Satellite Communications

- Satellite-based antenna(e) in stable orbit above earth.
- Two or more (earth) stations communicate via one or more satellites serving as relay(s) in space.
- Uplink: earth->satellite.
- Downlink: satellite->earth.
- Transponder: satellite electronics converting uplink signal to downlink.
Orbits

- Shape: circular, elliptical.
- Plane: equatorial, polar.
- Altitude: geostationary (GEO), medium earth (MEO), low earth (LEO).

GEO Satellites

- Most common type.
- Orbit at 35,863 Km above earth and rotates in equatorial plane.
- Many GEO satellites up there!

GEO: Plus’s and minus’s

- Plus’s:
  - Stationarity: no frequency changes due to movement.
  - Tracking by earth stations simplified.
  - At that altitude, provides good coverage of the earth.
- Minus’s:
  - Weakening of signal.
  - Polar regions poorly served.
  - Delay!
  - Spectral waste for point-to-point communications.

LEO Satellites

- Circular or slightly elliptical orbit under 2,000 Km.
- Orbit period: 1.5 to 2 hours.
- Coverage diameter: 8,000 Km.
- RTT propagation delay < 20ms (compared to > 300ms for GEOs).
- Subject to large frequency changes and gradual orbit deterioration.
LEO Constellations

- Advantages over GEOs:
  - Lower delay, stronger signal, more localized coverage.
  - But, for broad coverage, many satellites needed.
  - Example: Iridium (66 satellites).

In Summary...

- GEOs
  - Long delay - 250-300 ms.
- LEOs
  - Relatively low delay - 40 - 200 ms.
  - Large variations in delay - multiple hops/route changes, relative motion of satellites, queuing.

Satellite Bandwidths

- "Typical" satellite has 12-20 transponders, each ranging from 36-50 Mbps. [Computer Networks, 3rd. Edition, A. Tanenbaum].
  - T1: 1.54 Mbps.
  - T2: 6.312 Mbps.
  - T3: 44.736 Mbps.
  - T4: 274.176 Mbps.
MANETs

- Mobile, (wireless), multi-hop ad-hoc networks.
- Formed by wireless hosts which may be mobile.
- Without (necessarily) using a pre-existing infrastructure.
- Routes between nodes may potentially contain multiple hops.
- Mobility cause routes to change.

Multi-hop

- May need to traverse multiple hops to reach destination.

Why MANETs?

- Ease of deployment.
- Speed of deployment.
- Decreased dependence on infrastructure.

Many Applications

- Personal area networking.
  - Cell phone, laptop, ear phone, wrist watch.
- Military environments.
  - Soldiers, tanks, planes.
- Civilian environments.
  - “Smart” environments.
- Emergency operations
  - Search-and-rescue
  - Policing and fire fighting
  - Monitoring and surveillance.
Many Variations

- Fully Symmetric Environment
  - All nodes have identical capabilities and responsibilities.
- Asymmetric Capabilities
  - Transmission ranges, battery life, processing capacity, and speed of movement may vary.
- Asymmetric Responsibilities
  - Only some nodes may route packets.
  - Some nodes may act as leaders of nearby nodes (e.g., cluster head).

Many Variations (cont’d)

- Traffic characteristics may differ in different ad hoc networks.
  - Bit rate,
  - Timeliness constraints,
  - Reliability requirements,
  - Unicast / multicast / geocast.
- May co-exist (and co-operate) with an infrastructure-based network.

Many Variations (cont’d)

- Mobility patterns may be different
  - People sitting at an airport lounge,
  - New York taxi cabs,
  - Students moving on campus,
  - Military movements,
  - Personal area network.

Many Variations (cont’d)

- Mobility characteristics
  - Speed,
  - Predictability
    - direction of movement
    - pattern of movement
  - Uniformity (or lack thereof) of mobility characteristics among different nodes
Challenges

- Limited wireless transmission range.
- Broadcast nature of the wireless medium.
  - Hidden terminal problem.
- Packet losses due to transmission errors.
- Mobility-induced route changes.
- Mobility-induced packet losses.
- Battery constraints.
- Potentially frequent topology changes.
- Ease of snooping on wireless transmissions.

Hidden Terminal Problem

Carrier Sense Does Not Work

- Station avoids collisions by sensing carrier before transmitting.
- Relevant contention at the receiver, not sender.
  - Collision happens when multiple signals interfere at receiver.
  - CS cannot avoid collisions at receiver.

Hidden terminals

- B can hear both A and C.
- But A and C cannot hear each other.
- If A is transmitting to B, and if C starts to transmit, hidden terminal scenario at B.
Exposed terminals

- B is sending to A.
- C is ready to transmit but detects carrier and defers transmission.
- But A is out of C’s range.

Research on MANETs

- Variations in capabilities & responsibilities
- Variations in traffic characteristics, mobility models, etc.
- Performance criteria (e.g., optimize throughput, reduce energy consumption)
- Increased research funding

= Significant research activity

One-size-fits-all?

- Perhaps using an adaptive/hybrid approach that can adapt to situation at hand.
- Difficult problem.
- Solutions usually try to address a subspace of the problem domain.

References

- Nitin Vaidya’s tutorials (www.crhc.uiuc.edu/~nhv/presentations.html).
- Stalling’s “Wireless Communications and Networks”.
- Rappaport’s “Wireless Communications, Principles and Practice”.

The Multiplexing Problem

A wireless channel
(how to divide resource among multiple recipients?)

Analogy: a highway shared by many users

Frequency-Division Multiplexing

Analogy: a highway has multiple lanes

Time-Division Multiplexing

Requirement: precise time coordination

Frequency-Time-Division
### Medium Access Control Protocols

Coordinate competing requests for medium.

**Logical Link Control (LLC):**
- Share of link and transport of data over the link.

**Medium Access Control (MAC):**
- Control medium access.

### Medium Access for Wireless

- **MAC from wired medium unsuitable.**
  - Special features of wireless medium.
    - Hidden, exposed, near/far terminals.
  - Example: Carrier Sense Multiple Access with Collision Detection (CSMA/CD)
    - Send as soon as the medium is free, listen into the medium if a collision occurs.

### The Hidden Terminal Problem

- A sends to B, C cannot receive A
- C wants to send to B
- If use CSMA/CD:
  - C senses a “free” medium, thus C sends to A.
  - Collision at B, but A cannot detect collision
  - Therefore, A is “hidden” for C

### The Exposed Terminal Problem

- B sends to A, C wants to send to D
- If use CSMA/CD:
  - C senses an “in-use” medium, thus C waits
  - But A is outside the radio range of C, therefore waiting is not necessary
  - Therefore, C is “exposed” to B
The Near and Far Terminal Problem

- A and B send to C
- Friis Law (power decay proportional to distance squared)
- B drowns out A’s signal (at the physical layer), so C cannot receive A

MAC approaches

- Contention.
- Round-robin.
  - Token-based.
- Reservation.

Round-Robin MAC

- Each station is allowed to transmit; station may decline or transmit (bounded by some maximum transmit time).
- Centralized (e.g., polling) or distributed control of who is next to transmit.
- When done, station relinquishes and right to transmit goes to next station.
- Efficient when many stations have data to transmit over extended period (stream).
- Examples: token-based protocols.
  - Token bus, token ring.

Reservation

- Time divided into slots.
- Station reserves slots in the future.
- Multiple slots for extended transmissions.
- Suited to stream traffic.
Contestation

- No control.
- Stations try to acquire the medium.
- Distributed in nature.
- Perform well for bursty traffic.
- Can get very inefficient under heavy load.
- Example: Aloha family.
- NOTE: round-robin and contention are the most common.

Contention-Based MAC Protocols

- Carrier sensing (listen before transmit): Stations sense the channel before transmitting a data packet (e.g., CSMA).
- Listen before and during transmission: Stations listen before transmitting and stop if noise is heard while transmitting (CSMA/CD).
- Collision avoidance (floor acquisition): Stations carry out a handshake to determine which one can send a data packet (e.g., MACA, FAMA, IEEE802.11, RIMA).
- Collision resolution: Stations determine which one should try again after a collision.

The ALOHA Protocol

- Developed @ U of Hawaii in early 70's.
- Packet radio networks.
- "Free for all": whenever station has a frame to send, it does so.
  - Station listens for maximum RTT for an ACK.
  - If no ACK, re-sends frame for a number of times and then gives up.
  - Receivers check FCS and destination address to ACK.

Collisions

- Invalid frames may be caused by channel noise or
- Because other station(s) transmitted at the same time: collision.
- Collision happens even when the last bit of a frame overlaps with the first bit of the next frame.
ALOHA's Performance 1

- Time
- $t_0$, $t_0 + t$, $t_0 + 2t$, $t_0 + 3t$
- Vulnerable

ALOHA's Performance 2

- $S = G e^{2G}$, where $S$ is the throughput (rate of successful transmissions) and $G$ is the offered load.
- $S = S_{\text{max}} = 1/2e = 0.184$ for $G = 0.5$.

Slotted Aloha

- Doubles performance of ALOHA.
- Frames can only be transmitted at beginning of slot: "discrete" ALOHA.
- Vulnerable period is halved.
- $S = G e^G$.
- $S = S_{\text{max}} = 1/e = 0.368$ for $G = 1$.

Carrier Sense Multiple Access

- The capacity of ALOHA or slotted ALOHA is limited by the large vulnerability period of a packet.
- By listening before transmitting, stations try to reduce the vulnerability period to one propagation delay.
- This is the basis of CSMA (Kleinrock and Tobagi, UCLA, 1975).
CSMA

- Station that wants to transmit first listens to check if another transmission is in progress (carrier sense).
- If medium is in use, station waits; else, it transmits.
- Collisions can still occur.
- Transmitter waits for ACK; if no ACKs, retransmits.

CSMA Protocol

1. Packet ready
2. Channel busy?
   - Yes: wait for a round-trip time
   - No: transmit
3. Channel busy?
   - Yes: delay packet transmission k times
   - No: compute random backoff integer k

CSMA (cont’d)

- Effective when average transmission time >> propagation time.
- Collisions can occur only when 2 or more stations begin transmitting within short time.
- If station transmits and no collisions during the time leading edge of frame propagates to farthest station, then NO collisions.

CSMA Flavors

- After detecting carrier, a station can persist trying to transmit after the channel is idle again.
- 1-persistent CSMA (IEEE 802.3)
  - If medium idle, transmit; if medium busy, wait until idle; then transmit with $p=1$.
  - If collision, waits random period and starts again.
- Non-persistent CSMA: if medium idle, transmit; otherwise wait a random time before re-trying.
- P-persistent: when channel idle detected, transmits packet in the first slot with $p$. 
CSMA/CD

- CSMA with collision detection.
- Problem: when frames collide, medium is unusable for duration of both (damaged) frames.
- For long frames (when compared to propagation time), considerable waste.
- What if station listens while transmitting?

CSMA/CD Protocol

1. If medium idle, transmit; otherwise 2.
2. If medium busy, wait until idle, then transmit with p=1.
3. If collision detected, transmit brief jamming signal and abort transmission.
4. After aborting, wait random time, try again.

Collision Avoidance

- Collision avoidance emulates collision detection in networks where stations are half duplex.
  - This is the case of wireless: full-duplex radios are $$$!
  - First protocol was proposed by Kleinrock and Tobagi (Split Reservation Multiple Access).
  - Many protocols have been proposed since then: MACA, MACAW, FAMA, RIMA.
- The objective of collision avoidance protocols is to eliminate the hidden-terminal problem of CSMA.
802.11
- IEEE standard for wireless LANs.
- Specifies the physical layer (FH, DS, Infrared) and the MAC.

802.11 Access Methods
- Distributed access control mechanism based on CSMA/CA: Distributed Coordination Function (DCF).
- Centralized control: Point Coordination Function (PCF) uses polling.

MAC layer
- PCF
- DCF
- Physical Layer

Contention-free Service (polling)
Contention Service (CSMA)

802.11 CSMA/CA
- RTS: source, destination, data+ACK duration.
- CTS: data+ACK duration.
- DATA and ACK.

Source
- D: RTS
- Data

Destination
- CTS
- ACK

Other
- Defer (RTS)
- Defer (CTS)

DIFS: new transmission
SIFS: switching modes

802.11 Exponential Backoff
- If station tries to transmit and medium is busy, increase maximum backoff time exponentially.
- Exponential backoff executed:
  - First attempt at transmitting frame and medium busy.
  - After retransmission attempt and medium busy.
- Backoff time decremented after successful RTS-CTS exchange.
802.11 Architecture
- Originally based on cellular concept.

Joining a BSS
- Entering cell, powering up, etc.
- Need synchronization information.
  - Gets it from AP (in cellular mode) or other station (in ad hoc mode).
  - Passive versus active scanning.
    - AP sends out beacons
    - Station tries to locate AP with probes.

Synchronization and Power Saving
- Performed by AP.
- Synchronization: AP periodically xmits beacon frames.
  - Contain AP's clock.
  - Stations correct their clocks accordingly.
- Power saving: AP buffers frames for stations in sleep mode.
  - Until stations wake up or request frames.
  - Beacon frames contain information on which stations have buffered frames.

802.11 Frame Types
- Data.
- Control: RTS, CTS, ACK.
- Management: Beacon (Xmitted like data frames but not forwarded to upper layers).
802.11 Frame Format

802.11 Frame
- Preamble
- Header
- MAC Data
- CRC
- Frame ID/Duration
- Addressing
- Frame body
- CRC

802.11 Ad Hoc Mode
- No infrastructure, i.e., no APs.
- Beacon generation and synchronization performed by stations.
- Other AP functions (e.g., power savings) not provided.

802.11 and MANETs (Xu and Saadawi, 2001)
- Does 802.11 perform well in MANETs?
- Interaction between the MAC, [routing (DSR)], and transport layers.
- Experimental setup:
  - ns-2+CMU Monarch extensions.
  - IEEE 802.11 MAC DCF (WaveLAN radios).
  - 8-node "string" topology: multi-hop.
  - TCP traffic.
- 2 problems: TCP throughput oscillation and unfairness.

TCP Throughput Oscillations
- No competing flows/background traffic.
- Problem: link disconnect at link layer.
  - At network layer: route error -> route discovery.
  - At transport layer: TCP timeout.
- Why? Even though node 2 isn't in range of node 4,
  - 4's xmission can still collide at 2;
  - Even if 2 receives CTS from 1, it defers from sending the RTS since it's exposed to 4.
- 802.11 designed to work well in single-hop, cellular-style networks, NOT in MANETs.
TCP Unfairness

- Not surprising!
- Why?

MACA

- Fixed-sized signaling packets.
- RTS(S->R) containing data length.
- When R hears RTS, replies with CTS.
- CTS(R->S) containing data length.
- When S hears CTS, sends data.
- Stations overhearing RTS, defer until after CTS; stations overhearing CTS, defer until after data.

MACAW

- 2 basic changes to MACA:
  - Message exchange.
  - Backoff algorithm.
  - RTS-CTS-DATA-ACK.
  - ACK added for reliability.

MACAW (Cont’d)

- RTS-CTS-DS-DATA-ACK.
  - Addresses exposed terminal problem.
    - Exposed terminal may not get CTS from its receiver.
    - If B is transmitting, C cannot hear CTS from its receiver.
    - And, if it tries to xmit and doesn't get response, it backs-off.
  - Data-Sending (DS) packet indicates RTS-CTS exchange was successful.
  - Overhearing stations defer transmission until after ACK.
Directional Antennas and Directional CS

- Spatial division MA.
- In use in cellular networks.
- Issues in MANETs:
  - Nodes don’t know their neighbors a priori.
  - Directional antennas may restrict number of neighbors.

CS and Virtual CS

- CS: performed at physical layer.
  - Senses channel and determines level of interference and noise.
- Virtual CS: performed at the MAC layer.
  - RTS-CTS
- Contention-based MACs:
  - Either CS or virtual CS, or both.
  - IEEE 802.11 DCF.

Directional Antennas and CS

- Physical CS may be impacted: carrier is no longer good contention indicator.
- Virtual CS: “directional” RTS and CTS cannot be heard by all “neighbors”.

DVCS: Goals

- Exploit directional antennas.
- But work with omnidirectional ones.
- Supports both directional transmission and reception.
IEEE 802.11 with DVCS

- Assume CA, i.e., RTS-CTS.
- Changes to 802.11:
  - Angle-of-arrival caching.
  - Beam locking/unlocking.
  - Directional NAV.

References

- Besides papers assigned for today, look at JJ’s 252 Winter 2002 reading list for additional MAC papers (www.soe.ucsc.edu/research/ccrg/CMPE252/)
- Yongguang Zhang’s CS397 page (www.cs.utexas.edu/users/ygz/395T/)