Remora: Sensing Resource Sharing Among Smartphone-based Body Sensor Networks

CSCI 780 Wireless Sensor Networks

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Based on slides from Matthew Keally

Shared Activities

Athletic Teams

University Students

Assisted Living

Activity Recognition with Body Sensor Networks

- Athletic Performance
- Health Care

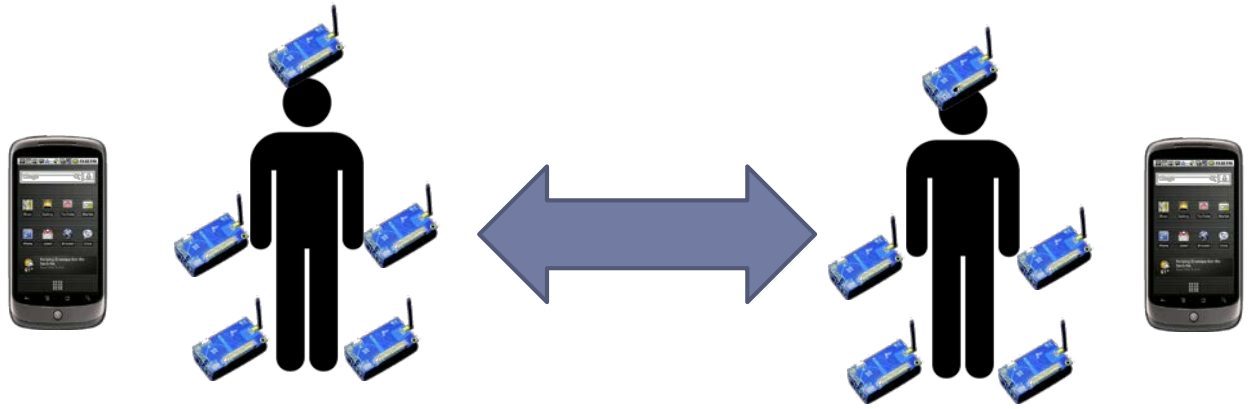
Why BSNs?

On-Body Sensors
+Sensing Accuracy
Flexibility

Phone
+User Interface
+Computational Power
+Additional Sensors

BSN Resource Sharing

- BSN users may be in physical proximity to one another
  - Assisted living or retirement communities
  - Athletic teams



- Share **sensors**: use fewer sensors and achieve higher accuracy
- Share **phone** classifiers: duty cycle to save phone energy

Remora

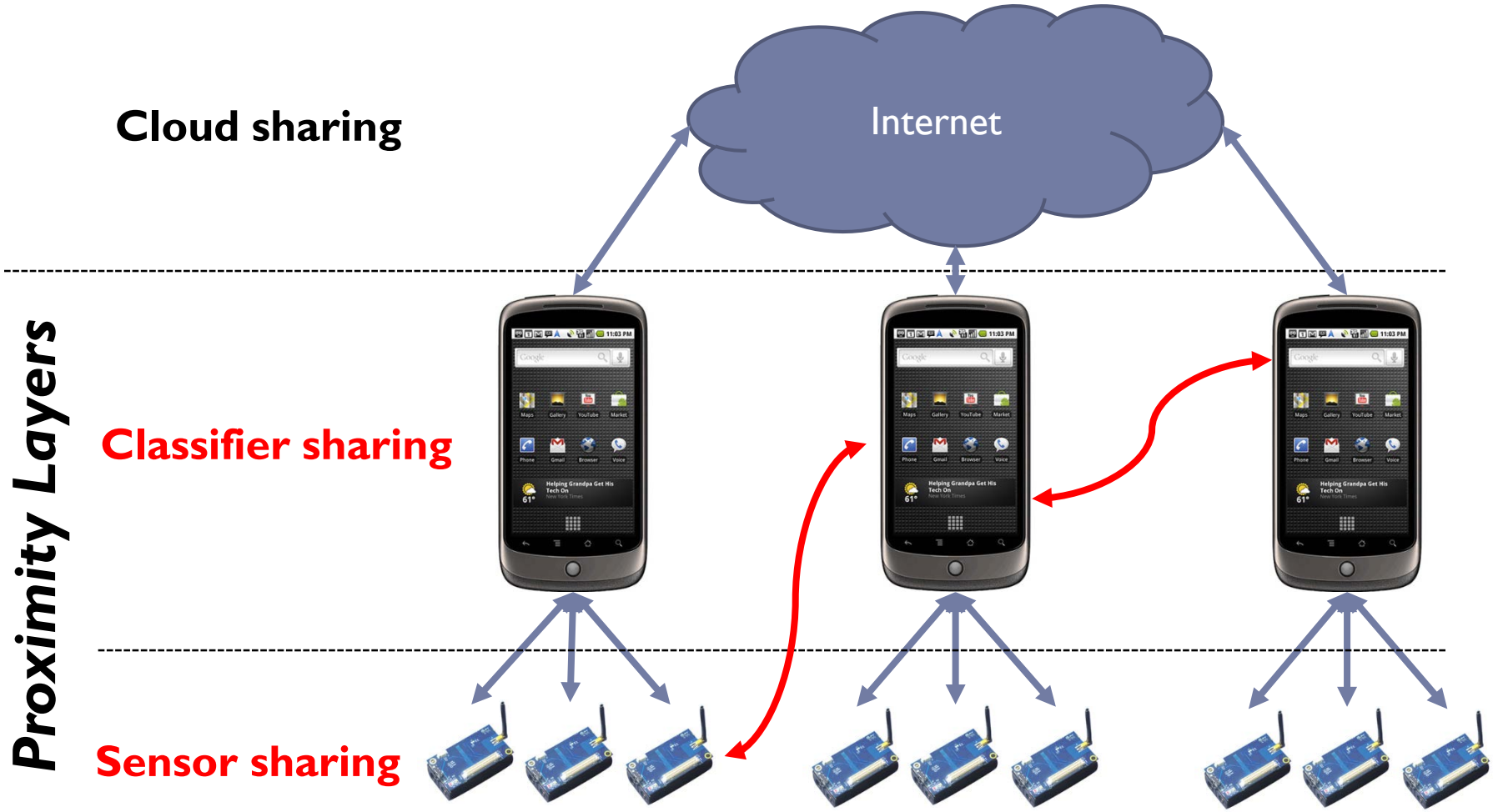
BSN Resource Sharing Challenges	Solutions
When does sharing provide an energy benefit?	Determine the costs and benefits of sharing with an empirically created time and power model
How to find *shared* resources that provide the best accuracy and energy benefits?	Neighboring BSNs *collaborate* to choose the most accurate sensors Neighboring BSNs *collaborate* to save phone energy
How to adapt to the dynamics of available neighbors?	We provide an ensemble classifier which easily adapts to changes in neighbor availability

Sharing increases accuracy by up to 30% and battery life by over 65%

Related Work

- Resources shared directly but do not share to achieve both high accuracy and energy efficiency
  - (Koukoumidis, MobiSys '11), (Miluzzo, MobiSys '10), (Lee, MobiSys '12)
- Shared resources with data relayed through a backend server
  - (Bajcy, BSN '09), (Bao, MobiSys '10), (Lane, UbiComp '11), (Rachuri, MobiCom '11)
- No sharing: BSN
  - (Abinali, UbiComp '10), (Lorincz, SenSys '09), (Chipara, SenSys '10), (Shih, MobiSys '09)
- No sharing: Phone only
  - (Chu, SenSys '11), (Miluzzo, SenSys '08), (Wiese, UbiComp '11), (Rachuri, MobiCom '11)

Sharing Hierarchy



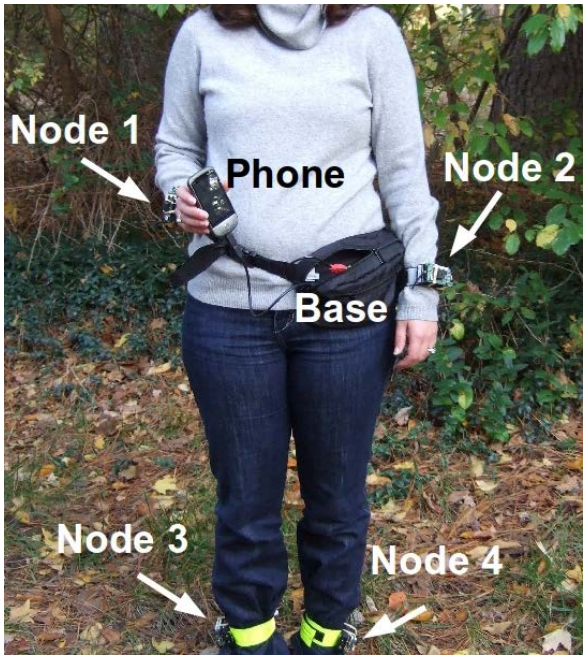
Feasibility

- Sharing Opportunity
  - MIT Reality Mining project: 25% of the time subjects in proximity
  - Evaluation: 30% of the time
- Privacy
  - Share only in physical proximity
  - Public/Private sensors
  - Coarse grained data aggregation

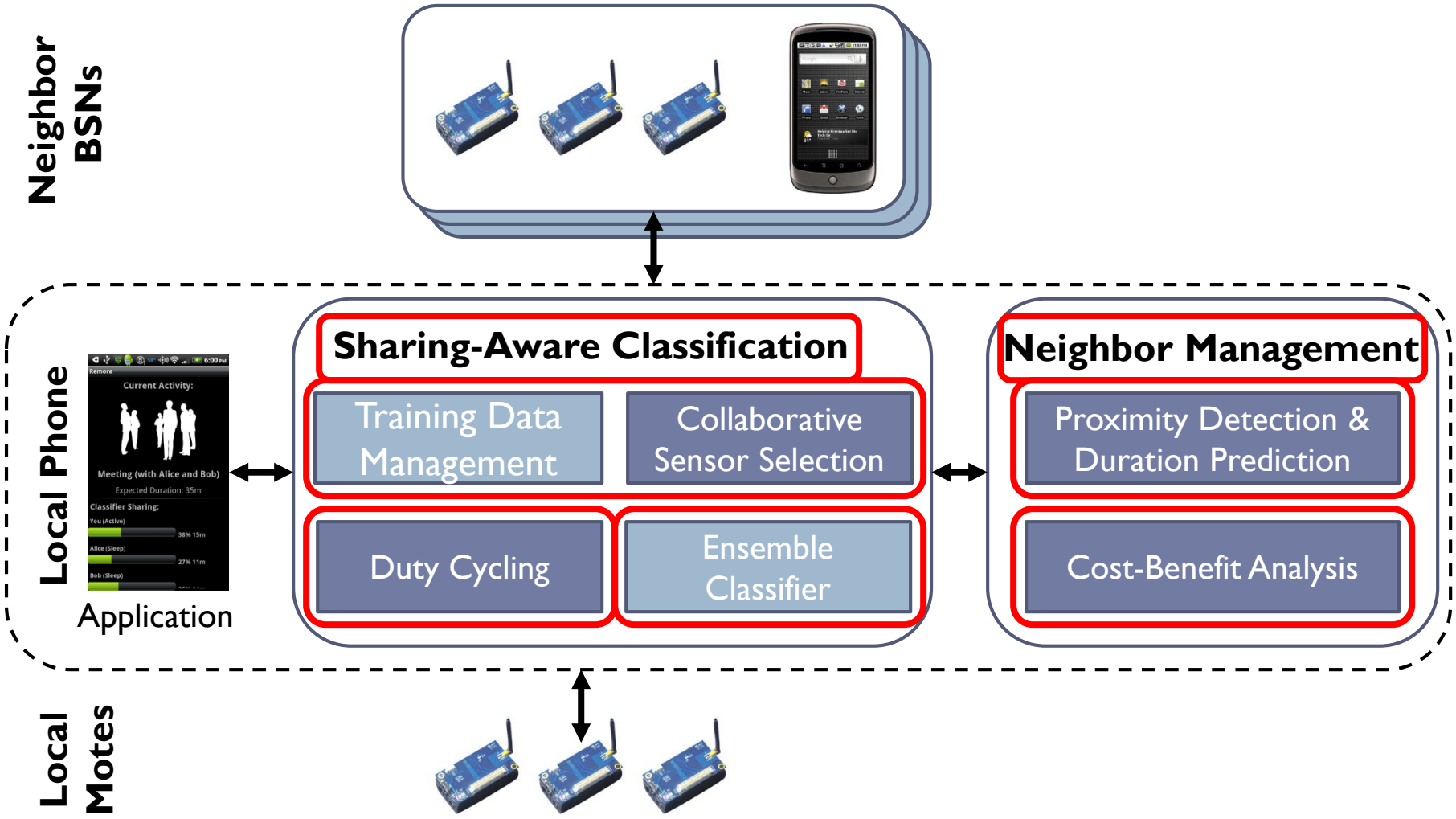
Hardware Configuration

- Android Phone
  - 3-axis accelerometer, WiFi/GPS Localization
- TelosB Base Station
  - Android kernel USB host mode enabled
- 4 IRIS Sensor Motes
  - 2-axis accelerometer, light, temperature, acoustic, RSSI

Node ID	Location
0	BS/Phone
1	R. Wrist
2	L. Wrist
3	R. Ankle
4	L. Ankle

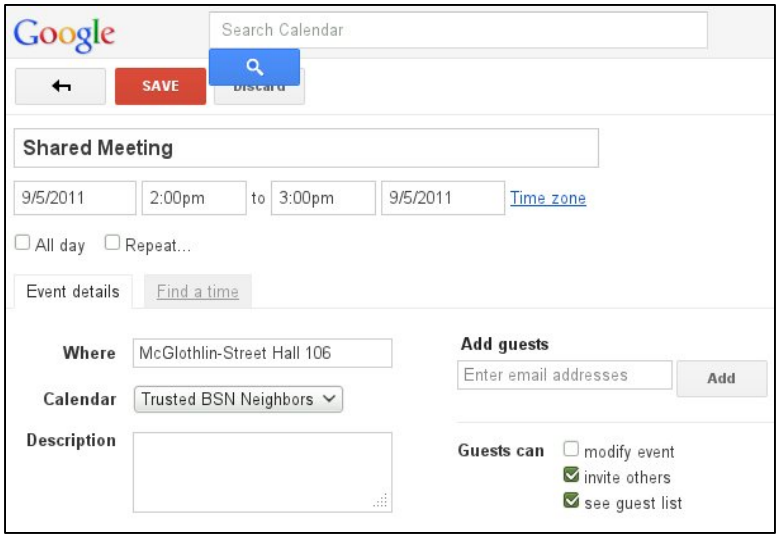


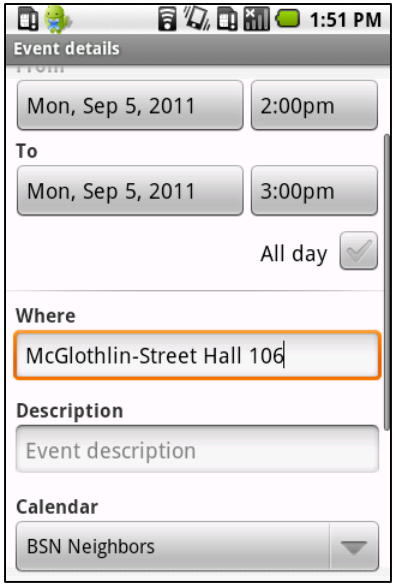
Remora Architecture



Proximity Detection and Duration Prediction

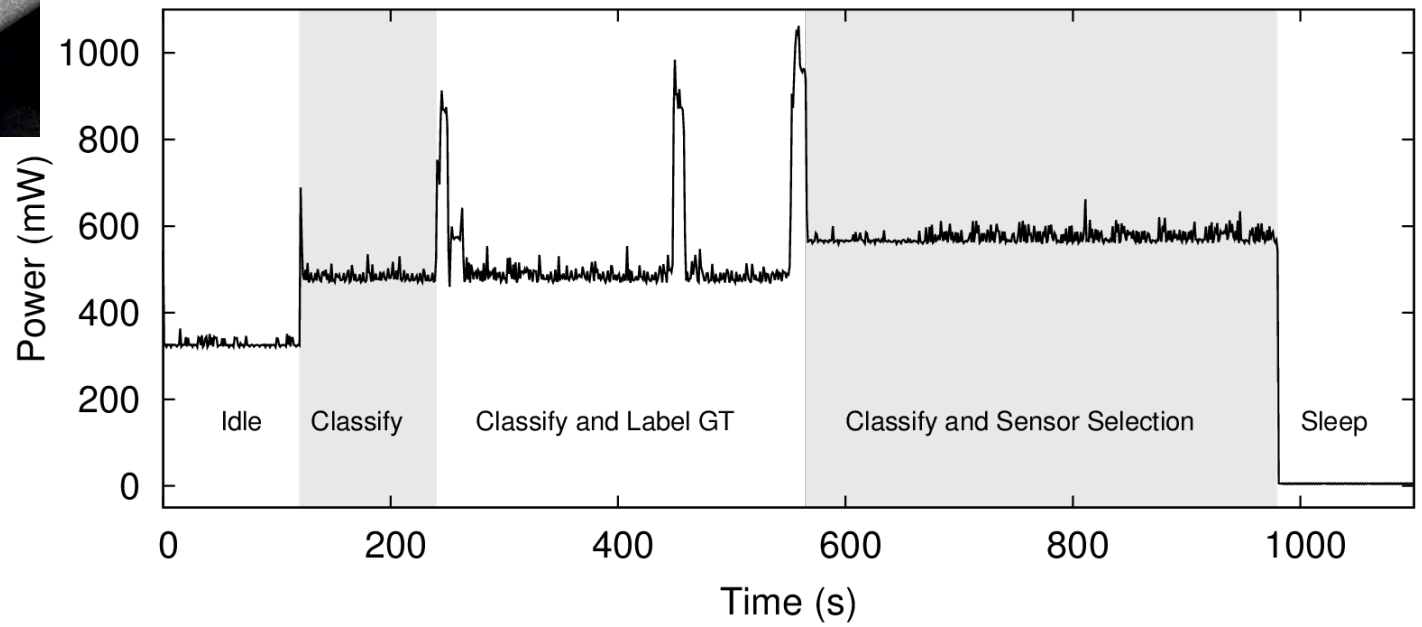
- Proximity Detection
  - Detect neighboring BSNs by overhearing data packets
  - Determine when neighbors leave
- Duration Prediction
  - Estimate how long a neighbor will be in proximity
  - Shared calendar or manual prompt





Empirical Cost Model: Power

- Remora implementation with HTC Hero and motes



Cost-Benefit Analysis

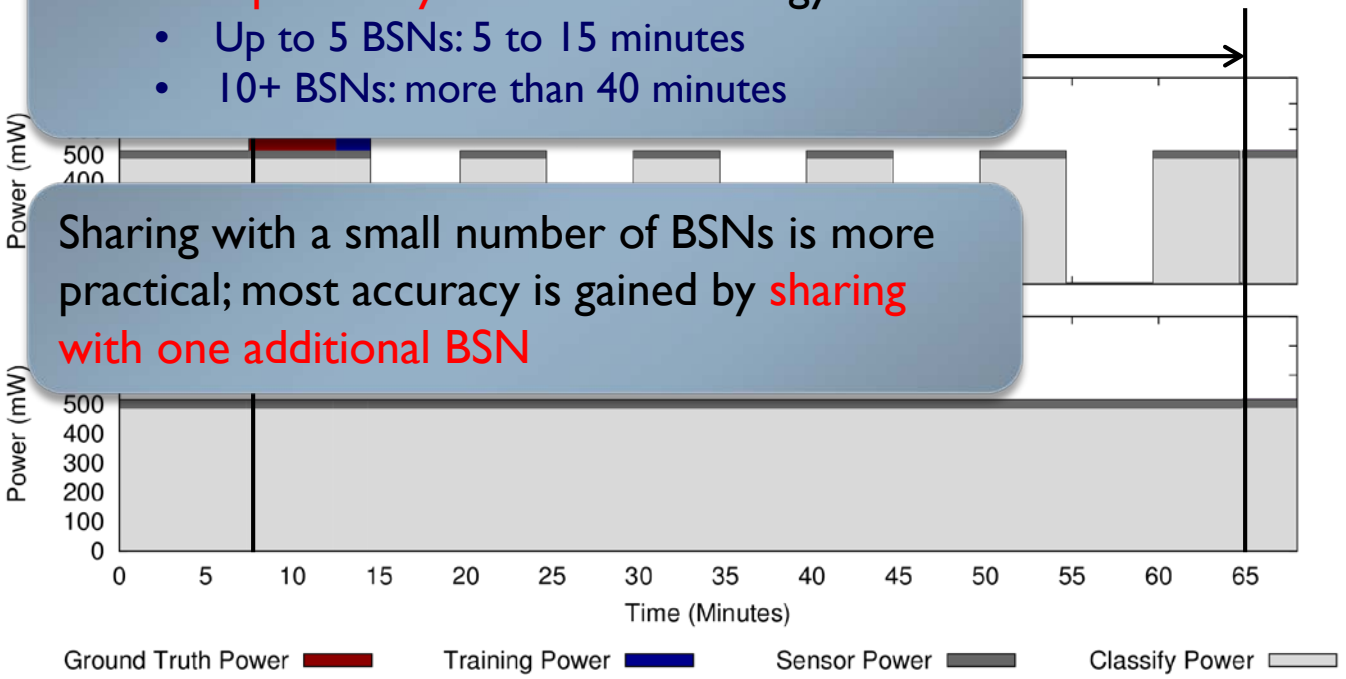
- Will sharing save energy when a neighboring BSN is detected?
  - Phone energy is the limiting factor in BSN lifetime
  - Duty cycle phone classifiers to save phone energy
- Compare indiv ion energy

Minimum proximity duration for energy benefit:
- Up to 5 BSNs: 5 to 15 minutes
- 10+ BSNs: more than 40 minutes

Sharing with a small number of BSNs is more practical; most accuracy is gained by sharing with one additional BSN

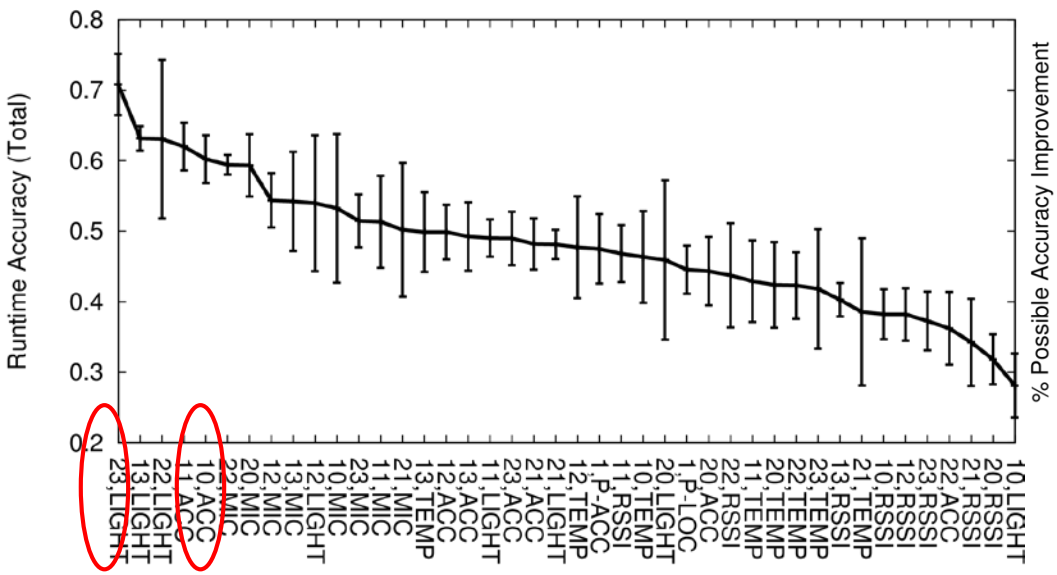
Sharing

No Sharing

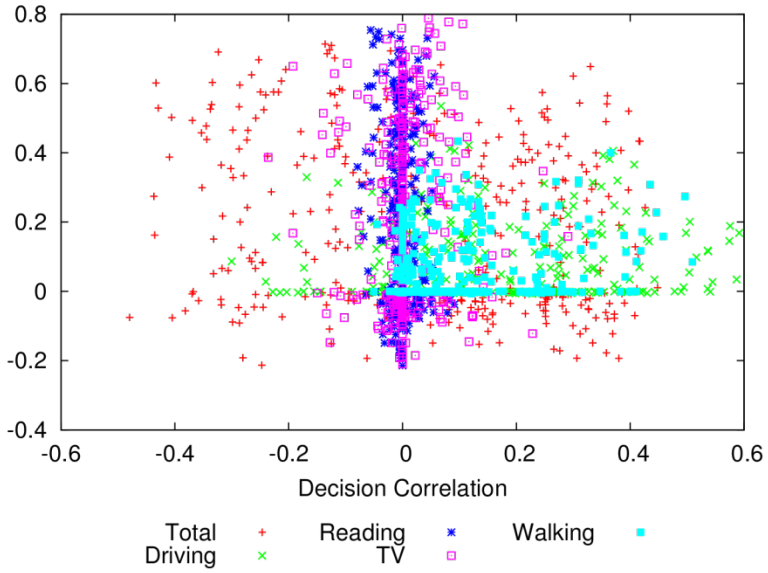


Sensor Selection Motivation

- Successful ensemble classifiers must have:
  - Accurate weak classifiers
  - Weak classifiers have diverse classification results



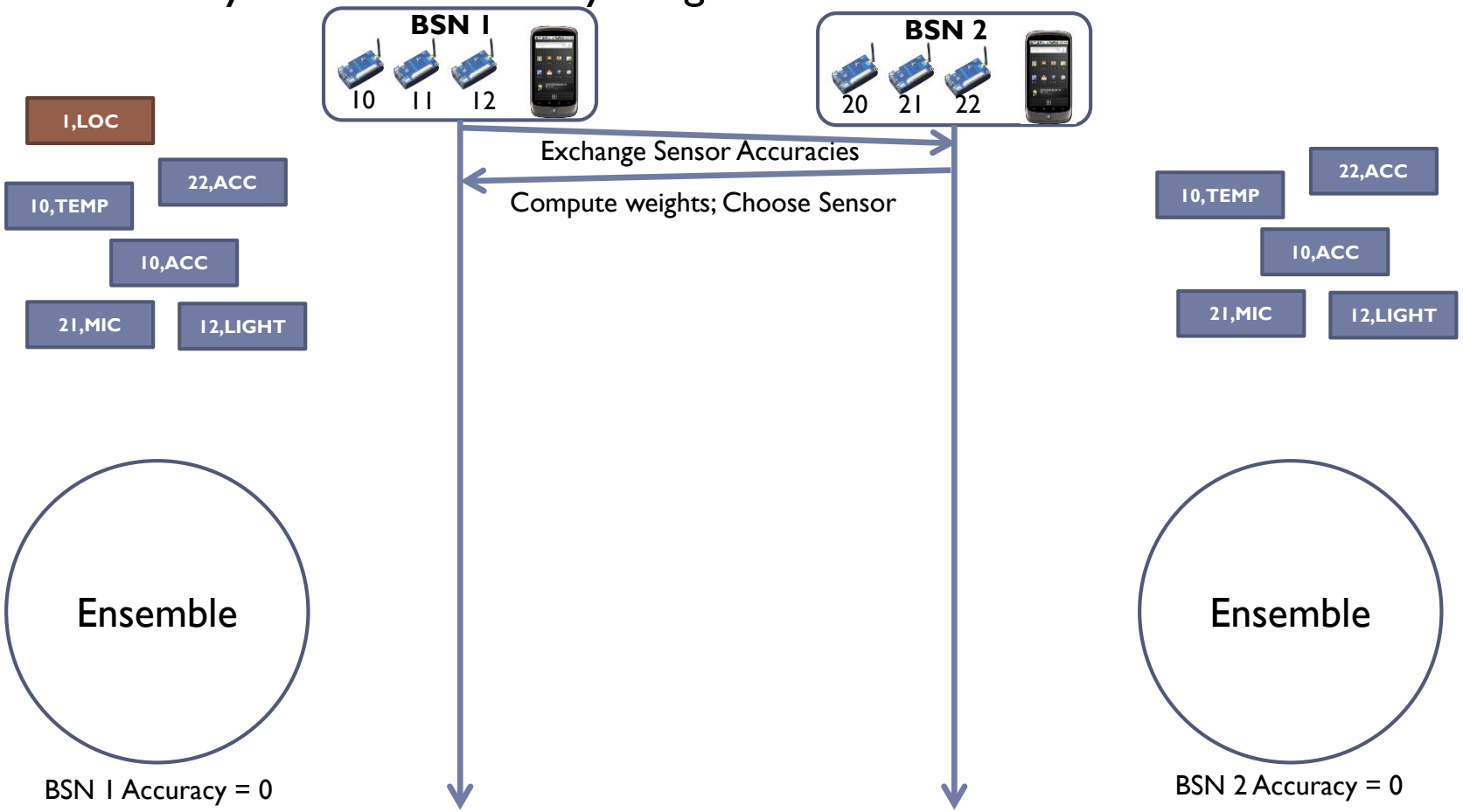
Individual Sensor Accuracy



Sensor-Cluster Correlation

Collaborative Sensor Selection

- Weight sensors by accuracy and decision correlation for all neighbors
- Iteratively choose sensors by weight



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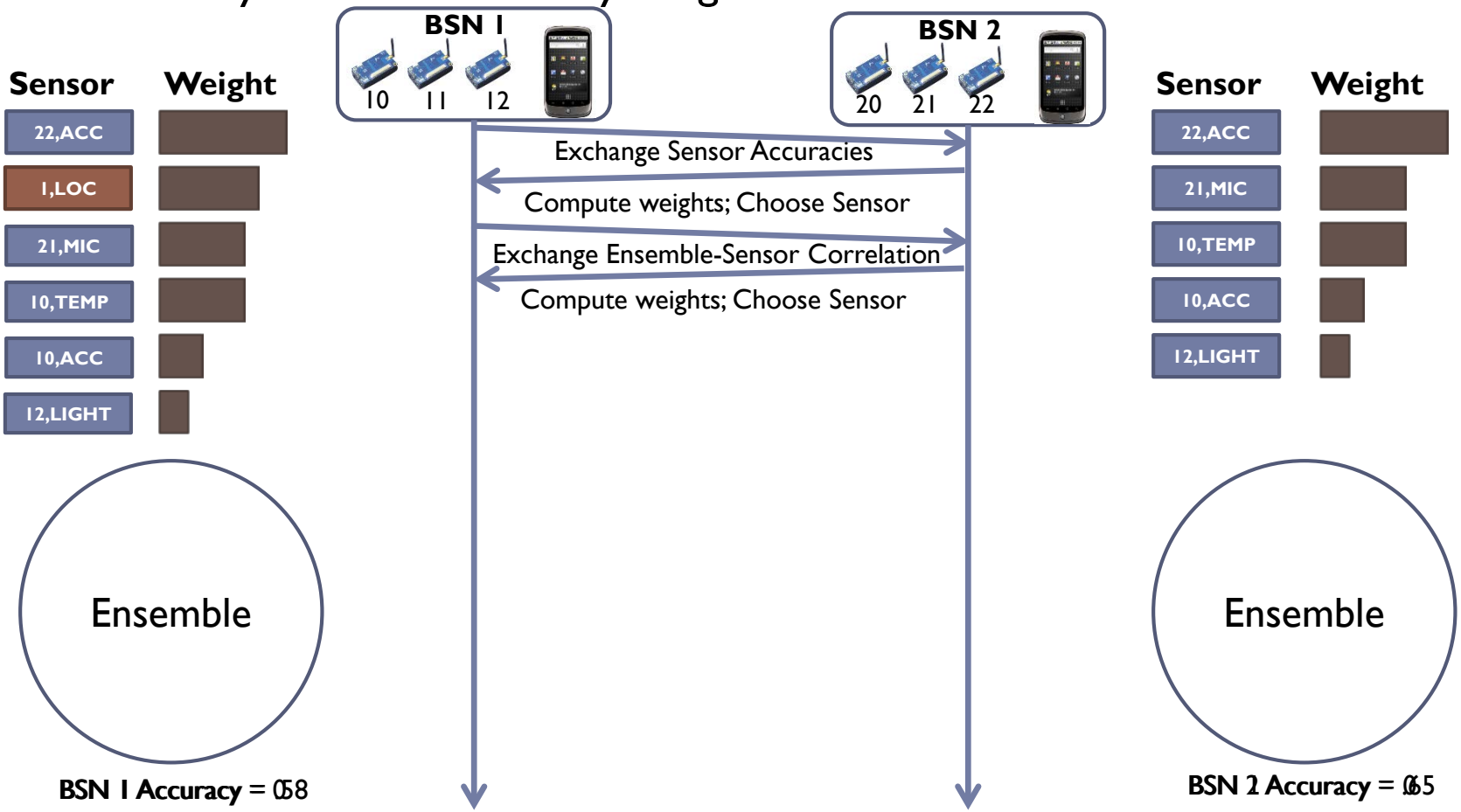

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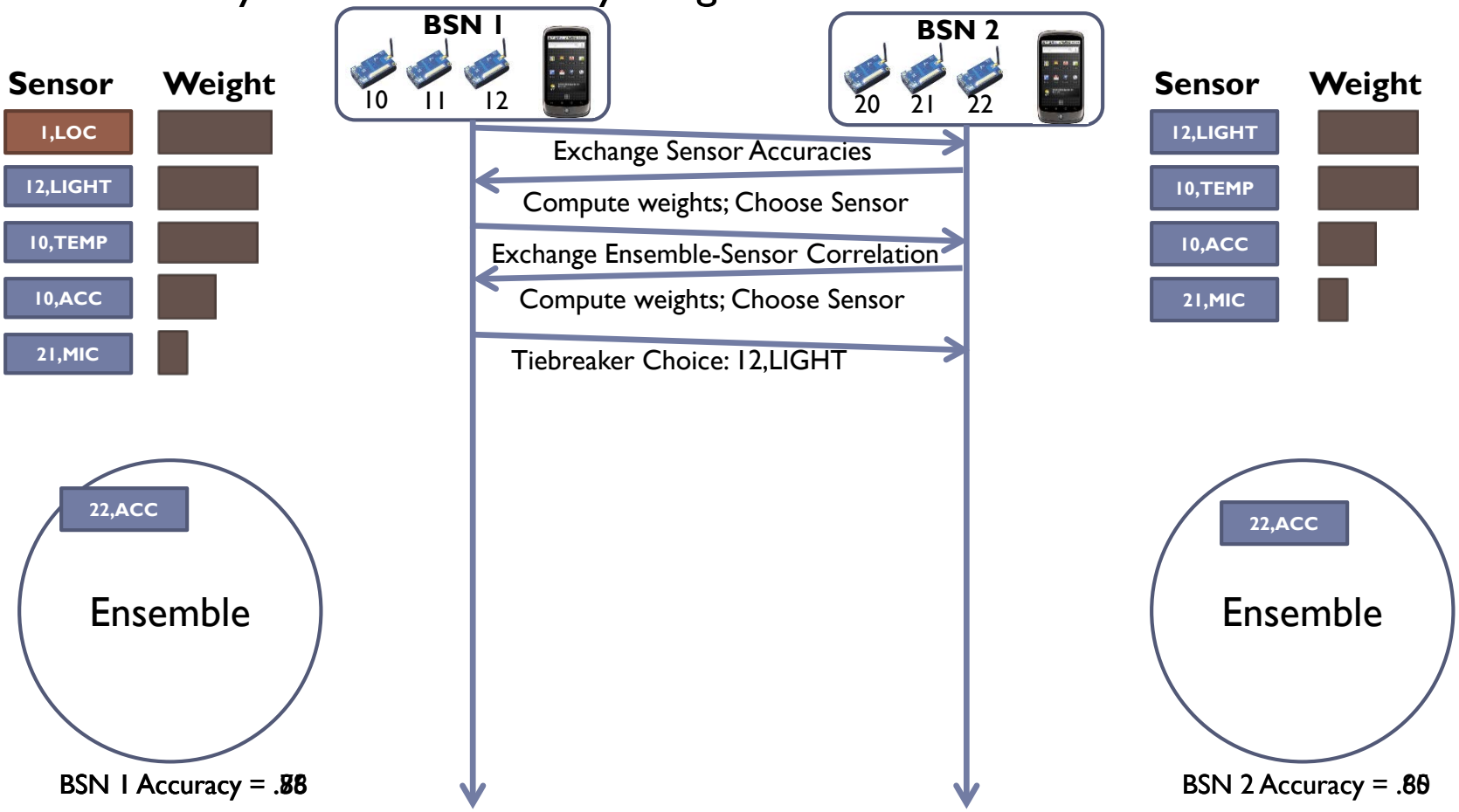

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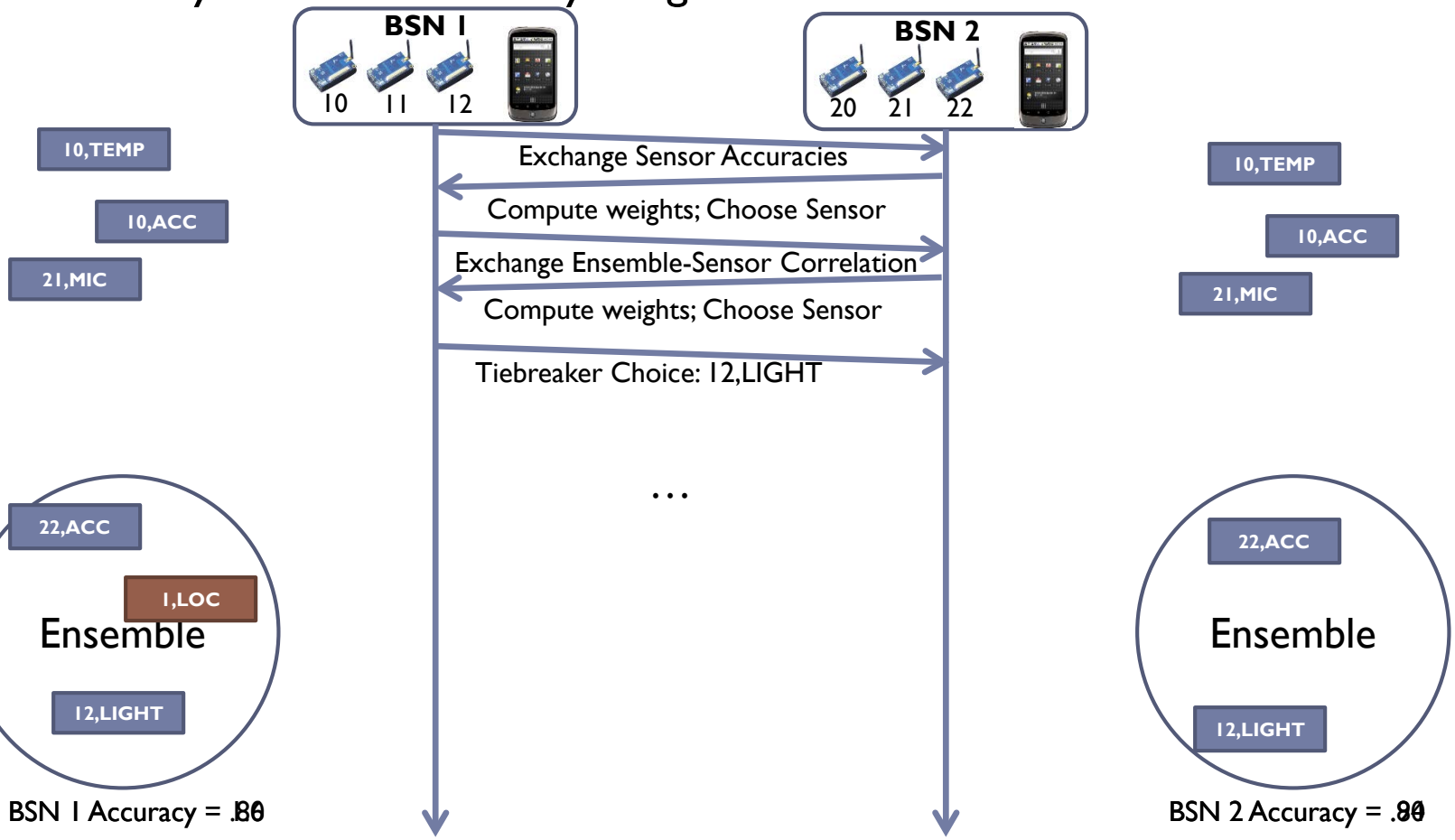
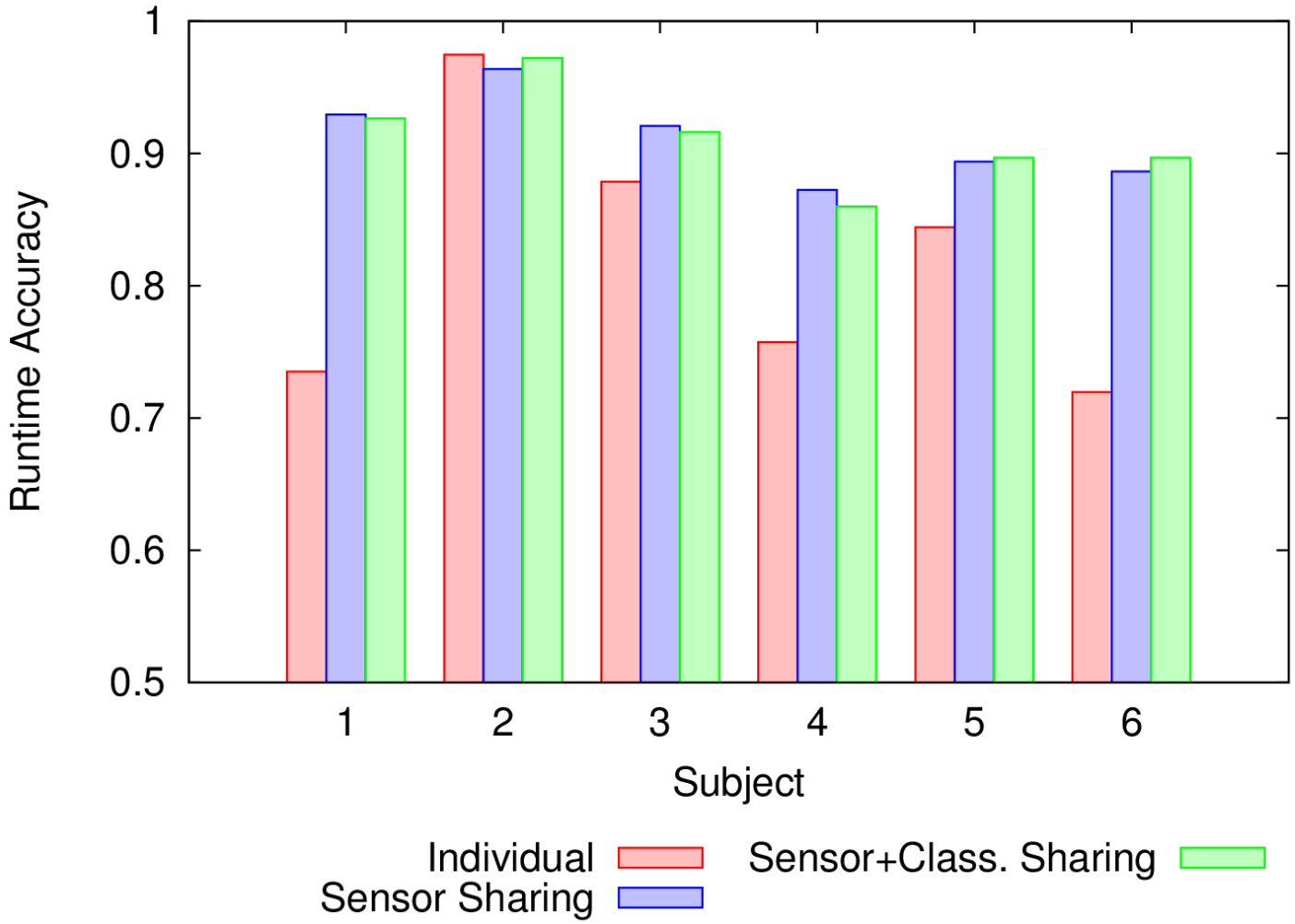


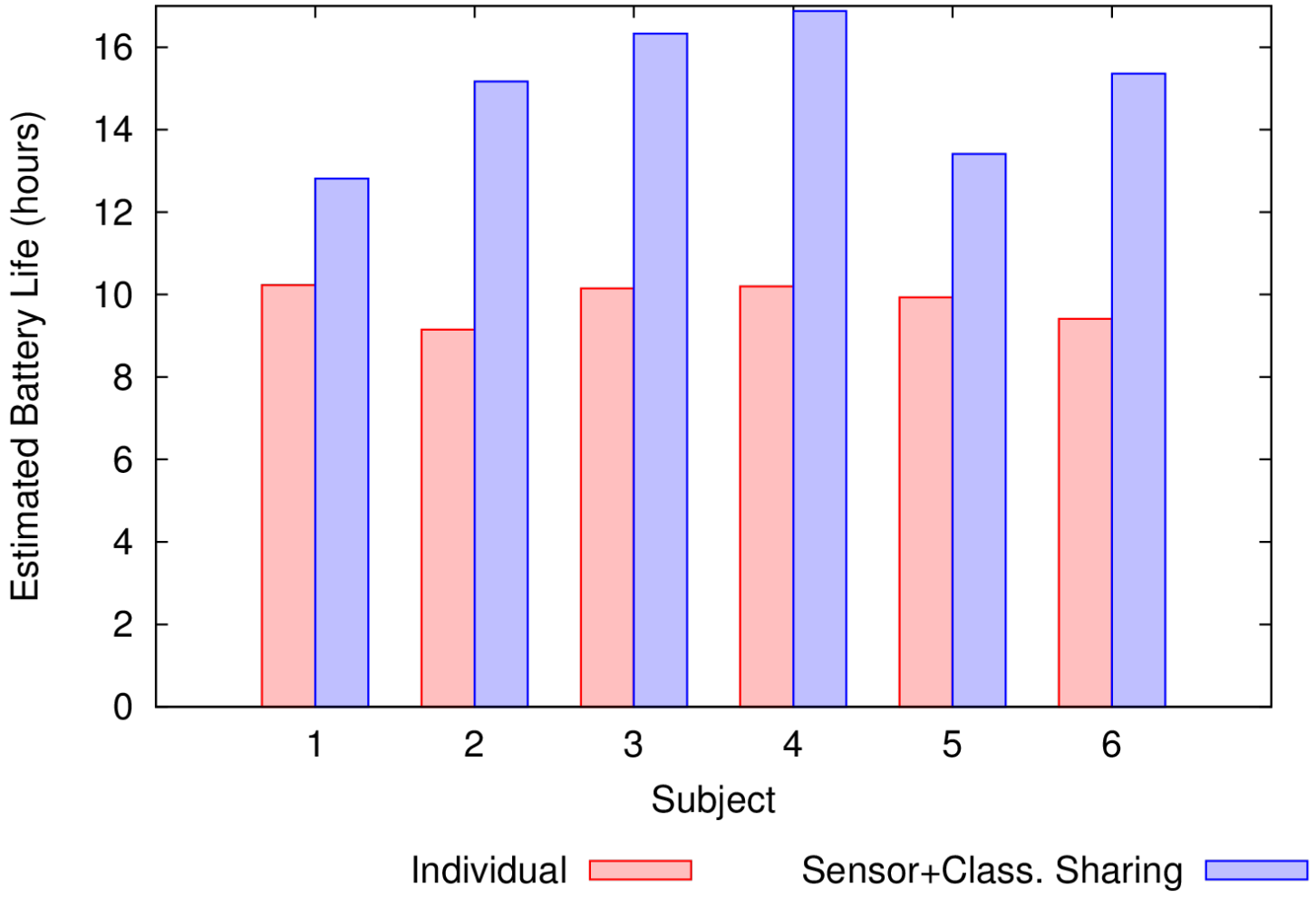
Evaluation

Parameter	Value
Number of Subjects	6
Duration	2 weeks
Activities	Riding a bus, Riding or driving a car, meeting, reading, running, watching TV, walking, working at a desk
Initial training data	30 aggregated samples (5 min) per activity
Comparison	Individual classification, sensor sharing, sensor and classifier sharing

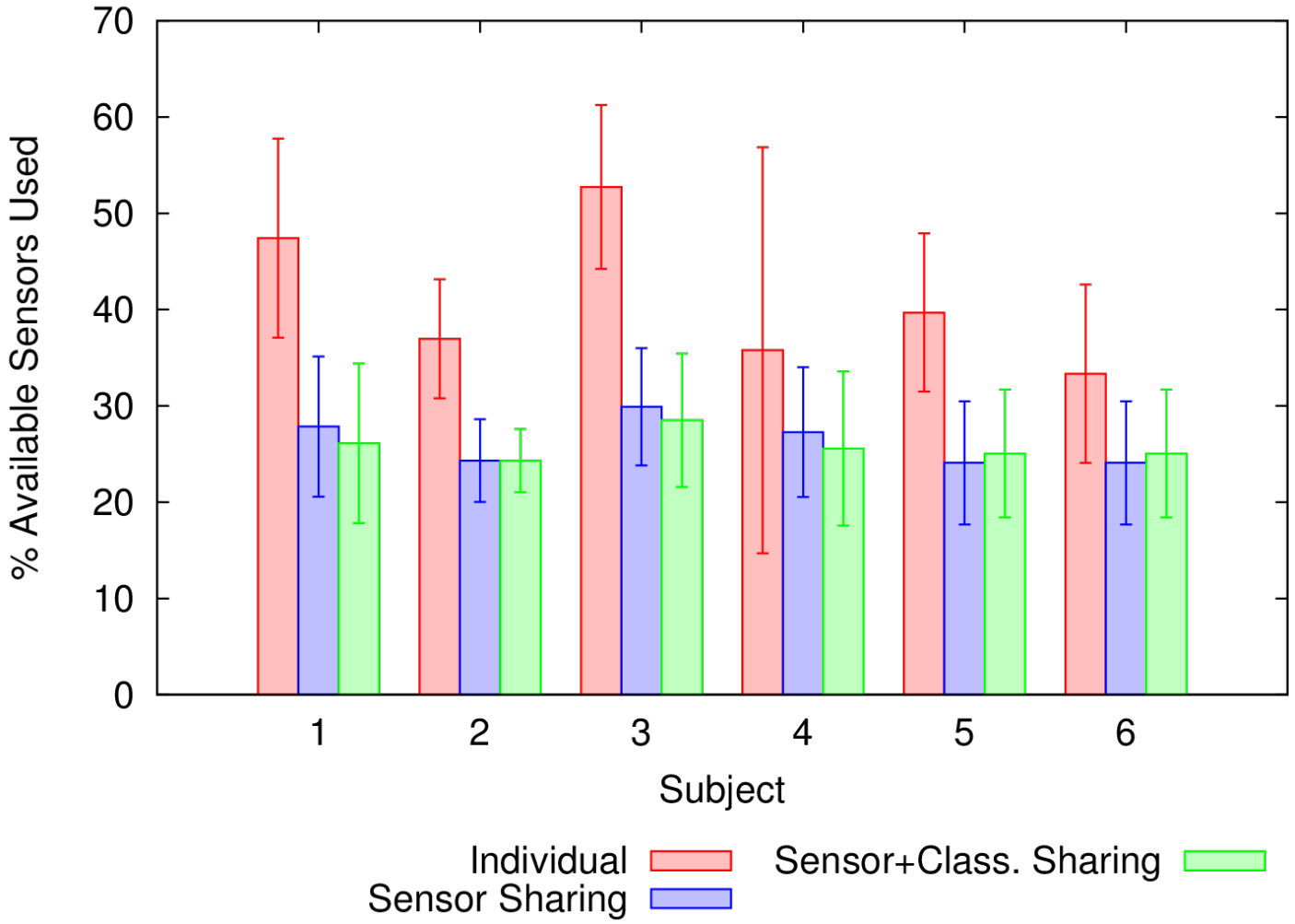
Accuracy


Runtime Accuracy
1
0.9
0.8
0.7
0.6
0.5
1
2
3
4
5
6
Subject
Individual
Sensor Sharing
Sensor+Class. Sharing

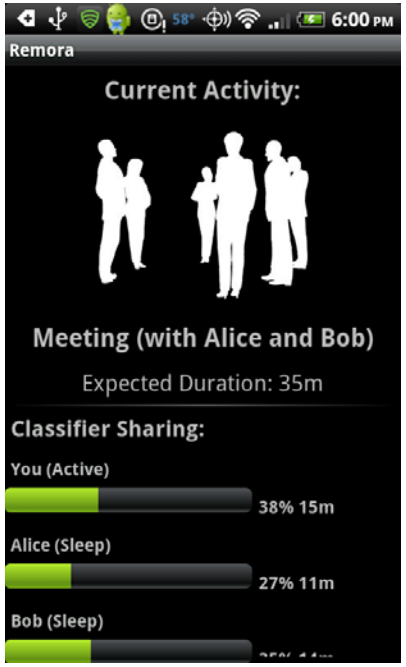
Battery Life



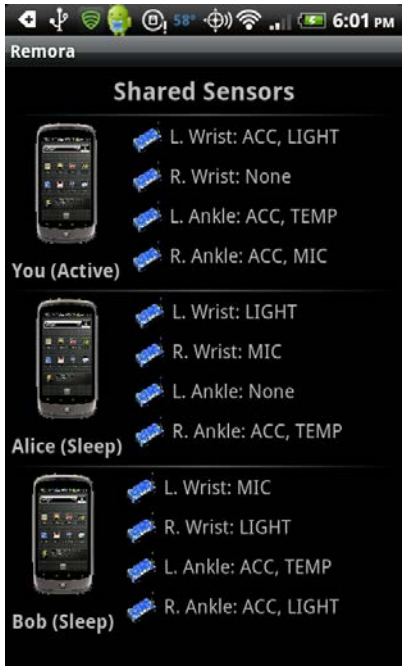
Sensor Utilization



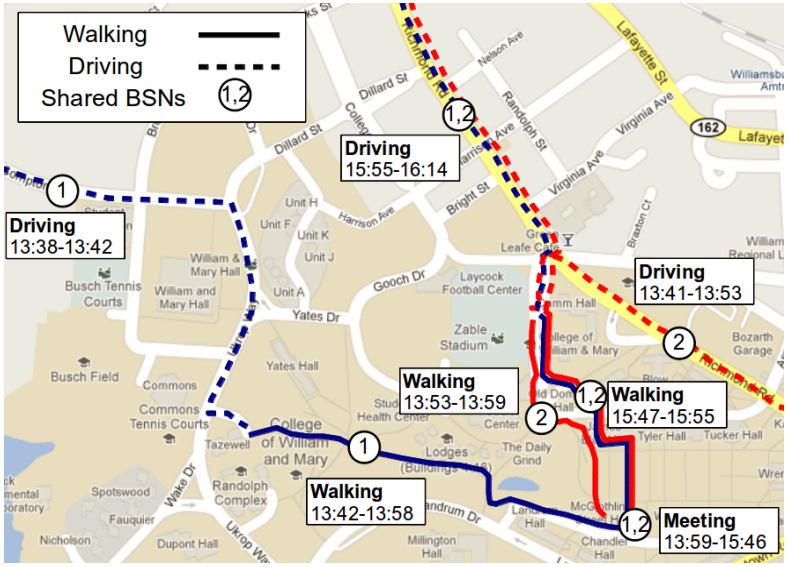
Applications



Shared Activities



Shared Sensors



Interaction History

Conclusion

- Sharing BSN resources provides accuracy and energy savings
  - Share sensors: increase accuracy, save sensor energy
  - Share classifiers: save phone energy
- We model the costs and benefits of sharing
  - Share only when energy can be saved
- Collaborative Sensor Selection allows all BSN participants to benefit
  - Use only the best sensors
  - Turn off redundant sensors

Discussion

- Who will use the proposed system: sharing of multiple BSNs?
  - What if each BSN is just a phone?
  - What if each BSN is just a wearable device?
- How to do better when coexisting human subjects perform different activities?
- What and how to share through cloud?
- Using sensing/computing resources from other non-BSN devices in environment?