EEC173B/ECS152C

Power Management for Ad Hoc Networks
- ◆ Power-Aware Routing
- ◆ Energy Conservation

(#1) 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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## (#2) 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

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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

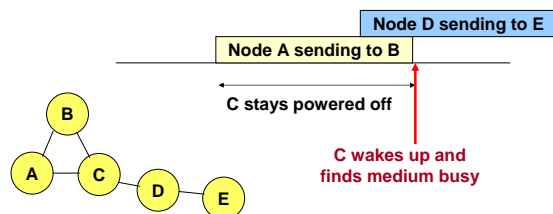Node A sending to B

Node C stays powered off
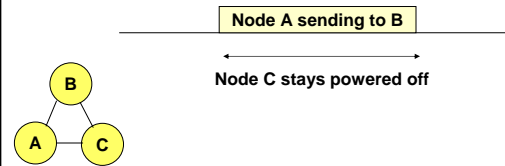
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PAMAS (Cont'd)

- 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

Node D sending to E

Node A sending to B

C stays powered off

C wakes up and finds medium busy

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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
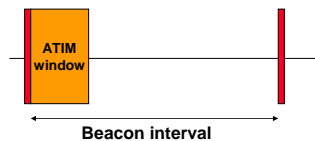
Beacon interval

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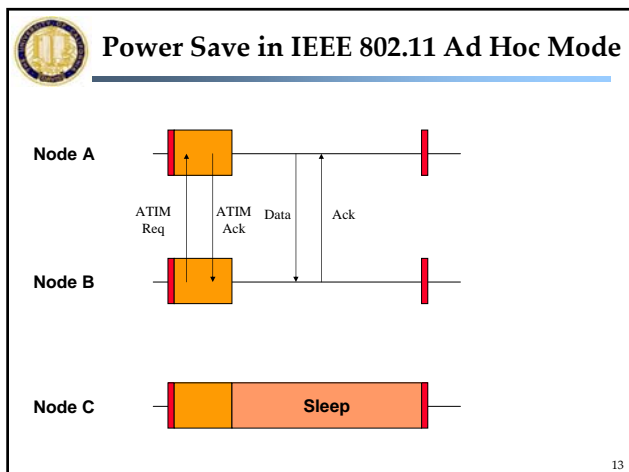 - ATIM =

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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

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Power Save in IEEE 802.11 Ad Hoc Mode

Node A

ATIM Req   ATIM Ack   Data   Ack

Node B

Node C | Sleep |

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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

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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]

| ATIM |

| ATIM |

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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
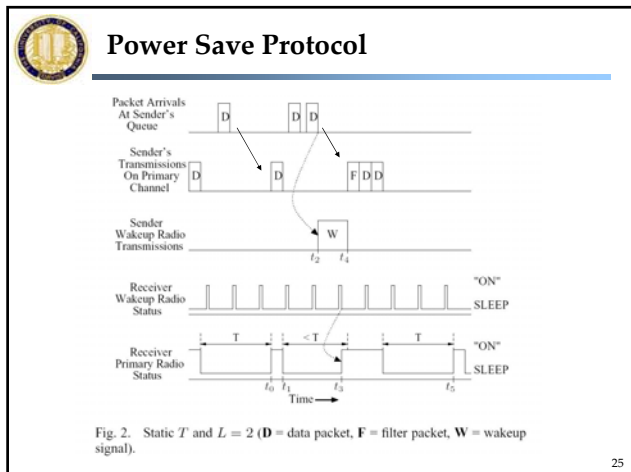
- Timeout is computed based on recent traffic rate

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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

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Power Save Protocol

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

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Energy Conservation: Power Control

Power control has two potential benefit

- Reduced interference & increased spatial reuse

- Energy saving

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Power Control

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


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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)

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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
  $d^\alpha + constant$

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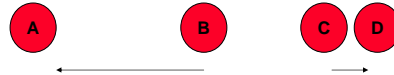 - Transmit to C from A via B, instead of directly from A to C
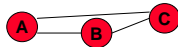
Power Control with 802.11

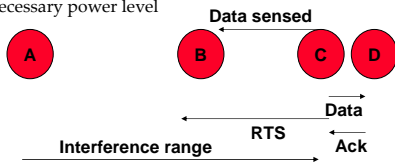- Transmit RTS/CTS/DATA/ACK at least power level needed to communicate with the received

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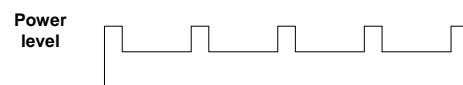
- Need to be able to change power level rapidly
- Transmitting RTS at the highest power level also reduces spatial reuse
 - Nodes receiving RTS/CTS have to defer transmissions

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
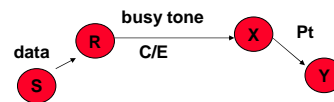
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- When some node X receives a busy-tone a power level Pr, it may transmit at power level Pt <= C/Pr
- Explanation:
  - Gain of channel RX = gain of channel XR = g
  - Busy tone signal level at X = Pr = g * C / E
  - Node X may transmit at level = Pt = 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

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