Mobile Millennium
Using Smartphones as Traffic Sensors

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Outline

- Motivation
- System architecture for GPS-based traffic flow monitoring
- Velocity field reconstruction
- Towards disaster preparation, response, and recovery
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New platform for sensing civil infrastructure

- **Arrival of the mobile internet - The next big thing?**
  - Mobile devices outnumber PCs 5:1
  - 1.4 million devices per day (Nokia Q2 2008)
  - **Redefining the mobile market:**
    - Google, Apple, Nokia, Microsoft, Intel, IBM, etc.
  - **Open source computing:**
    - Symbian Foundation, Android, Linux

- **Smart phones open the door for**
  - Location based services
  - Context awareness
  - Mobility tracking

- **Sensing and communication suite**
  - GSM, GPRS, WiFi, bluetooth, Infrared, GPS, accelerometer, light sensor, camera, microphone

[Courtesy J. Shen, Nokia Research Center Palo Alto]
Field Operational Test: Mobile Millennium

- **Mobile Millennium is a field operational test**
  - Partnership between UC Berkeley, Nokia, Navteq Caltrans, and US DOT SafeTrip 21 initiative
  - Participating users download Mobile Millennium Traffic Pilot (available at [traffic.berkeley.edu](http://traffic.berkeley.edu)) on a GPS and java enabled phone
  - Phones **send and receive** live information on map application
  - Project duration at least 6 months
  - **Mobile Millennium is a precursor to a mainstream product**

- **Launch**
  - *Mobile Millennium was launched on November 10th 2009 from the UC Berkeley campus*
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Managing data quality through spatial sampling

- **Virtual trip lines**
  - Virtual trip lines are geographical markers which trigger a position and speed update whenever a probe vehicle passes.
  - VTLs provide location awareness -- critical for sensing.
  - Framework for managing data quality and privacy.

[B. Hoh et. al 2008]
Cyber physical system architecture

- **Sensing**
  - Crowd sourcing: millions of mobile devices as new sources for data
  - Sensor motion tightly coupled with underlying physical system

- **Communication**
  - Existing cell phone infrastructure to collect raw data and receive traffic information

- **Data assimilation**
  - Real-time, online traffic estimation

- **Privacy management**
  - Encrypted transactions
  - Client authentication
  - Data anonymization
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Mathematical formulation of the problem

- **Governing equation**
  - First order hyperbolic conservation law – *Lighthill Whitham Richards PDE:*
    \[
    \frac{\partial \rho}{\partial t} + \frac{\partial q(\rho)}{\partial x} = 0
    \]
    Initial condition:
    \[
    \rho(x, 0) = \rho_0(x)
    \]
  - Expresses conservation of density of vehicles on the road.
  - Shock (queue) capturing
  - Can be transformed into a stochastic velocity evolution equation:
    \[
    \theta_{k+1} = F_k(\theta_k) + w_k
    \]
  - Measurements are modeled with additive noise
    \[
    y^{(i)}_k = H^{(i)}_k \theta^{(i)}_k + \epsilon^{(i)}_k
    \]

- **Ensemble Kalman filter**
  - Model forecast
    - Velocity evolution is nonlinear, non-differentiable
    - Monte Carlo method to approximate the mean and error covariance
  - Measurement update
    - Kalman gain computed using the ensemble error covariance

[Lighthill-Whitham, 1955; Richards, 1956; Work, Tossavainen, Jacobson, Bayen 2009]
Highway Field Experiment: Mobile Century

- **Prototype System**
  - Run Feb. 8, 2008
  - Multi-lane highway with heavy morning and evening congestion
  - Ground truth: Loop detectors, HD film crew on bridges.
  - Rich data set for future traffic modelling and estimation research

![Map of San Francisco Bay with routes](image)

- 165 UC Berkeley Graduate Student Drivers
- 100 rental cars
- 70+ Support Staff
Revealing the previously unobservable

5 car pile up accident (not Mobile Century vehicles)

- Captured in real time
- Delay broadcast to the system in less than one minute

Estimate from cell phones

Estimate from inductive loops
Arterial Experiment: New York City

• **New York City Demonstration**
  – 3 mile loop, 20 cars with cell phones
  – Nov 17, 2008; 8:00-11:00am
  – Coincides with the 2008 Intelligent Transportation Systems World Congress
  – **Ground truth:** HD video cameras collect actual travel times of vehicles

• **Objectives**
  – Collecting data where there is no existing sensing coverage
  – Modelling arterial traffic without using detailed timing information from the 30+ signals
  – Defining usable metrics for arterial congestion
  – Study GPS performance in urban areas
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Seismic preparation, response, and recovery

- **Preparation**
  - Ubiquitous sensing. We are collecting data where there currently is none.
  - Data is useful for understanding and modeling traffic patterns on surface streets
  - Invaluable planning tool

- **Response**
  - Mobile internet and Web 2.0 have tremendous potential as an information dissemination platform
    - How to leverage this potential?
  - After catastrophic event, will the monitoring infrastructure survive?
    - 5.6 magnitude earthquake in San Jose towers survived [SF Chronicle, 2007]
    - Networks fail because of congestion; Emergency systems need to be centered around SMS
      - Backup power mandate (FCC)

- **Recovery**
  - No need to deploy dedicated infrastructure. The system can come online as soon as the communication infrastructure is available
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Discussion

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