Context-for-Wireless: Context-Sensitive Energy-Efficient Wireless Data Transfer

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Motivation

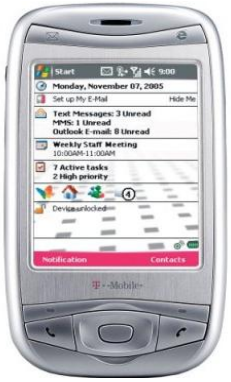
- Ubiquitous wireless connectivity enables new apps
  - Example: Our OrbitECG health monitoring system
- Wireless data transfer is power hungry
- Objective: Reduce wireless energy consumption
  - Use context information to take advantage of multiple wireless interfaces on modern devices
- 35% battery life increase in field trial
  - Phone running ECG reporting application

Outline

- **Reality check**
  - Network availability in daily life
  - Wireless energy cost
  - Cellular & Wi-Fi are complementary
- Energy-efficient data transfer
  - Problem: Selecting between network interfaces
  - Solution: *Context-for-Wireless*
  - Field validation
- Conclusion

Reality Check

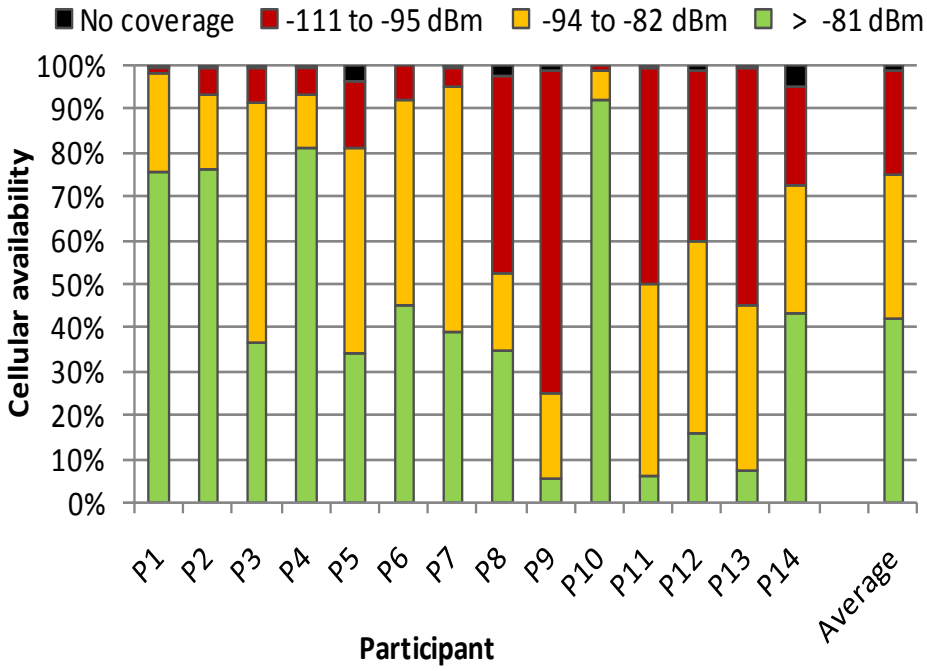
- Commercial Windows Mobile Phones
  - GSM, EDGE, Wi-Fi, Bluetooth
- Custom software
  - RateLogger: Cellular / Wi-Fi data rates
  - TowerLogger: Cellular / Wi-Fi signal levels
    - Acceleration logging using Orbit Sensor
- Power measurements
  - Model for wireless transfer energy cost
  - Measured with battery inside phone



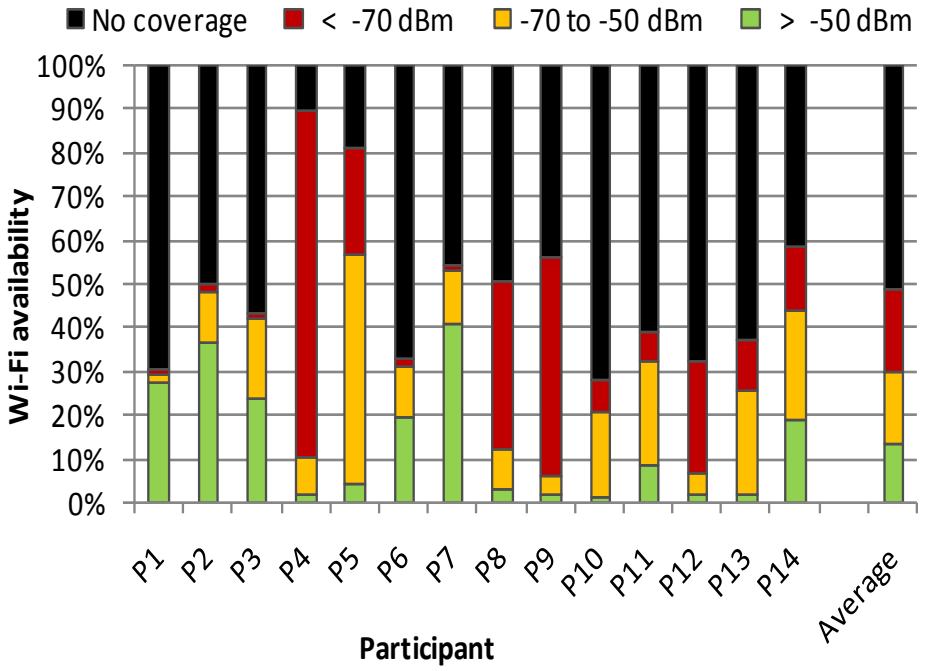
Network Conditions in Daily Life

- 14 participants from Rice, 3-4 weeks

Cellular availability: 99%



Wi-Fi availability: 49%



Complementary Energy Profiles

	Cellular	Wi-Fi
Checking for availability / Establishing a connection	None*	High 5 J
Maintaining a connection	None* 1–6 J/min	High 20–60 J/min
Energy per MB transfer	High upload: 95–125 J download: 40–50 J	Low upload: 7–11 J download: 5–7 J
Coverage	High 99%	Medium 49%

- We should combine their strengths

* We assume phones are always connected to the cellular network

Outline

- Reality check
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  - Cellular & Wi-Fi are complementary
- **Energy-efficient data transfer**
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Energy-Efficient Data Transfer

- Combining the strengths of Cellular and Wi-Fi
  - Cellular always on
  - Wi-Fi powered off when not in use

- For each data transfer, should the device attempt Wi-Fi to save energy?

Attempt Wi-Fi?		Energy Cost of Data Transfer
No attempt		Cellular transfer
Attempt	Unsuccessful	Wi-Fi establishment + Cellular transfer
	Successful	Wi-Fi establishment + Wi-Fi transfer

Energy Cost of Data Transfer

- Wi-Fi establishment: ~ 5 J
- Cellular / Wi-Fi transfer: depends on size, network conditions
  - Signal Strength used in our energy model
  - Cellular signal strength / availability: FREE!
  - Wi-Fi signal strength / availability: COSTLY!

Attempt Wi-Fi?		Energy Cost of a Data Transfer
No attempt		Cellular transfer
Attempt	Unsuccessful	Wi-Fi establishment + Cellular transfer
	Successful	Wi-Fi establishment + Wi-Fi transfer

Should the Device Attempt Wi-Fi?

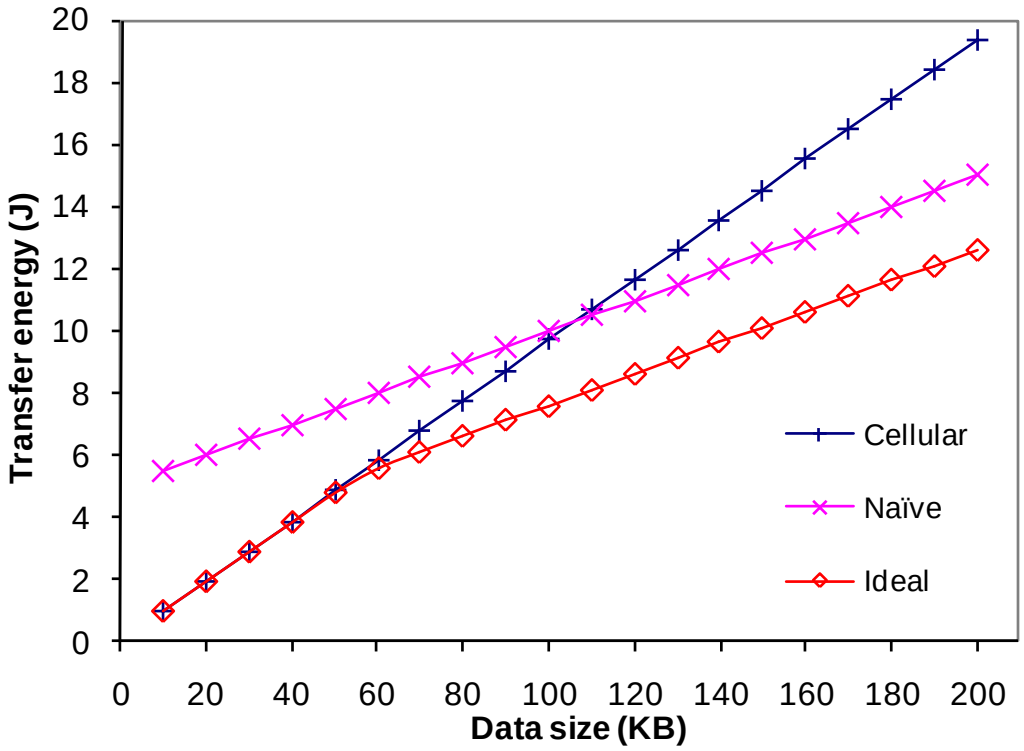
- Naïve
  - Always attempt Wi-Fi
  - If unsuccessful, use Cellular
- Ideal
  - Wi-Fi conditions known
  - Choose most energy efficient interface

Should the Device Attempt Wi-Fi?

- Context-for-Wireless
  1. Use context information to estimate Wi-Fi conditions without powering up the interface
  2. Calculate and compare *expected* energy costs for each interface

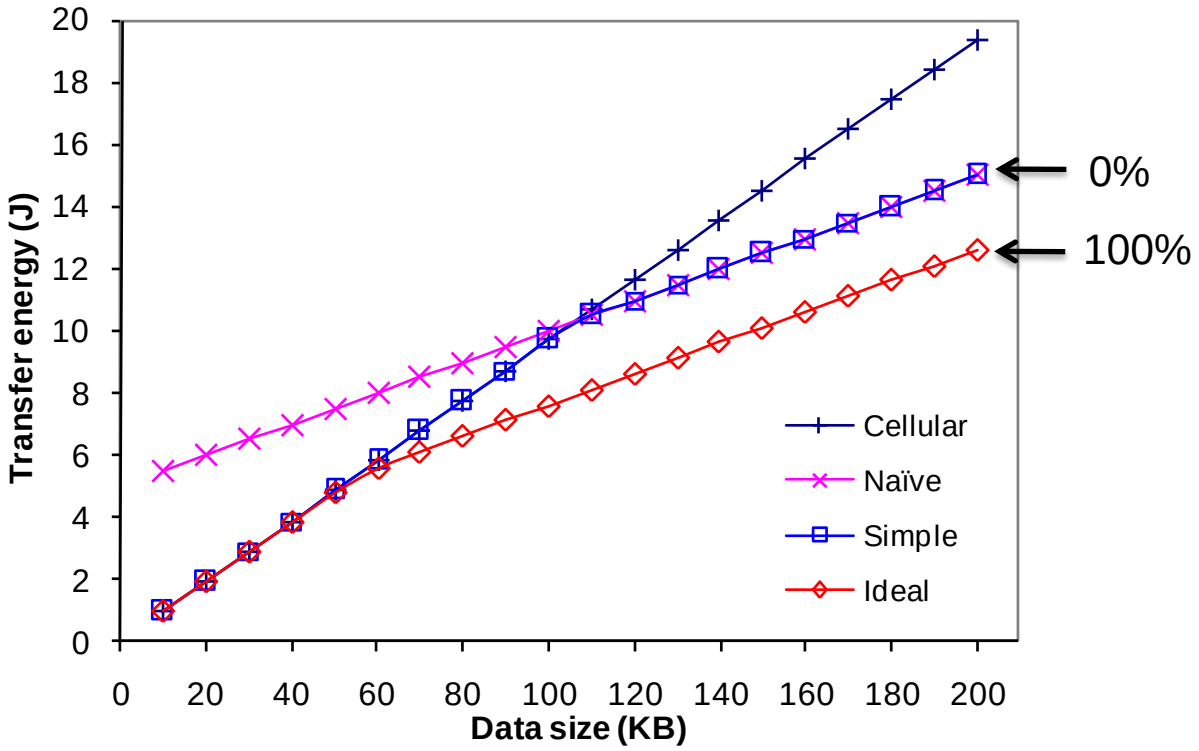
Potential Energy Saving

- Average energy cost for a transfer
  - Using network condition traces from TowerLogger
  - Using energy model from measurements



Simple Estimation Algorithm

- Use each person's average Wi-Fi condition
  - Large energy saving over cellular-only
  - We use as baseline (0%), compared to Ideal (100%)



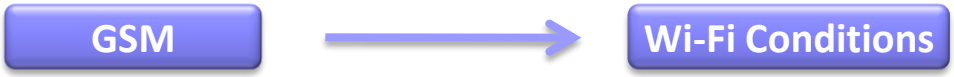
Hysteretic Estimation Algorithm

- Network conditions are related in time
  - Re-use last measured Wi-Fi conditions up to a specific time
  - Attempt Wi-Fi for transfer after that time
  - Simple, no extra hardware

History + Cell ID Estimation Algorithm

- History: People spend days in a predictable fashion
  - Network conditions related at same time in different days
  - Use Wi-Fi conditions in 1-hour partitions to train
- Cell ID: Network conditions related to location

  - GPS is power hungry, outdoors only
  - GSM localization requires training to ground truth
  - We directly train based on GSM Cell IDs and Wi-Fi conditions



- History + Cell ID Estimation uses both
  - More weight for estimation with higher certainty
  - Slightly favor Cell ID

Acceleration Estimation Algorithm

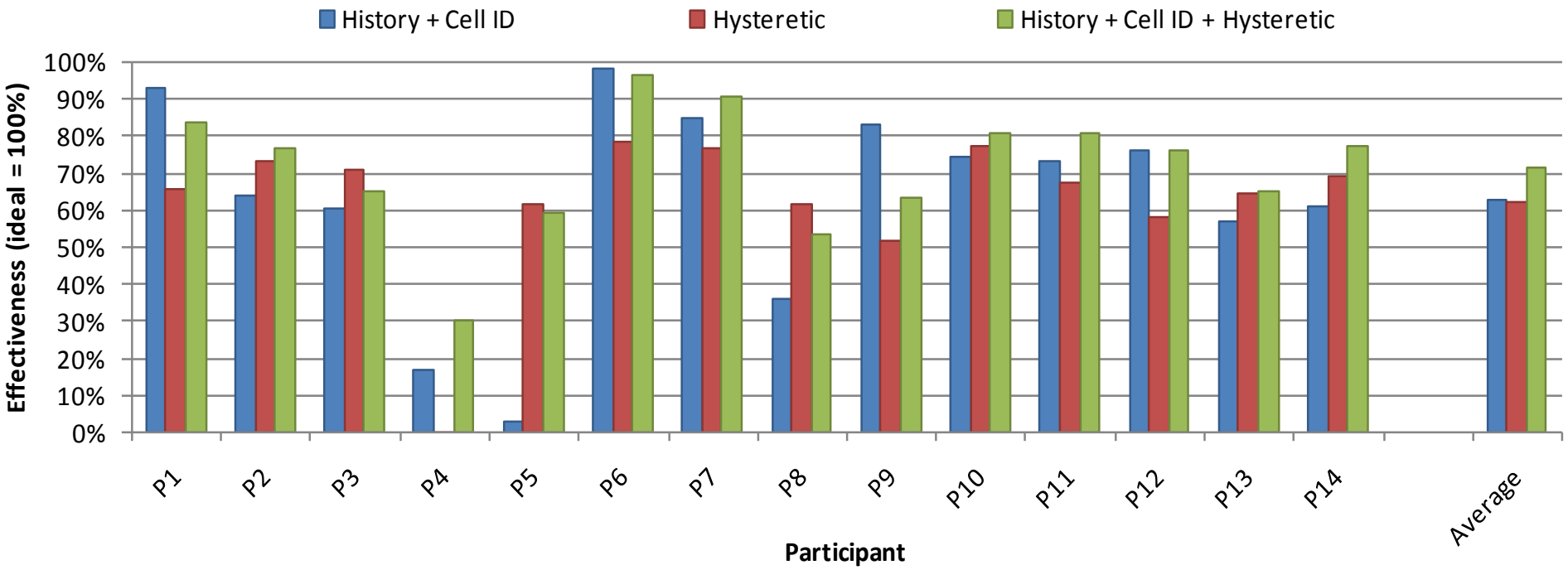
- Network conditions relatively constant at a fixed location
  - Use motion sensing to detect change in location
    - 3-axis accelerometer on Orbit Sensor, 32 Hz, 8 bit, Bluetooth
    - Some new devices have built-in accelerometer (for UI)
  - Re-use last measured Wi-Fi conditions if movement below threshold.

Combination Algorithms

- Determine validity of previous measurement
  - Hysteretic
  - Acceleration
- Determine conditions
  - History + Cell ID
- Re-use last measured network conditions if valid
- Use History + Cell ID if change anticipated

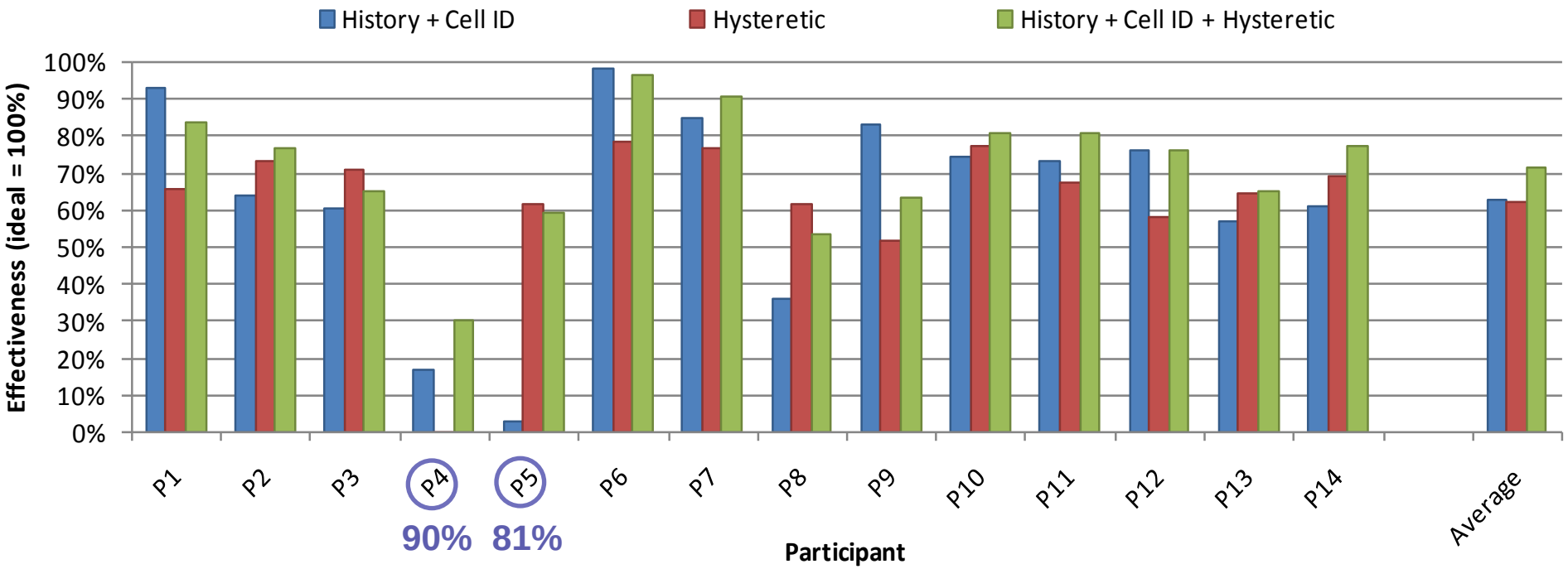
Performance Evaluation

- Real-life network traces from Tower Logger
- Simulated ECG reporting application
  - 5 min. transfer interval
  - 270 kB data size



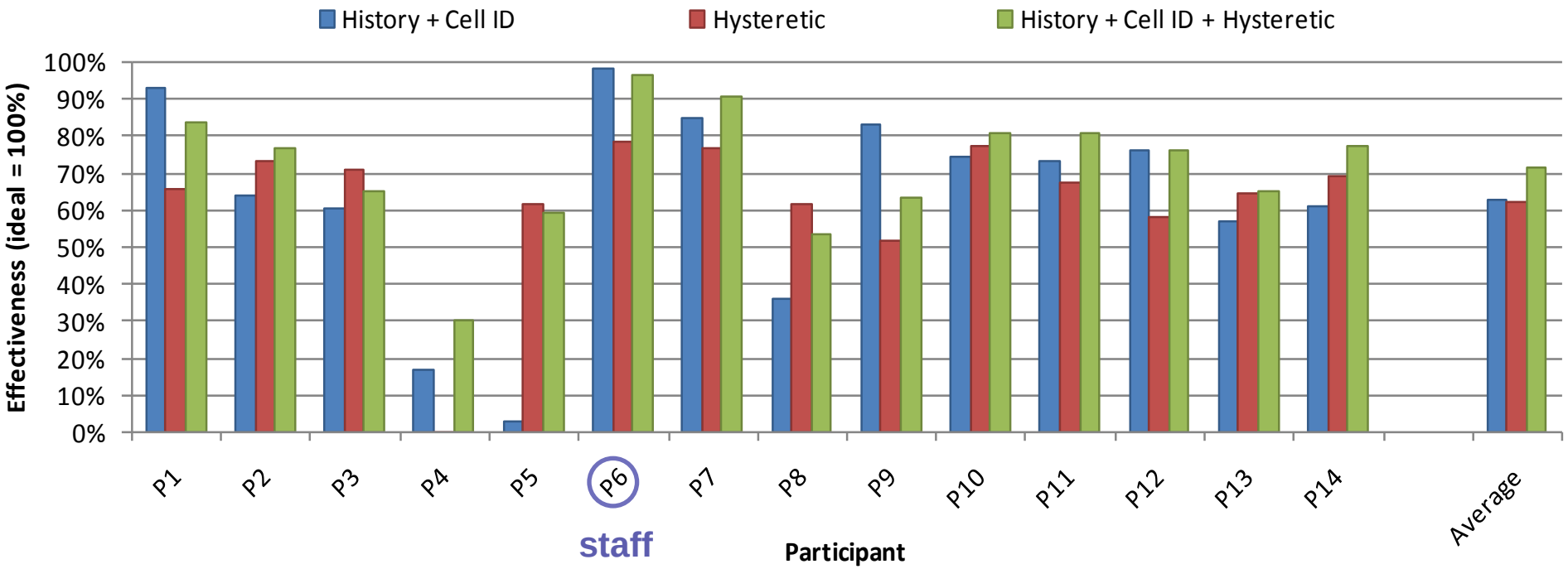
Findings

- Our estimation algorithms had a hard time when Wi-Fi availability -> 100%



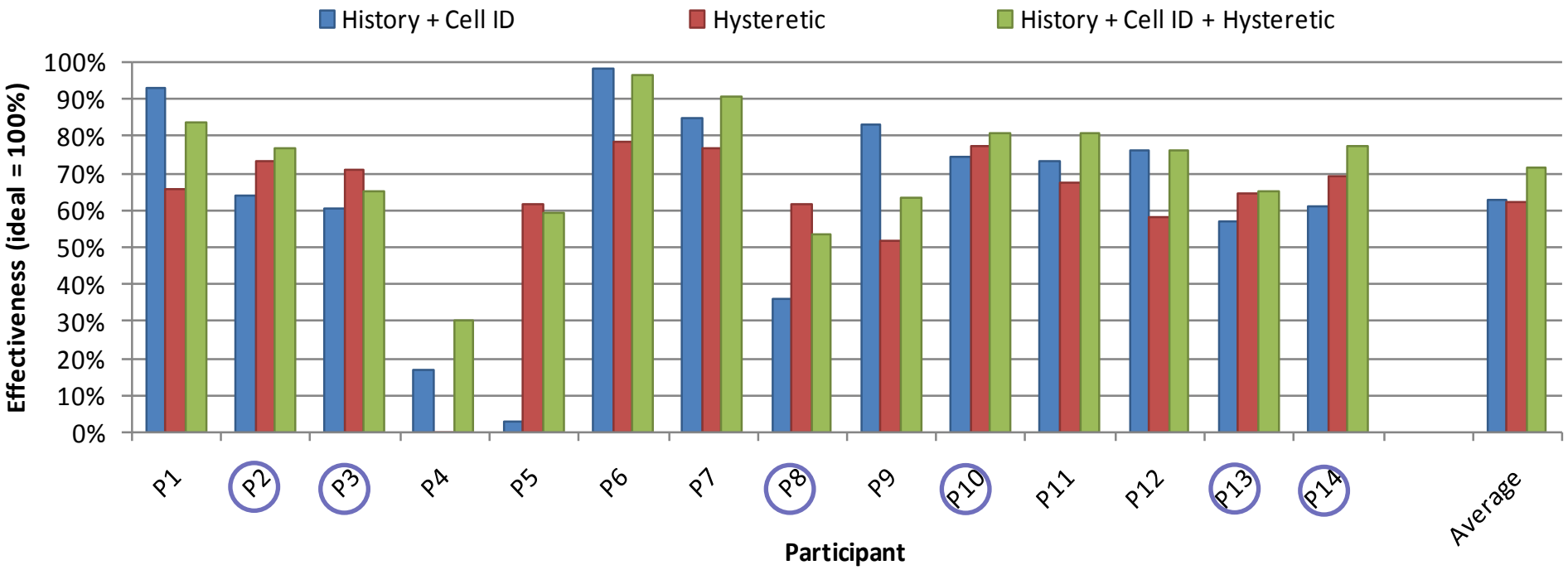
Findings

- History + Cell ID Estimation is more effective for users with regular schedules
  - One staff member – regular hours and location
  - Others were students and faculty – flexible hours



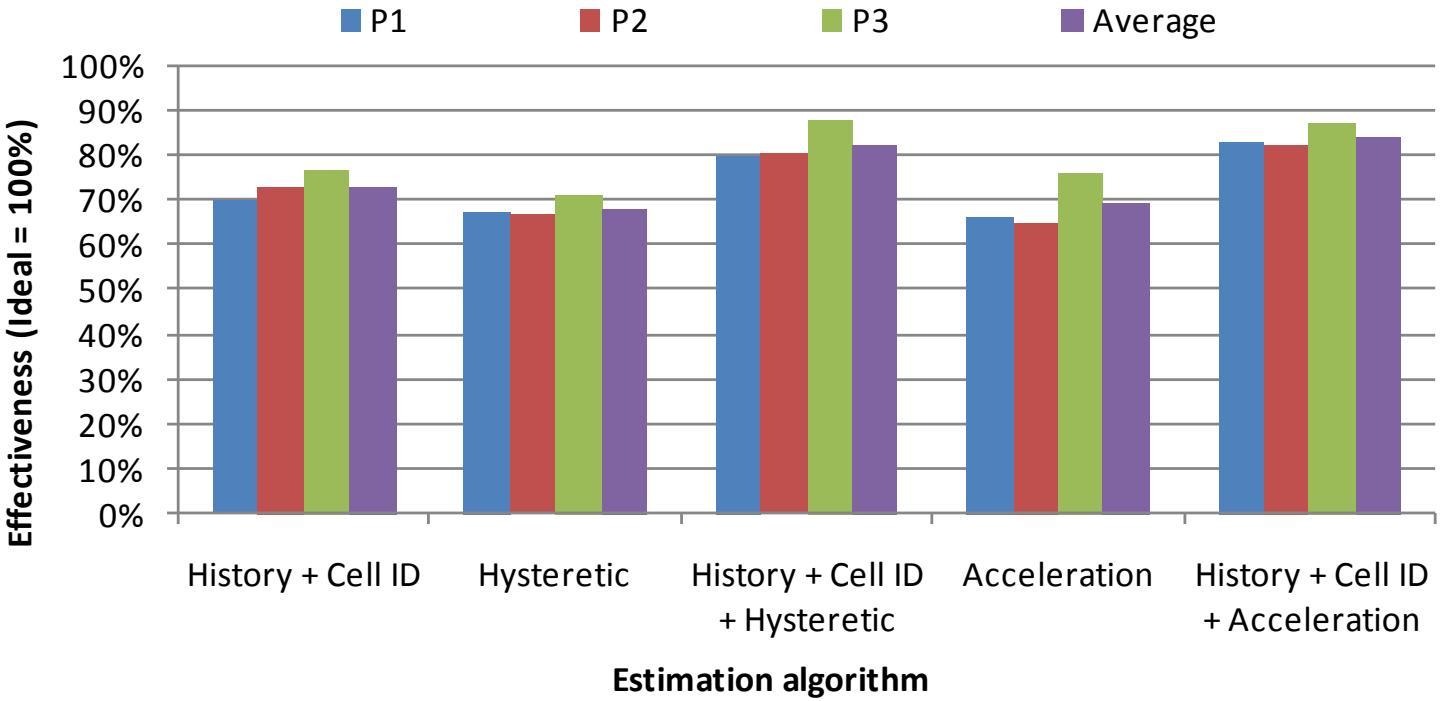
Findings

- History + Cell ID Estimation is more effective for users with long commutes
  - Participants lived close to campus whenever Hysteretic Estimation was more effective



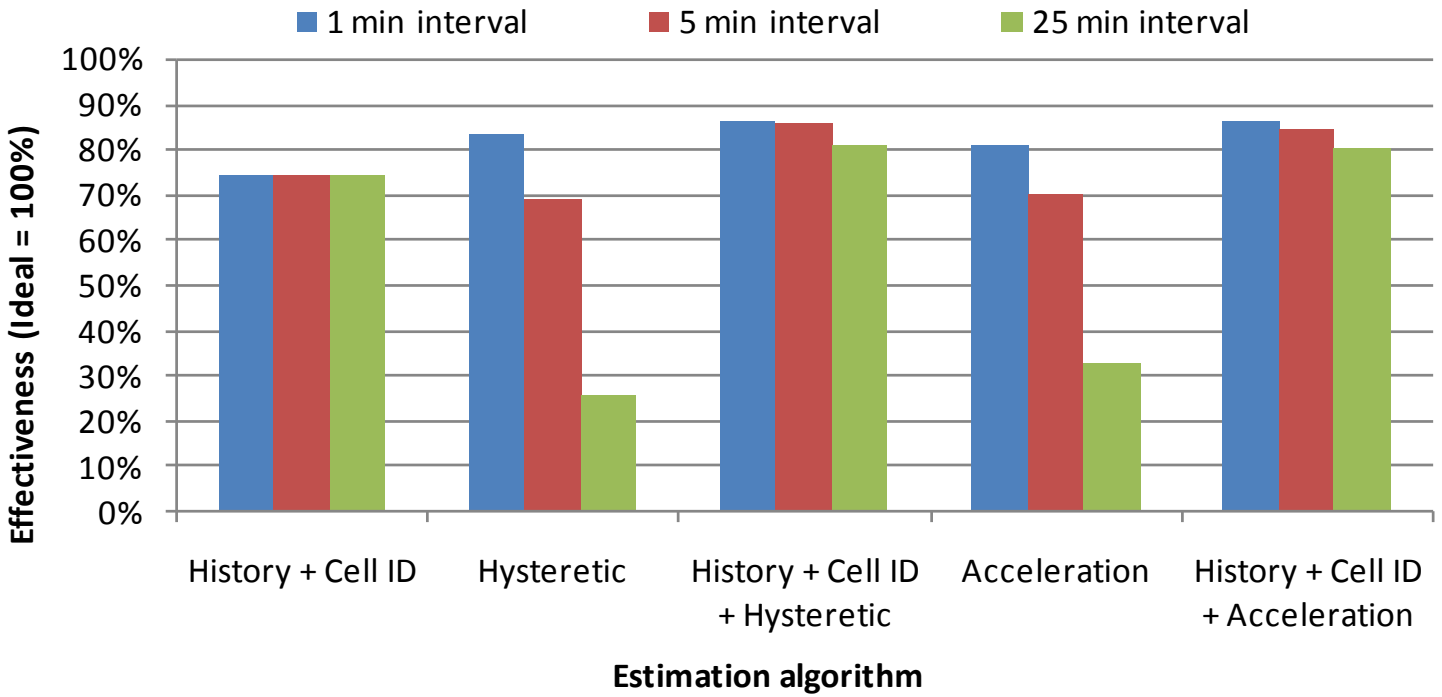
Findings

- P1, P2, P3 had acceleration logging
  - We used a very simple motion sensing algorithm
  - We expect Acceleration Estimation to perform better
    - Using more sophisticated motion sensing algorithms
    - For close locations with different Wi-Fi conditions



Findings

- Both Hysteretic and Acceleration Estimation are more effective for shorter transfer intervals
  - User less likely to have moved
  - Measured conditions more likely to remain valid



Field Validation

- Implement same ECG reporting application
  - Upload 270 kB every 5 min., retry failed transfers
  - 1. Cellular only mode
  - 2. Context-for-Wireless mode
    - Hysteretic Estimation
  - Measure battery life with normal phone usage
    - Two participants, six experiments each
- System Battery life: 15.4 h -> 20.8 h (+35%)

Conclusion

- Cellular and Wi-Fi have complementary strengths
- Optimally selecting between wireless interfaces can considerably increase system battery life
  - Requires knowing network conditions
- Context information (*Context-for-Wireless*) can be effectively used for selecting between interfaces
  - Previous conditions
  - History
  - Visible Cell IDs
  - Acceleration (motion sensing)
- We used GSM EDGE and 802.11 Wi-Fi
  - Same for future technologies with long & short range interfaces

Related Work

- Employing multiple wireless interfaces
  - Wake-on-Wireless
    - Low power radio signals Wi-Fi wakeup
  - Coolspots
    - Bluetooth to improve Wi-Fi energy efficiency
  - Armstrong *et al.*
    - Selected wireless interface based on data size
- We use context information to estimate Wi-Fi conditions (Context-for-Wireless)
  - Judiciously select between wireless interfaces
    - Improve energy efficiency using Wi-Fi
    - Maintain ubiquitous coverage through cellular

Questions and Comments

- Traces and source code will be available online
  - http://www.recg.org
- Traces will also be available on 

  - http://crawdad.cs.dartmouth.edu