Mobile Wireless Networking
The University of Kansas EECS 882
Energy Management

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EM.1 Resource tradeoffs and energy
EM.2 Battery management
EM.3 Transmission power management
EM.4 System power management
Energy Management

EM.1 Resource tradeoffs and energy
EM.2 Battery management
EM.3 Transmission power management
EM.4 System power management

Resource Tradeoffs

Introduction

• The network is a complex system of resources

what are they?
Resource Tradeoffs

Introduction

- The network is a complex system of resources
  - processing
  - memory
  - bandwidth (or channel capacity)
  - latency
  - energy or power
  - cost: $€¥₣₩
• **Energy**: capacity of a system to do work
  - unit: [J] (Joule)
    - named after James Prescott Joule (1818–1889)
  - 1 J = 1 kg·m(m/s²)
    - the ability to accelerate 1 kg at 1m/s² over 1 m
  - a battery stores energy

**Energy and Power**

Definitions: Energy

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**Energy and Power**

Definitions: Power

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- **Power**: *rate* at which energy is transferred
  - unit: 1W (Watt) = 1 J/s
    - named after James Watt (1739–1819)
  - instantaneous power: \( P = \frac{dE}{dt} \)
  - a battery provides power
Energy and Power
Role in Communications and Networks

Role in communications and networks?

Energy and Power
Role in Communications

- Energy is needed to power devices
  - transceivers (radio and wired)
  - intermediate systems (routers and switches)
  - end systems
- Energy used to transfer information between devices
  - electron movement in a wire
  - photon movement in fiber
  - electromagnetic waves in free space
Energy and Power

Sources for Computer and Network Systems

Sources of energy?

• Fixed or tethered devices: power grid
  – network infrastructure: routers and switches
  – compute and file servers
  – computing devices
    • desktop computers
    • laptops and PDAs when docked
• Energy conservation is important
  – ecologically
  – economically
Energy and Power
Sources for Computer and Network Systems

• Untethered devices: batteries
  – PDAs
  – mobile telephones
  – laptop computers when not docked
  – sensors
• Energy conservation important
  – maximise lifetime between battery charge or change
  – difficult or impossible to change in some sensor devices
  – economic and ecological reasons
• Vast majority of untethered devices battery powered


Energy and Power
Sources for Computer and Network Systems

• Untethered devices: energy harvesting
  – sensors
  – PDAs
  – mobile telephones and PDAs
• Power drawn from environment
  – solar
  – wind turbines
  – biomechanical
  etc.
• Relatively immature technologies

Energy Management
EM.2 Battery Management

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Batteries
Definitions

- Battery
  - electrochemical device for storing electric potential energy
  - capacity specified as \([\text{V}[\text{A-hr}]] = [\text{W-hr}] = [\text{J}]\)

- Battery voltage parameters
  - \(V_{oc}\) fully charged open circuit voltage under no load
  - \(V_i\) operating voltage under load
  - \(V_{cut}\) cut-off threshold defining discharge state
Batteries
Technology

- Battery technology has improved over time
  - Pb acid
  - NiCd
  - NiMH
  - Li ion
  - Li polymer
- Battery life still a major system constraint
  - fundamental breakthroughs needed for orders-of-magnitude improvements

Batteries
Challenges

- Problem: maximise time to discharge $V_{cut}$
  - time to recharge or replace
- Battery energy discharge is
  - nonlinear over time
  - dependent on current drain
  - dependent on duty cycle (constant vs. pulsed)
- These effects
  - make battery power management more challenging
  - but can be exploited
Batteries
Characteristics Affecting Power Management

- Lower current drain extends battery life
  
  communication management scheme?

- lower data rate: spread communication over time
Batteries
Characteristics Affecting Power Management

• Lower current drain extends battery life
  – lower data rate: spread communication over time

• Batteries recover some charge when idle
  – rebound effect
  – allow batteries to rest
    • pulsed discharge
    • alternate between two batteries
Batteries
Power Management Strategies

- Smart battery technologies
  - control drain characteristics
- Device, component, and system engineering
  - low power circuits
  - energy-aware circuits; selective power
  - efficient algorithms (reduce processing)
- Communication and network strategies
  - MAC layer
  - link layer
  - network layer
  - transport and application layers
Batteries
Power Management Strategies

- Smart battery technologies
- Device, component, and system engineering
- Communication and network strategies
  - MAC: controlling medium access to maximise rebound
  - link layer: packet scheduling to spread over time
  - network layer: traffic shaping to reduce burstiness
  - transport layer: reduce burstiness and chattiness
  - application layer: energy aware applications
    - eliminate unneeded communication
    - data compression

Battery Management
MAC Strategies

- Battery-aware MAC
  - aware of and exploits discharge characteristics
- Transceiver-aware MAC
  - schedules medium access to correspond to node wakup
Battery Management
MAC Strategy Example: BAMAC

- **BAMAC**: battery-aware MAC protocol
  [Jayashree, Mahoj, Murthy 2003]
  - exploits recovery effect of idle batteries
- **BAMAC operation**
  - packets contain header field for remaining charge estimate
  - each node has remaining charge estimate of neighbours
  - back-off times are higher for nodes with lower charge

Battery Management
Link Strategy Example: Lazy Scheduling

- **Lazy packet scheduling**
  [Prabhakar, Biyikoglu, El Gamal 2001]
  - minimise energy while satisfying delay constraint
Battery Management

Network Strategy: Energy-Aware Routing

- Energy-aware routing protocols
  - remaining node charge is a routing metric
  - nodes with higher charge are favoured
- Example protocols
  - BEE: battery energy-efficient routing
    [Chiasserini, Nuggehalli, Srinivasan 2002]
  - many other research proposals
    - some domain specific, e.g. for sensor networks

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Transmitter Characteristics

- TPO: transmitter power output
  - power [W] of RF energy generated by transmitter
- ERP: effective radiated power
  - effective power after gains and losses are included
  - e.g. antenna gain

Transmitter Power Characteristics

- Higher transmission power
  - effects?
Transmission Power

Characteristics

- Higher transmission power
  - longer range
  - faster battery discharge
  - less stealth

Transmission Power

Effect of Increasing Power

- Transmission Power

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Transmission Power
Effect of Increasing Power

- Transmission power
  - low:
    - no connectivity
Transmission Power
Effect of Increasing Power

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Transmission Power
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- Transmission power
  - low:
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    - partitioned islands
  - sufficient
    - connected
Transmission Power
Effect of Increasing Power

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  - sufficient
    - connected
    - biconnected
Transmission Power
Effect of Increasing Power

- Transmission power
  - low:
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  - sufficient
    - connected
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  - excessive
    - wasted energy
    - lack of stealth
Transmission Power

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Transmission Power
Effect of Increasing Power

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    - lack of stealth
    - highly connected: self jamming "parking lot problem"
**Transmission Power**

Adaptive Power Control

- Adaptive transmission power
  - each node adjusts
  - control number of neighbors: degree of connectivity
- Biconnected graph
  - single link cut avoids partition
- May be more stealthy
  - in cases of lower transmission power

**How to adapt?**

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**Adaptive Transmission Power**

Link Affinity

- Link affinity
  - nodes measure signal strength of neighbors
- Nodes dynamically adjust transmission power
  - minimum power to reach neighbours
  - control degree of connectivity
  - time-varying strength can compensate for mobility
- Can be adapted to 802.11
  - distributed power control loop: add header field
  - CTS returns strength of RTS
  - data packet returns strength of CTS
Adaptive Transmission Power

Distributed Topology Control

- Distributed topology control
  - remove links that have lower-power two-hop alternates
- Distributed topology control for directional antennae
  - choose lowest power neighbors in each sector

Energy Management

EM.4 System Power Management

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System Power Management
Overview

Energy Management
Further Reading

Energy Management

Acknowledgements

Some material in these foils is based on the textbook

- Murthy and Manoj,
  Ad Hoc Wireless Networks:
  Architectures and Protocols