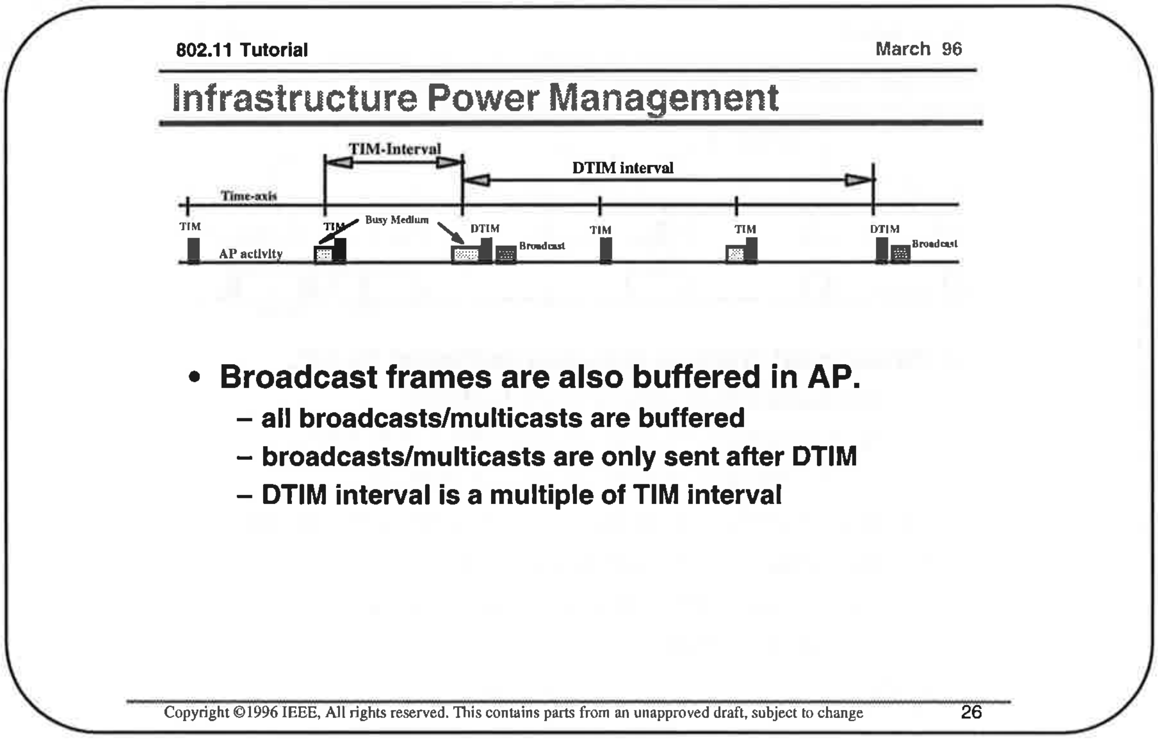

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Infrastructure Power Management

- Broadcast frames are also buffered in AP.
  - all broadcasts/multicasts are buffered
  - broadcasts/multicasts are only sent after DTIM
  - DTIM interval is a multiple of TIM interval

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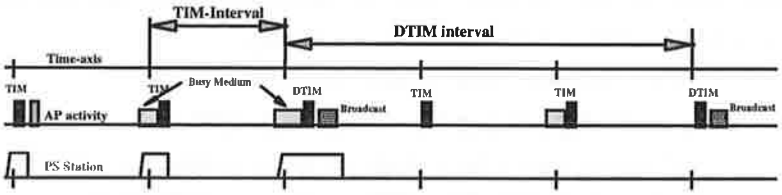
Infrastructure Power Management



- **Broadcast frames are also buffered in AP.**
  - **– all broadcasts/multicasts are buffered**
  - **– broadcasts/multicasts are only sent after DTIM**
  - **– DTIM interval is a multiple of TIM interval**
- **Stations wake up prior to an expected (D)TIM.**

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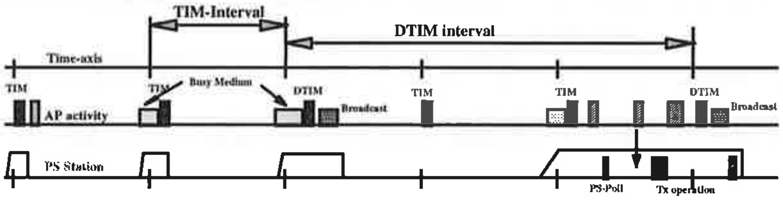
Infrastructure Power Management



- **Broadcast frames are also buffered in AP.**
  - **– all broadcasts/multicasts are buffered**
  - **– broadcasts/multicasts are only sent after DTIM**
  - **– DTIM interval is a multiple of TIM interval**
- **Stations wake up prior to an expected (D)TIM.**
- **If TIM indicates frame buffered**
  - **– station sends PS-Poll and stays awake to receive data**
  - **– else station sleeps again**

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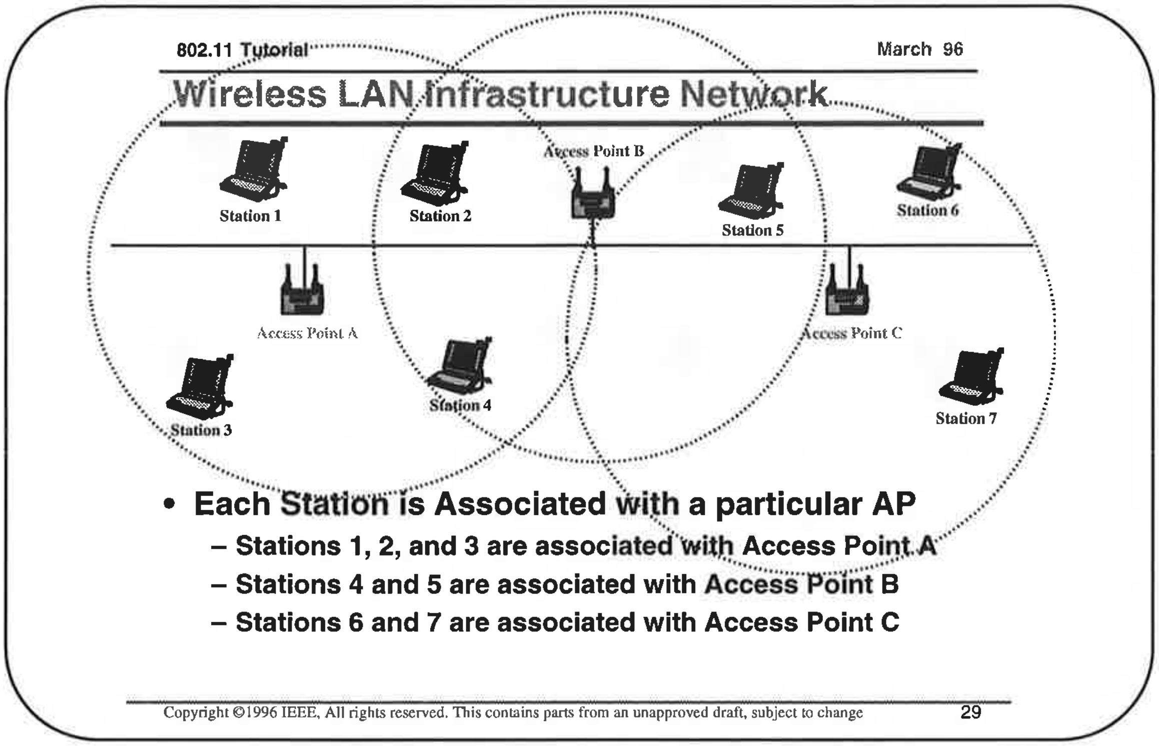

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Wireless LAN Infrastructure Network

- Each Station is Associated with a particular AP
  - Stations 1, 2, and 3 are associated with Access Point A
  - Stations 4 and 5 are associated with Access Point B
  - Stations 6 and 7 are associated with Access Point C

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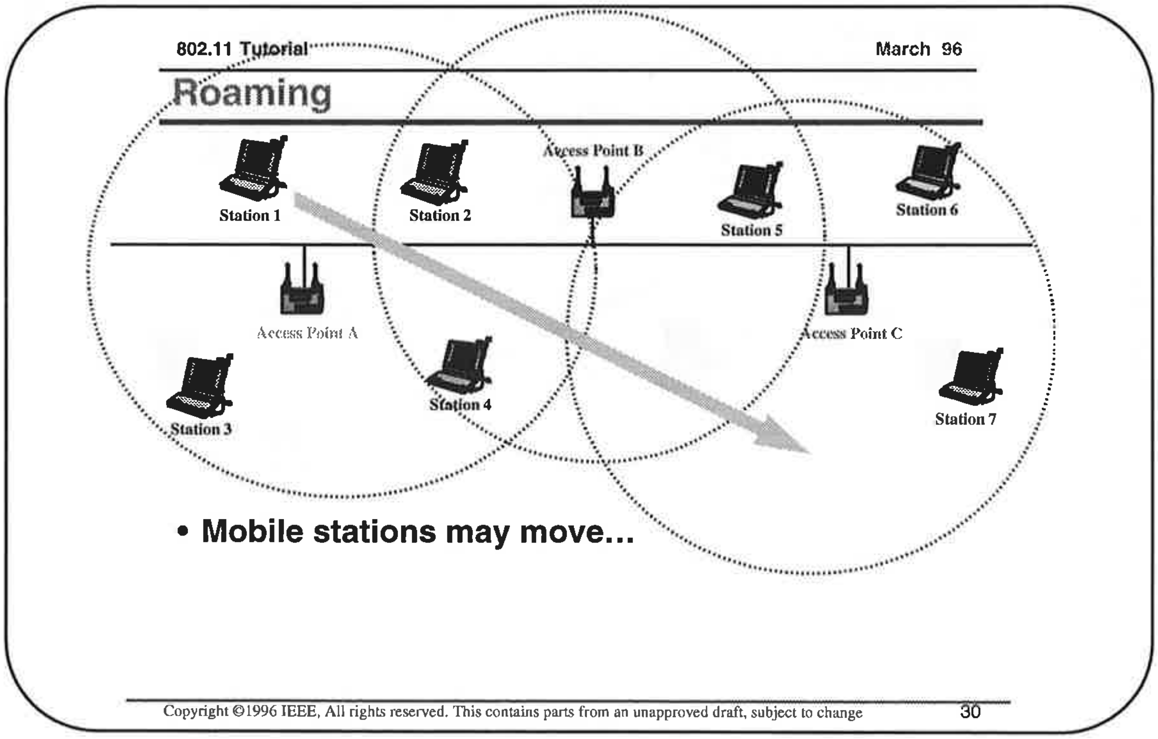

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Roaming

- Mobile stations may move...

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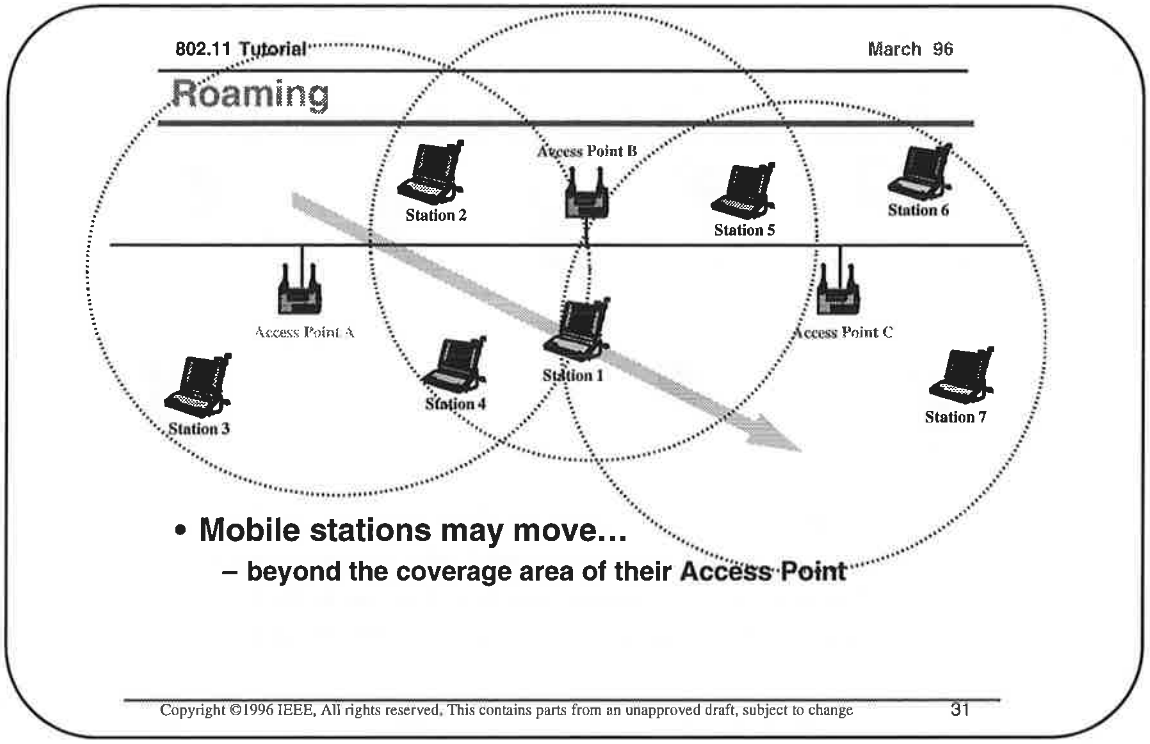

Roaming

- **Mobile stations may move...**
  - **beyond the coverage area of their Access Point**

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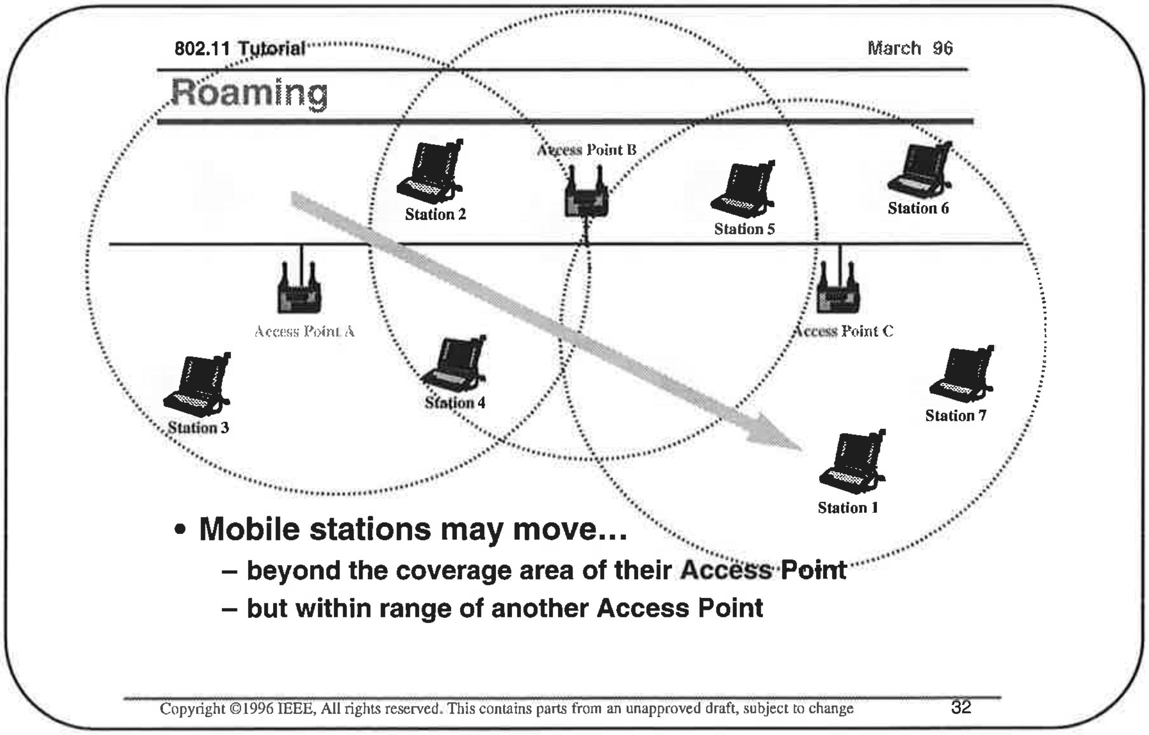

Roaming

- **Mobile stations may move...**
  - **beyond the coverage area of their Access Point**
  - **but within range of another Access Point**

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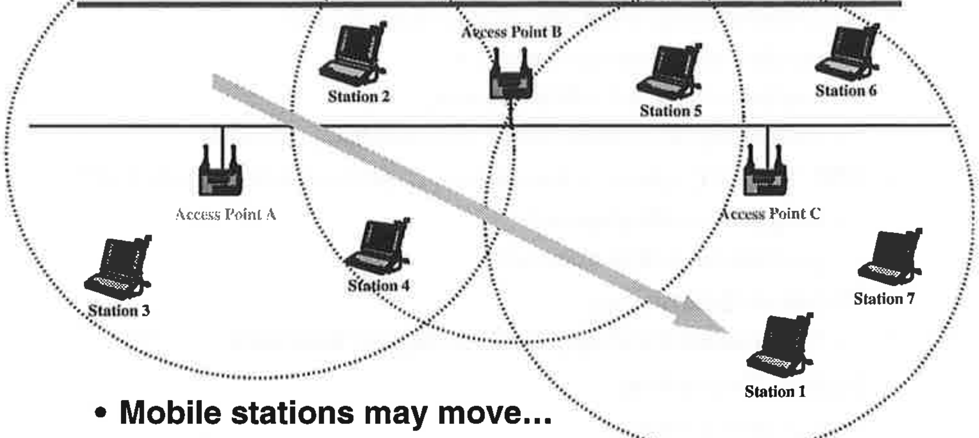
Roaming



- Mobile stations may move...
  - beyond the coverage area of their Access Point
  - but within range of another Access Point
- Reassociation allows station to continue operation

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Roaming Approach

- Station decides that link to its current AP is poor
- Station uses scanning function to find another AP
  - or uses information from previous scans
- Station sends Reassociation Request to new AP
- If Reassociation Response is successful
  - then station has roamed to the new AP
  - else station scans for another AP
- If AP accepts Reassociation Request
  - AP indicates Reassociation to the Distribution System
  - Distribution System information is updated
  - normally old AP is notified through Distribution System

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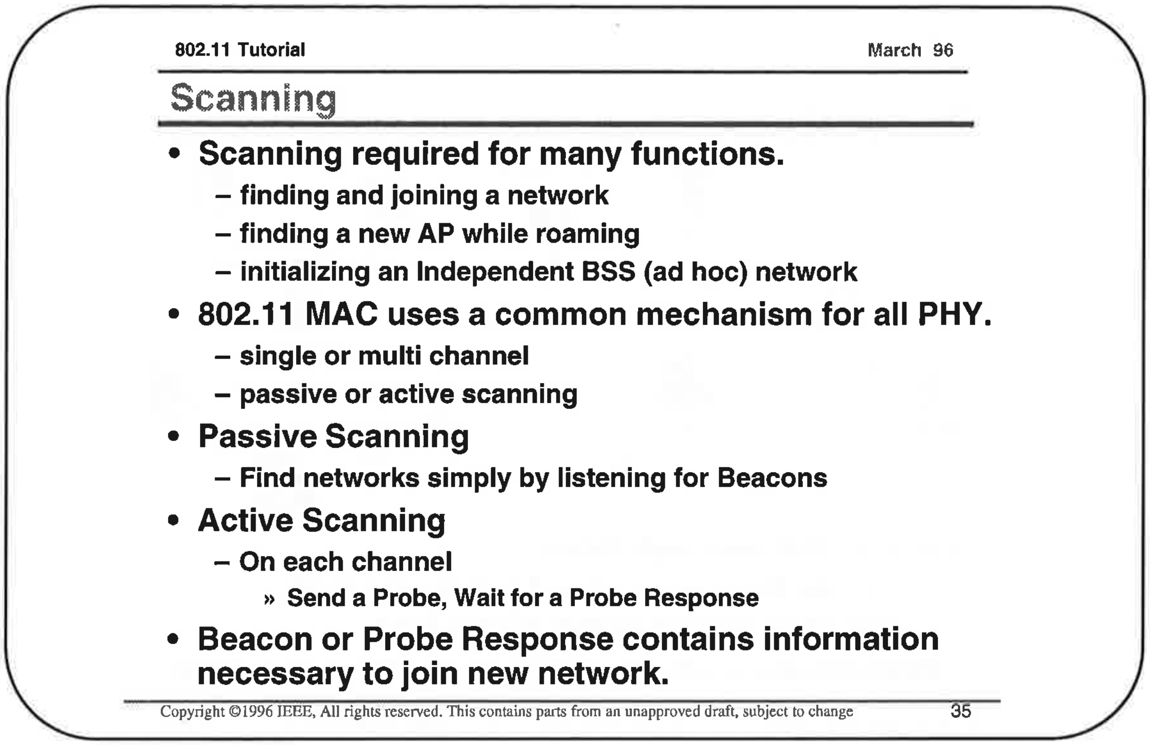

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Scanning

- **Scanning required for many functions.**
  - finding and joining a network
  - finding a new AP while roaming
  - initializing an Independent BSS (ad hoc) network
- **802.11 MAC uses a common mechanism for all PHY.**
  - single or multi channel
  - passive or active scanning
- **Passive Scanning**
  - Find networks simply by listening for Beacons
- **Active Scanning**
  - On each channel
    - » Send a Probe, Wait for a Probe Response
- **Beacon or Probe Response contains information necessary to join new network.**

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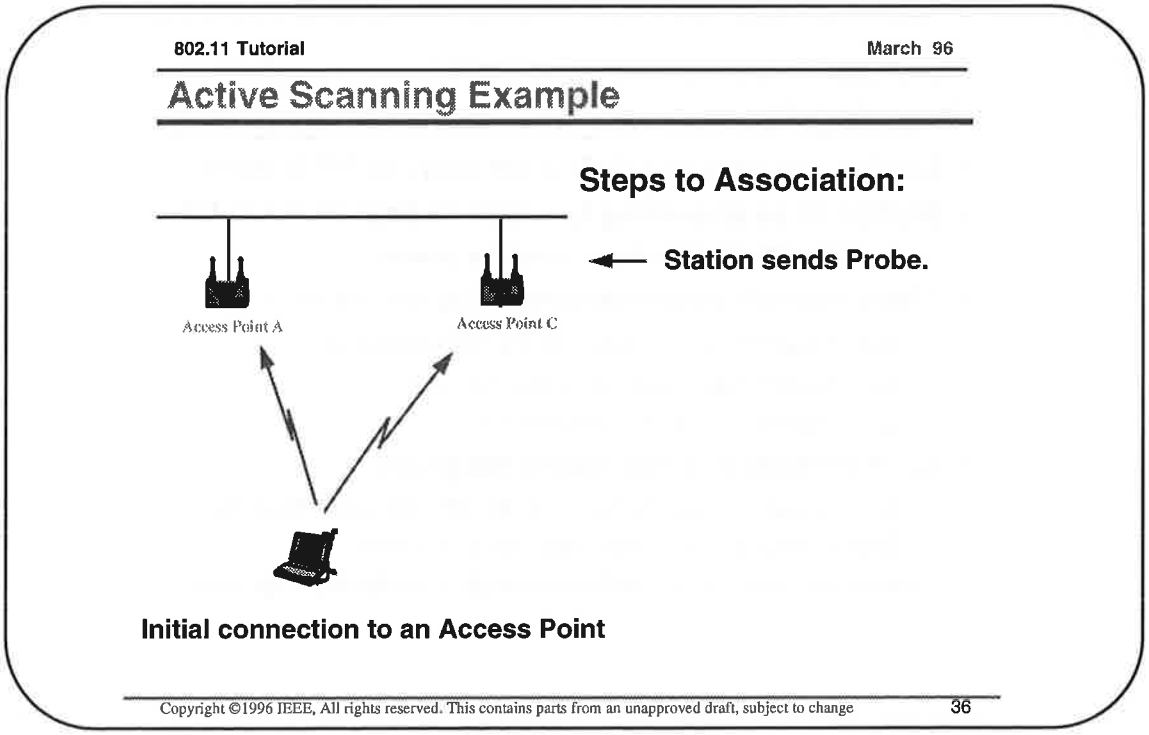

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Active Scanning Example

Steps to Association:

← Station sends Probe.

Initial connection to an Access Point

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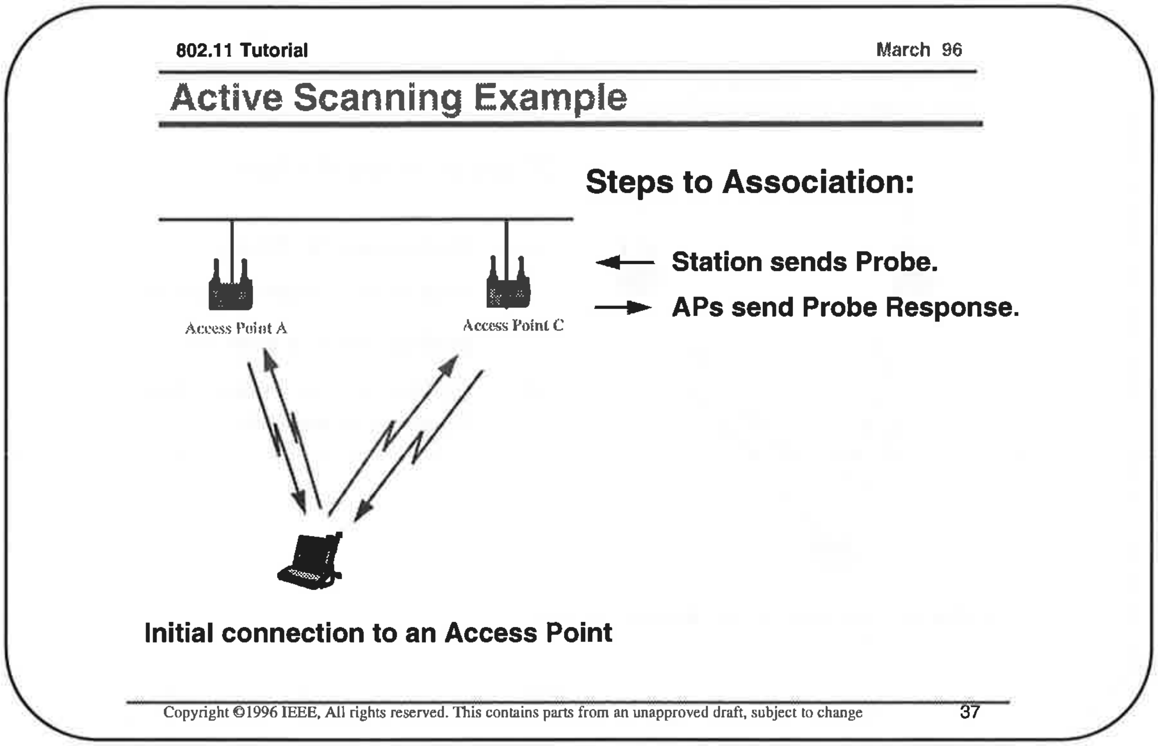

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Active Scanning Example

Access Point A
Access Point C

Steps to Association:

- ◄— Station sends Probe.
- —► APs send Probe Response.

Initial connection to an Access Point

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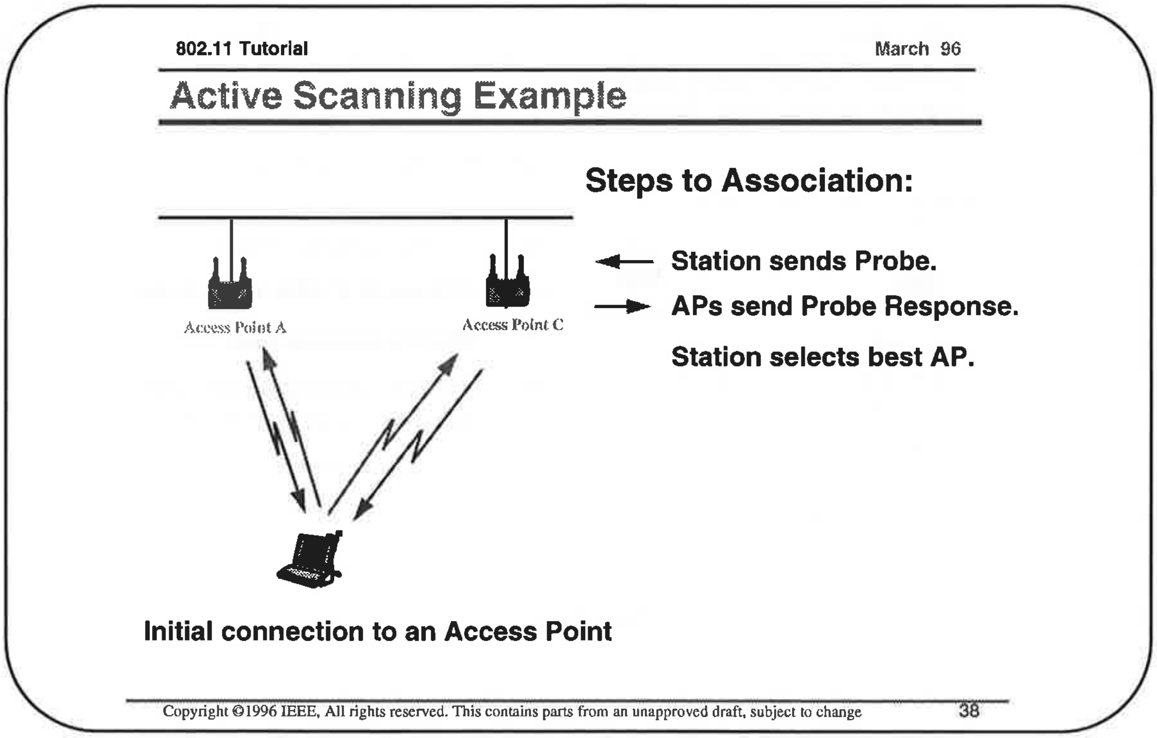

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Active Scanning Example

Access Point A
Access Point C

Steps to Association:

- ◄— Station sends Probe.
- —► APs send Probe Response.
- Station selects best AP.

Initial connection to an Access Point

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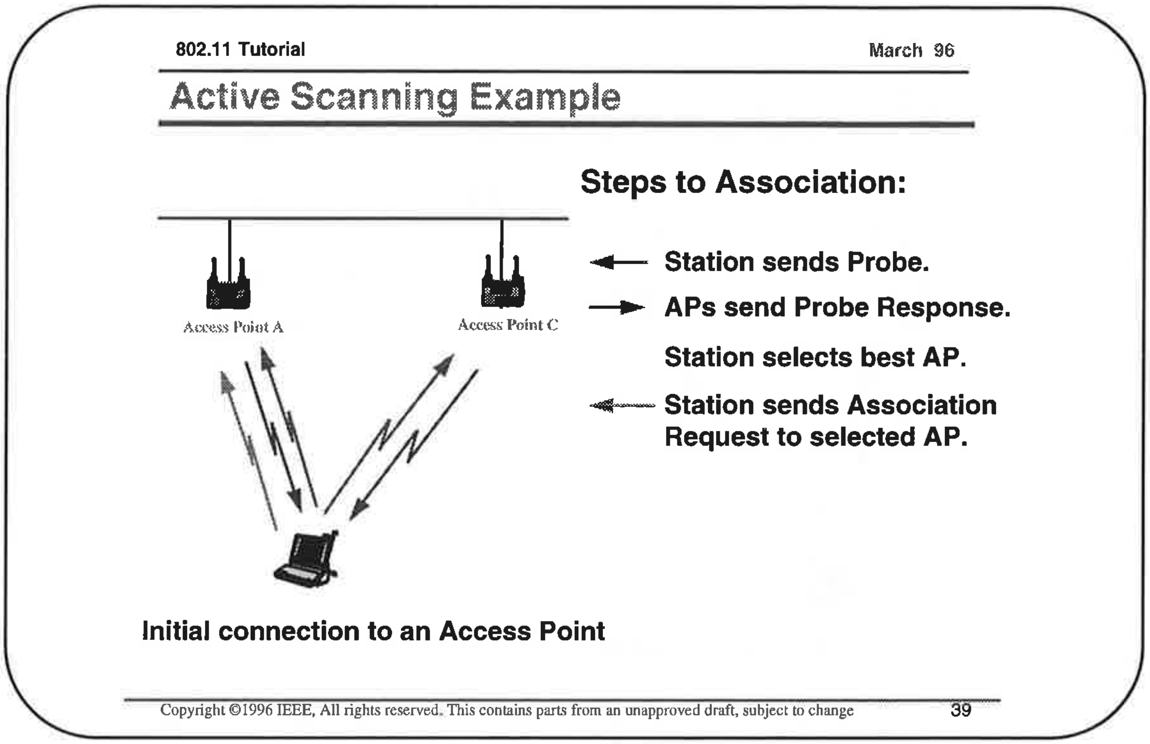

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Active Scanning Example

Access Point A
Access Point C

Steps to Association:

← Station sends Probe.

→ APs send Probe Response.

Station selects best AP.

← Station sends Association Request to selected AP.

Initial connection to an Access Point

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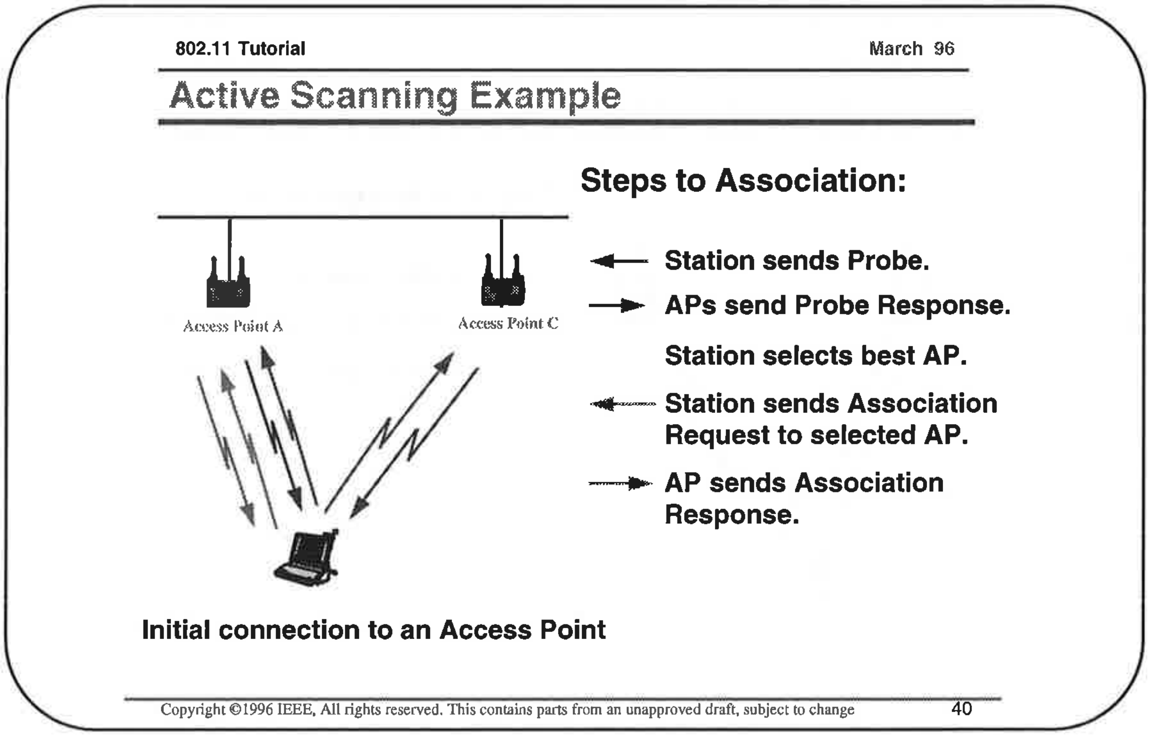

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Active Scanning Example

Access Point A
Access Point C

Steps to Association:

← Station sends Probe.

→ APs send Probe Response.

Station selects best AP.

← Station sends Association Request to selected AP.

→ AP sends Association Response.

Initial connection to an Access Point

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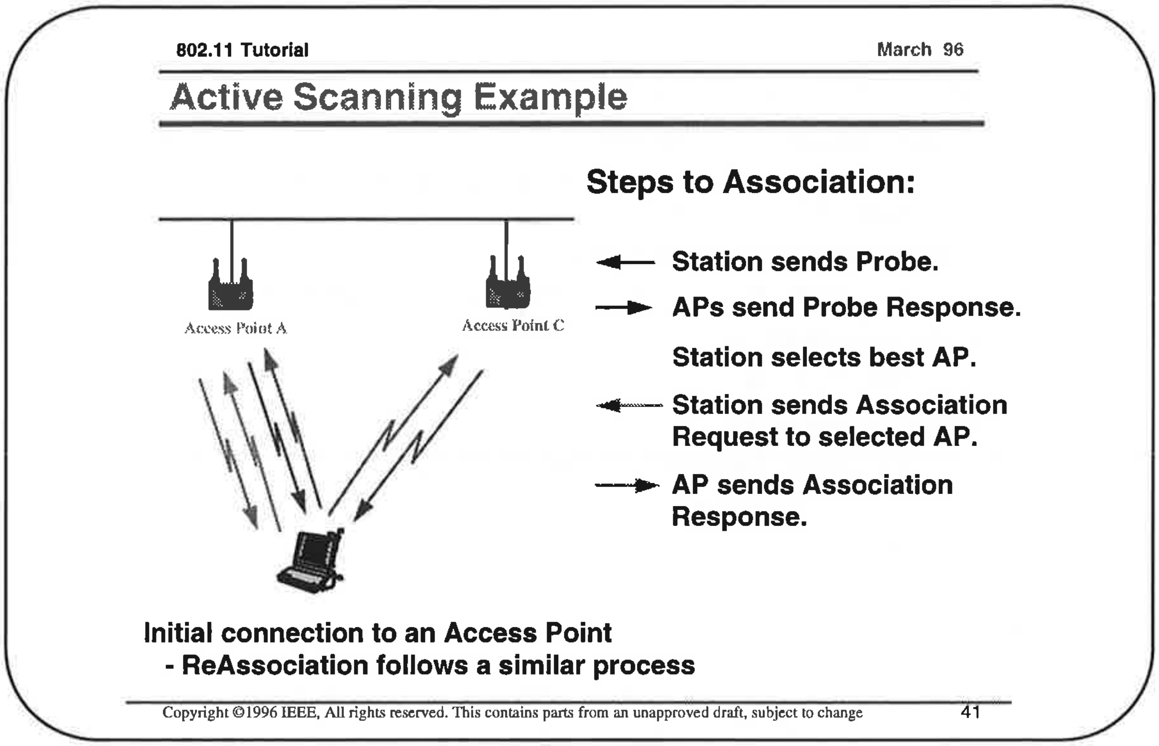
Access Point A
Access Point C

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Active Scanning Example

Steps to Association:

- ← Station sends Probe.
- → APs send Probe Response.
- Station selects best AP.
- ← Station sends Association Request to selected AP.
- → AP sends Association Response.

Initial connection to an Access Point
- ReAssociation follows a similar process

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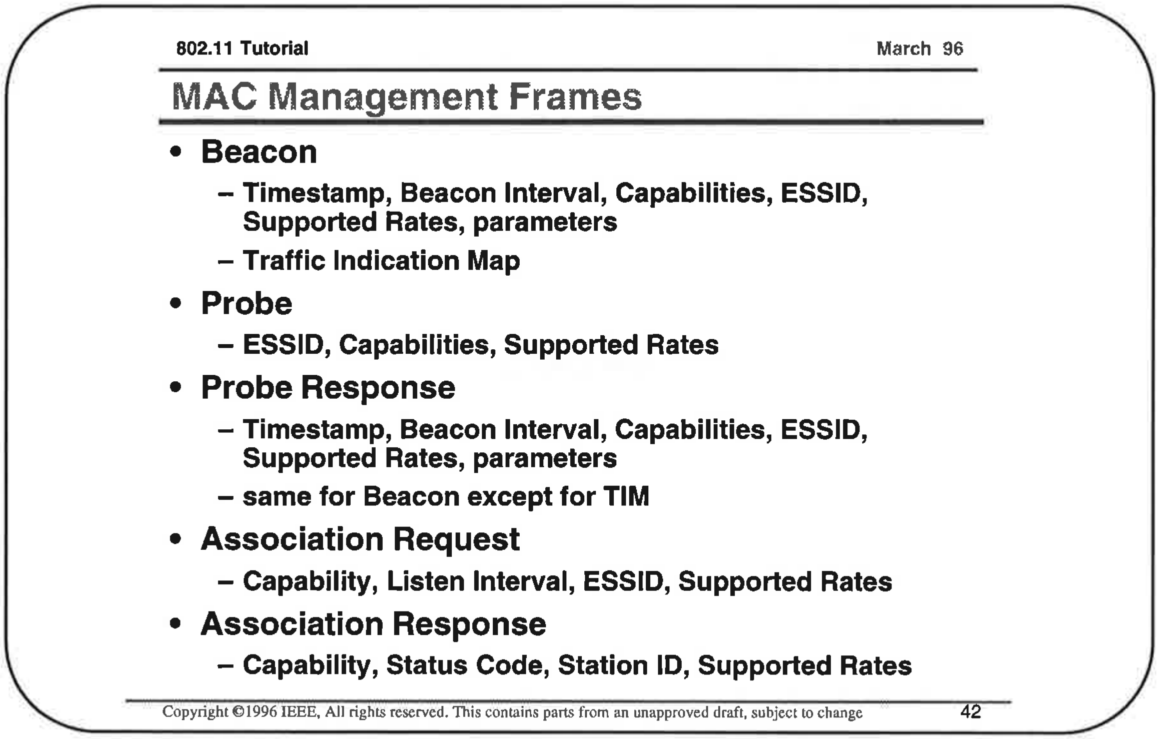

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MAC Management Frames

- **Beacon**
  - Timestamp, Beacon Interval, Capabilities, ESSID, Supported Rates, parameters
  - Traffic Indication Map
- **Probe**
  - ESSID, Capabilities, Supported Rates
- **Probe Response**
  - Timestamp, Beacon Interval, Capabilities, ESSID, Supported Rates, parameters
  - same for Beacon except for TIM
- **Association Request**
  - Capability, Listen Interval, ESSID, Supported Rates
- **Association Response**
  - Capability, Status Code, Station ID, Supported Rates

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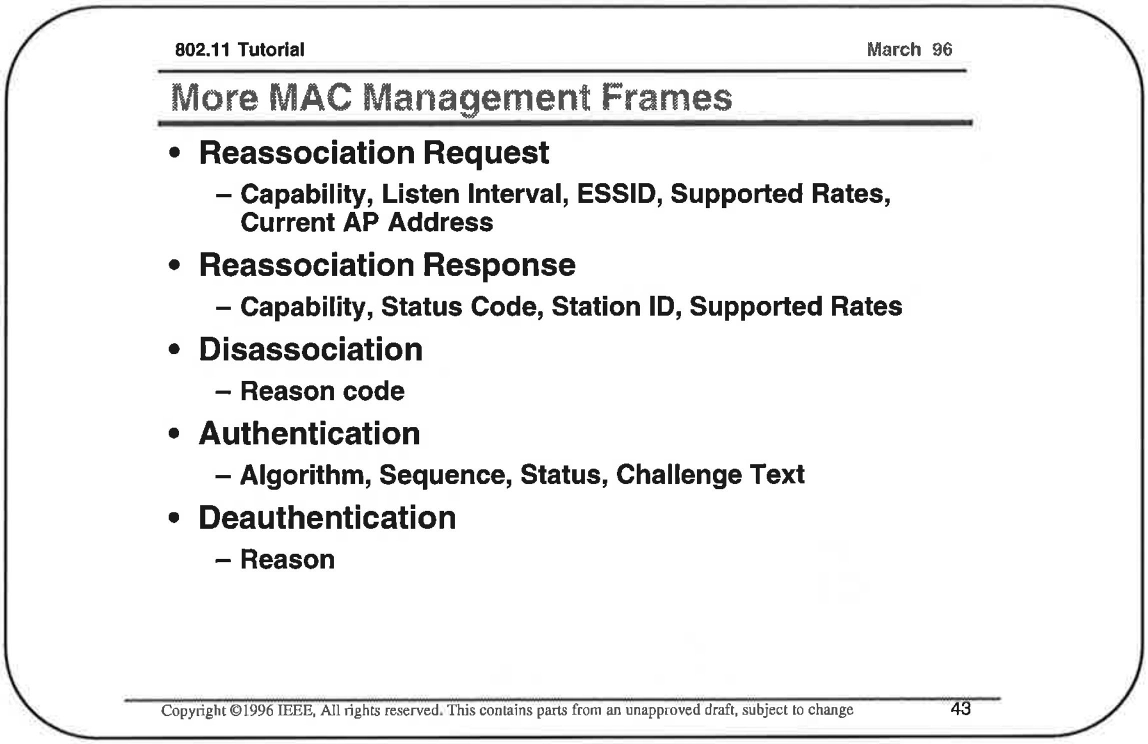

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More MAC Management Frames

- Reassociation Request
  - Capability, Listen Interval, ESSID, Supported Rates, Current AP Address
- Reassociation Response
  - Capability, Status Code, Station ID, Supported Rates
- Disassociation
  - Reason code
- Authentication
  - Algorithm, Sequence, Status, Challenge Text
- Deauthentication
  - Reason

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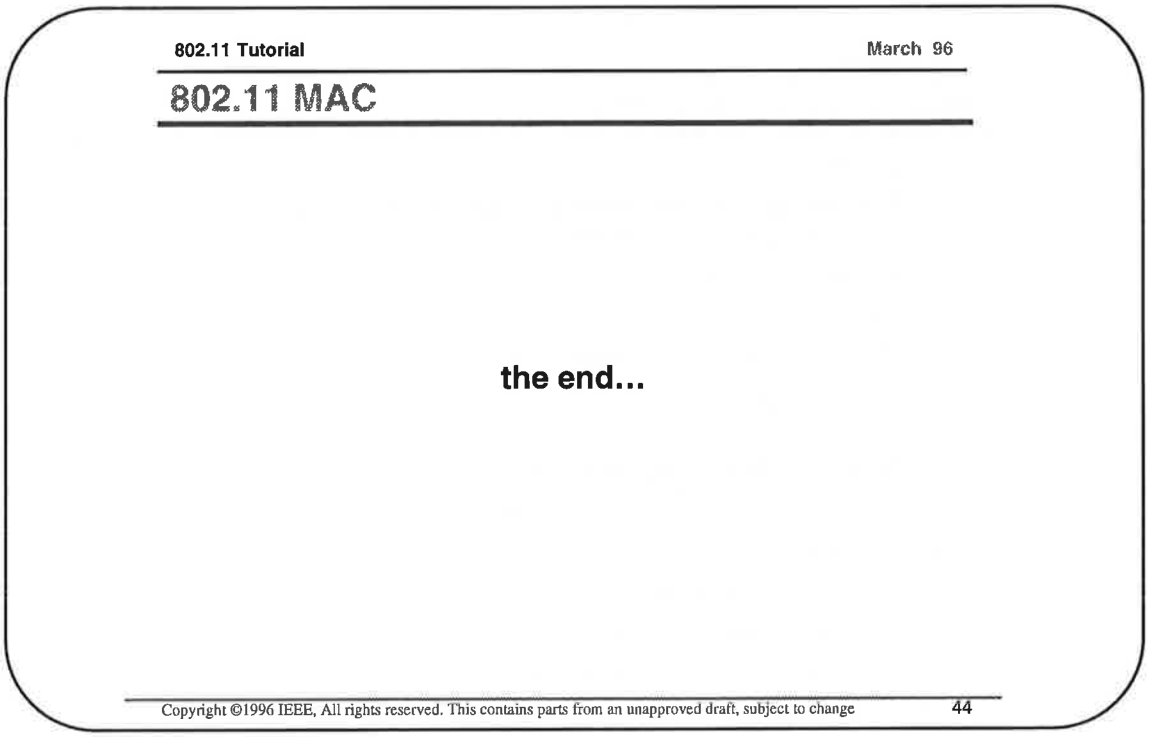

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802.11 MAC

the end...

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