Lecture 6
Mobile Ad-Hoc Networks: MAC

Reading:

- "MAC Protocols for Ad Hoc Wireless Networks," in *Ad Hoc Wireless Networks: Architectures and Protocols*, Chapter 6.
- "A Survey, Classification and Comparative Analysis of Medium Access Control Protocols for Ad Hoc Networks" by Raja Jurdak, Cristina Videira Lopes, and Pierre Baldi; University of California, Irvine, http://www.comsoc.org/livepubs/surveys/public/2004/jan/index.html
- E. Royer, S.-J. Lee and C. Perkins, "The Effects of MAC Protocols on Ad hoc Network Communication," *Proceedings of the IEEE Wireless Communications and Networking Conference (WCNC '00)*, 2000.

MAC Protocols

- Provide "rules" for channel access
- In MANETs, no centralized control
  - Nodes independently determine access
  - Local nodes elected to control channel access
  - Nodes coordinate amongst themselves locally to determine channel access
- Goals for MAC protocols for MANETs
  - High channel efficiency
  - Low power
  - Scalable
  - Fair
  - Support for prioritization
  - Support for heterogeneous nodes
  - Distributed operation
  - QoS support
  - Low control overhead

Characterization of MAC Protocols

- Channel separation and access
- Topology
- Power
- Transmission initiation
- Traffic load and scalability
- Range

Cannel Separation and Access

- Common channel vs. multiple channels
- Typical use of channel
  - Data transmission
  - RTS/CTS handshake
  - Carrier sensing
  - Periodic information exchange
  - Reservations
- Can use single channel for all packets
- Send some packets (e.g., overhead) on one channel and other packets (e.g., data) on other(s)
- Multiple channels allow more simultaneous users

Single Channel

- All nodes share the medium for transmission of data and control messages
- Collisions and contention
  - Handshake protocol
  - ACKs
  - Backoff protocol
- Examples
  - CSMA
  - MACA, MACAW, FAMA
  - MACA-BI, RIMA-SP: receiver-initiated approaches
  - MARCH: string of RTS-CTS-CTS-CTS…
  - DPC/ALP: consecutive increase in RTS power
  - PS-DCC: calculate sending probability based on current network load

Multiple Channels

- Can separate channels in time, frequency, space, etc.
- Typically, one channel for control, other(s) for data
- Examples
  - BTMA, DBTMA: separate busy-tone channel
  - PAMAS: RTS/CTS sent on control channel
  - DCAPC: one control channel, multiple data channels
  - GRID-B: channel borrowing from neighboring cells

Multiple Channels (cont.)

- TDMA-based separation
  - Time segmented into frames, slots
  - Nodes maintain synchronization
  - Best with real-time, periodic data
  - Examples
    - FPRP, CATA, SRMA/PA: each slot has reservation and information subslots
    - Markowski: traffic classes, window-splitting contention resolution
    - ADAPT: nodes “own” slots but others may use
    - D-PRMA: continuous reservations for voice

Multiple Channels (cont.)

- FDMA-based separation
  - Allows multiple nodes to transmit simultaneously
  - Examples
    - MCSMA: CSMA on each channel
- CDMA-based separation
  - Simultaneous transmissions via code separation
  - Examples
    - MC-MAC: one common control signal code, N data codes
    - IEEE 802.11: DSSS or FHSS channel separation
    - RICH-DP: reserve hops in frequency hopping scheme, RTR scheme

Multiple Channels (cont.)

- SDMA-based separation
  - Directional antennas to transmit in particular direction
  - Examples
    - Lal: poll direction with RTR, directional RTS and CTS returned
    - MMAC: directional carrier sensing, directional RTS
- Hybrid schemes
  - Combine channel separation methods
  - Examples
    - PRMA: TDMA and FDMA
    - Jin, Bluetooth: CDMA/TDMA

Topology

- Ad hoc network features
  - Mobility
  - Heterogeneous node capabilities
- Types of topologies
  - Centralized
    - Base station used for network control and management
    - Not useful for MANETs
  - Flat: single and multi-hop
    - Completely distributed approach
  - Clustered
    - Local cluster head elected and used for network control

Flat Topologies

- Nodes make independent decisions to access the channel
  - Local coordination via handshaking, carrier sensing
- Single-hop: concerned only with immediate neighbors
  - Scalability issues
  - CSMA, MACA, FAMA, MACA-BI, RIMA-SP, 802.11, etc.
- Multi-hop: some notion of nodes outside local neighborhood
  - Can aid in scalability and power efficiency
  - Most use multiple channels
  - PAMAS, DCA-PC, DCP/ALP
  - MARCH: directly uses notion of multi-hop path

Clustered Topologies

- Elect local cluster head to perform control/management of network resources
- Reduces burden on nodes, increases burden on cluster head
  - Good for heterogeneous networks
- Clustering protocols differ in
  - Election of cluster head
  - Cluster maintenance
  - Channel access
- Examples
  - VBA: elect CH based on lowest IP address
  - WCA: elect CH based on weighting of distance to nbrs, battery power, mobility and connectivity; allows roaming between clusters
  - Jin, GPC: elect CH based on battery power
  - Bluetooth: elect CH (Master) as node that initiated cluster (piconet)

Power Consumption

- Radio operates in 3 modes: transmit, receive, standby
- Relative powers
  - $P_{TX} > P_{RX} >> P_{SB}$ for long-range communication
  - $P_{TX} \sim P_{RX} > P_{SB}$ for short-range, low power transceivers
- Different MAC protocols will be “low-power” depending on model of transceiver power dissipation
- Time delay and power dissipation switching between states

Reducing Energy Consumption

- Reduce transmit power
  - Use "just enough" to reach intended destination
  - Examples
    - GPC, DCAPC, DCA-PC, DPC/ALP
- Place nodes in standby mode as much as possible
  - Nodes do not need to be on when not receiving data
  - Requires nodes to know when they must listen to the channel and when they can "sleep"
  - MAC protocols cannot use "promiscuous" mode to listen to other conversations
  - Node must know when other nodes have data to tx to it
  - Examples
    - PAMAS, Bluetooth, HIPERLAN

Reducing Energy Consumption (cont.)

- Tradeoff energy consumption and delay in receiving a message
- Approaches
  - Directory approach: BS broadcasts directory of packets waiting in its queue
    - Node receives directory and knows when to wake up and listen for data
  - Grouped-TDMA approach: nodes grouped and each group wakes up at given slot to determine if data needs to be received
  - Pseudo-random approach: nodes have unique pseudo-random sleep/wake cycles known to BS

Reducing Energy Consumption (cont.)

- Collisions should be minimized
  - Retransmissions expend energy
  - Introduce delays
  - Reduce number of ACKs required
  - Use contention for reservations and contention-free for data transmission
- Allocate contiguous slots for transmission/reception
  - Avoids power/time in switching from Tx to Rx
- Have node buffer packets and transmit all packets at once
  - Allows node to remain asleep for long time
  - Trade-off in delay to receive packets and buffer size

Reducing Energy Consumption (cont.)

- Make protocol decisions based on battery level
  - Choose cluster head to have plenty of energy
  - Give nodes with low energy priority in contention
  - Examples
    - WCA, DPC/ALP, Jin GPC
- Reduce control overhead
  - Need control to avoid collisions, but reduce as much as possible
  - Examples
    - MARCH

Reducing Energy Consumption (cont.)

- Centralized scheduling is most energy-efficient
- Energy advantages depend on relative power in the transmit and receive mode
- Adapt protocol to traffic and network for most energy efficient approach

Transmission Initiation

- Sender-initiated
  - Most protocols follow this approach
  - Sender attempts to access channel when it has data
- Receiver-initiated
  - Receiver attempts to clear channel for transmissions
  - Send request-to-transmit (RTR) to all neighbors or specific node
  - Polling for data
  - Only efficient if large amount of traffic on network

Traffic Load and Scalability

- Highly loaded networks
  - Receiver-initiated approaches
  - Adjust sending probability based on network load
  - Channel borrowing for non-uniform load
  - TDMA approaches for periodic sources
- Dense networks
  - Transmission power control
  - Directional antennas
- Voice and real-time traffic
  - Priorities
  - Reservations

Interaction Between MAC and Routing

- Why should the MAC protocol affect the routing protocol? What affects would you expect the MAC protocol to have on the routing protocol and vice versa?
- Royer et al. study
  - Routing protocols
    - WRP: triggered + periodic routing updates
    - FSR: non-uniform updates with more accurate information for closer destinations
    - AODV: reactive protocol, uses Hello messages
  - MAC protocols
    - CSMA: non-persistent
    - MACA: RTS/CTS with no CS
    - FAMA: RTS/CTS with CS
    - IEEE 802.11: CSMA/CA with RTS/CTS/ACK

Simulation Results

- Packets delivered
  - AODV only protocol to vary depending on MAC– why should the MAC affect this protocol more?
  - With 802.11, AODV performs best– why might this be the case?
- Control overhead
  - WRP: control traffic increases as mobility increases– why?
  - FSR: control traffic relatively constant
  - AODV: overhead varies with MAC and mobility– why?
- Normalized routing load
  - WRP consistently high
  - FSR and AODV: similar performance, varies based on MAC
- Overall, AODV more dependent on MAC than on-demand protocols