Announcements

- First reading report assigned.
  - Due date: 04.24.2003.
- Reminders:
  - Project 2 proposal due 04.17.2003.
  - Project 1 due 04.22.2003.

Today

- Finish MACs.
- MACAW (cont'd).
- DVCS.
- PAMAS.
- Mobile IP.

MACAW

- Inspired 802.11.
- 2 basic changes to MACA:
  - Message exchange.
  - Backoff algorithm.
Message Exchange

- RTS-CTS-DATA-ACK.
  - ACK added for reliability.

Backoff Mechanism

- Tries to avoid the unfairness problem of exponential backoff.
- Proposed fix: sharing of congestion information among nodes.
- Backoff counter information in the packet header.
  - Stations hearing packet, copy value as their own backoff counter.
  - After successful transmission, all stations have same backoff counter.

Message Exchange

- RTS-CTS-DS-DATA-ACK.
  - Addresses exposed terminal problem.
  - Exposed terminal may not get CTS from receiver.
  - If B is transmitting to A, C cannot hear CTS from A.
  - It doesn’t know whether RTS-CTS succeeded.
  - And, if it tries to emit 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 slot.

More on Message Exchange

- RRTS
  - Tries to solve unfairness.
  - Use receiver to contend on behalf of sender.
  - If receiver receives RTS and cannot respond with CTS (e.g., it’s deferring due to a CTS), at next contending period, sends RRTS to RTS sender.
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: CSMA/CA with option for Virtual CS.

Directional Antennas and CS

- CS and VCS assume omni-directional transmission.
- Physical CS may be impacted by directional transmission.
  - 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 Network Allocation Vector (DNAV).

AOA Caching

- Nodes cache AOA info (from received/overheard signals).
- When node wants to Xmit, looks up AOA cached info. If so, beamforms in that direction for RTS Xmission.
- Otherwise, RTS Xmitted omnidirectionally.
- Cached info is updated/invalidated.

Beam locking/unlocking

- Maximize Xmission/reception in given direction.
- Locking:
  - After receiving RTS, for CTS Xmission.
  - After receiving CTS after RTS Xmission.
- Unlocking: after ACK Xmission.

DNAV

- Regular 802.11: uses NAV, network allocation vector.
  - NAV: virtual CS indicator.
  - Time access to medium deferred (based on receiving RTS/CTS).
- DNAV: directional NAV.
  - Direction- and width-specific.
  - Updated based on physical layer info.
  - Directional Xmission: channel available when no DNAV covers that direction.
  - Omni-direction Xmission: channel available when no DNAVs.
DVCS Example

A

B

DVCS Example

CTS

A

B

DATA

CTS

A

B

DATA

CTS

A

B

ACK
**DNAV: Direction and Width**
- Direction set based on AOA.
- AOA better than direction based on physical location.
- Path losses (scattering, reflection, etc.).
- Width:
  - Narrower beams improve channel utilization. Why?
  - Omni-directional antennas' width is 360° (DVAV = NAV).

**Antenna Model**
- Electrically steerable antenna.
- Omni-directional operation possible.
- Antenna reports AOA and gain to MAC.
- Antenna patterns change (side and back lobes) as it changes direction.
  - Simulated 10 patterns (0-54°, ±6°).
  - Beamwidth = 45° (between 0-3dB of max. gain).
  - DNAV = 74° (between 0-9dB of max. gain).

**Experimental Setup**
- Simulations using QualNet.
- MAC and physical layer parameters.
- Others: number of nodes, field size, traffic model, mobility pattern, etc.

**Performance Metrics and Scenarios**
- Packet delivery ratio: "reliability".
- Throughput: peak performance.
- Mobility versus no mobility.
- Physical CS versus no physical CS.
- Interoperability with omni antennas.
Summary of Results

- Increased network capacity (especially with mobility).
- Physical CS helps, especially with mobility.
- Reduces interference effect caused by concurrent transmissions.
- No mobility: AODV modified not to start route discovery on link breakage when a route exists.
- Interoperability:
  - DVCS inter-operates with 802.11.
  - Performance improvement in mixed settings.

PAMAS

- Goal: energy efficiency.
- Approach:
  - Contention-based (based on MACA).
  - Low power radio mode when node is idle.
  - Separate signaling channel for RTS-CTS.

Energy model

- Idle mode consumes orders of magnitude less power than transmission or receiver modes.
- Overhearing!
Observations

- RTS-CTS exchange on separate signaling channel.
  - Does not affect data exchange.
- Busy tone also on signaling channel.
  - Sent by data receiver.
  - Protects receiver from transmissions by neighbors.
  - Collides with RTS-CTS exchange from interfering nodes.

Overhearing

- Power off radio to avoid overhearing.
- Nodes power off if:
  - No packets to transmit, and neighbor begins transmitting.
  - Packet to send, but at least one neighbor is receiving (neighbor sends busy tone).

Powering off

- For how long?
- Use probes to determine duration of idle mode.

Duration of Idle Period

- If node has empty queue, powers off for duration of transmission.
  - When node comes up, if its queue still empty and channel busy, uses probes to do binary search to determine time last transmission will end.
- If node has non-empty queue, transmits RTS when comes up.
  - If busy tone received, it contains duration of transmission.
  - If no response (e.g., if busy tone collides), binary search.
Performance Trade-off

- Power savings versus delay/throughput.
- If nodes are off because it cannot transmit or receive, delay not impacted.
- But, length of off-time should not be no longer than needed.
- PAMAS favor delay/throughput over energy efficiency.

Mobile IP

Where is mobility managed?

- Application
- Session
- Transport
- Network
- Data-link
- Physical
- Mobile-IP: extension to IP architecture.
  - Manages mobility at the IP layer.
  - Hides mobility from upper layers.

Mobile IP: Goals

- Nodes can receive datagrams no matter where they attach to the Internet.
- IMHP (Internet Mobile Host Protocol) as Mobile IP precursor.
- Problem with IP:
  - IP address uniquely identifies host’s PoA.
  - Host must attach to network specified by its IP address to be able to send/receive datagrams.
Mobile IP

- Internet standard for "last-hop" mobility support in IP networks (RFC 2290).
- How do we deliver IP packets when the endpoints move?
  - Mobile host must be able to communicate after changing its link-layer point-of-attachment to the Internet.
  - Mobile host must be able to communicate using its permanent (home) IP address.

Mobile IP: Design Issues

- Issues:
  - Impact on IP addressing.
  - Impact on routing.
- Key design considerations:
  - Scale.
  - Routing updates (size and frequency).
  - Simplicity.
  - Incremental deployment.

Terminology

- Home Agent (HA)
- Foreign Agent (FA)
- Mobile Host (MH)
- HN
- FN

Terminology (Cont’d)

- Similar to cellular.
- Mobile Node (MN or MH): node changing its PoA.
- Correspondent Host (CH).
- Home Network (HN) and Foreign Network (FN).
Terminology (Cont’d)

- Mobility Agents:
  - Home Agent (HA): router on MN’s HN that tunnels datagrams to MH when away and keeps MH’s current location info.
  - Foreign Agent (FA): router on foreign network; delivers datagrams to MH while on FN.
- Home Address (HoA) and Care-of Address (CoA):
  - HoA: MH’s permanent address on HN.
  - CoA: MH’s temporary address on FN.

Mobile-IP: Basic Operation

- MH normally uses its home address HoA.
- When MH visits a foreign network,
  - Registration with FA.
    - Discover mobile agent and CoA.
  - Registration with HA.
    - Binding update (HoA -> CoA).
  - Communicating with MN: use HoA.
  - HA forwards packet from HoA to CoA.

Discovering Agents

- Agents periodically beacon advertisements

Agent Discovery

- Agent advertisement (beaconing):
  - Mobile agent broadcast agent advertisement at regular intervals (“I am here”).
- Agent solicitation:
  - MH can poll (“anyone here?”).
  - Mobile agent responds to poll.
Discovering Agents
MH polls: agent responds.

Agent Advertisement
- Allow for the detection of mobility agents.
- Follows ICMP router advertisement message.
- Let the MH know whether the agent is a HA, or a FA.
- List one or more available care-of addresses.
- Inform the MN about special features provided by FA.
  - Example: Alternative encapsulation techniques, header compression.

Registration
- When away, MH registers its CoA with HA (binding update).
- Binding: (HoA->CoA)
  - Binding has a lifetime.
- Registration process
  - MH sends a registration request with CoA.
  - HA authenticates request.
  - HA approves or disapproves the request.
  - HA adds necessary information to its routing table.
  - HA sends registration reply back to MH.
**CoA**

- Two types of CoA:
  - FA’s IP address.
  - MH’s temporary address
    - Locally-assigned address in the foreign network
    - E.g., DHCP address

- Advantages/disadvantages?

**Tunneling**

- HA tunnels datagrams destined to MH when MH is away.
  - Datagrams sent to MH, intercepted by HA and tunneled to its CoA.
  - Tunnel terminates at MH CoA (either the MH or the FA).

**Encapsulation**

- Tunneling requires encapsulation.
  - Sending the original packet (CH->MH) in another packet (HA->CoA).
- Default encapsulation mechanism:
  - IP-within-IP (tunnel).
  - Tunnel header: new IP header inserted by the tunnel source (home agent).
  - Destination IP: CoA
Tunneling in Mobile IP

The Triangle Routing Problem
- Aka, "dogleg" routing.
- MH->CH: direct.
- CH->MH: CH->HA->MH
  - Inefficient
- Solution: route optimization.
  - Deliver binding updates directly to CH.

Route Optimization
- Binding caches:
  - Nodes can keep caches with CoA for MHs.
  - If node has entry for MH, sends data directly.
  - Otherwise, "triangulates" with HA.
  - Binding cache entries have TTL.
  - HA, FA, or MH can send binding cache updates to CH.

“Smooth” Handoffs
- MH moving among FN.
- New CoA registered with HA.
- Previous FA not necessarily notified.
  - Old registration will expire.
- New data delivered to new CoA.
- In-flight data?
  - Dropped and retransmitted by upper layers, or
  - FA notified of new CoA; FA forwards data to new CoA.
Authentication

- Malicious nodes can infiltrate FNs.
- Mobile IP registration includes authentication info exchange.
  - MH-HA.
  - MH-FA.
  - HA-FA.
- Protection against replay attacks.
  - Timestamp and nonces.

Mobility Support in IPv6

- FA’s functionality performed by MH.
  - Node support for address auto-configuration.
  - MH can obtain CoA for current PoA.
  - MH informs CH of its new CoA.
    - IPv6’s destination options.
    - Piggybacked in data packet from MH to CH.

IPv6 Mobility Support (Cont’d)

- HA functionality practically unchanged.
  - Keeps MH CoA information.
  - Tunneling using IPv6 encapsulation.
    - MH then sends CoA to CH.
  - Acknowledgement of CoA information reception.

IPv6 Mobility Support (Cont’d)

- IPv6 destination options used to deliver mobility-related information.
  - Binding update option: MH->CH and ->HA.
    - Bindings need updating or refreshing.
  - Binding ACK option: HA->MH.
  - Binding request option: CH->MH.
    - CH may solicit binding update from MH.
Movement Detection

- IPv6 neighbor and router discovery.
- Router discovery to discover new routers/network prefixes.
- Unsolicited router advertisements.
- Router solicitation messages.
- Neighbor discovery's unreachability detection for default router reachability.
- Lower-layer information (e.g., signal strength/quality).

Handoffs

- Overlapping cells:
  - MH should still accept packets at previous CoA even after reporting new CoA.
  - Why?
- Router-assisted handoffs:
  - No overlap.
  - MH sends binding update to router for previous CoA.
  - Routers as HA for node's previous CoA.

TCP Performance in Mobile-IP (Choong)

- Source of overhead: triangle routing.
  - Additional processing at HA and FA.
  - Additional delay due to "triangulation".
  - Additional delay due to fragmentation (extra IP header).
  - Handoffs.

Goal

- Determine the impact on TCP performance of
  - Combined overhead sources.
  - Individual overhead sources.
Methodology

- Several scenarios that compound or isolate overhead sources.
- Compare performance of between scenario pairs.
- FTP transfer between MH and CH.
- Metric: TCP throughput.

Summary of Results

- Dogleg routing as main cause of TCP throughput degradation.
  - Solution: route optimization.
- Handoff is second.
  - Mobile-IP's inherent delay in re-establish connectivity with new FA.
  - Solutions:
    - Increase frequency of router advertisements.
    - Use link-layer information to trigger handoff.