EEC173B/ECS152C, Winter 2006

MANET Power Management

- Power-Aware Routing
- Energy Conservation

Acknowledgment: Selected slides from Prof. Nitin Vaidya

Power-Aware Routing

Define optimization criteria as a function of energy consumption. Examples:

- Minimize energy consumed per packet
- Minimize time to network partition due to energy depletion
- Maximize duration before a node fails due to energy depletion

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Power-Aware Routing

- [SWR98] S. Singh, M. Woo, and C.S. Raghavendra, "Power-Aware Routing in Mobile Ad Hoc Networks," *ACM Mobicom*, 1998.
- Assign a weight to each link
- Weight of a link may be a function of energy consumed when transmitting a packet on that link, as well as the residual energy level
  - Low residual energy level may correspond to a high cost
- Prefer a route with the smallest aggregate weight

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Power-Aware Routing

Possible modification to DSR to make it power aware (for simplicity, assume no route caching):

- Route Requests aggregate the weights of all traversed links
- Destination responds with a Route Reply to a Route Request if
  - it is the first RREQ with a given ("current") sequence number, or
  - its weight is smaller than all other RREQs received with the current sequence number

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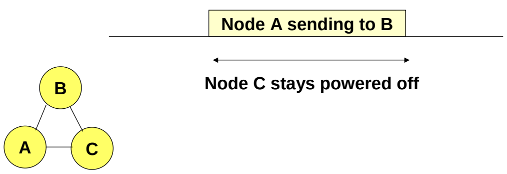
Energy Conservation

- 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

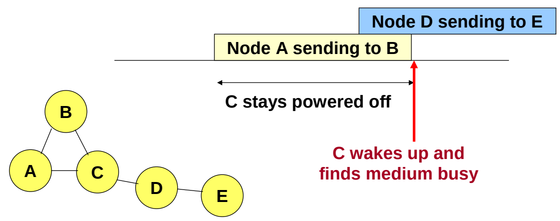
Power Aware Multi-Access Protocol (PAMAS)

- [SR98] S. Singh and C. S. Raghavendra, "PAMAS – Power-aware multi-access protocol with signaling for ad hoc networks," *ACM SIGCOMM CCR,* 1998.
- A node powers off its radio while a neighbor is transmitting to someone else



PAMAS (Cont'd)

- 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



PAMAS (Cont'd)

- 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 see silence, collision, or a unique response it takes varying actions
- Node C (using procedure above) determines the duration of time to go back to sleep

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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

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Another Proposal in PAMAS

- To avoid the probing, a node should switch off the interface for data channel, but not for the control channel (which carries RTS/CTS packets)
- Advantage: Each sleeping node always know how long to sleep by watching the control channel
- Disadvantage: This may not be useful when hardware is shared for the control and data channels
  - It may not be possible turn off much hardware due to the sharing

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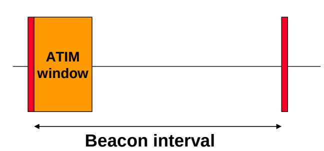
Power Save in IEEE 802.11 Ad Hoc Mode

- Time is divided into beacon intervals



- Each beacon interval begins with an ATIM window
  - ATIM =

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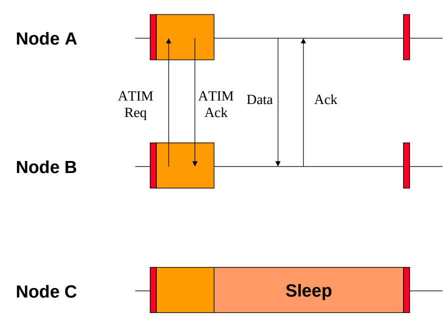
Power Save in IEEE 802.11 Ad Hoc Mode

- 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

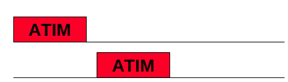


Power Save in IEEE 802.11 Ad Hoc Mode

- 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]

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Motivation

- Sleep mode power consumption << Idle power consumption

Radio State	Power Consumption (mW)
Transmit	81
Receive/Idle	30
Sleep	0.003

Power Characteristics for a Mica2 Mote Sensor

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Design Alternatives

- Synchronous: Once a host enters sleep mode, it wakes up at a pre-determined time
  - Timer-based
- Asynchronous: A sleeping host can be woken up at any time by a neighbor
- Hybrid: Synchronous + Asynchronous

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Using Wake-up Radio

- [MV04] M. Miller and N. H. Vaidya, "Minimizing Energy Consumption in Sensor Networks Using A Wakeup Radio," *IEEE WCNC*, 2004.
- Add second, low-power radio to wakeup neighbors on-demand
- Low-power wake-up can be achieved using
  - Simpler hardware with a lower bit-rate and/or less decoding capability, or
  - A periodic duty cycle (e.g., as in STEM [UCLA]) using a "normal" radio
    - Latter approach used in the illustration here

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Actions of a Sleeping Host

- Periodically listen to a wake-up channel
  - Duty cycle affects energy consumption
- If wake-up channel sensed busy:
  - Turn on data radio
  - Receive a "filter" packet on data radio
  - If filter intended for another host, go back to sleep

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Actions of a Sender Host

- Transmit a wake-up signal "long enough" if the intended receiver is expected to be sleeping
- Transmit a filter packet specifying intended receiver
- Transmit data to the receiver

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Purely Asynchronous Mechanism

- In a purely asynchronous approach, each packet burse is preceded by a "wake-up" signal
- Might wake-up too many hosts near the transmitter – referred as "full" wakeup
  - ➔ *Energy cost*

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Add a Synchronous Component

- Each sleeping host will wake-up after a pre-defined interval of time ("timeout")
  - Referred as "triggered" wakeup
- If a transmitter cannot wait until then, it may send a wake-up signal
  - Send wake-up signal if queue size exceeds threshold L or a delay bound
- Timeout is computed based on recent traffic rate

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Timeout for Triggered Wakeups

- If too small, host may wake-up when there are no packets pending for it
- If too large, too many "full" wakeups

Power Save Protocol

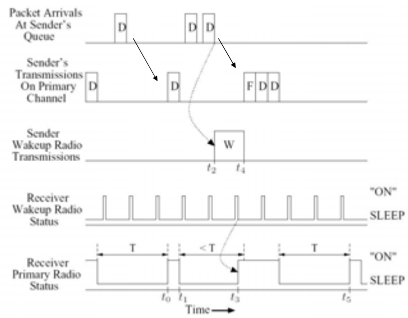


Fig. 2. Static T and $L = 2$ (**D** = data packet, **F** = filter packet, **W** = wakeup signal).

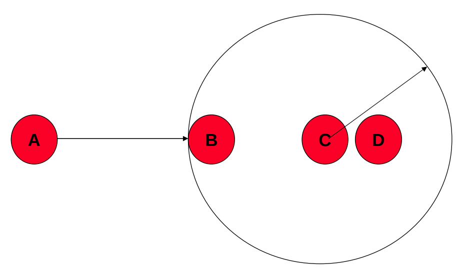
Energy Conservation: Power Control

Power control has two potential benefit

- Reduced interference & increased spatial reuse
- Energy saving

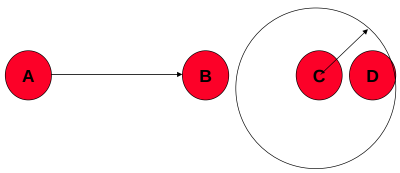
Power Control

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



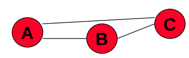
Power Control

- 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)



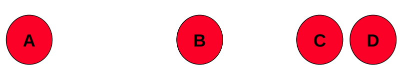
Power Control

- Received power level is proportional to $1/d^{\alpha}$, $\alpha >= 2$
- If power control is utilized, energy required to transmit to a host at distance d is proportional to d^{α} + constant
- Shorter hops typically preferred for energy consumption (depending on the constant)
  - Transmit to C from A via B, instead of directly from A to C



Power Control with 802.11

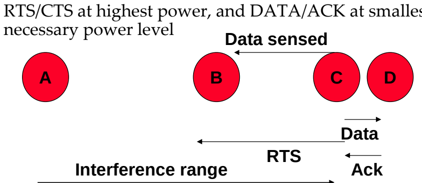
- Transmit RTS/CTS/DATA/ACK at least power level needed to communicate with the received



- A/B 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

A Plausible Solution

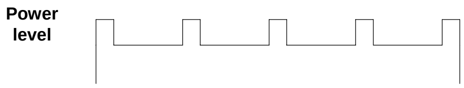
- RTS/CTS at highest power, and DATA/ACK at smallest necessary power level



- A cannot sense C's data transmission, and may transmit DATA to some other host
- This DATA will interfere at C
- This situation unlikely if DATA transmitted at highest power level
  - Interference range ~ sensing range

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 [Jung02tech]



- Need to be able to change power level rapidly
- Transmitting RTS at the highest power level also reduces spatial reuse
  - Nodes receiving RTS/CTS have to defer transmissions

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Caveat

- Energy saving by power control is limited to savings in transmit energy
- Other energy costs may not change, and may represent a significant fraction of total energy consumption

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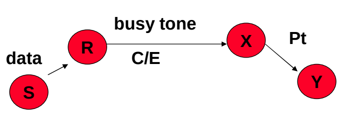
Power Controlled Multiple Access (PCMA)

- [MBW01] J. P. Monks, V. Bharghavan, and W. Hwu, "A Power Controlled Multiple Access Protocol for Wireless Packet Networks," *IEEE Infocom*, 2001.
- If receiver node R can tolerate noise E, it sends a busy tone at power level C/E, where C is an appropriate constant
- When some node X receives a busy-tone a power level Pr, it may transmit at power level Pt <= C/Pr



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Power Controlled Multiple Access (PCMA)

- If receiver node R can tolerate noise E, it sends a busy tone at power level C/E, where C is an appropriate constant
- When some node X receives a busy-tone a power level Pr, it may transmit at power level Pt <= C/Pr
- Explanation:
  - Gain of channel RX = gain of channel XR = g
  - Busy tone signal level at X = Pr = g * C / E
  - Node X may transmit at level = Pt = C/Pr = E/g
  - Interference received by R = Pt * g = E

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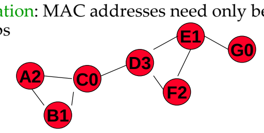
PCMA

- Advantage
  - Allows higher spatial reuse, as well as power saving using power control
- Disadvantages:
  - Need a separate channel for the busy tone
  - Since multiple nodes may transmit the busy tones simultaneously, spatial reuse is less than optimal

Small Addresses Save Energy

- [SKS01] C. Schurgers, G. Kulkarni, and M. B. Srivastava, "Distributed Assignment of Encoded MAC Addresses in Sensor Networks," *ACM Mobihoc*, 2001.
- 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

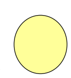
Question

- How to exploit directional antennas in ad hoc networks ?
  - Medium access control
  - Routing

Antenna Model

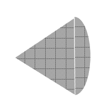
In Omni Mode:

- Nodes receive signals with gain $\mathbf{G^o}$
- While idle a node stays in omni mode



In Directional Mode:

- Capable of beamforming in specified direction
- Directional Gain $\mathbf{G^d}$ $\mathbf{(G^d > G^o)}$
- Directional mode has sidelobes



Symmetry: Transmit gain = Receive gain

Directional Communication

Received Power

$\propto$

(Transmit power) *(Tx Gain) * (Rx Gain)

Directional gain is higher

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Potential Benefits of Directional Antennas

- Increase "range", keeping transmit power constant
- Reduce transmit power, keeping range comparable with omni mode
  - Several proposal focus on this benefit
  - Assume that range of omni-directional and directional transmission is equal

    ➔Directional transmissions at lower power

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