CS 640: Introduction to Computer Networks

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Lecture 23 -
CSMA/CA, Ad Hoc and Sensor Networks

Scenarios and Roadmap

- Point to point wireless networks
  - Example: Your laptop to CMU wireless
  - Challenges:
    - Poor and variable link quality (makes TCP unhappy)
    - Many people can hear when you talk
  - Pretty well defined.
- Ad hoc networks (wireless++)
  - Rooftop networks (multi-hop, fixed position)
  - Mobile ad hoc networks
  - Adds challenges: routing, mobility
  - Some deployment + some research
- Sensor networks (ad hoc++)
  - Scatter 100s of nodes in a field / bridge / etc.
  - Adds challenge: Serious resource constraints
  - Current, popular, research.

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IEEE 802.11 Wireless LAN

- 802.11b
  - 2.4-2.5 GHz unlicensed radio spectrum
  - up to 11 Mbps
  - direct sequence spread spectrum (DSSS) in physical layer
    - all hosts use same chipping code
  - widely deployed, using base stations
- 802.11a
  - 5-6 GHz range
  - up to 54 Mbps
- 802.11g
  - 2.4-2.5 GHz range
  - up to 54 Mbps
- All use CSMA/CA for multiple access
- All have base-station and ad-hoc network versions

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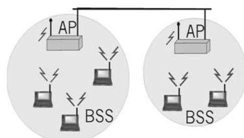
IEEE 802.11 Wireless LAN

- Wireless host communicates with a base station
  - Base station = access point (AP)
- Basic Service Set (BSS) (a.k.a. "cell") contains:
  - Wireless hosts
  - Access point (AP): base station
- BSS's combined to form distribution system



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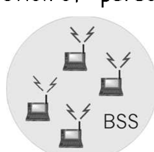
Ad Hoc Networks

- Ad hoc network: IEEE 802.11 stations can dynamically form network *without* AP
- Applications:
  - Laptops meeting in conference room, car
  - Interconnection of "personal" devices



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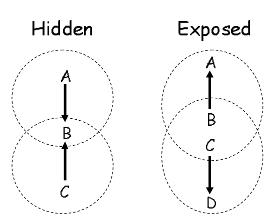
CSMA/CD Does Not Work

- Collision detection problems
  - Relevant contention at the receiver, not sender
    - Hidden terminal
    - Exposed terminal
  - Hard to build a radio that can transmit and receive at same time



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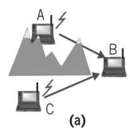
Hidden Terminal Effect

- Hidden terminals: A, C cannot hear each other
  - Obstacles, signal attenuation
  - Collisions at B
  - Collision if 2 or more nodes transmit at same time
- CSMA makes sense:
  - Get all the bandwidth if you're the only one transmitting
  - Shouldn't cause a collision if you sense another transmission
- Collision detection doesn't work
- **CSMA/CA: CSMA with C**ollision **A**voidance



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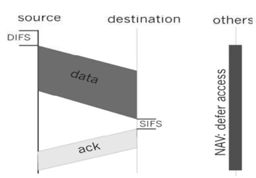
IEEE 802.11 MAC Protocol: CSMA/CA

802.11 CSMA: sender
- If sense channel idle for DIFS (Distributed Inter Frame Space) then transmit entire frame (no collision detection)
- If sense channel busy then binary backoff

802.11 CSMA: receiver
- If received OK return ACK after SIFS -- Short IFS (ACK is needed due to hidden terminal problem)



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Collision Avoidance Mechanisms

- Problem:
  - Two nodes, hidden from each other, transmit complete frames to base station
  - Wasted bandwidth for long duration!
- Solution:
  - Small reservation packets
  - Nodes track reservation interval with internal "network allocation vector" (NAV)

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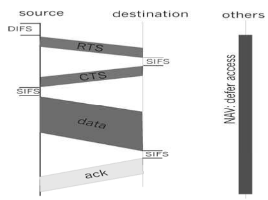
Collision Avoidance: RTS-CTS Exchange

- Explicit channel reservation
  - Sender: send short RTS: request to send
  - Receiver: reply with short CTS: clear to send
  - CTS reserves channel for sender, notifying (possibly hidden) stations
- RTS and CTS short:
  - collisions less likely, of shorter duration
  - end result similar to collision detection
- Avoid hidden station collisions
- Not widely used/implemented
  - Consider typical traffic patterns



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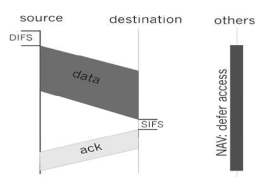
IEEE 802.11 MAC Protocol

802.11 CSMA Protocol: others

- NAV: Network Allocation Vector; maintained by each node
- 802.11 RTS frame has transmission time field
- Others (hearing CTS) defer access for NAV time units
- Reserve bandwidth for NAV time units



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Ad Hoc Routing

- Find multi-hop paths through network
  - Adapt to new routes and movement / environment changes
  - Deal with interference and power issues
  - Scale well with # of nodes
  - Localize effects of link changes

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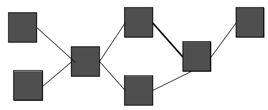
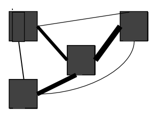
Traditional Routing vs Ad Hoc

- Traditional network:
  - Well-structured
  - ~O(N) nodes & links
  - All links work ~= well
- Ad Hoc network
  - N^2 links - but many stink!
  - Topology may be really weird
    - Reflections & multipath cause strange interference
  - Change is frequent





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Problems using DV or LS

- DV loops are very expensive
  - Wireless bandwidth << fiber bandwidth…
- LS protocols have high overhead
- N^2 links cause very high cost
- Periodic updates waste power
- Need fast, frequent convergence

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Proposed protocols

- Destination-Sequenced Distance Vector (DSDV)
- Dynamic Source Routing (DSR)
- Ad Hoc On-Demand Distance Vector (AODV)

- Let's look at DSR

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DSR

- Source routing
  - Intermediate nodes can be out of date
- On-demand route discovery
  - Don't need periodic route advertisements
- (Design point: on-demand may be better or worse depending on traffic patterns…)

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DSR Components

- Route discovery
  - The mechanism by which a sending node obtains a route to destination
- Route maintenance
  - The mechanism by which a sending node detects that the network topology has changed and its route to destination is no longer valid

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DSR Route Discovery

- Route discovery - basic idea
  - **Source** broadcasts route-request to **Destination**
  - Each node forwards request by adding own address and re-broadcasting
  - Requests propagate outward until:
    - Target is found, or
    - A node that has a route to Destination is found

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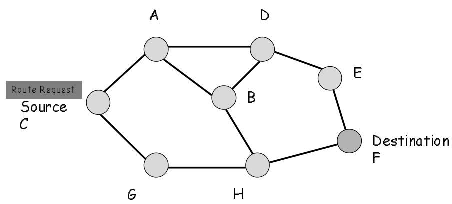
C Broadcasts Route Request to F



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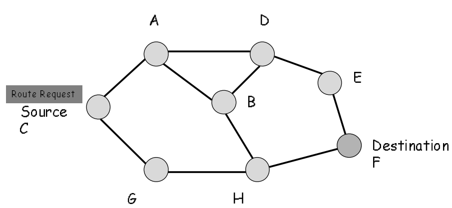
C Broadcasts Route Request to F



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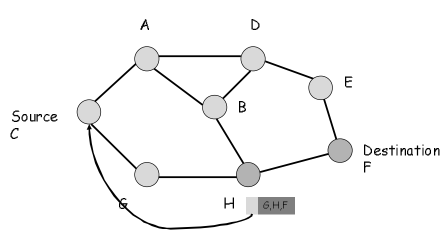
H Responds to Route Request



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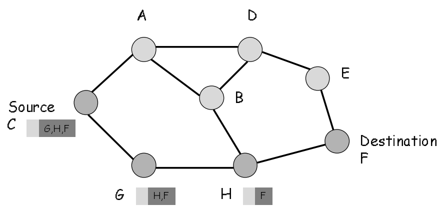
C Transmits a Packet to F



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Forwarding Route Requests

- A request is forwarded if:
  - Node is not the destination
  - Node not already listed in recorded source route
  - Node has not seen request with same sequence number
  - IP TTL field may be used to limit scope
- Destination copies route into a Route-reply packet and sends it back to **Source**

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Route Cache

- All source routes learned by a node are kept in Route Cache
  - Reduces cost of route discovery
- If intermediate node receives RR for destination and has entry for destination in route cache, it responds to RR and does not propagate RR further
- Nodes overhearing RR/RP may insert routes in cache

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Sending Data

- Check cache for route to destination
- If route exists then
  - If reachable in one hop
    - Send packet
  - Else insert routing header to destination and send
- If route does not exist, buffer packet and initiate route discovery

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Discussion

- Source routing is good for on demand routes instead of a priori distribution
- Route discovery protocol used to obtain routes on demand
  - Caching used to minimize use of discovery
- Periodic messages avoided
- But need to buffer packets
- How do you decide between links?

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Capacity of multi-hop network

- Assume N nodes, each wants to talk to everyone else. What total throughput (ignore previous slide to simplify things)
  - O(n) concurrent transmissions. Great! But:
  - Each has length O(sqrt(n)) (network diameter)
  - So each Tx uses up sqrt(n) of the O(n) capacity.
  - Per-node capacity scales as 1/sqrt(n)
    - Yes - it goes down! More time spent Tx'ing other peoples packets…
- But: If communication is local, can do much better, and use cool tricks to optimize
  - Like multicast, or multicast in reverse (data fusion)
  - Hey, that sounds like … a sensor network!

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Sensor Networks - smart devices

- First introduced in late 90's by groups at UCB/UCLA/USC
- Small, resource limited devices
  - CPU, disk, power, bandwidth, etc.
- Simple scalar sensors – temperature, motion
- Single domain of deployment
  - farm, battlefield, bridge, rain forest
- for a targeted task
  - find the tanks, count the birds, monitor the bridge
- Ad-hoc wireless network

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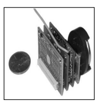
Sensor System Types – Smart-Dust/Motes

- Hardware
  - UCB motes
  - 4 MHz CPU
  - 4 kB data RAM
  - 128 kB code
  - 50 kb/sec 917 Mhz radio
  - Sensors: light, temp.,
    - Sound, etc.,
  - And a battery.

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Sensors and power and radios

- Limited battery life drives most goals
- Radio is most energy-expensive part.
- 800 instructions per bit. 200,000 instructions per packet. (!)
- That's about one message per second for ~2 months if no CPU.
- Listening is expensive too. :(

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Sensor nets goals

- Replace communication with computation
- Turn off radio receiver as often as possible
- Keep little state (4 KB isn't your pentium 4 ten bazillion gigahertz with five ottabytes of DRAM).

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Power

- Which uses less power?
  - Direct sensor -> base station Tx
    - Total Tx power: distance^2
  - Sensor -> sensor -> sensor -> base station?
    - Total Tx power: n * (distance/n) ^2 =~ d^2 / n
  - Why? Radios are omnidirectional, but only one direction matters. Multi-hop approximates directionality.
- Power savings often makes up for multi-hop capacity
  - These devices are *very* power constrained!
- Reality: Many systems don't use adaptive power control. This is active research, and fun stuff.

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Example: Aggregation

- Find avg temp in the 7th floor of this bldg.
- Strawman:
  - Flood query, let a collection point compute avg.
    - Huge overload near the CP. Lots of loss, and local nodes use lots of energy!
- Better:
  - Take local avg. first, & forward that.
    - Send average temp + # of samples
  - Aggregation is the key to scaling these nets.
- The challenge: How to aggregate.
  - How long to wait?
  - How to aggregate complex queries?
  - How to program?

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