Announcements

Homework 1:
Midterm on 05.10.
  MAC.
  Unicast routing.
  Multicast routing.
Today

Topology and power management.

Topology management as power management strategy.
Where to place power management?

Hardware-based solutions: turn-off display, slow down disk, etc.

Software-based solutions:

Different layers:

MAC: power-controlled transmissions, idle time management.

Routing: finding energy-efficient routes.

Transport: idle time management.

Power management interface to application.

Application is able to control trade-off between power savings and performance-related requirements (delay).
Power-Controlled MAC

[Monks01]

Goal:
Power-control for better channel utilization.

Focus:
Multi-hop wireless networks.
CSMA/CA-based protocols.
Contetion-Based CA

Sender-receiver acquire floor before data transmission.
RTS/CTS + carrier sensing.
   Node transmits only if does not sense carrier and is not deferring.
Multiple concurrent transmissions in neighborhood not allowed.
Spatial reuse

One approach: nodes acquire only a “minimum area” sufficient for correct data transmission.

Problem: nodes need to use fixed power for symmetry, i.e., a node’s RTS/CTS must reach every node whose transmission may cause collision at that node; node must assume worst-case transmission power from other nodes.

Even if power is controlled for data transmission (for power savings), for channel reuse, it’s like using fixed power.
Proposed approach

Adaptive floor acquisition.
Use signal strength of received control packet to bound transmission power.
Transmitter (including hidden terminals) bounds transmission power as a function of received CTS strength.
PCMA protocol

Power-Controlled Multiple Access. “Bounded-power” model.

Request-power-to-send (RPTS)/acceptable-power-to-send (APTS).

Determine minimum transmission power for successful reception.

Exchange sequence: RPTS-APTS-DATA-ACK.

Busy tone periodically pulsed by receiver on busy tone channel: maximum noise tolerance.

Indicates upper bound on transmit power for other transmitters.
More on PCMA

Idle node monitors busy tone channel to determine its power bound.

Power bound = maximum power received on busy tone channel.

When node has data to send, sends RPTS at its power bound on DATA channel. RPTS contains transmission and noise power at source.

When destination receives RPTS, it measures receive power and computes channel gain using information in the packet.
PCMA (cont’d…)

Receiver computes power level for APTS and data packet which it includes in the APTS. On receiving APTS, source sends data packet at power specified in APTS; if it times out before receiving APTS, backs off and starts over.

Receiver starts sending busy tones on busy tone channel as it starts receiving data; busy tone’s power is such as to prevent nearby nodes from transmitting but not nodes farther away.
PCMA (cont’d…)

When node senses busy tone, it computes its transmit power for that node accordingly; transmit power at node defined by most sensitive receiver (least transmission power tolerance).

Narrow busy tones to avoid busy tone collisions. After successful data reception, receiver sends ACK.

If ACK goes through, source resets backoff timer and back to idle; otherwise increases backoff and starts over.
Evaluation

Single-hop network.
Comparison with 802.11 and ideal protocol (global knowledge of link gains, noise, transmission power bounds).
PCMA shows improvement in channel utilization (2 times 802.11’s aggregate bandwidth in dense networks).
Overhead? Multi-hop? Mobility?
Topology Control
What’s topology control?

When nodes are deployed, how do they organize into a network?
Neighbor-discovery protocol.
If neighborhood is sparse, use all neighbors.
What if neighborhood is dense?
Use a subset of neighbors.
How?
Approaches to topology control

Adjust transmit power.
Turn nodes on/off.
Motivation:

Ad hoc network nodes are typically energy constrained.

Radio in overhearing, listening, or idle consumes reasonable amount of energy.
Geographical Adaptive Fidelity. Designed to operate in concert with routing protocols. Energy conservation by turning off “redundant nodes”. Assumes nodes know their location. Use “node equivalence” to turn off radios.
Node equivalence

Routing fidelity: uninterrupted connectivity between communicating nodes.

Nodes are equivalent if a subset of them can be turned off without changing network connectivity.
Node equivalence (cont’d)

Node equivalence varies with communication end-points. Example: for (1,4), 2 and 3 are equivalent for (1,5) only 3.
Virtual Grids

Area where nodes are distributed divided into virtual grids.

Given 2 adjacent grids, all nodes in one grid can communicate with all nodes in the other.

Hence, all nodes in each grid are equivalent.
Sizing Virtual Grids

Maximum distance between nodes $\leq R$, or:

$$r^2 + (2r)^2 \leq R^2$$

or

$$r \leq \frac{R}{(5)^{1/2}}$$
GAF Operation

Nodes in sleeping, discovery, and active states.

Nodes start in discovery: radio on, find other nodes within grid.

Nodes exchange (node id, grid id, timer).

Node uses its location and grid size to determine grid id.

Timer ($T_d$) determines when node sends out discovery message and switches to active.
GAF (cont’d)

In active mode, nodes periodically broadcast discovery message. While in active, timer ($T_a$) determines when node goes back to discovery. While in discovery or active, node can sleep if it finds equivalent nodes. Timer ($T_s$) determines when node wakes up and enters discovery.
Tuning GAF

Ideally, only one node active per grid.

Node ranking:

Who handles routing?

“Active” node ranked higher than “discovery” node.

Nodes with longer lifetime are ranked higher.

Discovery interval can also be influenced by node’s lifetime (rank).

Highly ranked nodes suppressing others.

Sleep interval can be set to current active interval.
GAF and Routing

GAF runs atop MANET routing. It decides nodes’ duty cycle and routing needs to adjust accordingly. Routing could be informed a priori so it could adjust before routes break.
GAF and Mobility

Use “expected node grid time” to influence nodes’ sleep time.

Expected node grid time: time node expects to leave grid; propagated in discovery message.

Sleep time is min (active time, expected node grid time).
GAF’s Performance

Simple analytical model for idealized energy conservation case.

\[ m = \frac{A}{(R/5^{1/2})^2}, \]  
where \( m \) is number of grids, \( A \) is the area, and \( R \) the range.

Under the uniform node distribution assumption, each grid has \( n/m \) nodes or \( (n*R^2)/5*A \), which is the maximum number of times lifetime is extended.
GAF’s Performance (cont’d…)

Simulation experiments.
Metrics: energy savings and reliability.
From paper…
Span [Chen02]

Span and GAF have common goals:

Energy conservation by turning off “redundant” nodes.

But in Span, no geographical information used.

Basic approach:

Distributed, localized algorithm for selecting subset of nodes (coordinators) that stay up, while others sleep.
Span Overview

Coordinators are adaptively selected among participating nodes.
Coordinators stay up and perform routing/forwarding.
Other nodes sleep.
Span goals

Enough coordinators so that every node is in-range of at least one coordinator. Rotates coordinators for load balancing. Minimize number of coordinators. Use only local information.
Span in Protocol Stack

Runs atop MAC and below routing.

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<td>Span</td>
<td>MAC</td>
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Basic operation

Nodes exchange periodic HELLO messages.

Containing current state, current coordinators, current neighbors.

Non-coordinator nodes periodically wake-up and decide what their role should be.
Becoming coordinator

Coordinator eligibility: non-coordinator should become coordinator if 2 of its neighbors cannot reach each other directly or via 1 or 2 coordinators.

- Not optimal.
- Tries to ensure at least 1 coordinator in each populated radio neighborhood.

Transmission of coordinator announcements randomized to prevent synchronization.
Coordinator withdrawal

Each coordinator periodically checks if it should withdraw.
Coordinator withdraws if every pair of nodes can reach each other directly or through 1 or 2 coordinators.
Nodes stay as coordinators for time inversely proportional to their remaining battery time.
Coordinators become tentative coordinators to give other nodes opportunity to become coordinators without losing connectivity.
Power-Aware Routing
Power-aware routing metrics [Singh98]

Traditional metrics (e.g., smallest number of hops, shortest delay, etc.) may impact battery life negatively.

Routes between 1 and 3, 2 and 4.
Energy-efficient metrics

Examples:
- Residual battery power.
- Minimize energy consumed/packet.
- Maximize time to network partition.
Incorporating new metrics

Shortest-path routing can directly incorporate some of the proposed metrics.

Cost function redefined to account for right metric.

Hybrid routing.

Change metrics over time.

Change metrics based on packets.
Power-Aware Routing

Tries to extend network lifetime by finding energy-efficient routes.

How?

Incorporate energy as routing metric.
Power-aware routing metrics

Traditional metrics (e.g., smallest number of hops, shortest delay, etc.) may impact battery life negatively.

Routes between 1 and 3, 2 and 4.
Energy-efficient metrics

Minimize energy consumed/packet.
  Tends to route around congested regions.
  Still may cause nodes to die before others.

Maximize time to network partition.
  Need to determine minimum set of nodes that if removed, cause network partition.
  Routing must load balance routing task among these nodes.
More energy-efficient metrics

Minimize node power variance.
Ensures nodes consume energy uniformly.
Keeps all nodes up for as long as possible.

Minimize cost/packet.
Define cost such that nodes with low energy levels are more expensive, or, node’s reluctance to forward packets.
Incorporating new metrics

Shortest-path routing can directly incorporate some power-aware routing metric.

Hybrid routing.
   Change metrics over time.
   Change metrics based on packets.
Energy Drain Rate [Kim et al.]

Considering only residual battery life is not enough.

Why?

Approach: drain rate.

Measures energy dissipation rate at node. Node monitors its energy consumption over time.

Communication-related tasks. Accounts for overhearing.
Computing the Drain Rate

Exponential weighted moving average.

$$\text{DR}_i = \alpha \cdot \text{DR}_{\text{old}} + (1-\alpha) \cdot \text{Dr}_{\text{sample}}$$

Alpha is currently set to 0.3. What does that mean?
Routing Cost Metric

Ratio between residual energy and the drain rate.

For node $i$, 

$$C_i = \frac{RBP_i}{Dr_i}$$

For a given route $r$, the maximum lifetime of the route is given by the minimum $C_i$ over the whole route.
Route Selection

From set of all possible routes between source and destination, select the one with highest lifetime.

Dynamics?

Proactive versus reactive routing.
Implementation Issues

Access to residual battery power at nodes.

Assume it is available from on-board battery monitoring systems.

For the drain rate (DR), consider only energy consumed by communication-related tasks.

Accurate?
Energy Model for DR

NIC’s energy consumption modeled by:

\[ E = m*p+n, \]

where \( p \) is packet size and \( m \) and \( n \) are constants that are operation-specific.
Implementation (cont’d…)

Extension to DSR.
Needs to refresh routes for updated energy consumption information.
Source collects all ROUTE REPLIES. ROUTE REPLY collects minimum $C_i$ over nodes on the path.
Evaluation

Simulations using ns-2.

Metrics:
  Lifetime: time until first node dies.
  Also, delay, throughput.

Dense versus sparse networks.

Mobility.

Comparison with existing power-aware mechanisms.
Results

From paper...
Power management at transport layer [Kravets98]

Goal: reduce power consumption.
Mechanism: turns off communication device during idle times.
  Transport layer protocol to control communication device on/off operation.

Challenges:
  When to suspend/restart communication.
  Tradeoff between power consumption and delay.
  Avoid wasting power at hosts trying to communicate with suspended host.
Application knows best...

Transport-layer power control interface allows application to make power management decisions based on its needs.
Proposed approach

Mobile host controls power management: decides when to suspend communication device.

- Controls delay versus power savings tradeoff.
- Power management protocol wakes up periodically by application’s request and decides whether to re-start communication.
No Power Management

(Wireless) card when not in TX mode is left in RX mode.
Proposed Technique

Suspension of network interface during idle communication periods.

Issues:

Monitor MH communication pattern.
Additional delay.
BS buffer overflow.
Power management protocol

Controls interaction between base station (BS) and mobile (MH).
MH is master and BS slave.
BS can only send data to MH if explicitly requested (WAKE_UP message).
   If data to send but in SLEEP mode, data is buffered.
MH States

Sleeping.
Can wake up by wakeup timer or data to send.
If timer, wakes up and send WAKE_UP message to BS.
If data, can send it or buffer it.
Waiting to hear from BS if it has data to send, and
Transmission/reception.
Timers

When should card be suspended?

Input from application.

Timer.

If timer expires and no communication occurred, go to sleep.

Tradeoffs in setting timer.

For how long?

Tradeoff?

Multiple applications.

Device transition states.
Implementation

Linux.

Suspend WaveLAN card: suspend system call to kernel.
Wake up the card: system call to kernel to restart driver.
Evaluation

Experimental evaluation.

Lucent WaveLAN card.
Transmit, receive, suspend modes.
No MAC-layer power-management.
2 communicating machines: MH and BS.
Multimeter samples voltage and current.
Different communication patterns: interactive (web and collaboration) and non-interactive (e-mail).
Results

Considerable power savings. Especially in power-constrained devices. Additional delay is tolerable considering non-interactive and even some interactive applications.