CMPE 257: Wireless Networking

SET 3:

Medium Access Control Protocols

MAC Protocol Topics

- IEEE 802.11
- Fairness
- Directional antennas
- Multiple channels
- Modeling and performance analysis (very limited!)
- Power efficiency and synchronization issues
- Scheduled channel access

IEEE 802.11 Standard

- PHY/MAC standard for wireless LANs
  - First standardized in 1997
  - Meet great success in starting from 1999
- Several working groups
  - IEEE 802.11a: high speed extension to the 5GHz band
  - 802.11b/g: high speed extension to the 2.4 GHz band
  - 802.11e: Quality of service (QoS) enhancement (still active)
  - 802.11i: Security enhancement
  - 802.11s: Mesh-networking support

Requirements

- Single MAC to support multiple PHYs
  - Handle ``hidden terminal'' problem
  - Provisions time-bounded service
- PHYs:
  - Direct sequence
  - Frequency hopping
  - Infrared (never implemented)

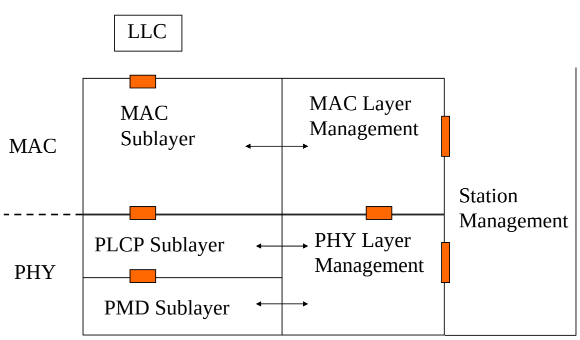
Architecture

- Infrastructure mode
  - Basic Service Set (BSS)
  - Access Point (AP) and stations (STA) take different roles
  - Distribution system (DS) interconnect multiple BSSs to form a single network (not specified in the standard).
- Ad hoc mode
  - Independent Basic Service Set (IBSS)
  - Single-hop (the standard makes this assumption either explicitly or implicitly)

Access Points

- Stations select an AP and “associate” with it
- Support roaming (not part of the standard)
- Provide other functions
  - time synchronization (beaconing)
  - power management support
  - point coordination function (PCF)
- Traffic typically (but not always) flows through AP
  - direct communication possible (in IEEE 802.11e)

802.11 Protocol Entities



802.11 Protocol Architecture

- MAC Entity
  - basic access mechanism
  - fragmentation
  - encryption
- MAC Layer Management Entity
  - synchronization
  - power management
  - roaming
  - MAC MIB
- Physical Layer Convergence Protocol (PLCP)
  - PHY-specific, supports common PHY SAP
  - provides Clear Channel Assessment (CCA) signal (carrier sense)

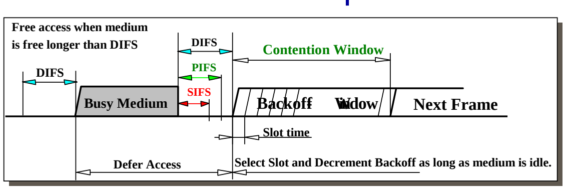
802.11 Protocol Architecture (cont.)

- Physical Medium Dependent Sublayer (PMD)
  - modulation and encoding
- PHY Layer Management
  - channel tuning
  - PHY MIB
- Station Management
  - interacts with both MAC Management and PHY Management

MAC in Detail

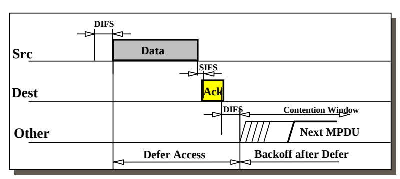
- Channel access mechanism
  - Distributed Coordination Function (DCF)
    - Carrier sense multiple access (CSMA) with immediate MAC-level ACK
    - RTS/CTS exchange (optional)
  - Point Coordination Function (PCF)
    - Polled access through AP and distributed access
    - Contention-free period (CFP) and contention period (CP)
    - Seldom implemented in practice
- Synchronization and power management

CSMA/CA Explained



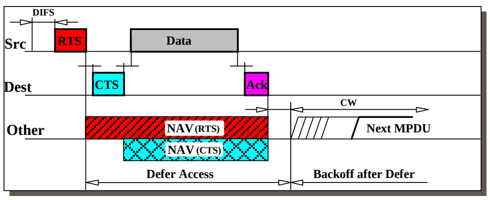
- Reduce collision probability where mostly needed.
  - Stations are waiting for medium to become free.
  - Select Random Backoff after a Defer, resolving contention to avoid collisions.
- Efficient Backoff algorithm stable at high loads.
  - Exponential Backoff window increases for retransmissions.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

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).**

RTS/CTS Based Access



- ***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 <u>must</u> be implemented.**
- **Use is controlled by a** ***RTS_Threshold*** **parameter per station.**
  - **To limit overhead for short frames.**

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.

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.

Comments on CSMA/CA

- IEEE 802.11 cannot avoid collisions of data packets (see [FAMA97]).
- CSMA/CA works fine when hidden terminals are just a few.
- For most single-hop wireless LANs, RTS/CTS is not useful (*turned off by default in practice*)
- Spatial reuse is reduced in multi-hop networks

Synchronization and Power Management

- 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

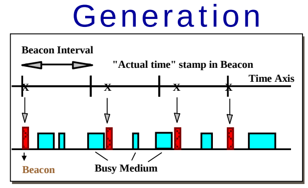
Synchronization in 802.11

- 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.

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

Infrastructure Beacon Generation



- **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.**

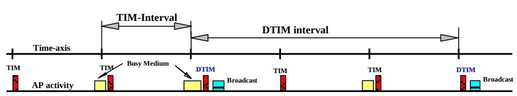
Power Management

- 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

Power Management Approach

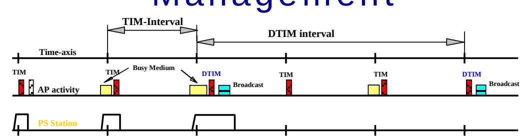
- Allow idle stations to go to sleep
  - station's power save mode stored in AP
- APs buffer packets for sleeping stations.
  - AP announces which stations have frames buffered
  - Traffic Indication Map (TIM) sent with every Beacon
- Power Saving stations wake up periodically
  - listen for Beacons
- 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

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

Infrastructure Power Management



- Broadcast frames are also buffered in AP.
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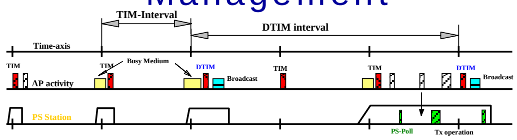
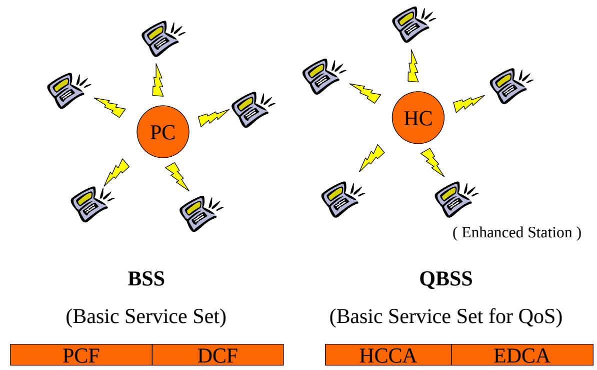
- Stations wake up prior to an expected (D)TIM.

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

IEEE 802.11E



IEEE 802.11E

- QoS enhancements
  - EDCA - Enhanced Distributed Coordinated Access (a.k.a. Enhanced DCF)
  - HCCA - Hybrid Coordination Function (through HC, Hybrid Controller) Coordinated Access (a.k.a. Enhanced PCF)
- TC – Traffic Categories
- TXOP – Transmission Opportunity
  - Granted by EDCF-TXOP or HC- poll TXOP
- AIFS – Arbitration Interframe Space
- Draft only – subject to change!

802.11e EDCA

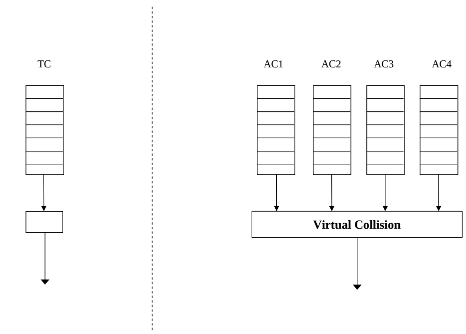
- Introduction of 4 Access Categories (AC) with 8 Traffic Classes (TC)
- MSDU are delivered through multiple backoffs within one station using AC specific parameters.
- Each AC independently starts a back off after detecting the channel being idle for AIFS
- After waiting AIFS, each back off sets counter from number drawn from interval [1,CW+1]
- newCW [AC] >= ((oldCW[TC] + 1) * PF) - 1

Access Category and Traffic Class

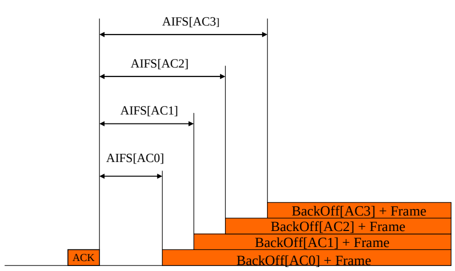
	AC_VO [0]	AC_VI [1]	AC_BE [2]	AC_BK [3]
AIFSN	2	2	3	7
CWmin	3	7	15	15
CWmax	7	15	1023	1023

- Prioritized Channel Access is realized with the QoS parameters per TC, which include :
  - AIFS[AC]
  - CWmin[AC]
  - PF[AC]

EDCA



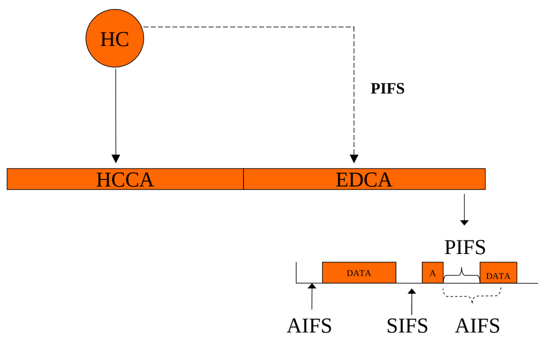
Access Category based Back-offs



HCCA (Hybrid Coordination Function Controlled Channel Access)

- Extends the EDCA access rules.
- CP : TxOP
  - After AIFS + Back off
  - QoS Poll ; After PIFS
- CFP : TxOP
  - Starting and duration specified by HC using QoS Poll.

Hybrid Coordinator



802.11e Operation in the CFP

- Guaranteed channel access on successful registration
- Each node will receive a TxOP by means of polls granted to them by the HC
- TxOP based on negotiated Traffic specification (TSPEC) and observed node activity
- TxOP is at least the size of one Maximum sized MSDU at the PHY rate.
- Access Point advertises polling list

Food for Thought

- Use your favorite network simulator, try to experiment with IEEE 802.11 in multi-hop networks and see how well or bad it performs in such networks. Any interesting findings?
- Simulate IEEE 802.11e in multi-hop networks and test its effectiveness for service differentiation.

References

- [IEEE99] *IEEE Standard for Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications*, IEEE Std 802.11-1999.
- [TK84] H. Takagi and L. Kleinrock, *Optimal Transmission Range for Randomly Distributed Packet Radio Terminals*, IEEE Trans. on Comm., vol. 32, no. 3, pp. 246-57, 1984.
- [WV99] L. Wu and P. Varshney, *Performance Analysis of CSMA and BTMA Protocols in Multihop Networks (I). Single Channel Case*, Information Sciences, Elsevier Sciences Inc., vol. 120, pp. 159-77, 1999.
- [WG02] Yu Wang and JJ, *Performance of Collision Avoidance Protocols in Single-Channel Ad Hoc Networks*, IEEE Intl. Conf. on Network Protocols (ICNP '02), Paris, France, Nov. 2002.

Acknowledgments

- Parts of the presentation are adapted from the following sources:
  - Mustafa Ergen, UC Berkeley, http://www.eecs.berkeley.edu/~ergen/docs/IEEE-802.11overview.ppt
  - Greg Ennis, Symbol Technologies, http://grouper.ieee.org/groups/802/11/Tutorial/archit.pdf
  - Phil Belanger, Aironet and Wim Diepstraten, Lucent Technologies, http://grouper.ieee.org/groups/802/11/Tutorial/MAC.pdf
  - Abhishek Karnik, Dr. Ratan Guha, University Of Central Florida, http://www.cs.ucf.edu/courses/cda4527/WLAN/80211.ppt