18-452/18-750
Wireless Networks and Applications
Lecture 11:
Mesh and Ad Hoc Networks

Peter Steenkiste

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http://www.cs.cmu.edu/~prs/wirelessS18/

Overview

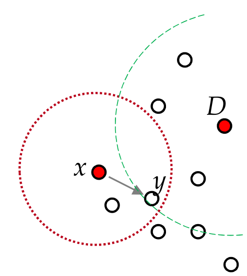
- **Ad hoc networking concept**
- **Proactive versus reactive routing**
- **Proactive, table based routing: DSDV**
- **Reactive routing DSR**
- **Geographic routing: GPSR**
- **Wireless link metrics**
- **Ad hoc networking examples**

Greedy Perimeter Stateless Routing (GPSR)

- **Use *positions* of neighboring nodes and packet destination to forward packets**
  - **No connectivity or global topology is assumed – no forwarding or path information anywhere!**
  - **Nodes are assumed to know their location**
  - **Need a mechanism for address-to-location look up**
- **Two forwarding techniques is used**
  - ***Greedy forwarding*, if possible**
  - ***Perimeter forwarding*, otherwise**

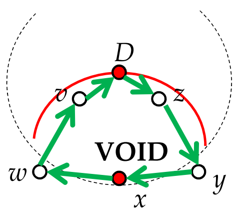
GPSR – Greedy forwarding

- **A sender/forwarder *x* chooses to forward to a neighbor *y* such that $\{d_{xy} + d_{yD}\}$ is minimum**



GPSR – Perimeter forwarding

- What happens if a node does not have a neighbor that is closer to the destination
- Right Hand Rule: you forward the packet to your first neighbor clockwise around yourself
  - Traverse an interior region in *clockwise* edge order
  - Guaranteed to reach a (reachable) destination for planar graph



These sequence of edges traversed is termed as *PERIMETER*

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Many Other Variants

- Hybrid approaches mix different solutions
  - » Use proactive routing for nearby nodes for reactive routing for far nodes
  - » Combine source routing with distance vector (AODV)
- Hierarchical: create a hierarchy of clusters
  - » Improve scalability be reducing routing overhead
  - » Can use different protocols for intra and inter cluster
- Many proposals for optimizations
  - » Links use different frequencies, multiple radios, etc.
  - » Link metrics that consider interference level, …
- Best solutions is highly context dependent: density, traffic load, degree of mobility, …

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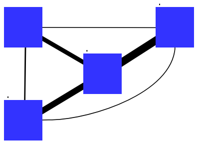
Link Metric

- Routing protocols for wired networks tend to use very simple link metrics
  - » Hop count (all links have cost of 1) or simple integers
  - » Performance of wired links is predictable!
- Wireless links can be very different and their performance can change unpredictably
  - » Hop count is a bad idea – why?
- Some links are so bad they are not really links
- Solution: Require a minimum PDR to qualify as a link
  - » PDR = Packet Delivery Rate
- Is that a sufficient solution?



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Factors Influencing "Link Quality"

- Signal strength and quality: affects the bit rate used for packets
  - » Bit rate affects the transmit time of packets
- Number of retransmissions needed to deliver packets
  - » Retransmissions delay packets and use up more bandwidth
- Interference from nearby nodes
  - » Interference limits the transmission opportunities a node has, i.e., it can take longer to get channel access
  - » Some links may also face more hidden and exposed terminal problems

ETX: Minimize Number of Transmissions

- Measure each link's packet delivery probability with broadcast probes
  - » Must also measure the reverse link – ACKs must be received too for a transmission to be successful!

  $P(delivery) = 1 / (d_f * d_r)$
- The link ETX is the average number of transmissions needed to deliver a packet

  $Link\ ETX = 1 / P(delivery) = d_f * d_r$
- Route ETX = sum of link ETX
  - » Pessimistic: not all links interfere with each other
- ETX only considers some factors: bit rate, short probes under-estimate loss rate, traffic load, hidden terminals, …

ETX: Sanity Checks

- ETX of perfect 1-hop path: 1
- ETX of 50% delivery 1-hop path: 2
- ETX of perfect 3-hop path: 3
- So, e.g., a 50% loss path is better than a perfect 3-hop path!
  - » A PDR threshold would probably fail here …
- But this ignores many real world factors!
  - » Examples?

ETT: Expected Transmission Time

- The bit rate used for transmission can have a very big impact on performance
  - » E.g., 802.11a rates range from 6 to 54 Mbps
  - » Bit range even much larger for more recent standards (but ad hoc only standardized up to
- ETT – expected *transmission time*

  ETT = ETX / Link rate

  = 1 / (P(delivery) * Bit Rate)
- Accounts for all major factors
  - » Traffic load and competition for transmission time by nearby links is still not accounted for
  - » Must update metric periodically

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Examples of Ad Hoc Networks

- Mesh networks, for example for last mile access to the home
  - » Reduces infrastructure cost significantly (no wires!)
  - » Routers are stationary, powered – simplifies routing
  - » Capacity is limited by may be ok in, e.g., rural areas
  - » 802.11s is a standard for WiFi mesh networking
- Vehicular networks: cars talk directly to each other, e.g., for safety applications
  - » No need for infrastructure, but security is a challenge
  - » Routing is very challenges (survey topic)
- Sensor networks (lecture, survey topic)
  - » Emphasis on low power and low traffic volume
  - » Ad hoc is an attractive solution for dense deployments

Summary

- Ad hoc networks face many challenges
  - » Bad links, interference, mobility, …
  - » Makes routing very challenging
  - » Limited support: hardware and driver limitations
- Many proposals!
  - » Proactive routing: variants of "wired" routing protocols
  - » Reactive routing: only establish a path when it is needed
  - » Geographic routing: use destination location info only
  - » Many variants and extensions
- Specific challenges depend on the application domains
  - » Mesh versus vehicular
  - » Active area of research

Outline

- Brief history
- 802 protocol overview
- Wireless LANs – 802.11 – overview
- 802.11 MAC, frame format, operations
- 802.11 management
- 802.11 security
- 802.11 power control
- 802.11*
- 802.11 QoS

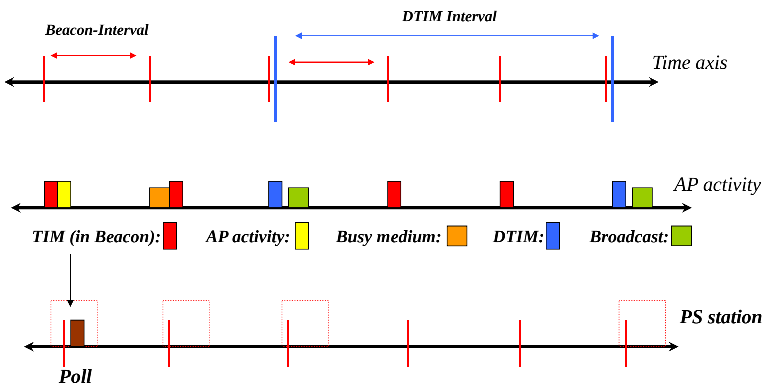
Power Management

- Goal is to enhance battery life of the stations
- Idle receive state dominates LAN adapter power consumption over time
- Allow stations to power off their NIC while still maintaining an active session
- Different protocols are used for infrastructure and independent BSS
  - » Our focus is on infrastructure mode

Power Management Approach

- Idle station to go to sleep
- AP keeps track of stations in Power Savings mode and buffers their packets
  - » Traffic Indication Map (TIM) is included in beacons to inform which power-save stations have packets waiting at the AP
- Power Saving stations wake up periodically and listen for beacons
  - » If they have data waiting, they can send a PS-Poll to request that the AP sends their packets
- TSF assures AP and stations are synchronized
  - » Synchronizes clocks of the nodes in the BSS
- Broadcast/multicast frames are also buffered at AP
  - » Sent after beacons that includes Delivery Traffic Indication Map (DTIM)
  - » AP controls DTIM interval

Infrastructure Power Management Operation



Some IEEE 802.11 Standards

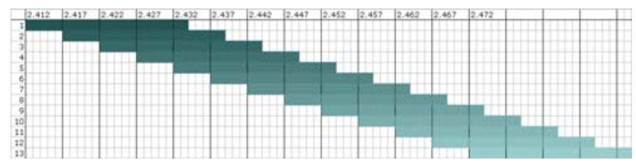
- » IEEE 802.11a
  - – PHY Standard : 8 channels : up to 54 Mbps : some deployment
- » IEEE 802.11b
  - – PHY Standard : 3 channels : up to 11 Mbps : widely deployed.
- » IEEE 802.11d
  - – MAC Standard : support for multiple regulatory domains (countries)
- » IEEE 802.11e
  - – MAC Standard : QoS support : supported by many vendors
- » IEEE 802.11f
  - – Inter-Access Point Protocol : deployed
- » IEEE 802.11g
  - – PHY Standard: 3 channels : OFDM and PBCC : widely deployed (as b/g)
- » IEEE 802.11h
  - – Suppl. MAC Standard: spectrum managed 802.11a (TPC, DFS): standard
- » IEEE 802.11i
  - – Suppl. MAC Standard: Alternative WEP : standard
- » IEEE 802.11n
  - – MAC Standard: MIMO : standardization expected late 2008

IEEE 802.11 Family

Protocol	Release Data	Freq.	Rate (typical)	Rate (max)	Range (indoor)
Legacy	1997	2.4 GHz	1 Mbps	2Mbps	?
802.11a	1999	5 GHz	25 Mbps	54 Mbps	~30 m
802.11b	1999	2.4 GHz	6.5 Mbps	11 Mbps	~30 m
802.11g	2003	2.4 GHz	25 Mbps	54 Mbps	~30 m
802.11n	2008	2.4/5 GHz	200 Mbps	600 Mbps	~50 m

802.11b Channels

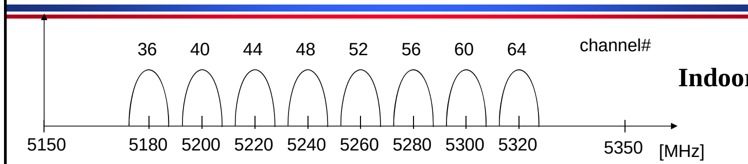
- In the UK and most of EU: 13 channels, 5MHz apart, 2.412 – 2.472 GHz
- In the US: only 11 channels
- Each channel is 22MHz
- Significant overlap
- Non-overlapping channels are 1, 6 and 11



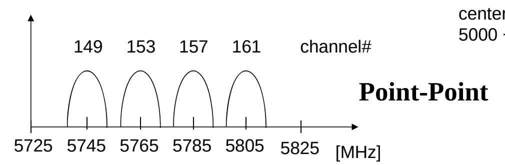
802.11b Physical Layer

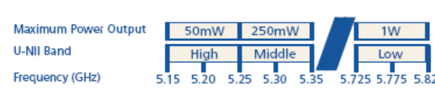
- FHSS (legacy)
  - » 2 & 4 GFSK
  - » Using one of 78 hop sequences, hop to a new 1MHz channel (out of the total of 79 channels) at least every 400milliseconds
- DSSS (802.11b)
  - » DBPSK & DQPSK
  - » Uses one of 11 overlapping channels (22 MHz)
  - » 1 and 2 Mbps: multiply the data by an 11-chip spreading code (Barker sequence)
  - » 5.5 and 11 Mbps: uses Complementary Code Keying (CKK) to generate spreading sequences that support the higher data rates
    - – Spreading code is calculated based on the data bits

802.11a Physical Channels



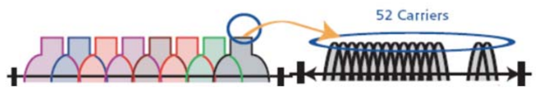
center frequency =
5000 + 5*channel number [MHz]





802.11a Modulation

- Use OFDM to divide each physical channel (20 MHz) into 52 subcarriers (20M/64=312.5 KHz each)
  » 48 data, 4 pilot



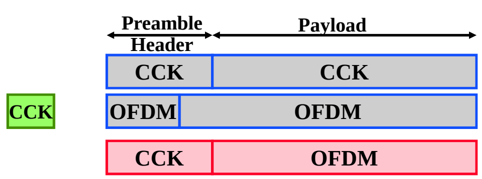
- Adaptive modulation
  » BPSK: 6, 9 Mbps
  » QPSK: 12, 18 Mbps
  » 16-QAM: 24, 36 Mbps
  » 64-QAM: 48, 54 Mbps

802.11a Discussion

- Uses OFDM in the 5 GHz band
  » Also used by 802.11g in 2.4 GHz (next slides)
- What are the benefits of 802.11a compared with 802.11b/g?
  » Greater bandwidth (up to 54Mb)
    – 54, 48, 36, 24, 18, 12, 9 and 6 Mbs
    – 802.11g (next slide) offers same benefit
  » Less potential interference (5GHz)
  » More non-overlapping channels
- But it does not provide interoperability with 802.11b, as 802.11g does
  » Cannot fall back to lower rates (not an issue in practice)
  » Cards typically support a and g

Going Faster: 802.11g

- 802.11g is the same as 802.11a, but in 2.4GHz band
  » Falls back to 802.11b for the lower rates (1,2, 5.5, 11 MHz)
  » Uses 802.11a OFDM technology for new rates (6 Mbs and up)
- Creates an interoperability problem since 802.11b cards cannot interpret OFDM signals
  » Interoperability mode: protection mechanism in hybrid environment: Send CCK CTS before OFDM packets or use(optional) hybrid packet
  » Can also run an 802.11n only network – reduces overhead



Spectrum and Transmit Power Management Extensions (802.11h)

- Support 802.11 operation in 5 GHz band in Europe: coexistence with primary users
  » Radar: cannot use bands if a radar is nearby
    – Allows opening up 11 more bands in 5 GHz band
  » Satellite: limit power to 3dB below regulatory limit
- Dynamic Frequency Selection (DFS)
  » Detect primary users and adapt
  » AP notifies stations to switch channel at some point in time
- Transmit Power Control (TPC)
  » Goal is to limit interference – also controlled by AP
- DFS and TPC have broader uses such as range and interference control, reduced energy consumption, automatic frequency planning, load balancing, ..

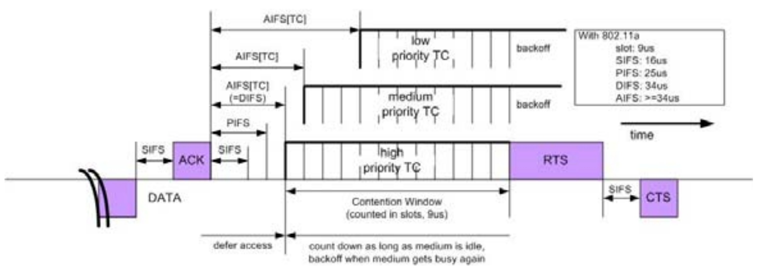
IEEE 802.11e

- Original intent was that 802.11 PCF could be used to provide QoS guarantees
  - » Scheduler in the PCF priorities urgent traffic
  - » But: overhead, “guarantees” are very soft
- 802.11e Enhanced Distributed Coordination Function (EDCF) is supposed to fix this.
  - » Provides Hybrid Coordination Function (HCF) that combines aspects of PCF and DCF
- EDCF supports 4 Access Categories
  - » *AC_BK (or AC0)* for Back-ground traffic
  - » *AC_BE (or AC1)* for Best-Effort traffic
  - » *AC_VI (or AC2)* for Video traffic
  - » *AC_VO (or AC3)* for Voice traffic

Service Differentiation Mechanisms in EDCF

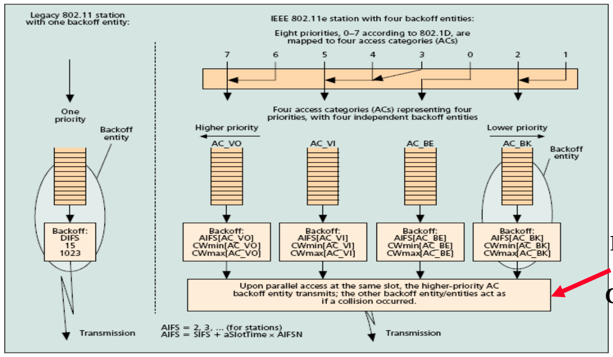
- The two types of service differentiation mechanisms proposed in EDCF are:
- *Arbitrate Inter-frame Space (AIFS) Differentiation*
  - Different AIFSs instead of the constant distributed IFS (DIFS) used in DCF.
  - Back-off counter is selected from [1, CW[AC]+1] instead of [0,CW] as in DCF.
- Contention Window (CWmin) Differentiation
  - Different values for the minimum/maximum CWs to be used for the back-off time extraction.

IEEE 802.11e: Priorities



Mapping different priority frames to different AC

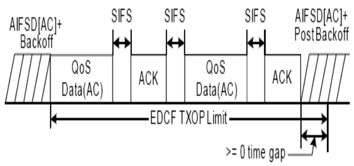
- Each frame arriving at the MAC with a priority is mapped into an AC as shown in figure below.



Resolves Virtual Collisions

Other 802.11 MAC Improvements

- *TXOP- **Transmission opportunity*** **(TXOP) is an interval of time during which a back-off entity has the right to deliver multiple MSDUs.**
  - » **A TXOP is defined by its starting time and duration**
  - » **Announced using a traffic specification (length, period)**
  - » **Can give more transmission opportunities to a station**
  - » **Can also limit transmission time (e.g. for low rate stations)**
- *CFB-* **In a single TXOP, multiple MSDUs can be transmitted.**
  - » ***"Contention Free Burst" (CFB)***
  - » ***Can use a block acknowledgement***



802.11p: Vehicular Networking

- **Basis for Dedicated Short Range Communication (DSRC)**
  - » **Connecting vehicles and road side units**
  - » **Dedicated band at 5.9 GHz**
  - » **Higher layers of protocol stack defined by WAVE**
  - » **Primary driver is vehicular safety such as reporting accidents, ..**
- **Differences with 802.11a**
  - » **Channels are 10 MHz wide; this means that symbol times are twice as long (more robust to ISI)**
  - » **Communication is between stations that are not associated or authenticated (no BSS ID)**

Really Old Slides