Supporting Energy-Efficient Uploading Strategies for Continuous Sensing Applications on Mobile Phones

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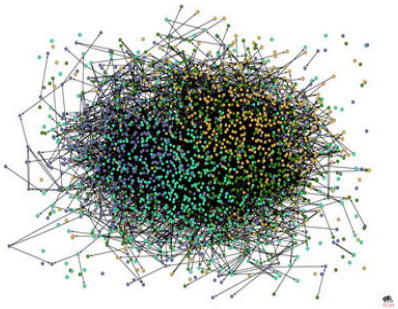
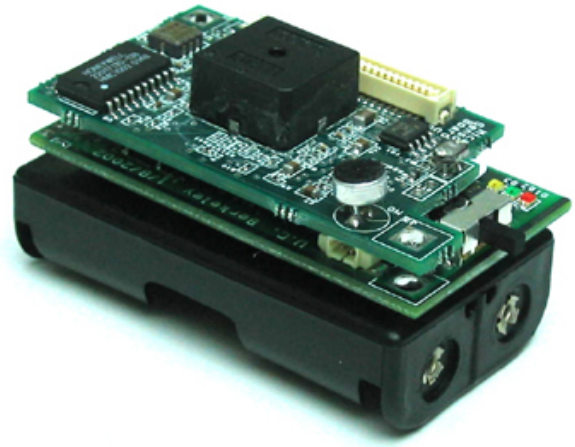
Joint with Mattia Piraccini, Kristof Fodor, Antonio Corradi and Andrew T. Campbell

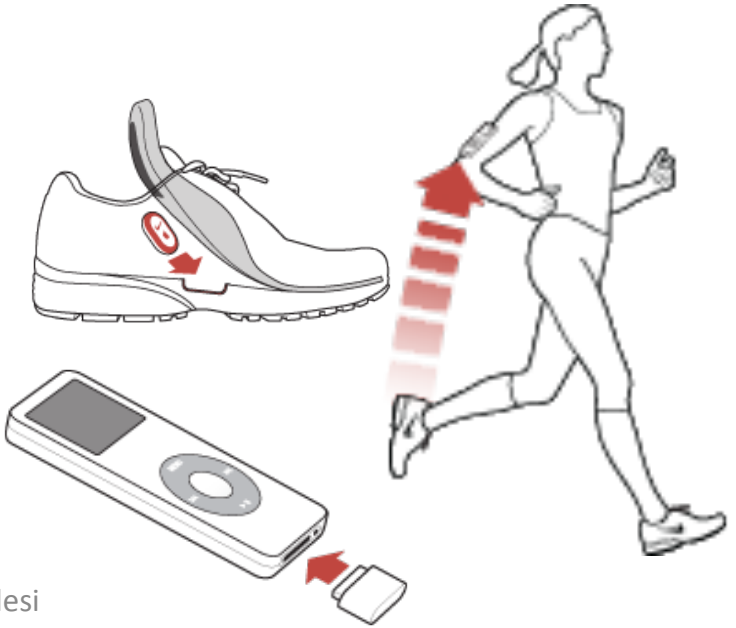
My Research Interests



- Intelligent mobile (sensing) systems
  - Algorithms and mechanisms for social computing and socially-aware mobile systems
- Large-scale network analysis&modelling
  - Temporal graphs and information diffusion models
  - Machine learning techniques applied to mobile and social network analysis

Sensor Networking: State of the Art





Continuous Sensing based on Mobile Phones

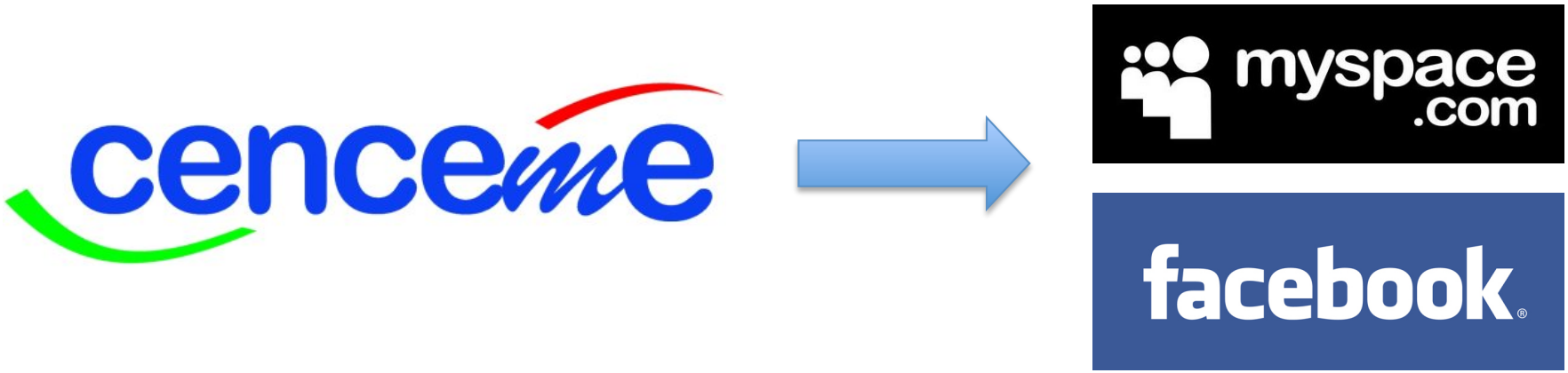
People-centric Continuous Sensing

- People at the center of the sensing process:
  - People carry phones (sensing devices with Internet connectivity)
  - People can collect data about themselves and from devices embedded in the environment

[Campbell et al. *The Rise of People Centric Sensing*. IEEE Internet Computing. July/August 2008.]

CenceMe

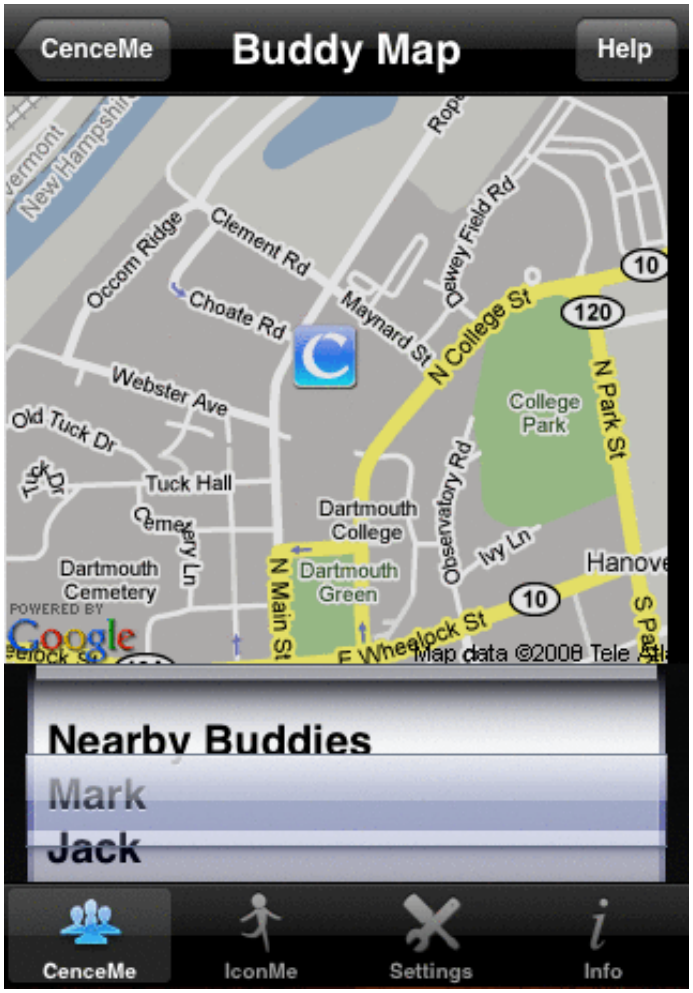
- A software for injecting ***presence information*** (activity, location, friends currently colocated with the person, etc.) in an automatic way into social networking applications (and more)



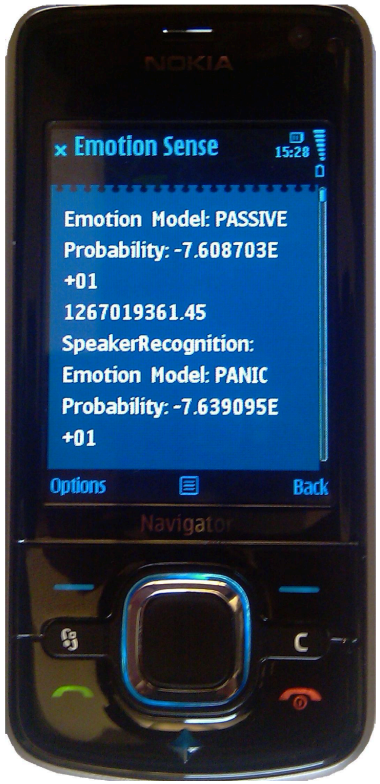
[Miluzzo et al. *Sensing Meets Social Networks: The Design, Implementation and Evaluation of the CenceMe Application*. In Proceedings of SenSys '08. November 2008.]

CenceMe


CenceMe
Help
I love this Italian restaurant
Mark
Jul 6, 2008 1:23 PM
wicked day for a run
Jack
May 2, 2008 4:13 PM
Preparing for the season
Derrick Rose
May 3, 2008 6:51 PM
in Philly for the weekend
Julia Smith
May 2, 2008 3:05 PM
CenceMe
IconMe
Settings
Info


CenceMe
Buddy Map
Help
Occom Ridge
Clement Rd
Choate Rd
Webster Ave
Old Tuck Dr
Tuck Hall
Dartmouth Cemetery
Dartmouth College
Dartmouth Green
Maynard St
Dewey Field Rd
N College St
College Park
N Park St
Observatory Rd
Ivy Ln
N Main St
Wheelock St
10
120
Nearby Buddies
Mark
Jack
CenceMe
IconMe
Settings
Info

EmotionSense



- Mobile platform for experimental sociology
- Automatic inference of:
  - Interactions (proximity and speech dynamics)
  - Speaker recognition
  - Emotion recognition

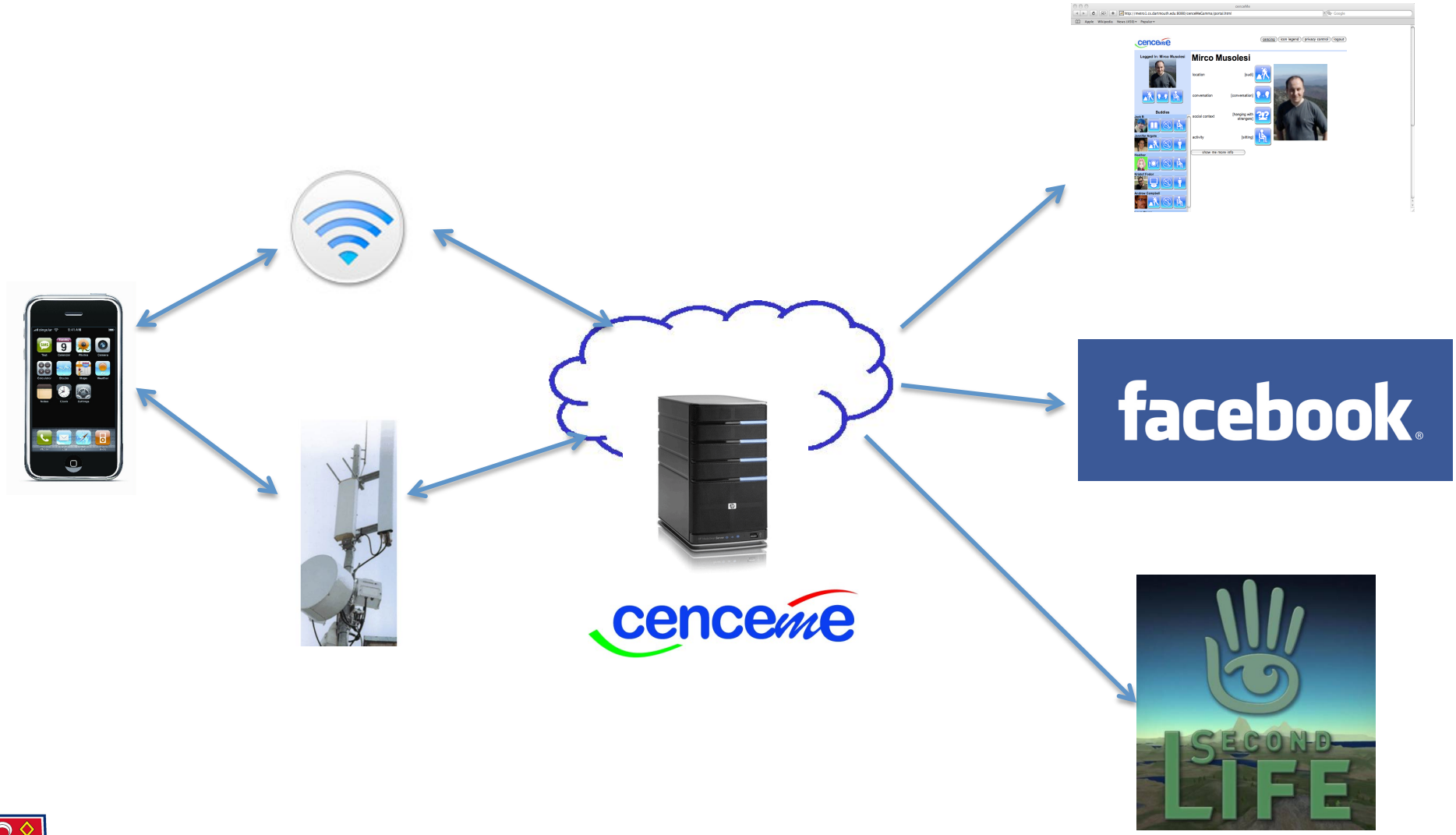
[Kiran K. Rachuri, Mirco Musolesi, Cecilia Mascolo, Jason Rentfrow, Chris Longworth and Andrius Aucinas. EmotionSense: A Mobile Phones based Adaptive Platform for Experimental Social Psychology Research. In *Proceedings of 12th ACM International Conference on Ubiquitous Computing (UbiComp'10)*. Copenhagen, Denmark. September 2010. To appear.]

Emotion Detection

- Based on Gaussian Mixture Models
  - Training based on Emotional Prosody and Transcripts library

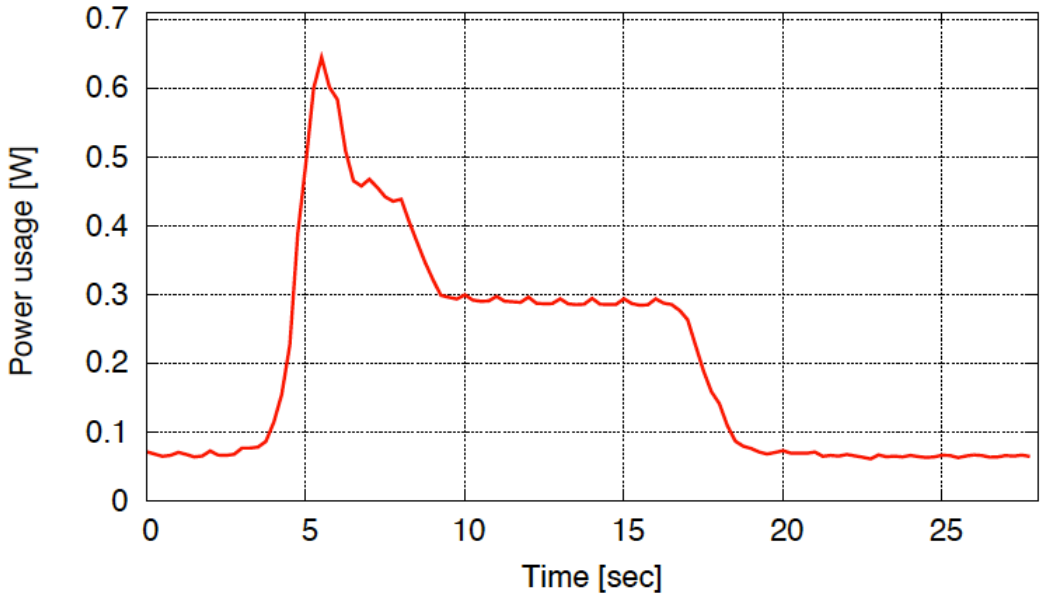
Broad emotion	Narrow emotions
Happy	Elation, Interest, Happy
Sad	Sadness
Fear	Panic
Anger	Disgust, Dominant, Hot anger
Neutral	Neutral normal, Neutral conversation, Neutral distant, Neutral tete, Boredom, Passive

Server-based Information Processing



Energy is the Key Issue for Continuous Mobile Sensing

GPRS connectivity is power-hungry



Energy consumption profile related to the transmission of 100 bytes using a Nokia N95 over GPRS.

A Possible Solution

Intelligent upload of discrete data for **continuous** sensing applications

[Mirco Musolesi, Mattia Piraccini, Kristof Fodor, Antonio Corradi and Andrew T. Campbell. Supporting Energy-efficient Uploading Strategies for Continuous Sensing Applications on Mobile Phones. In *Proceedings of the 8th International Conference on Pervasive Computing (Pervasive '10)*. Helsinki, Finland. May 2010.]

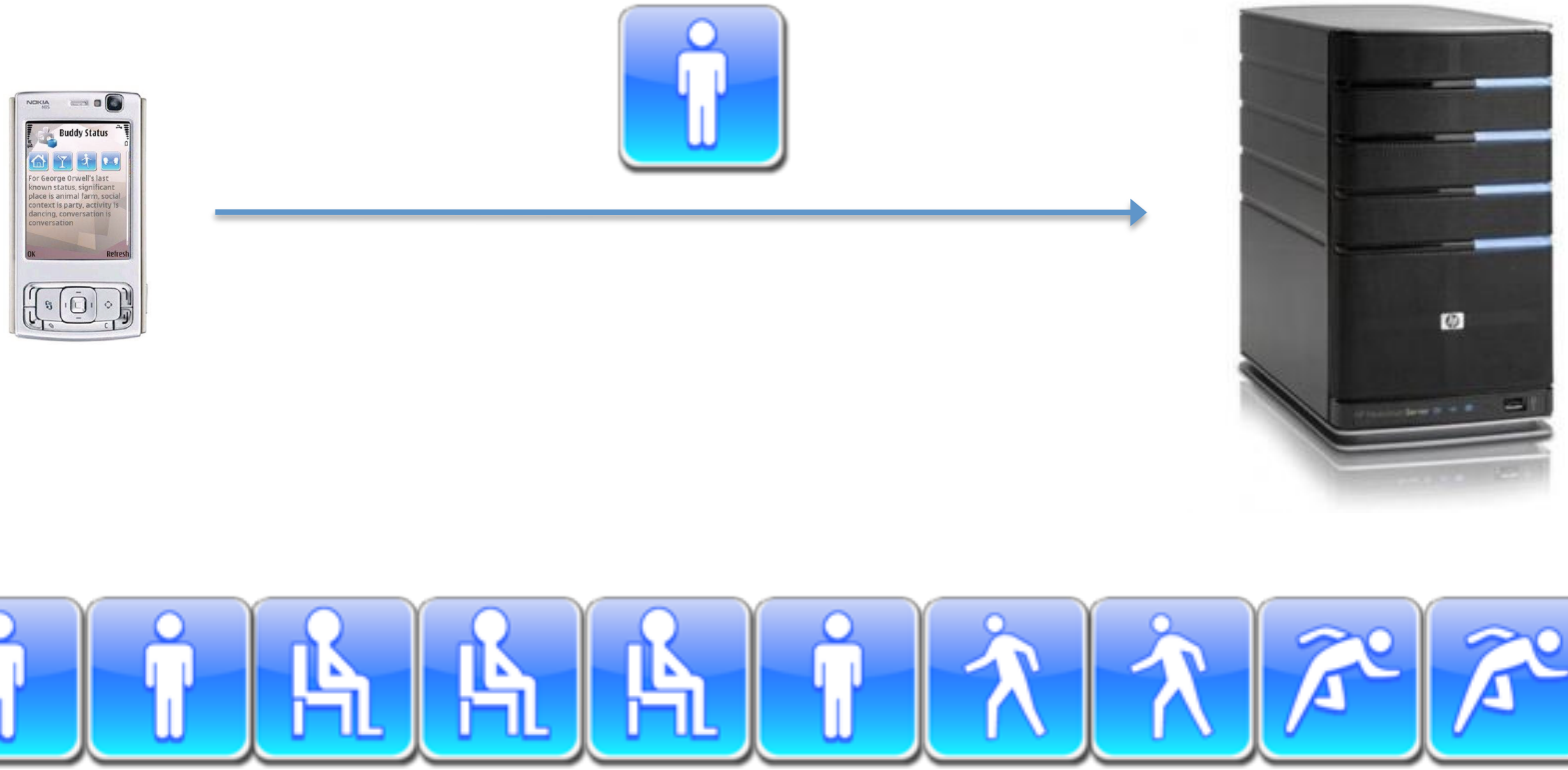
Streams of States

In our study:

A set of states *S*

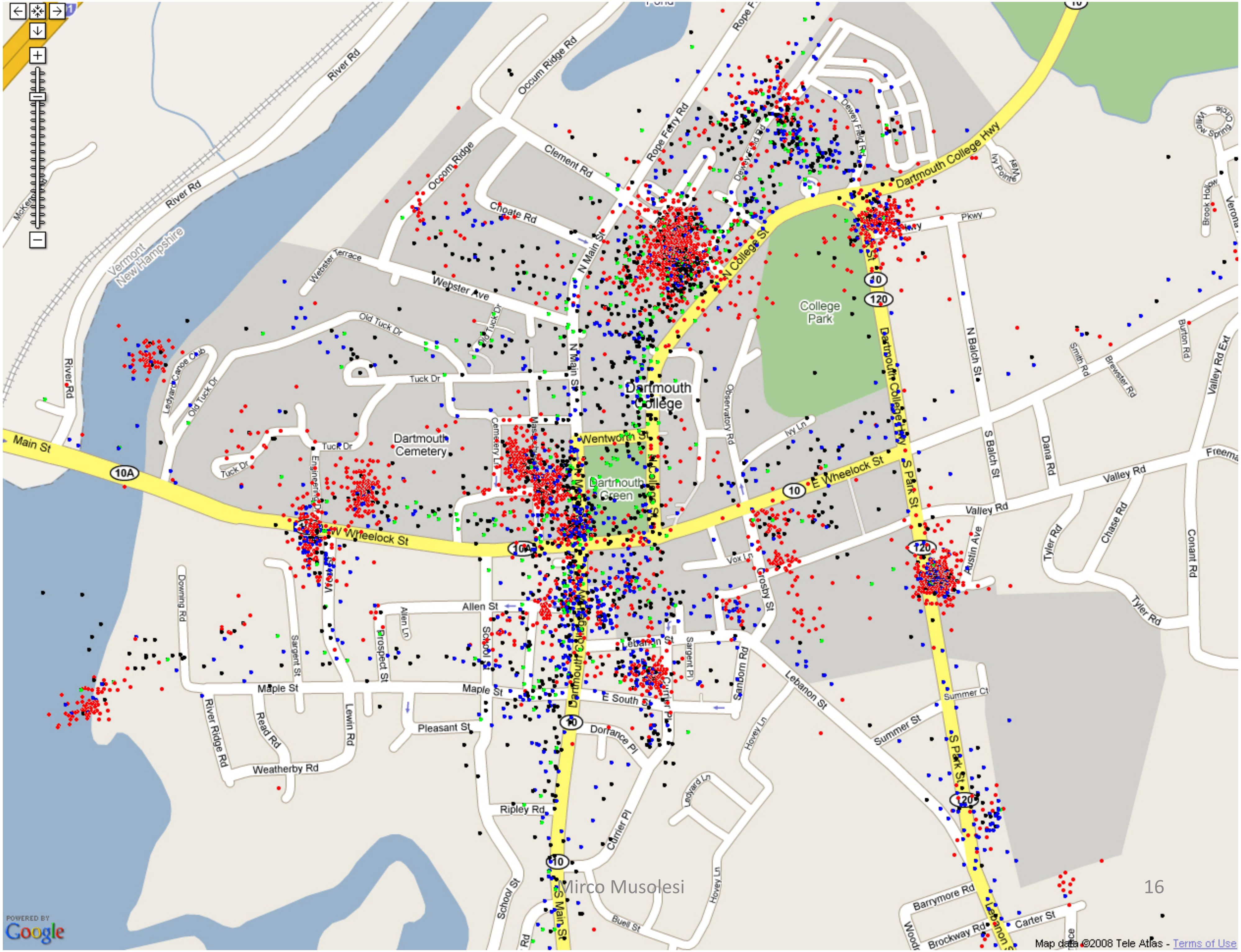
S = {Running, Walking, Sitting, Standing, …}

Solution: Intelligent Uploading of Updates



Our Dataset

- Study based on real measurements
  - 20 students and staff members from the CS and Biology Departments at Dartmouth College
  - Collected using the CenceMe app for Nokia N95
- Dataset containing activity and location information (soon available on CRAWDAD)
- Two weeks of data:
  - for evaluating prediction techniques, the first was used for training and the second for testing



River Rd
Occum Ridge Rd
Rope Ferry Rd
Clement Rd
Choate Rd
Occom Ridge
Webster Terrace
Webster Ave
Old Tuck Dr
Tuck Dr
Ledyard Canoe Club
Vermont
New Hampshire
Main St
10A
W Wheelock St
Dartmouth Cemetery
Cemetery Ln
N Main St
Dartmouth College
Wentworth St
Dartmouth Green
N College St
Dartmouth College Hwy
College Park
Observatory Rd
Ivy Ln
E Wheelock St
10
120
S Park St
N Balch St
S Balch St
Dana Rd
Valley Rd
Tyler Rd
Chase Rd
Conant Rd
Austin Ave
Smith Rd
Brewster Rd
Burton Rd
Valley Rd Ext
Brook Hollow
Ivy Pointe Way
Dewey Field Rd
Downing Rd
Sargent St
Allen St
Allen Ln
Prospect St
School St
Maple St
River Ridge Rd
Read Rd
Lewin Rd
Pleasant St
Weatherby Rd
Ripley Rd
Vox Ln
Crosby St
Sanborn Rd
Lebanon St
Sargent Pl
E South St
Currier Pl
Dorrance Pl
Hovey Ln
Ledyard Ln
Summer St
Summer Ct
Barrymore Rd
Brockway Rd
Carter St
Buell St
S Main St
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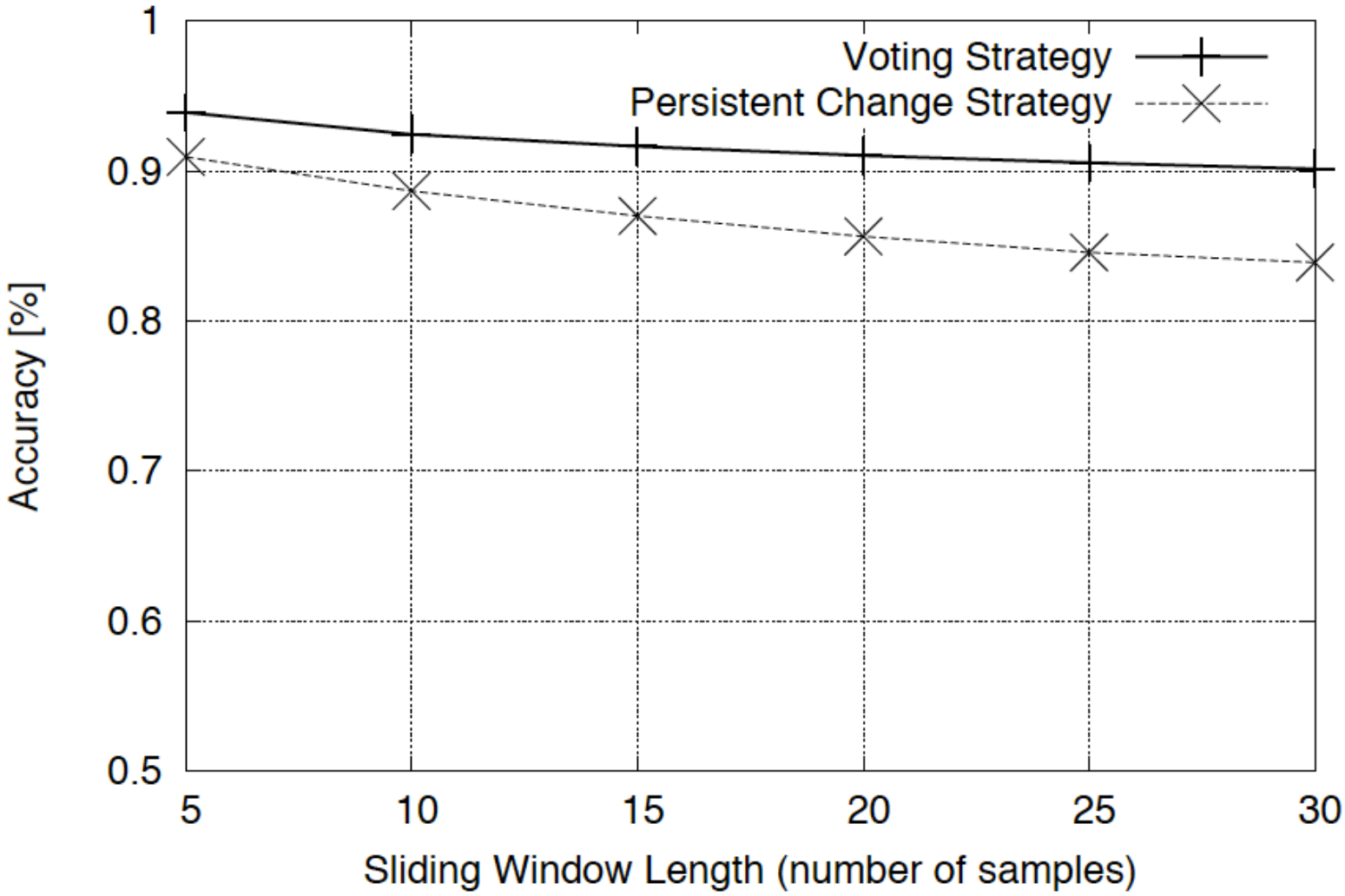
Online Strategies: Stream Analysis Techniques

- Strategies assuming **continuous availability** of network connectivity
- Uploading decision made by analysing the stream of states

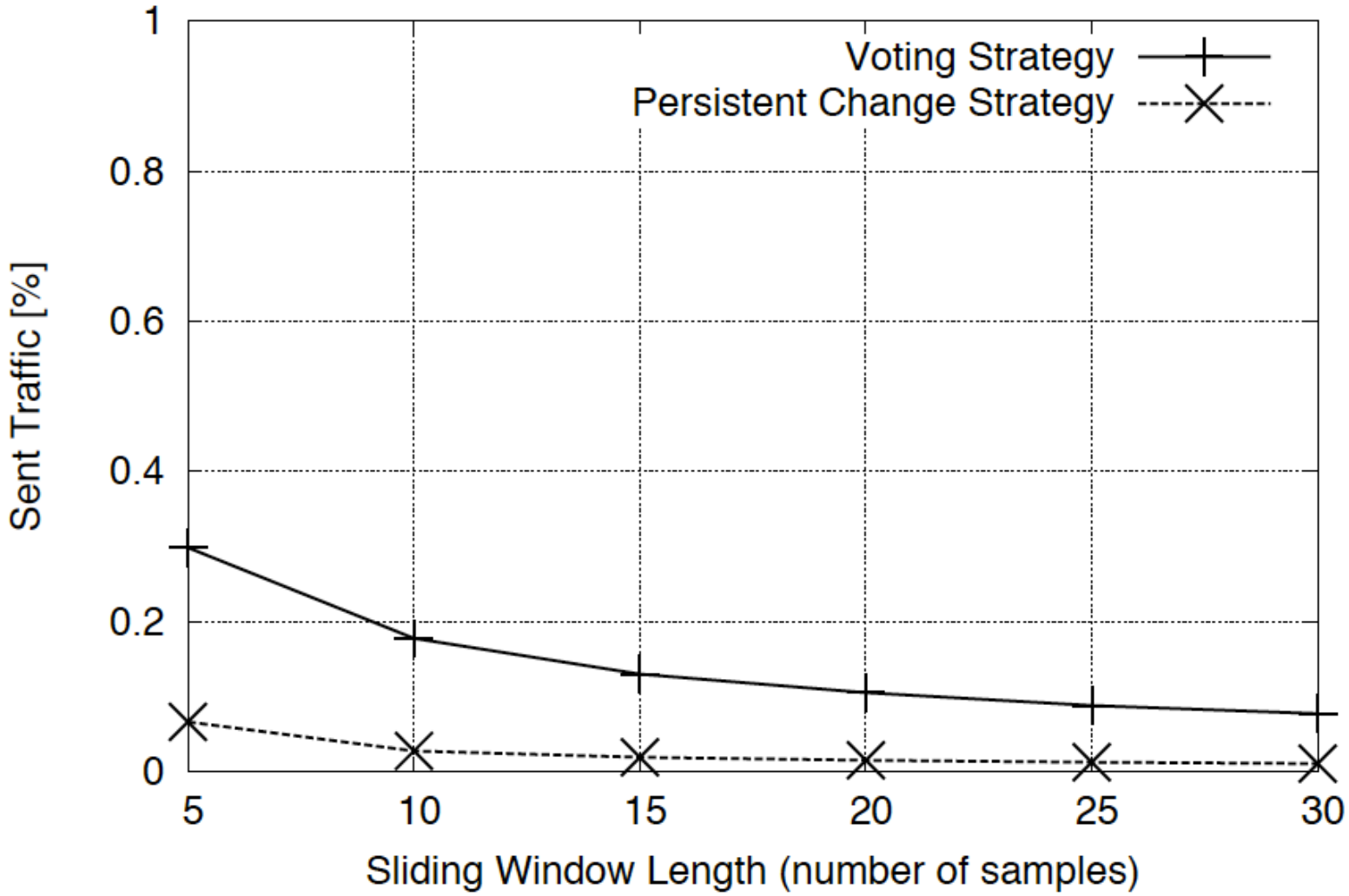
Phone activity classifier

Activity Representation Accuracy for Online Strategies



Percentage of Traffic Sent

[with respect to upload]



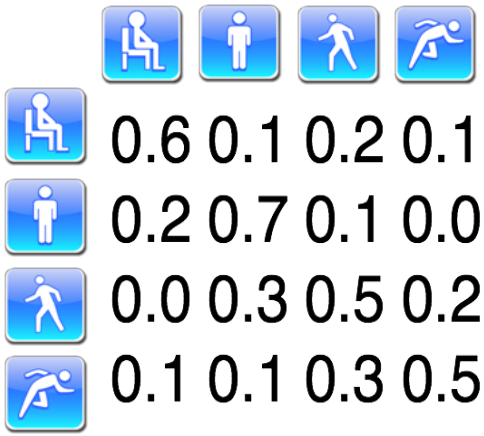
Offline Strategies: Markov Chain based Prediction

- In online strategies the back-end server is not involved in the process
- When the mobile device is disconnected from the Internet, the back-end can just make the last known state available or publish an *unknown state message*
- ***An alternative strategy is to try to forecast the next state during a disconnection***

Offline Strategies: Markov Chain based Prediction

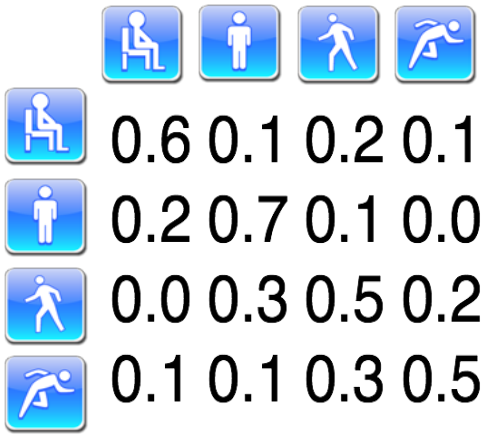
- Strategies used in presence of
  - continuous connectivity (voluntary disconnections)
  - but also intermittent (involuntary disconnections)
- Use of a **transition matrix** to model the sequence of the state changes on the server also during a disconnection from the mobile client
- Distributed decisions made on the phones
  - Back-end server not involved in the decision process

Transition Matrix



Used by the server to generate the sequence of the states when no fresh information is available

Transition Matrix



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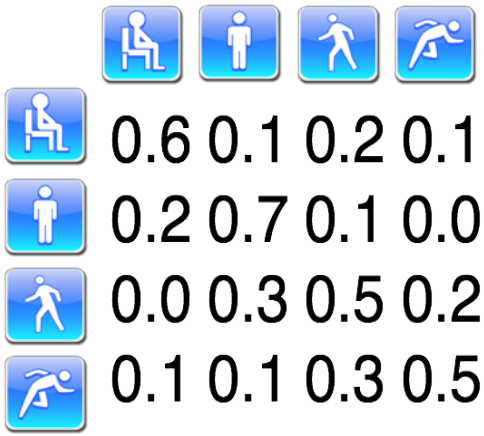
Transition Matrix



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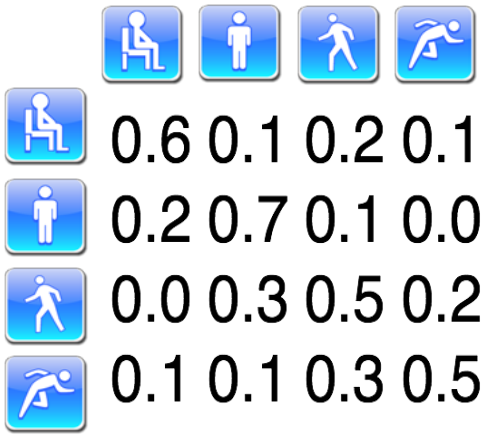
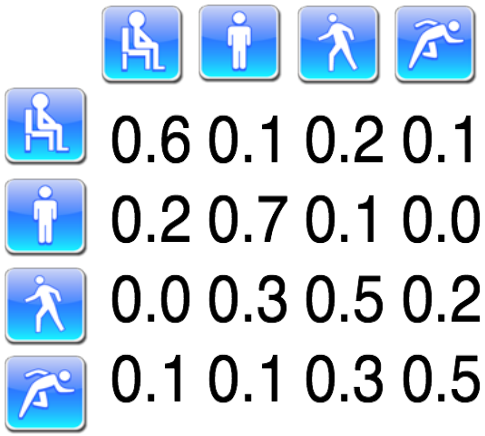
Transition Matrix



Used by the server to generate the sequence of the states when no fresh information is available

Transition Matrix



Used by the server to generate the sequence of the states when no fresh information is available

Transition Matrix Uploading Mechanism

M_{phone}

Run-time matrix

0.7 0.2 0.2 0.1
0.2 0.7 0.1 0.0
0.1 0.2 0.5 0.2
0.1 0.1 0.2 0.6

M_{server}

Server-side matrix

0.6 0.1 0.2 0.1
0.2 0.7 0.1 0.0
0.0 0.3 0.5 0.2
0.1 0.1 0.3 0.5

M_{server}

Server-side matrix

0.6 0.1 0.2 0.1
0.2 0.7 0.1 0.0
0.0 0.3 0.5 0.2
0.1 0.1 0.3 0.5

Phone keeps two matrices:
- its current estimation
- the current estimation of the server

Transition Matrix Uploading Mechanism

M_{phone} Run-time matrix

M_{server} Server-side matrix

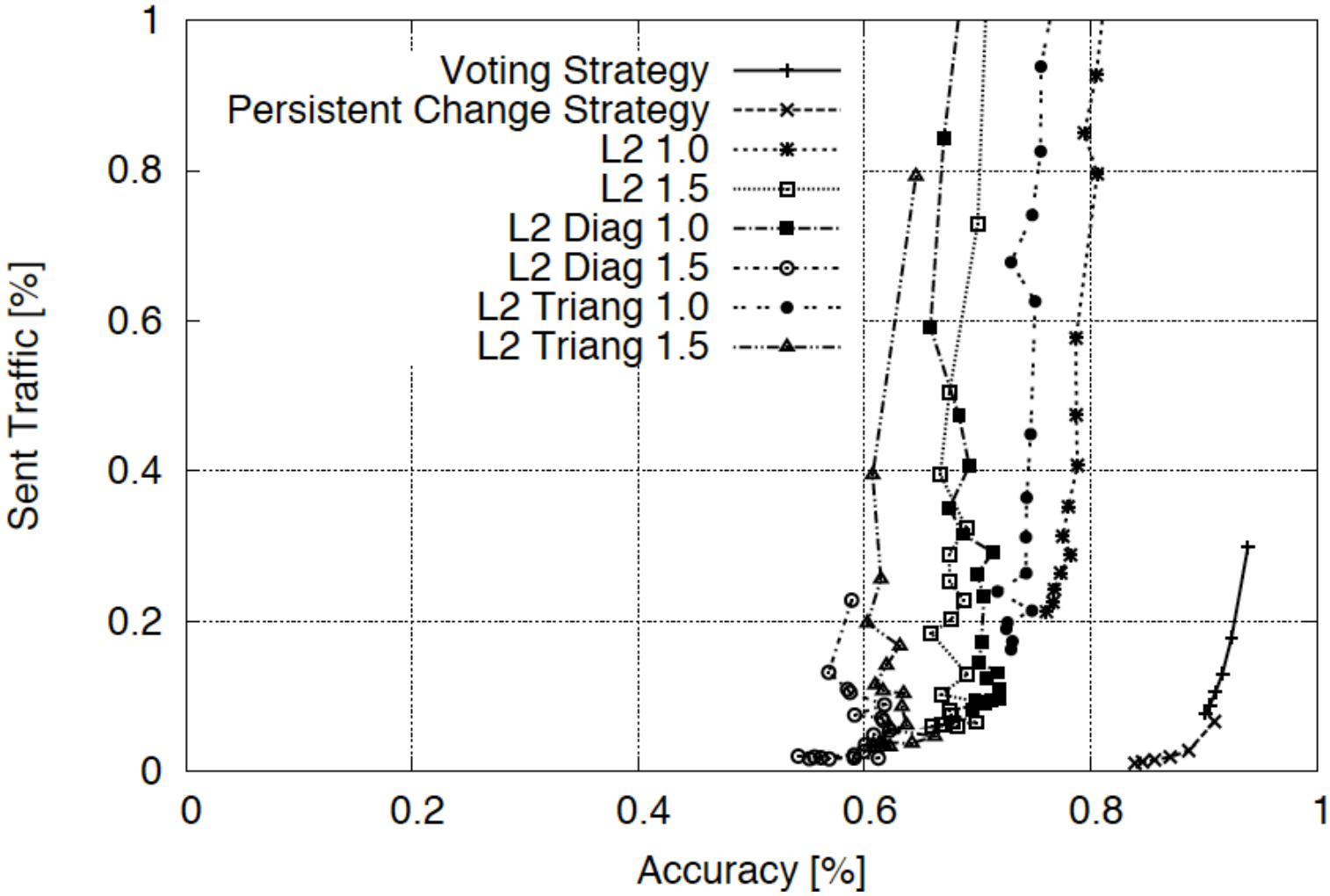
M_{server} Server-side matrix

$$L\left(\begin{matrix}0.7 & 0.2 & 0.2 & 0.1\\ 0.2 & 0.7 & 0.1 & 0.0\\ 0.1 & 0.2 & 0.5 & 0.2\\ 0.1 & 0.1 & 0.2 & 0.6\end{matrix}, \begin{matrix}0.6 & 0.1 & 0.2 & 0.1\\ 0.2 & 0.7 & 0.1 & 0.0\\ 0.0 & 0.3 & 0.5 & 0.2\\ 0.1 & 0.1 & 0.3 & 0.5\end{matrix}\right) > th \quad \begin{matrix}0.6 & 0.1 & 0.2 & 0.1\\ 0.2 & 0.7 & 0.1 & 0.0\\ 0.0 & 0.3 & 0.5 & 0.2\\ 0.1 & 0.1 & 0.3 & 0.5\end{matrix}$$

If and only if the *distance L* is greater than a certain threshold *th*, the matrix is sent to the server

[in the paper you can find a thorough analysis for different distance metrics]

Accuracy Vs Traffic Overhead



Questions?

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