Medium Access Control (MAC) Protocols for Ad hoc Wireless Networks -IV

CS: 647
Advanced Topics in Wireless Networks

Drs. Baruch Awerbuch & Amitabh Mishra
Department of Computer Science
Johns Hopkins University
Outline

- Wireless MAC Issues
  - Hidden terminal problem
  - Exposed terminal problem
  - Capture

- MAC Performance Metrics

- Wireless MAC Classification

- Distributed Wireless MAC Protocols
  - CSMA/CA
  - 802.11 MAC
    - DCF
    - Backoff
  - Fairness
  - Energy/Power
Fairness Issue

- Many definitions of fairness plausible

- Simplest definition: All nodes should receive *equal* bandwidth
Fairness Issue

- Assume that initially, A and B both choose a backoff interval in range [0, 31] but their RTSs collide.
- Nodes A and B then choose from range [0, 63].
  - Node A chooses 4 slots and B choose 60 slots.
  - After A transmits a packet, it next chooses from range [0, 31].
  - It is possible that A may transmit several packets before B transmits its first packet.

![Diagram of two flows](image)
Fairness Issue

- Unfairness occurs when one node has backed off much more than some other node.

![Diagram of node connections]

Two flows
MACAW Solution for Fairness

- When a node transmits a packet, it appends the $cw$ value to the packet, all nodes hearing that $cw$ value use it for their future transmission attempts.

- MACAW proposes maintaining $cw$ independently for each receiver.

- Using per-receiver $cw$ is particularly useful in multi-hop environments, since congestion level at different receivers can be very different.
Another MACAW Proposal

- For the scenario below, when node A sends an RTS to B, while node C is receiving from D, node B cannot reply with a CTS, since B knows that D is sending to C.

- When the transfer from C to D is complete, node B can send a Request-to-send-RTS to node A [Bharghavan94Sigcomm]
  - Node A may then immediately send RTS to node B.

![Diagram](attachment:diagram.png)
This approach, however, does not work in the scenario below

- Node B may not receive the RTS from A at all, due to interference with transmission from C.
Outline

- Wireless MAC Issues
  - Hidden terminal problem
  - Exposed terminal problem
  - Capture

- MAC Performance Metrics

- Wireless MAC Classification

- Distributed Wireless MAC Protocols
  - CSMA/CA
  - 802.11 MAC
    - DCF
    - Backoff
  - Fairness
  - Priority Scheduling
  - Power
Priority Scheduling

- Given packets belonging to different priority classes, packets with higher priority should be transmitted first.

- Since the packets may be at different nodes sharing the wireless channel, how to coordinate access?
Priorities in 802.11

- CTS and ACK have priority over RTS

After channel becomes idle

- If a node wants to send CTS/ACK, it transmits SIFS duration after channel goes idle

- If a node wants to send RTS, it waits for DIFS > SIFS
SIFS and DIFS
Variation in Backoff Interval \cite{Aad01}

- For high priority packets
  - Backoff interval in $[0, C_{Wh}]$

- For low priority packet
  - Backoff interval in $[C_{Wh}+1, CW_l]$

- Higher priority packets use small backoff intervals
  - Higher probability of transmitting a high priority packet before a pending low probability packet
With this scheme, if two high priority packets collide, they will have to choose a new backoff interval, and may be transmitted after a low priority packets.

Example:
- Packet H1 : backoff interval 9 slots
- Packet H2 : backoff interval 9 slots
- Packet L : backoff interval 13 slots

When H1 and H2 collide
- Packet L : backoff interval is now 4 slots
- Assume that H1 and H2 pick backoff intervals 6 and 7 slots respectively, after collision
- Packet L will be transmitted first
Second Mechanism [Aad01]

- High priority packets always choose backoff in $[0,CWh]$

- Low priority packets wait for LIFS idle period before counting down where
  \[ LIFS = DIFS + CWh \]

- Ensures that high priority packets will always get a chance to transmit before a low priority packet can
Example

H

busy

H backoff

H

DIFS

L

busy

LIFS

H

LIFS

L backoff
Disadvantage: When no high priority packets, low priority packet unnecessarily wait for long periods of time.

How to avoid priority reversal, and also minimize wait for low priority packets? [Yang02Mobihoc]
Priority Using Black Bursts
[Hiperlan/1,Sobrinho96,99]

- All nodes begin the priority contention phase together

- Higher priority node transmit a longer burst than low priority node

- After transmitting its burst, a node listens to the channel

- If channel still busy, the node has lost contention to a higher priority node
Outline

- Wireless MAC Issues
  - Hidden terminal problem
  - Exposed terminal problem
  - Capture

- MAC Performance Metrics

- Wireless MAC Classification

- Distributed Wireless MAC Protocols
  - CSMA/CA
  - 802.11 MAC
    - DCF
    - Backoff
  - Fairness
  - Priority Scheduling
  - Energy Conservation
Energy Conservation

- Since many mobile hosts are operated by batteries, MAC protocols which conserve energy are of interest.

- Two approaches to reduce energy consumption:
  - **Power save**: Turn off wireless interface when desirable.
  - **Power control**: Reduce transmit power.
Power Aware Multi-Access Protocol (PAMAS) [Mobicom'98Singh]

- A node powers off its radio while a neighbor is transmitting to someone else

![Diagram showing Node A sending to B and Node C staying powered off]
Power Aware Multi-Access Protocol (PAMAS)

- What should node C do when it wakes up and finds that D is transmitting to someone else?
  - C does not know how long the transfer will last

Node A sending to B

Node D sending to E

C stays powered off

C wakes up and finds medium busy
PAMAS

- PAMAS uses a control channel separate from the data channel.

- Node C on waking up performs a binary probe to determine the length of the longest remaining transfer:
  - C sends a probe packet with parameter L.
  - All nodes which will finish transfer in interval $[L/2, L]$ respond.
  - Depending on whether node C sees silence, collision, or a unique response it takes varying actions.
Disadvantages of PAMAS

- Use of a separate control channel

- Nodes have to be able to receive on the control channel while they are transmitting on the data channel
  - And also transmit on data and control channels simultaneously

- A node (such as C) should be able to determine when probe responses from multiple senders collide
Power Save in IEEE 802.11 Ad Hoc Mode

- Time is divided into beacon intervals

- Each beacon interval begins with an ATIM window
  - ATIM = ??
Power Save in IEEE 802.11 Ad Hoc Mode

- If host A has a packet to transmit to B, A must send an ATIM Request to B during an ATIM Window.

- On receipt of ATIM Request from A, B will reply by sending an ATIM Ack, and stay up during the rest of the beacon interval.

- If a host does not receive an ATIM Request during an ATIM window, and has no pending packets to transmit, it may sleep during rest of the beacon interval.
Power Save in IEEE 802.11 Ad Hoc Mode

Node A
- ATIM Req
- ATIM Ack
- Data
- Ack

Node B
- Sleep

Node C
Power Save in IEEE 802.11 Ad Hoc Mode

- Size of ATIM window and beacon interval affects performance [Woesner98]

- If ATIM window is too large, reduction in energy consumption reduced
  - Energy consumed during ATIM window

- If ATIM window is too small, not enough time to send ATIM request
Power Save in IEEE 802.11 Ad Hoc Mode

- **How to choose ATIM window dynamically?**
  - Based on observed load [Jung02infocom]

- **How to synchronize hosts?**
  - If two hosts’ ATIM windows do not overlap in time, they cannot exchange ATIM requests
  - Coordination requires that each host stay awake long enough (at least periodically) to discover out-of-sync neighbors [Tseng02infocom]
Impact on Upper Layers

- If each node uses the 802.11 power-save mechanism, each hop will require one beacon interval
  - This delay could be intolerable

- Allow upper layers to dictate whether a node should enter the power save mode or not [Chen01mobicom]
Energy Conservation

- Power save

- Power control
Power Control

- Power control has two potential benefit

- Reduced interference & increased spatial reuse

- Energy saving
Power Control

- When $C$ transmits to $D$ at a high power level, $B$ cannot receive $A$’s transmission due to interference from $C$
Power Control

- If C reduces transmit power, it can still communicate with D
  - Reduces energy consumption at node C
  - Allows B to receive A’s transmission (spatial reuse)
Power Control

- Received power level is proportional to $1/d^\alpha$, $\alpha \geq 2$

- If power control is utilized, energy required to transmit to a host at distance $d$ is proportional to $d^\alpha + \text{constant}$

- Shorter hops typically preferred for energy consumption (depending on the constant) [Rodoplu99]
  - Transmit to $C$ from $A$ via $B$, instead of directly from $A$ to $C$
Power Control with 802.11

- Transmit RTS/CTS/DATA/ACK at least power level needed to communicate with the received

A

B

C

D

- A/B do not receive RTS/CTS from C/D. Also do not sense D’s data transmission

- B’s transmission to A at high power interferes with reception of ACK at C
- Transmitting RTS at the highest power level also reduces spatial reuse.

- Nodes receiving RTS/CTS have to defer transmissions.
Modification to Avoid Interference

- Transmit RTS/CTS at highest power level, DATA/ACK at least required power level
- Increase DATA power periodically so distant hosts can sense transmission [Jung-Infocom02]

- Need to be able to change power level rapidly
Caveat

- Energy saving by power control is limited to savings in transmit energy
- Other energy costs may not change
- For some 802.11 devices, the energy consumption of the wireless interface reduces only by a factor of 2 when transmit power reduced from max to min possible for the device
Small Addresses Save Energy

[Schurgers01mobihoc]

- In sensor networks, packet sizes are small, and MAC addresses may be a substantial fraction of the packet.

- **Observation**: MAC addresses need only be unique within two hops.

- Fewer addresses are sufficient: Address size can be smaller. [Schurgers00mobihoc] uses Huffman coding to assign variable size encoding to the addresses.

- Energy consumption reduced due to smaller addresses.
MAC Summary

- Designing MAC protocols for ad hoc networks is very difficult

- Issues to consider:
  - Hidden/exposed terminal
  - Collision avoidance
  - Congestion control
  - Fairness
  - Reliability
  - Energy efficiency

- IEEE 802.11 DCF (RTS/CTS/DATA/ACK) widely used, but many other protocols are proposed
What you should know ... (1)

- Wireless Mac issues
  - Half Duplex operation,
  - Time Varying Channel, Burst Errors
  - Performance parameters for MAC
  - Hidden Nodes
  - Exposed Nodes
  - Captured Nodes
  - MACA Mac Protocol
  - RTS-CTS Mechanisms
  - Limitations of RTS-CTS mechanisms
What you should know ... (2)

- Functions and operation of the MAC layer
  - Minimum frame exchange protocol
  - RTS-CTS extension
- Operation of access mechanisms
  - Operation of basic access mechanism
  - Role of timing intervals
  - Operation of DCF, DCF with RTS-CTS and PCF
- Fairness Issues
- Energy Issues