Bartendr: A Practical Approach to Energy-aware Cellular Data Scheduling

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A moving phone experiences signal strength variations
Signal strength affects radio power and throughput.
Signal strength affects radio power and throughput.

The graph on the left shows the distribution of power (mW) across different signal strengths (RSSI) ranging from -100 to -30 dBm. The graph on the right illustrates the cumulative distribution function (CDF) of throughput (Mbit/s) for various signal strengths, with labels indicating signal strength in dBm.
Signal strength affects radio power and throughput.
Signal strength affects radio power and throughput.
Energy efficiency can be improved

A moving phone experiences signal strength variations. Signal strength affects communication energy.

Applications can hold off until signal increases and prefetch while signal is strong.
Energy efficiency can be improved

A moving phone experiences signal strength variations. Signal strength affects communication energy.

Applications can hold off until signal increases and prefetch while signal is strong.
Applications can receive when signal is strong

Background **sync** - 5 min interval sync could be more efficient if done sometime between 4 to 6 min

**Streaming** media - Consume buffer when the signal is weak, prefetch when the signal is strong
Application energy measurements

Drove with a mobile power monitor connected to a Palm Pre
Email sync energy consumption

![Graph showing energy consumption vs. signal strength (RSSI)]
Email sync energy consumption

![Diagram showing energy consumption vs. signal strength (RSSI).]
YouTube energy consumption

![Graph showing energy consumption vs signal strength (RSSI)]
Applications must schedule communication

Sync
Schedule wakeup

Streaming
Fill the buffer efficiently

Problem
When to schedule communication to save energy?

Predict signal strength

Schedule syncs
Schedule streaming
Applications must schedule communication

Sync
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Streaming
Fill the buffer efficiently

Problem
When to schedule communication to save energy?
- Predict signal strength
- Schedule syncs
- Schedule streaming

Challenge
Scheduling must save more energy than it consumes.
### Obstacles to energy efficient scheduling

<table>
<thead>
<tr>
<th>energy consumer</th>
<th>consumption</th>
<th>Bartendr</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Signal prediction</strong></td>
<td>GPS is 400 mW and slow to fix, WiFi must be in receive mode</td>
<td>phone already maintains signal strength, cell id, and neighbor cells</td>
</tr>
<tr>
<td>locating the phone on a path</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1D not 2 or 3D)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Sync scheduler</strong></td>
<td>1 J to wake up 0.5 J to sleep</td>
<td>schedule syncs minutes into the future</td>
</tr>
<tr>
<td>wakeup and sleep</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Streaming scheduler</strong></td>
<td>3 - 10 s of radio power after communication (at least 400 mW)</td>
<td>consider the radio’s power state when scheduling a stream</td>
</tr>
<tr>
<td>radio energy tail</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Signal strength variation on a path
Signal strength variation on a path

![Signal strength variation on a path](image)
Predicting signal strength with previous drives

1. Find location in a previous drive
   Signal strength, cell id, neighbor list

2. Look ahead for future signal strength
   12 seconds in the future
Predicting signal strength with previous drives

1. Find location in a previous drive
   Signal strength, cell id, neighbor list

2. Look ahead for future signal strength

![Graph showing signal strength over time with predicted and actual lines.](image-url)
Scheduling when to sync

Wake-up, sync, schedule, sleep

Uses threshold for efficient sync

Schedules for either *first* or *widest* signal

![Graph showing energy consumption vs. signal strength (RSSI)]
Scheduling when to sync

Wake-up, sync, schedule, sleep

Uses threshold for efficient sync

Schedules for either **first** or **widest** signal

![Graph showing signal strength over time](image)
Scheduling when to receive a stream

Challenge
1. Tradeoff between strong signal and radio tail energy
2. Signal prediction error due to speed variations
3. Throughput prediction error due to congestion

Approach
1. Minimize predicted energy - dynamic programming algorithm
2. Update schedule with latest signal prediction
3. Schedule based on remaining buffer
Evaluation methodology

Simulated energy consumption of naive and scheduled syncs and streaming

Several 17 km drives of throughput and signal for prediction and simulation of energy consumption

Started at many points in the drive
Syncing simulation

fraction of naive energy

forced delay (s)

prediction window (s)

ideal +

first △

widest ○
Syncing simulation

![Graph showing fraction of naive energy vs prediction window and forced delay](image)
Syncing simulation

- **Fraction of Naive Energy**
- **Forced Delay (s)**
- **Prediction Window (s)**
- **Ideal**
- **First**
- **Widest**

![Graph showing the relationship between fraction of naive energy and prediction window for different forced delays.](image)
Streaming simulation

fraction of naive energy

stream length (s)

64 kbit/s

128 kbit/s
Related work

Breadcrumbs (A. J. Nicholson et al.)
Predicts WiFi network quality for a mobile device

Experiences in a 3G Network (Liu et al.) and
An empirical study on 3G network capacity and performance (Tan et al.)
Long term throughput at a location varies

TailEnder (N. Balasubramanian et al.) and
Cool-Tether (A. Sharma et al.)
Batching and prefetching reduce radio energy tail
Signal strength affects energy consumption

Applications like sync and streaming can improve energy efficiency by deferring and prefetching

Previous drives can predict signal strength without breaking the energy bank

Scheduling can reduce energy consumption by up to 50% for large workloads and 10% for small