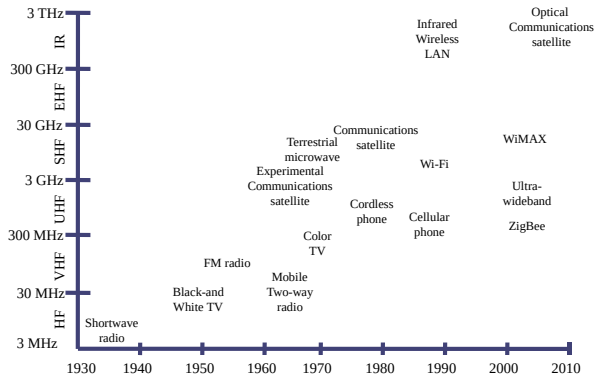
15-744: Computer Networking

L-22 Energy Efficient Wireless

Overview

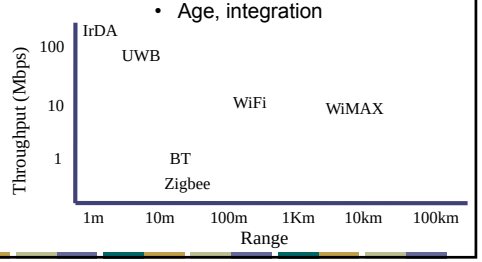
- Cellular Overview
  - History
  - Technology
- Bartendr: energy-aware scheduling
- Energy efficiency in sensor nets
- Catnap

Wireless Technologies



Why so Many?

- Diverse application requirements
  - Energy consumption
  - Range
  - Bandwidth
  - Mobility
  - Cost
- Diverse deployments
  - » Licensed versus unlicensed
  - » Provisioned or not
- Technologies have different
  - Signal penetration
  - Frequency use
  - Cost
  - Market size
  - Age, integration



Some History…

- Wireless telegraph invented by Guglielmo Marconi in 1896
- Tesla credited with first radio communication in 1893
- First telegraphic signal traveled across the Atlantic ocean in 1901
- Used analog signals to transmit alphanumeric characters

Mobile phones

- 2-way 2-party communication using digital transmission technology
- In 2002 the number of mobile phones exceeded that of land lines
- More than 1 billion mobile phones!
- The only telecommunications solution in developing regions

- How did it all start?

The Cellular Idea

- In December 1947 Donald H. Ring outlined the idea in a Bell labs memo
- Split an area into cells with their own low power towers
- Each cell would use its own frequency

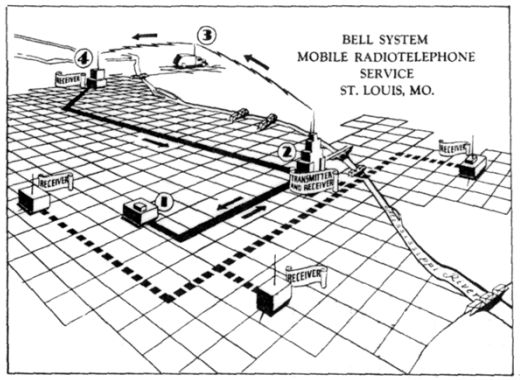
- Did not take off due to “extreme-at-the-time” processing needs
  - Handoff for thousands of users
  - Rapid switching infeasible – maintain call while changing frequency

The origin of mobile phone

- America’s mobile phone age started in 1946 with MTS – weighing 40 Kg!
- First mobile phones very bulky, expensive and hardly portable
- Operator assisted with 250 maximum users

The MTS Network

http://www.privateline.com/PCS/images/SaintLouis2.gif



… the Remaining Component

- In December 1947 the transistor was invented by William Shockley, John Bardeen, and Walter Brattain
- Why no portable phones at that time?
- A mobile phone needs to send a signal – not just receive and amplify
- The energy required for a mobile phone transmission still too high for the high power/high tower approach – required a car battery

… and the Regulatory Bodies

The FCC commissioner Robert E. Lee said that mobile phones were a status symbol and worried that every family might someday believe that its car had to have one.

Lee called this a case of people “frivolously using spectrum” simply because they could afford to.

From The Cell-Phone Revolution, AmericanHeritage.com

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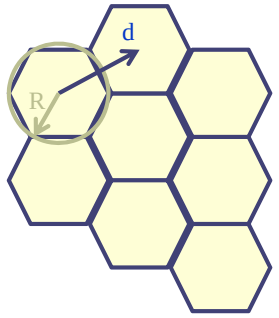
The Advent of Cellular Networks

- Mobile radio telephone system was based on:
  - High power transmitter/receivers
  - Could support about 25 channels
  - in a radius of 80 Km
- To increase network capacity:
  - Multiple low-power transmitters (100W or less)
  - Small transmission radius -> area split in cells
  - Each cell with its own frequencies and base station
  - Adjacent cells use different frequencies
  - The same frequency can be reused at sufficient distance

The Hexagonal Pattern

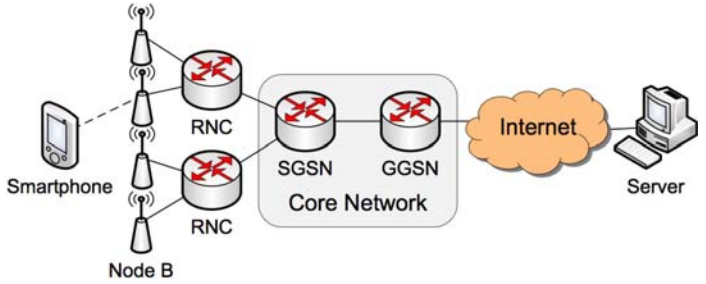
- A hexagon pattern can provide equidistant access to neighboring cell towers
- d = √3R
- In practice, variations from ideal due to topological reasons



Frequency reuse

- Each cell features one base transceiver
- Through power control cover the cell area while limiting the power leaking to other co-frequency cells
- Frequency reuse not possible for adjacent towers!
- The number of frequency bands assigned to a cell dependent on its traffic

3G Network Topology



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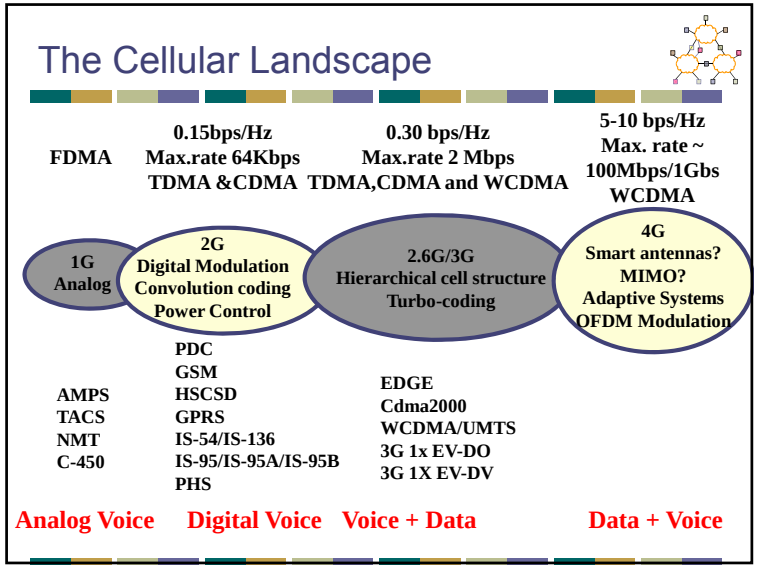
The Cellular Landscape



Cellular versus WiFi

Implications for Cellular

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Key Observations and Ideas

- Signal strength for cellular varies widely depending on location
- Energy consumption is strongly correlated with signal strength
  - High pathloss -> radio uses higher power
  - Weak signal -> lower transmit rate -> longer transmission times for given number of bits
- Idea driving Bartendr
  - Try to communicate when signal is strong
  - Defer appropriate transmissions if needed

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Summary of Contributions

- Observed relationship between signal strength
  - Power consumption
  - Throughput
- Prediction of signal strength based on history
- Scheduling to minimize energy use
- Evaluation based on both measurements and simulation

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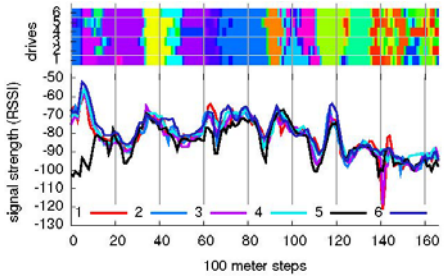
Signal Strength Depends on Location



- RSSI depends on distance from tower, objects blocking LoS
- Results are fairly consistent across multiple trips

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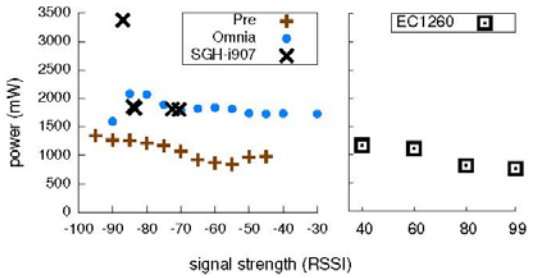
Signal Strength vs Power



- Power drops as RSSI increases
- Technology dependent

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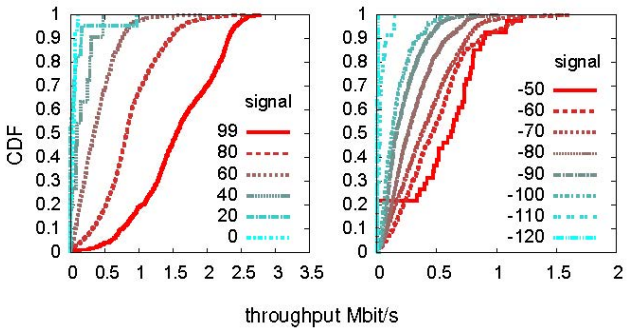
Throughput Depends on Signal Strength



- Results of differences in bit error rate and transmission rates

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Choice of Applications

- Idea is to delay transmission until signal strength is good.
- Interactive applications are generally not suitable:
  - VoIP, web browsing, …
- Some applications are “delay tolerant”
  - E.g. “sync” style apps: e-mail, facebook, …
- Some applications have predictable future data needs
  - E.g. video streaming

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Signal Prediction

- Goal is to infer location in a track so future signal strengths can be derived
  - Phone stores tracks of common trips
  - Must also figure out direction
- Use current signal strength to find location
- Can also use list of basestations to differentiate between multiple locations
  - Learn from handoffs
- Decided not to use GPS (power hungry)

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Scheduling Bartendr

- Sync sleeps until predicted signal strength reaches a certain threshold
  - First: wait until exceeds for the first time
  - Widest: wait until it exceeds for longest time
- Streaming breaks stream into N frames that are scheduled in M time slots
  - Goal is to minimize total energy
  - Translates into a dynamic programming problem

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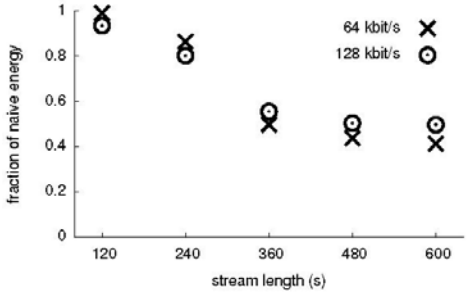
Simulation Results Sync



- Results in significant savings over naïve algorithm
  - Fetch all the data right away

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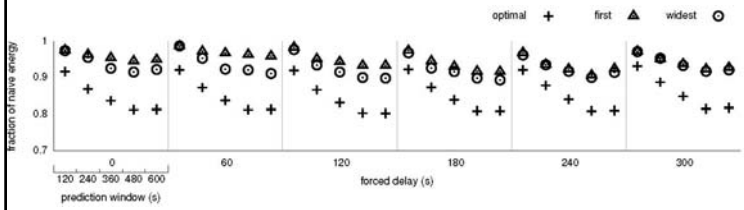
Simulation Results Streaming



- Again nice improvements over time
  - But note the y-axis scale
- Gets less than 50% of “optimal” improvement

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Discussion

- Shows relationship between power consumption and received signal strength
- Reduces energy consumption by scheduling transmissions for certain apps
- Does not require infrastructure support

- Somewhat artificial problem
- Fairly strong assumptions on driver behavior

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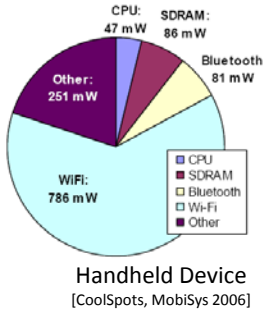
Understanding Energy Consumption



Handheld Device
[CoolSpots, MobiSys 2006]

For laptops, Wifi consumes around 10% of the total power

Need to consider device characteristics

Energy Saving Options

- Wifi Power Save Mode (802.11 PSM)
  - Turns off the wireless card
  - Takes around 50ms
- Deeper Sleep Modes
  - E.g., Suspend to RAM (S3), Hibernation
  - Whole system goes into sleep mode
  - Takes around 10-15 sec

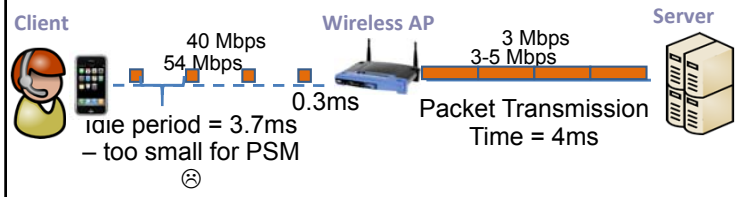
Range of options but need to consider cost of using a particular sleep mode

Can we use these sleep modes?

- 802.11 PSM
  - Yes, but only when no application is using the wireless interface
    - Can hurt application performance, e.g. VoIP
  - "Enter sleep mode if no network activity for X amount of time"
- S3 Mode
  - Cannot use it while applications are running

Sleep modes not useful **during** data transfers

BW Discrepancy in typical end-to-end transfers



Catnap leverages this opportunity to provide up to 2-5x energy savings during data transfers

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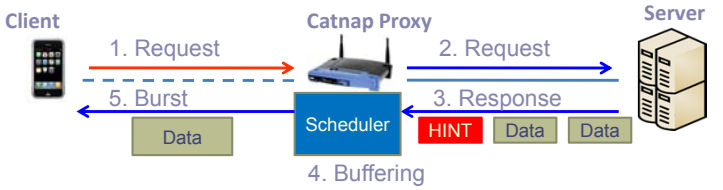
Catnap: Key Idea

- Many apps consume data in blocks
  - Web object, file, etc.
  - Initial packets can be delayed as long as the finish time of the block is the same

Idle time is large enough to make both PSM and S3 modes effective

Catnap Design Overview



1. Decoupling of Wired and Wireless Segments

2. ADU Hint -- Length of ADU

3. Scheduler – Decides when to send data to client

All changes are on the proxy

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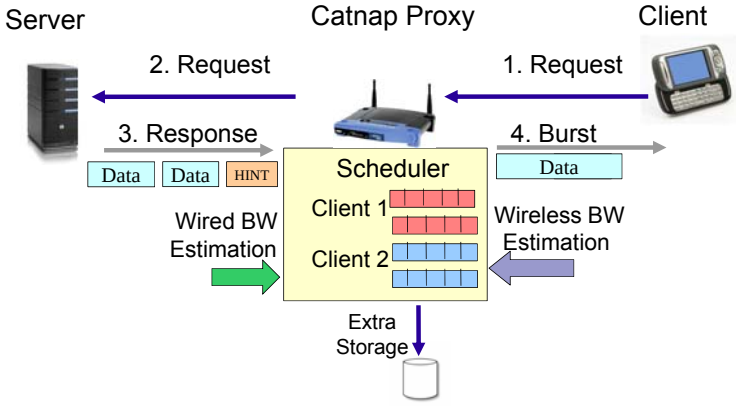
Scheduler



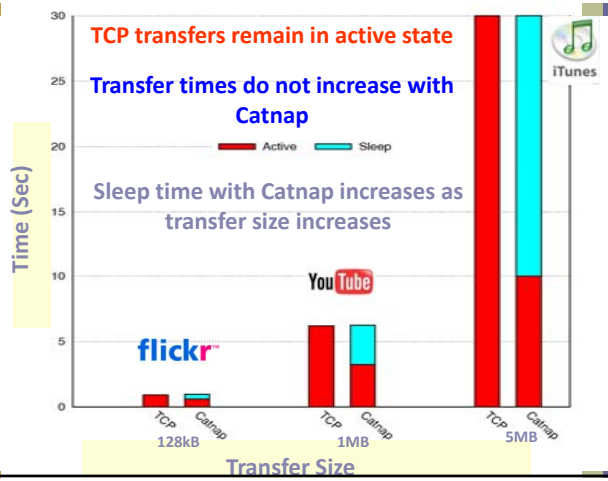
Key Points: Decoupling, Hint from Server, Scheduling

Scheduling

- Decides when to schedule transmission
- How much can you sleep?
  - (Finish Time – Burst Time – Cost)
- Calculating Finish Time
  - Depends on the wired available bandwidth
  - Important to calculate it properly
- Burst Time
  - Depends on wireless available bandwidth
  - Precision less important than wired bandwidth

Adaptation is important!

How much can the NIC sleep?



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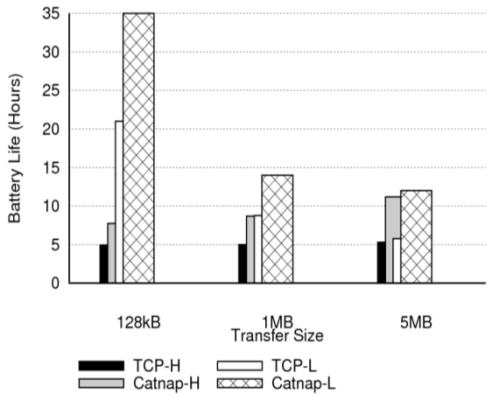
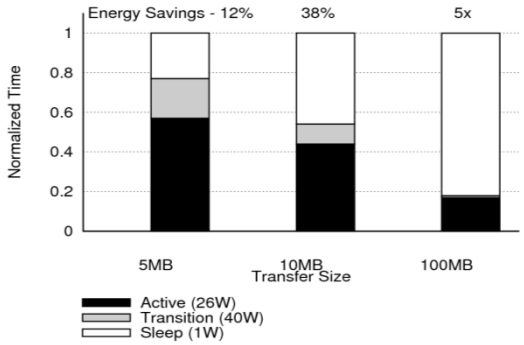
Battery Life Improvement



S3 Mode



Discussion

- Catnap with unmodified Clients and Servers
  - Web and Email applications
- Objects smaller than 128kB
  - Batch mode: multiple small transfers scheduled together
  - Slight increase in transfer times
- Faster transmissions on wireless
  - “UDP-Blast” can provide 20% more sleep time compared to TCP

Announcements

- Final is two weeks from today (Dec 3)
  - In class
  - Similar to midterm but emphasis on material from second half of the semester
- Project presentations are on Dec 5
  - 15 minute talks + some time for questions
  - Will announce room and time
- Project reports due on Dec 13 at noon

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