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Wireless MAC

Foundation MAC Protocol

Tutorial presentation for the 802.11 PHY subgroup

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Overview / Agenda:

- Overview / Basic Access mechanism — Wim
  - DCF access scheme.
  - Simulation results.
  - Functions required from the PHY.
  - PCF access scheme (optional).
- Power Management provisions — Greg
  - Functions required from the PHY.
- Roaming provisions — Phil
  - Scanning provisions
  - Functions required from the PHY.
- Synchronization provisions — Phil
  - Synchronization timer
- Frame formats — Greg
- Quiz results — Wim/John

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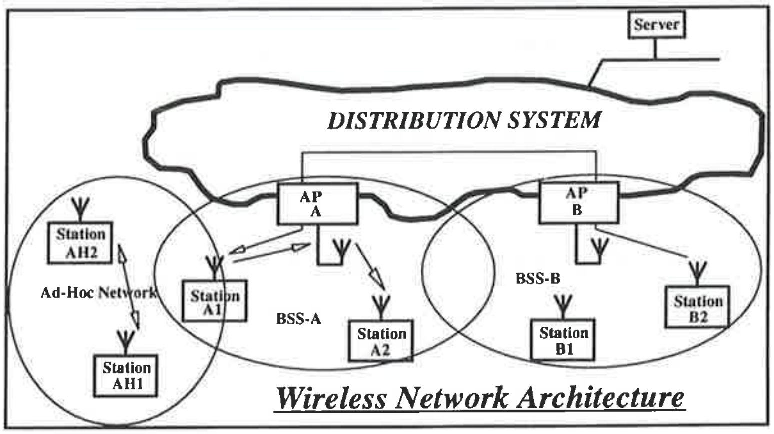
Wireless Network Architecture



802.11 MAC Requirements:

- Single MAC to support multiple PHY's.
  - Support single and multi-channel PHY's.
- Also PHY's for future bands like:
  - 1.9 GHz PCS band (Voice and / or Data band).
  - Future 5.2 GHz.
  - Other ISM bands (915 MHz and 5.8 GHz)
- Support Infrastructure mode.
- Support Ad-Hoc mode.
- Support mobility.
  - "Roaming" provisions.
  - Power Conservation Management provisions.

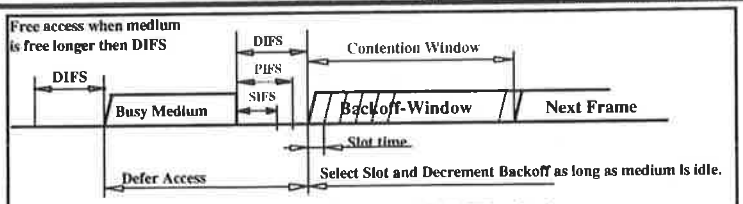
Supported services:

- Asynchronous Data Service:
  - Short response time with high instantaneous throughput, suitable for Bursty traffic.
  - *No BSS isolation required.*
- Contention Free Service (optional):
  - Time Bounded service (can be dimensioned for Voice).
    - » Connection oriented (reserved bandwidth).
    - » Allows mixed Voice/Data operation.
    - » Allows variable bitrates (frame sizes).
  - Asynchronous Contention Free Service.
    - » Allows "centralised Control".
  - *Requires sufficient BSS isolation.*

Basic Access Protocol:

- Use Distributed Access Protocol for efficient medium sharing without overlap restrictions.
- 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 CCA" funtion to protect against "Hidden Nodes".
- Support Ad-Hoc operation seamlessly, so does not require any infrastructure.
  - Ad-Hoc can overlap with Infrastructure.

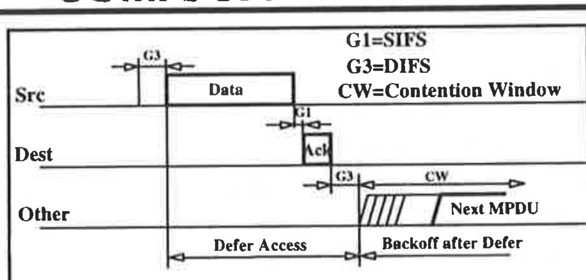
CSMA/CA explained:



CSMA/CA Access Methodology with PCF priority

- Reduce collision probability where mostly needed.
- Efficient Backoff algorithm stable at high loads.
  - Exponential Backoff for retransmissions.
- Implement different fixed priority levels.
  - To allow immediate Ack and PCF coexistence.
- When no Ack received then retransmit frame after a random backoff (up to max. limit).

CSMA/CA+Ack Protocol



Directed DATA/Ack MPDU

- Defer access based on CCA and NAV state.
- Direct access when medium is sensed free longer then DIFS, otherwise defer and backoff.

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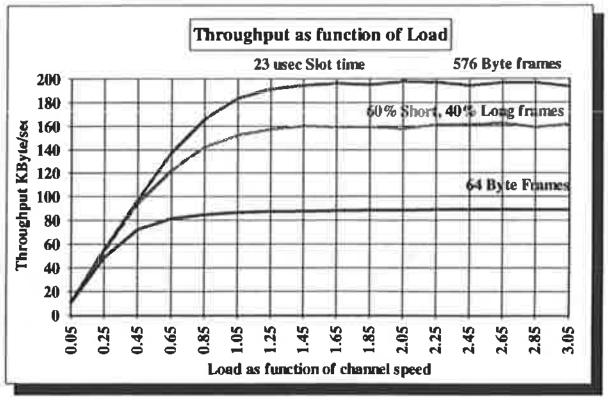
Throughput efficiency:



- **Efficient and stable throughput.**

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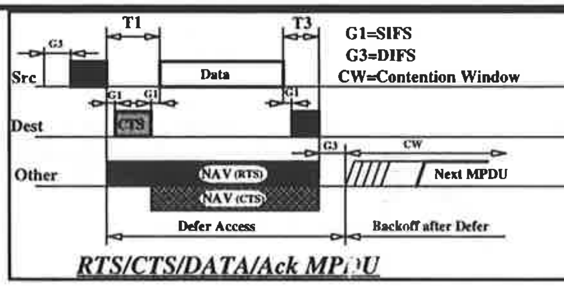
RTS/CTS medium reservation:



- **Net Allocation Vector (NAV) follows "Duration" info in RTS and CTS.**
- **Use of RTS / CTS is optional but <u>must</u> be implemented.**
- **Defer on NAV and "CCA", also for the Contention Free service.**
- **RTS / CTS use is controlled by a NoRTS parameter per station. Can be usefull for long inbound frames.**

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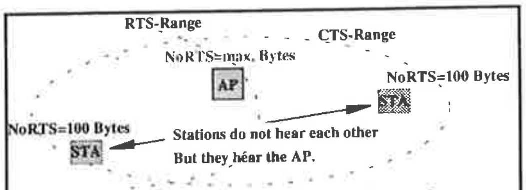
NoRTS parameter:

- RTS/CTS is not benificial for short frames.



Hidden Nodes in Infrastructure Networks

- The NoRTS parameter indicates per station that frames shorter then the parameter will be transmitted without RTS/CTS.
- Allows optional use on long inbound frames.

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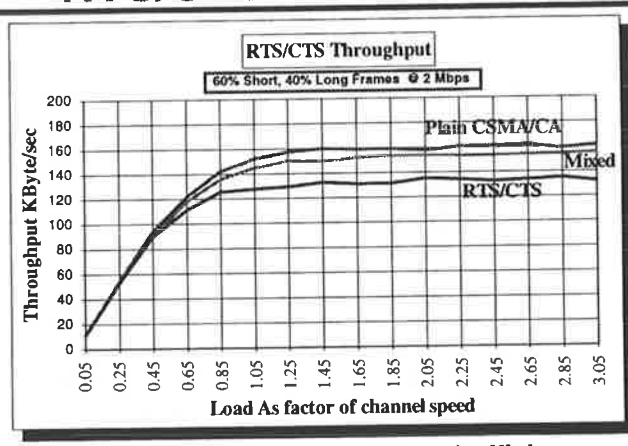
RTS/CTS Performance:



Good mixed use (long inbound frames) efficiency.

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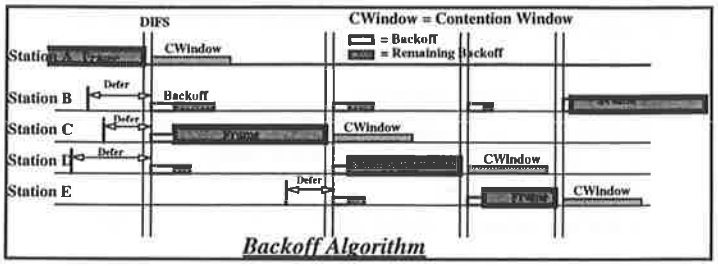
Backoff timer behaviour:



- **Backoff timer elapses only when medium is Free.**
- **So higher relative priority for stations that were already deffering.**
- **Exponential Contention window increase at every retransmission.**

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Required PHY Functions:

- ***Continuous* "Clear Channel Assessment" (CCA) signal indicating when medium is Free.**
- **PHY frequency channel selection under MAC control.**

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Important PHY parameters:

- The following parameters have effect on the *throughput* performance and *access delay*:
  - CCA response time.
  - Net Rx-Tx turnaround time.
  - Slot time=CCA response + Rx-Tx turnaround + medium delay (determines the collision window)
  - PHY preamble time.
  - Tx-Rx turnaround + medium delay determines SIFS.
  - CCA sensitivity level.
  - Channel switching delay.
- It is better to decrease the Rx-Tx turnaround time while increasing the PHY preamble length (this decreases the slot time).

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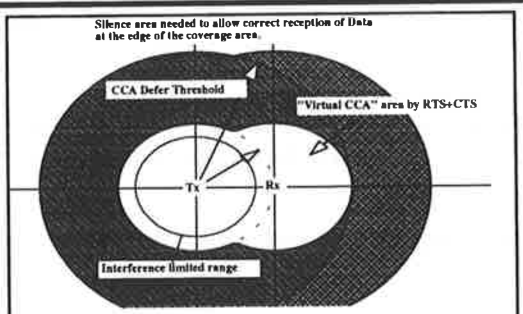
CCA sensitivity:



CCA versus "Virtual CCA" relation

- CCA sensitivity determines "Hidden node" vulnerability.
- Interference area is much larger then coverage area.

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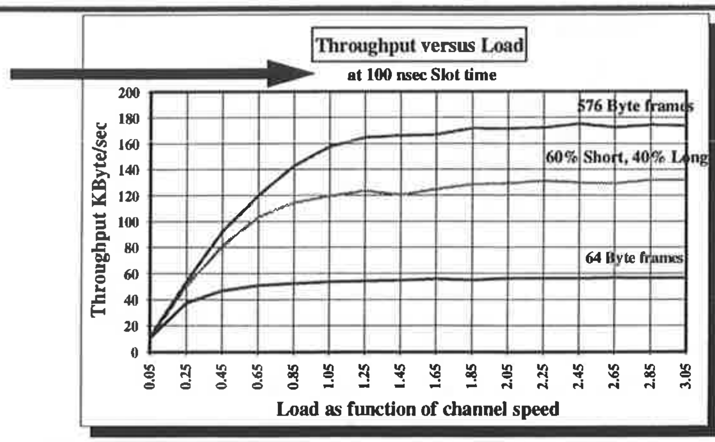
Effects of Tx-Rx turnaround:



- Throughput drops with 15-30%

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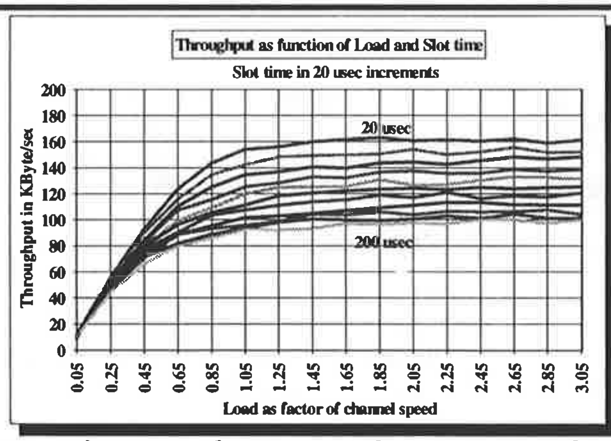
Effect of Turnaround times:



- Throughput performance drops at equal cw.

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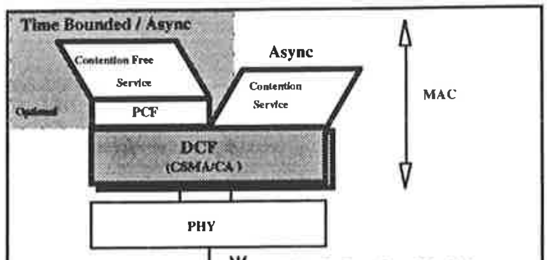
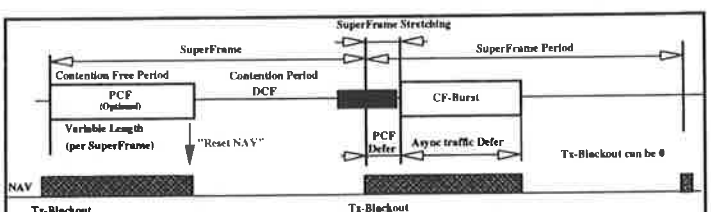
Coordination Functions:



MAC Service Model

- Contention Free Service uses Point Coordination Function (PCF) on a DCF Foundation.
- Async Data, Voice or mixed implementations possible.
- Contention Free capability is a minimum burden for the Async service implementation.

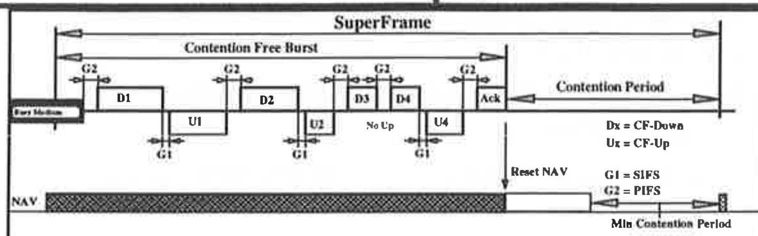
Point Coordination Function



PCF SuperFrame Composition

- SuperFrame to allow mixed "Contention" and "Contention Free" operation under PCF control.
- NAV prevents "Contention" traffic until reset by the last PCF transfer or other contention traffic.
- Both PCF and DCF Defer for each other causing SuperFrame Stretching.

PCF Burst operation



PCF Protocol mechanism

- CF-Burst by Polling bit in CF-Down frame.
- Immediate response by Station on a Poll.
- Stations to maintain NAV to protect Up-traffic.
- Variable length or no response possible.
- "Reset NAV" bit in last frame from AP.
- "Ack Previous Frame" bit in Header.

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Next:

Power Conservation Management

- Why is it important?
- Principle of operation.
- Infrastructure and Ad-Hoc operation.
- Dynamic behaviour.
- Functions required from the PHY.

Power Management:

- *Power Conservation Management* is very important to support mobility (battery life).
- Idle receive state is dominating power consumption.
- Current LAN's assume Rx is always ready to receive.
- Basic power conservation principles:
  - Turn transceiver off as much as possible.
  - Assure that traffic is temporarily buffered while stations are sleeping.
  - Solution should be application independent, and provide high throughput when needed.

Power Management principle:

- Need application independent solution.
- MAC transmitter need to buffer packets until remote receiver is Awake.
- Transmitter announces for which station frames are buffered.
- Transmitter and receiver needs to be synchronized.
  - Transmitter needs to know when Rx is Awake.
  - Rx needs to be Awake when relevant data is expected.
  - Accurate synchronization needed to allow extreme low Power operation.

Basic operation:

- Synchronize all stations.
  - AP in Infrastructure Networks.
  - Distributed among stations in Ad-Hoc networks.
- Stations can be in different PM-modes and can dynamically switch PM-modes.
  - CAM: Continuous active mode.
  - TAM: Temporary active mode.
  - PSM: Power Save Mode (two flavours).
- Transmitters know the PM-mode of the receivers.
  - Two bits in each frame header.
- Transmitters will send "Traffic Information Map" (TIM) at regular intervals indicating buffer status.

Station Power Save states:

- Transmit State:
  - Transmitter is turned On.
- Awake State:
  - Receiver is fully powered and capable to receive.
- Doze State:
  - Transceiver is not able to transmit or receive, and consumes very low power. TIM interval Timer and some other circuitry may still be active.
- Stations using Power Save mode will cycle from Doze to Awake, only when relevant traffic is expected, or just before a transmission starts.
  - Stations can maintain in an awake state until a no activity timer expires (no Tx or Rx to station activity) (TAM).
- CAM stations will be continuous Awake.

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Power Conservation modes:

- Two different Power Save Modes available:
- PSNP: Power Save Non-Polling.
  - Buffered traffic will immediately follow the DTIM.
  - Stations identified in the DTIM stay awake to accept traffic.
  - Stations need to listen to every (D)TIM (in Beacon).
  - Multicast traffic will follow every DTIM.
- PSP: Power Save Polling.
  - Stations do not have to listen to every TIM. This allows very long sleep times.
  - Stations identified in the TIM need to retrieve the buffered frames by a Poll cycle.
  - This allows very low power operation (months on battery)

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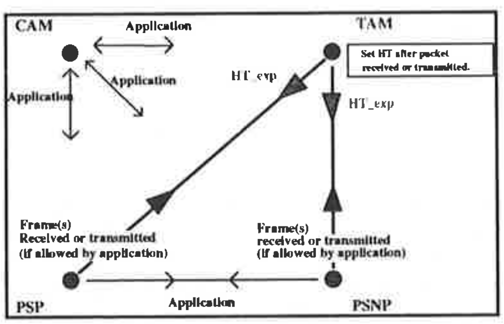
Dynamic behaviour support:



- Stations can dynamically switch to TAM mode.
- Return to PSM after "No-activity" time-out is signalled to remote through PM bits.

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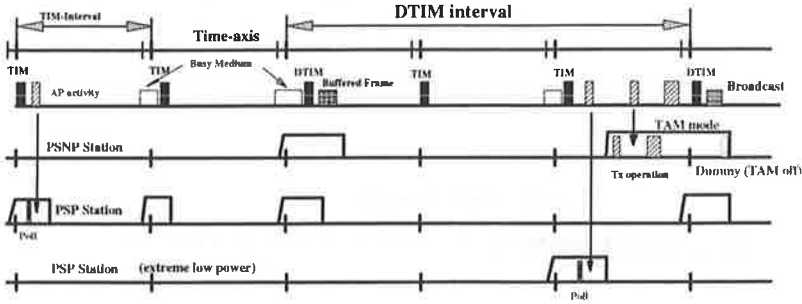
Infrastructure mode:

Example: DTIM at every 3 TIM intervals.



Infrastructure Power Management Basic operation

- **Synchronization allows station awakening just before a (D)TIM.**

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Ad-Hoc Power Management

- **Stations are synchronized using distributed Beacons.**
- **All stations have a common awake period.**
- **Stations that want to send will announce frames using a short ATIM frame in the common awake period.**
  - Short frames will be send without a prior ATIM.
  - The PSP mode is not supported.
- **Stations that do not receive an ATIM during the common awake w!!l go to sleep again.**
- **Others will stay awake to accept the actual frame.**

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Required PHY functions:

For Power Management:

PHY Sleep/Awake under MAC control.

Fast wake-up time.

MAC need to know when PHY is stable (Tx and Rx)

CCA activation also in the middle of a frame (response time less critical).

Support for Mobility

- Stations may move from one BSS to another
- MAC must support fast BSS transitions
  - switch to a new AP when the current AP is unacceptable
  - find the "best AP" to associate
  - join the BSS of that AP
- Initial "association" support.
  - find the desired BSS
  - join the desired BSS

How to find other stations

- All networks send Beacons at known interval
- Stations use Scanning to find:
  - a specific BSS at initialization time
  - a better Access Point when "roaming"
    - » triggered by deteriorating signal quality or other events like "No Beacon" time out
- Scanning stations tune to channels other than the one used by their current BSS.
  - to see what else is out there
  - they are "off line" during scans
    - » can go into PSP mode to ensure frames are buffered
- The MAC determines which channel to use.

Passive Scanning:

Find networks simply by listening.

Beacons are sent at a known rate.

Scanner listens to each channel.

- waits at least Beacon Interval on empty channels

Practical for PHYs with a few channels or with a short Beacon Interval.

When network found, save Network ID and Timestamp delta.

- only information required to "tune" to that network

Active Scanning:

Can be much faster than passive scanning.

On each channel, scanner sends a Probe .

- Request message sent to broadcast address
- NetworkID specifies the network for which the scanner is looking.

Wait for a Probe Response.

- wait for a bounded time T1
- if detect energy, wait longer

Multiple Probe Responses are possible.

- more than one AP on same channel
- ad hoc network

Scanning for APs:

More than one AP may be on the same channel.

- scanner wants to hear all Probe Responses.
- Probe responses should be randomized in time.
- Fast responses possible
  - when no activity on channel then Wait T1
  - when activity then Wait T2
  - when no response, then scan next channel.

Directed Probe Response.

- invokes positive ACK protocol
- automatic collision recovery

Scanning for Ad-Hoc Networks

Any station in the BSS may respond.

Access Backoff before Probe Response.

If collision then

- sender does Backoff with larger Contention Window
- other station may respond before retries...

Initializing Ad-Hoc Networks:

1. Scan (BSSID = specific) for 5 seconds
2. If hear something then JoinNet.
3. else StartNet.
4. Stay active (don't go in power save mode) for T3 seconds.

JoinNet

- adopt NetworkID and timing of that BSS.

StartNet

- SYNCed =1
- send Beacons to establish BSS timing

Scanning Conclusion:

Scanning required for many functions.

- joining a network
- initializing an ad hoc network
- maintaining a single ad hoc network
- finding a new AP for BSS transitions

Foundation MAC uses a common technique that supports all.

- PHY independent
- single or multi channel
- passive or active scanning

Required PHY Functions:

To support Scanning:

MAC tells PHY "Go to channel x "

(Channel selection delay must be known)

PHY to provide a Signal Level/Quality indication to the MAC per frame.

Next:

- Timing Synchronization function (TSF).
  - What is it used for.
  - How is it done.
- Beacon to distribute Timing Synchronization.
- Use of TSF for Frequency Hopping PHY's.

TSF applications:

Power Management

- Beacons are sent at well known intervals
- All station timers in BSS are synchronized
- Beacons may contain TIM element
- Stations can wake up just before expected Beacon

Superframe Timing

- TSF Timer used to predict start of Contention Free burst
- Beacon is not required in each superframe

Hop Timing for Frequency Hopping PHY

- TSF Timer used to time Dwell Interval
- stations' TSF Timers synchronized, so hop at same time
- Beacon is not required on each hop

Synchronization Approach:

All stations maintain a local synchronization timer.

Timing Synchronization Function (TSF)

- keeps timers in synch
- centralized in infrastructure networks
- distributed function for ad hoc networks

Beacons provide timing reference for each BSS.

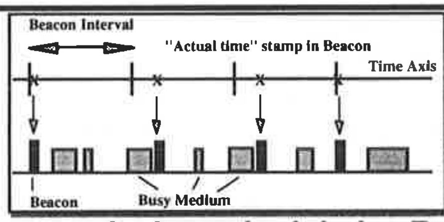
- not required to hear every Beacon to stay in synch
- Beacons used to calibrate local clocks

Flexible Beacon Interval

- BSS parameter

Fully Compatible with CSMA (Beacons can defer).

Beacon Generation



Beacon transmission scheduled at Beacon Interval.

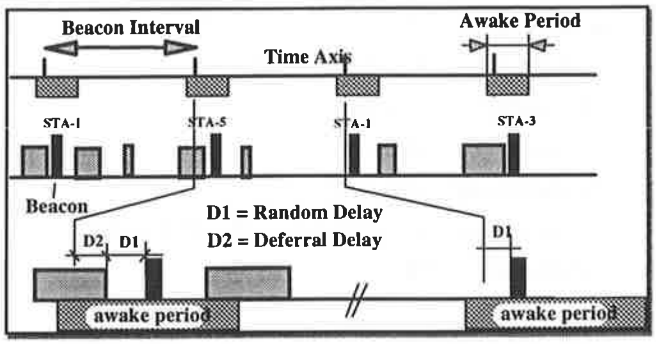
Transmission may be delayed by CSMA deferral.

- subsequent transmissions at expected Beacon Interval
- not relative to last Beacon transmission

Timestamp contains timer value at transmit time.

AP sends Beacons in infrastructure networks.

Ad-Hoc Beaconing:



Distributed Beaconing

- any station in BSS may send a Beacon (distributed)
- Beacon generation is randomized in time

More Ad-Hoc Beaconing:

Ad Hoc Beacon Sender's actions:

- wake up before expected Beacon time
- defer to current transmission if any
- execute access backoff procedure
  - even when network was idle
  - randomizes send attempts
- if heard another Beacon cancel Beacon transmission
  - else transmit Beacon

Beacon collisions are possible.

- Beacons are multicasts so no retransmission
- other station likely to succeed after collision

Only SYNCed stations send Beacons.

Timer Accuracy:

Timestamp included in every Beacon.

- Sending station's TSF timer in microseconds
- 31 bit value and 1 bit SYNC flag

Beacon sender actions:

- Timestamp is sender's timer at SFD transmission time.

Beacon receiver actions:

- Save local TSF timer when Beacon SFD received.
- Validate received Beacon.
- If OK, compare saved timer with Beacon timestamp
- Difference is amount to adjust local station timer
  - could adjust for propagation and transceiver delay

Precise synchronization is possible.

Frequency Hopping and TSF:

STAs use their TSF timer to maintain hop synch.

Only PHY dependency is Max. TSF value.

- maximum TSF value is total time for hop sequence
  - MaxTSF = NumHops * Dwell_Interval
- TSF timer value describes progress in hopping sequence
  - which hop and how long in that hop

STAs independently time Dwell_Interval.

- each station knows when to hop (MAC)

Hop stretching could be possible.

Hop timing fields not required in MAC header.

Dwell_Interval and Beacon_Interval independent.

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Synchronization Conclusion:

Time synch. is required for many MAC functions.

- Proposed a general mechanism that can be used for:
  - Power Management
  - Superframe Timing in Contention Free Service
  - Hop synchronization in FHSS PHYs

Network events are timed by station TSF timers.

- Not necessary to send frames to indicate network events
- Stations can maintain sync while sleeping or out of range

TSF is efficient.

- periodic Beacon transmission calibrates timers
- time fields not required in all MAC frames

TSF is precise (microsecond accuracy is possible)

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Required PHY functions:

For synchronization support:

PHY frequency channel selection under MAC control (Go to channel x).

Fixed deterministic PHY delay

(no variable buffering)

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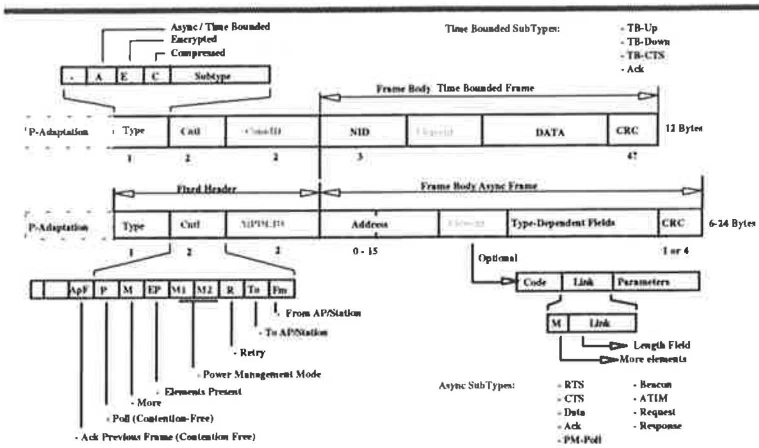
Frame Format:



Async and Time Bounded Frame structure

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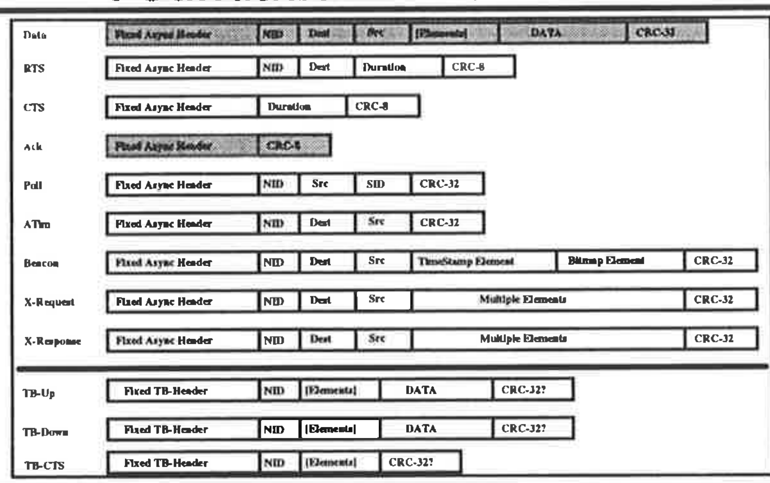
Foundation MAC Frames:



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PHY Requirement summary:

- *Continuous* "Clear Channel Assessment" (CCA) signal indicating when medium is Free.
- PHY frequency channel selection under MAC control. "Go to channel x"
- PHY Sleep/Awake under MAC control.
- Fast wake-up time. MAC need to know when PHY is stable (Tx and Rx)
- CCA activation also in the middle of a frame (response time less critical).
- PHY to provide a Signal Level/Quality indication to the MAC per frame.
- Fixed deterministic PHY delay

Quiz results:

1:	F	Nack
2:	A	32
3:	D	"free" appears twice
4:	B	harmless
5:	B	DIFS<PIFS
6:	A	all the buffered frames are sent immediately
7:	D	A & B
8:	B	false
9:	B	false
10:	D	