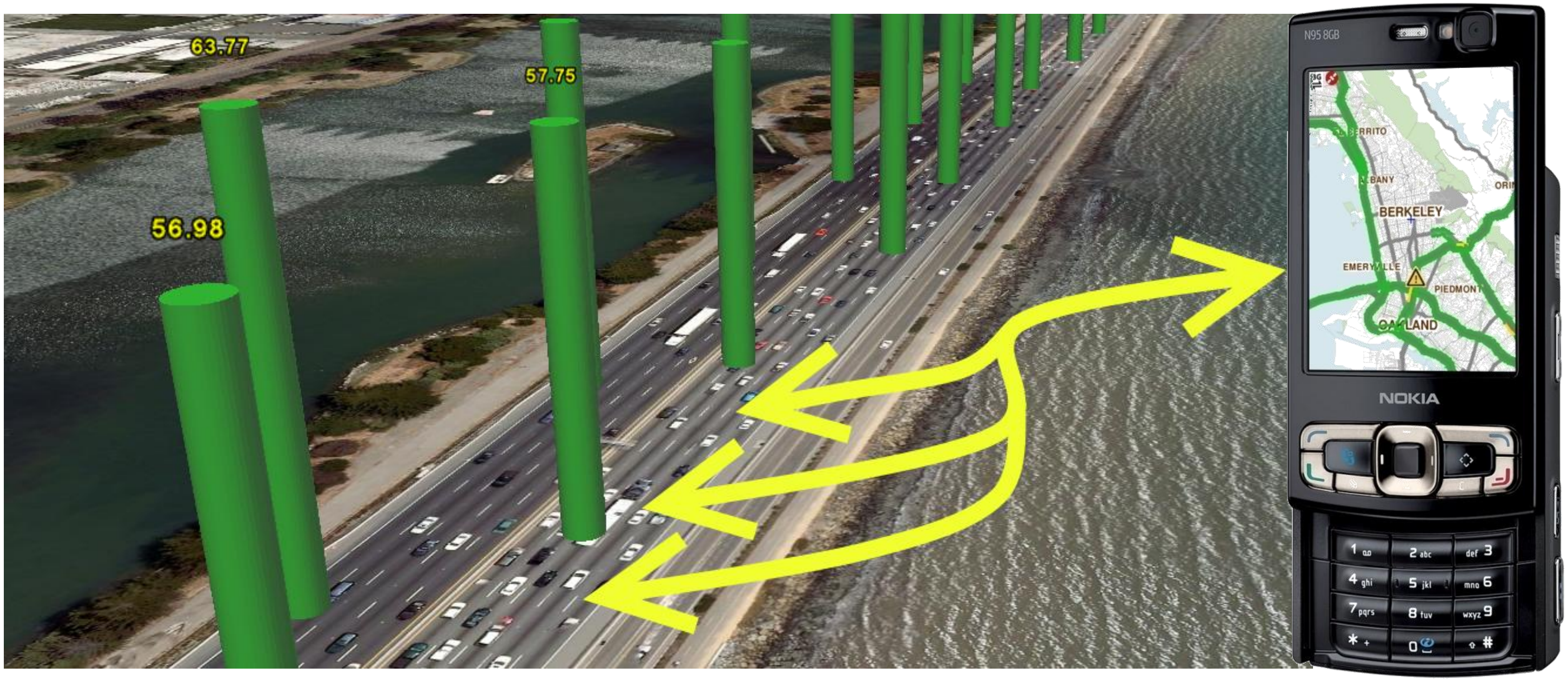
Mobile Millennium

Using Smartphones as Traffic Sensors

UC Berkeley



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NOKIA Connecting People · NAVTEQ · SafeTrip-21 Innovation for a Nation on the Move · Caltrans · institute of transportation studies ITS · california center for innovative transportation

Outline

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

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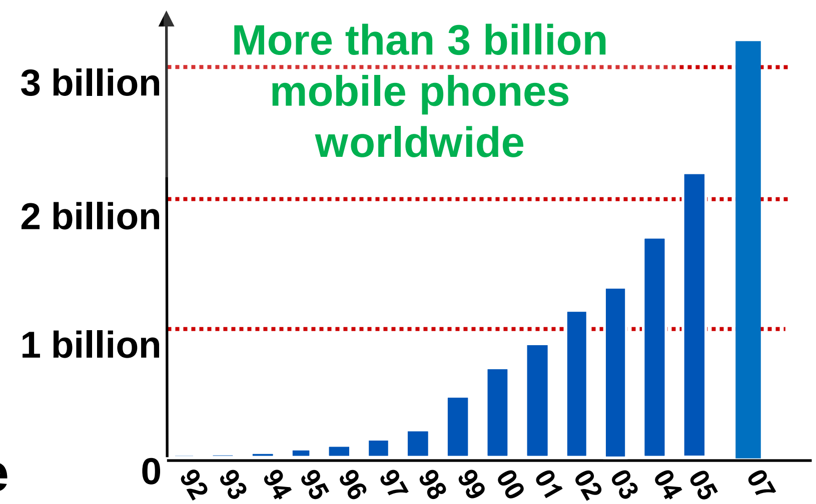
New platform for sensing civil infrastructure

- 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*) 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 10^{th} 2009 from the UC Berkeley campus**

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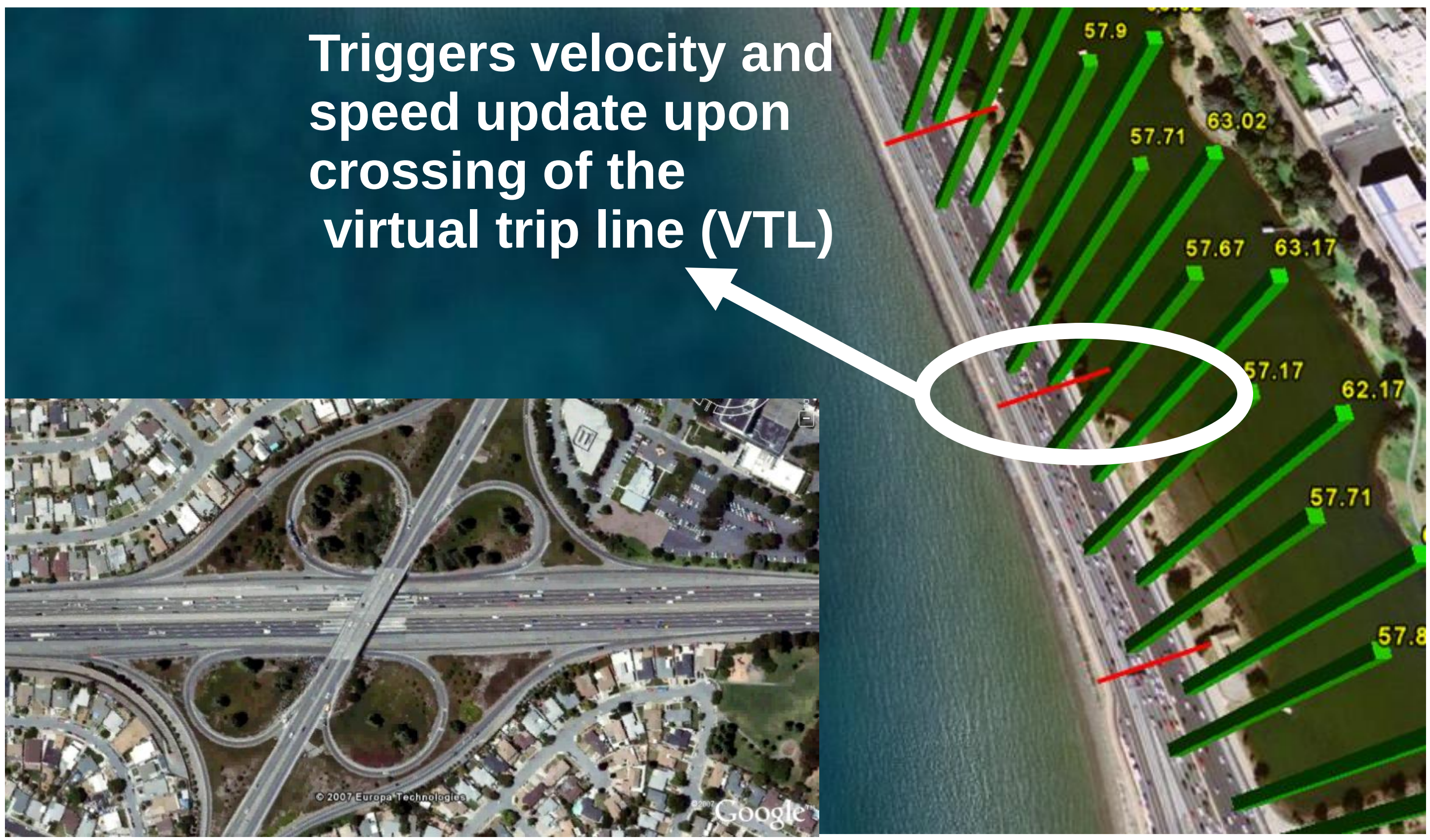
Managing data quality through spatial sampling

- **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.

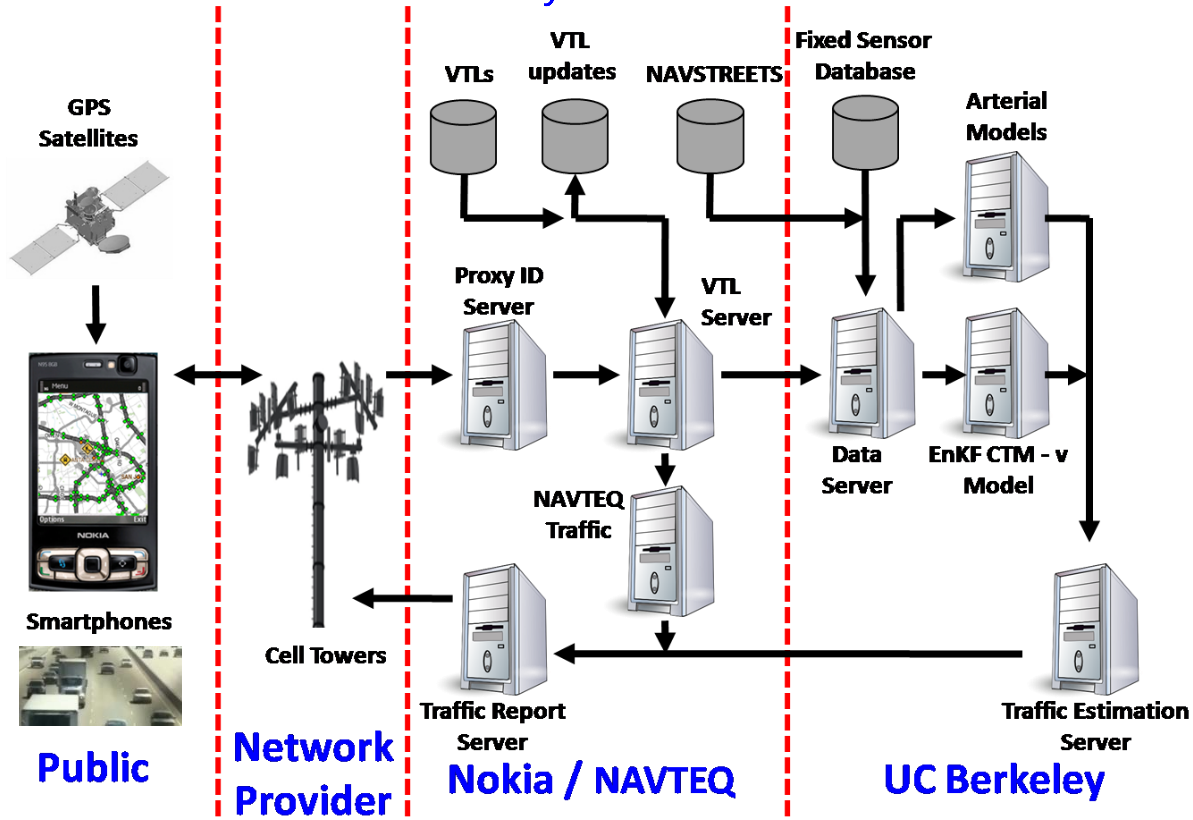


[B. Hoh et. al 2008]

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

Mobile Millennium system architecture



Data transmission

Data assimilation

Data generation, info distribution

Data aggregation

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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**

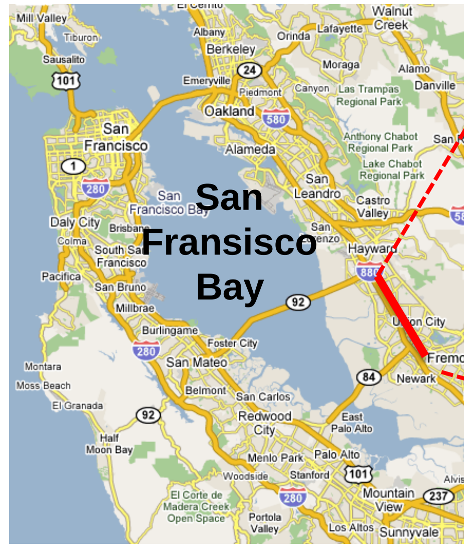
$$y_k^{(i)} = H_k^{(i)} \theta_k^{(i)} + \epsilon_k^{(i)}$$

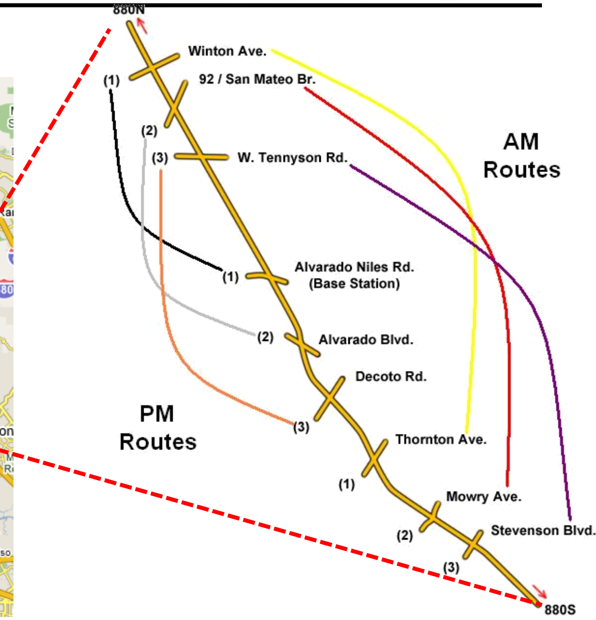
- **Ensemble Kalman filter**
  - **Model forecast**
    - **Velocity evolution is nonlinear, non-differentiable**
    - **Monte Carlo method to approximate the mean and error covariance**
  - **Measurement update**
    - **Kalman gain computed using the ensemble error covariance**

[Lighthill-Whitham, 1955; Richards, 1956; Work, Tossavainen, Jacobson, Bayen 2009]

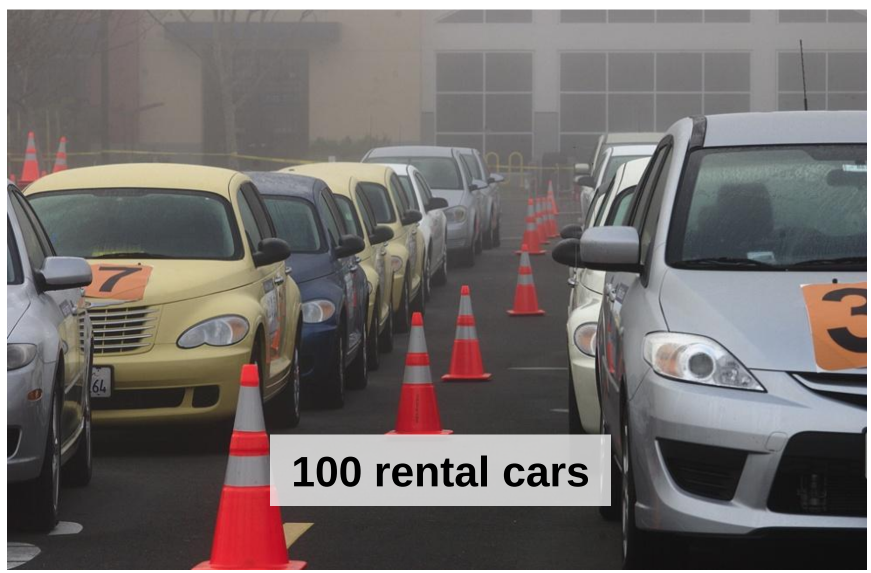
Highway Field Experiment: Mobile Century

- **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**






165 UC Berkeley Graduate Student Drivers


100 rental cars

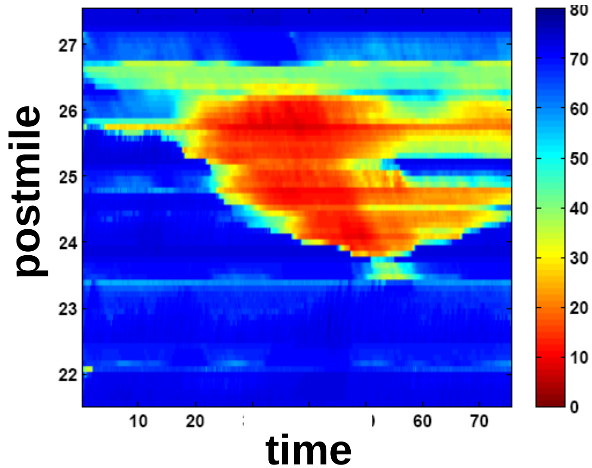

70+ Support Staff

Revealing the previously unobservable

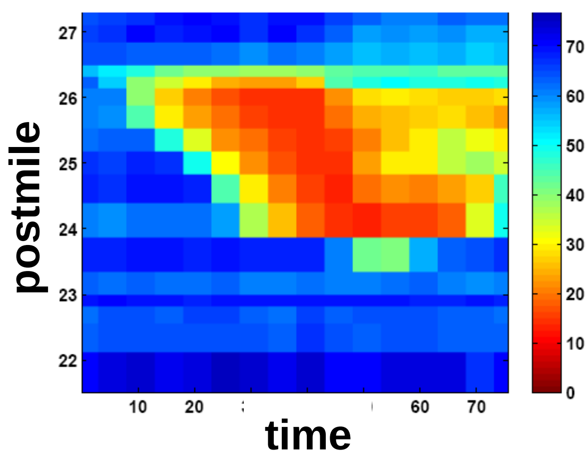
5 car pile up accident (not Mobile Century vehicles)

- 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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