Dynamic sensing policies for monitoring arterial road traffic

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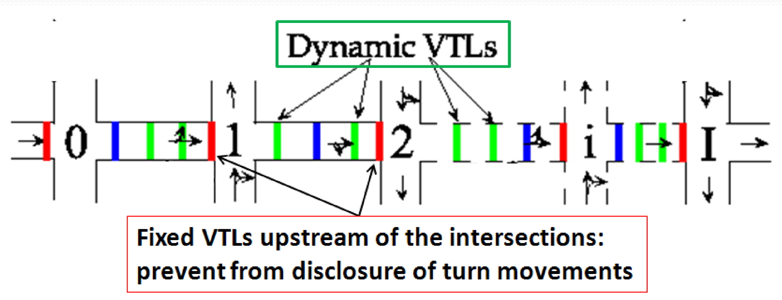
Arterial Traffic Estimation

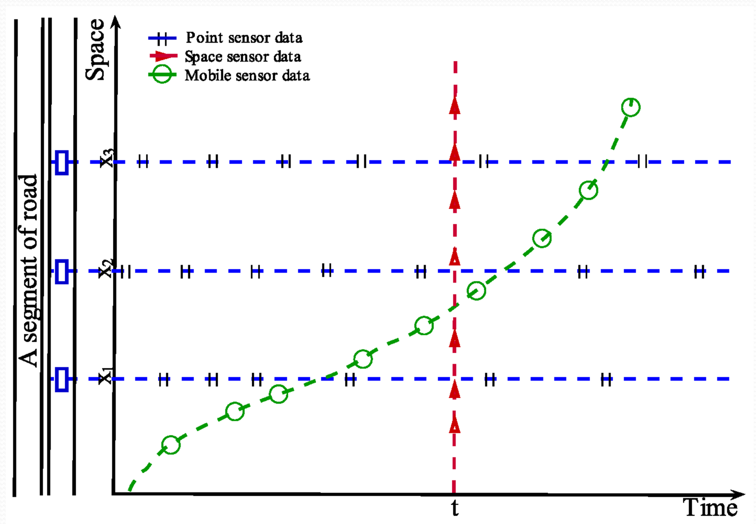
• **Participatory sensing** in privacy preserving environment: *Virtual Trip Lines* (VTLs) [1] are virtual markers embedded in the memory of the phone. This sensing paradigm provides travel time measurements at defined locations.

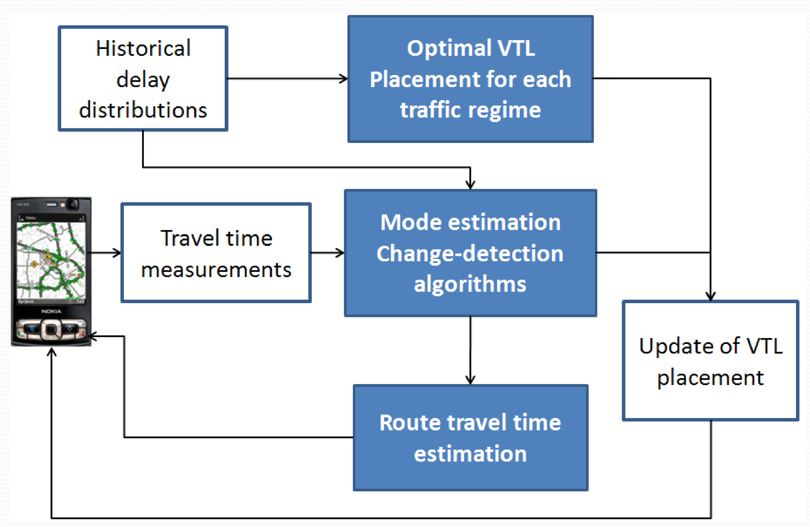
• On arterial networks, disclosure of **turn directions** is privacy sensitive.

➢ Design of an estimation scheme that does not need this information.



• Static VTL deployments do not take **full advantage of the mobility of probes**. A **dynamic placement of VTLs**, based on an interaction between the phone client and the backend server increases the value of the information sensed by the phone, by adapting it to the current traffic conditions.





Mode Detection

• Derive **conditional probability distributions** for link travel times given different discrete traffic regimes (representing level of congestion) and VTL locations.

• Define **optimal VTL location** for each traffic regime.

• Detect traffic regime for each link in the network.

➢ After a change is detected, update the VTL placement schemes to accurately estimate the delay patterns for the new traffic regime.

Algorithm:

• **Sequential hypothesis testing (SPRT)**

Threshold test on the cumulative likelihood ratio

$$S_0 = 0$$
$$S_{i+1} = \log \Lambda_i + S_i$$

$$\delta_N = \begin{cases} H_1 & \text{if } S_N \geq A_U \\ H_0 & \text{if } S_N \leq A_L \end{cases}$$

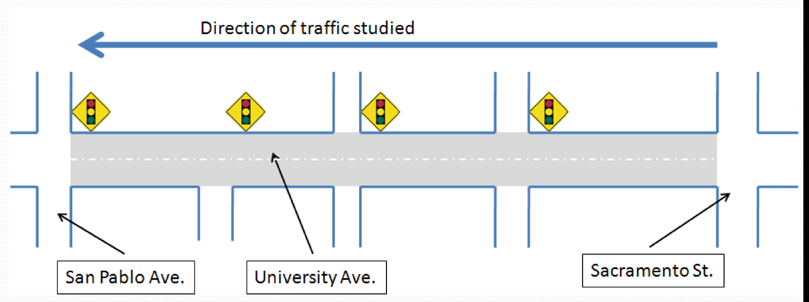
δ_N mode detected at measurement N

• **Quickest detection** or **mode change detection** using CUSUM statistics. The CUSUM statistics is updated when new measurements are available and mode change is detected when the statistics reaches a certain threshold.

Experiment Design and numerical results

• Field test data collected in Berkeley, CA. The network focuses on one major arterial road (University Ave.) for travel time estimation and adaptive VTL placement. The intersection with San Pablo Ave. causes recurring congestion.

• Simulation of VTL data from 3 second sampled trajectory data.



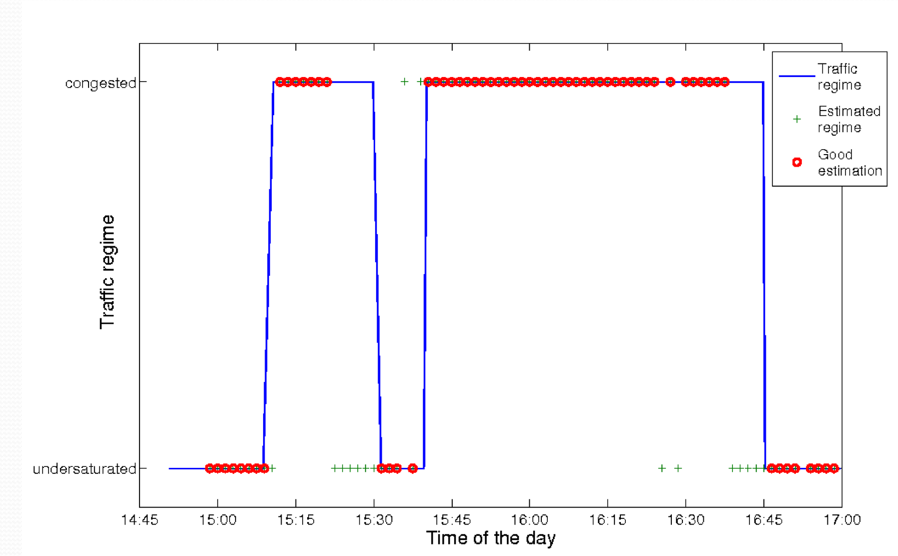
• For different VTL placements, estimate travel time distributions in different traffic regimes.

• Define optimal VTL placements for the different regimes.

• Mode estimation, VTL location update and route travel time estimation

• True regime detected more than 80% of the time. System robust against false alarms.

• Mean absolute route travel time error of 50 seconds (25%) on a route of length 1 km, mostly due to travel time variations.



Model and Sensing Process

• Arterial traffic flow modeled as a random process. Probability distribution of delay and route travel time parameterized by the sensing locations for different traffic regimes.

➢ VTLs location upstream of the maximum queue reach to observe the actual delay experienced by the vehicles.

• <u>Example</u>: single intersection under congested traffic conditions, the probability of measuring a delay *d* for a VTL placed at location *x* is

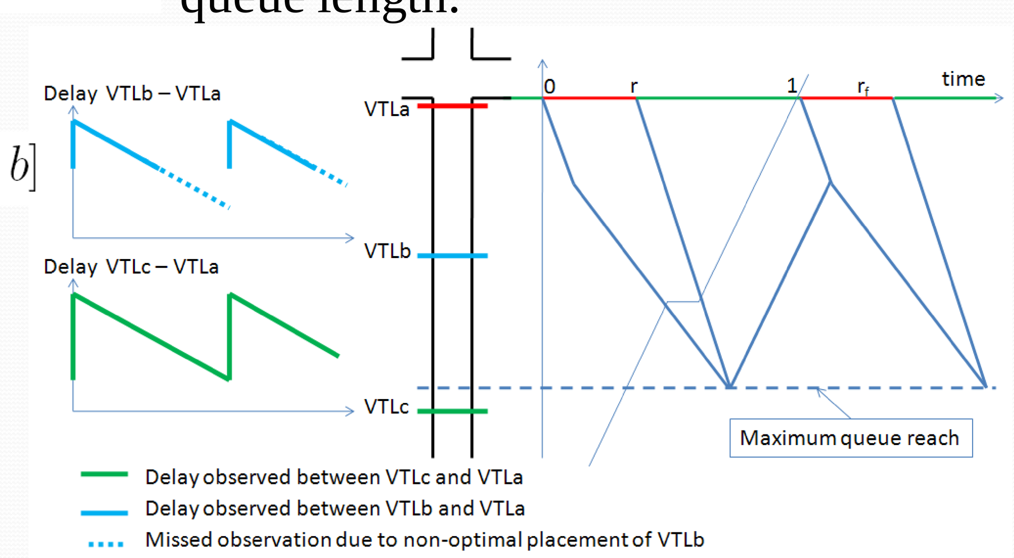
$p(d|x) = \mathcal{U}(d_{\min}, d_{\max})$ if the VTL is located before the queue length (independent of the location),

$p(d|x) = \mathcal{U}(d_x, d_{\max}),\ d_x > d_{\min}$ if the VTL is located beyond the queue length.

$\mathcal{U}(a, b)$ uniform distribution on $[a,\ b]$

$d_{\min}$, $d_{\max}$ minimum (resp. maximum) delay experienced

d_x minimum delay measured for a VTL located at *x*



Privacy and Dynamic Sensing

• **Privacy aware sensing architecture**:

– Probe vehicles generate travel time updates, send to the ID proxy

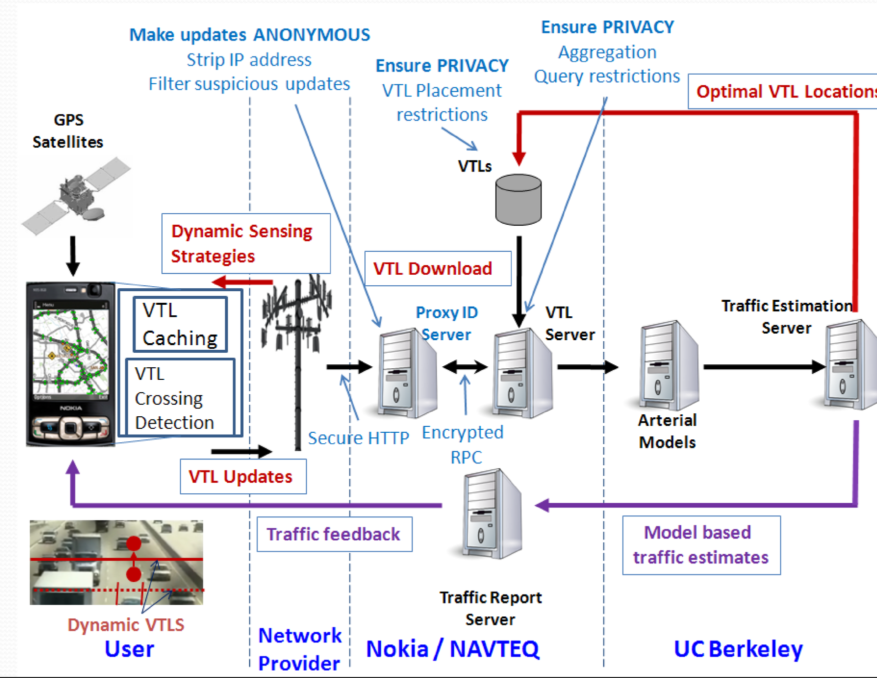
– ID proxy anonymizes the measurements and forwards to the VTL server

– VTL server aggregates measurements from numerous probes and forward to the traffic estimation server

– Traffic estimation server computes route travel time distributions and estimates traffic regime. Send travel time estimations and change of VTL locations request if traffic regime has changed

– VTL server then ID proxy send travel time estimations and updated VTL locations to the probes.

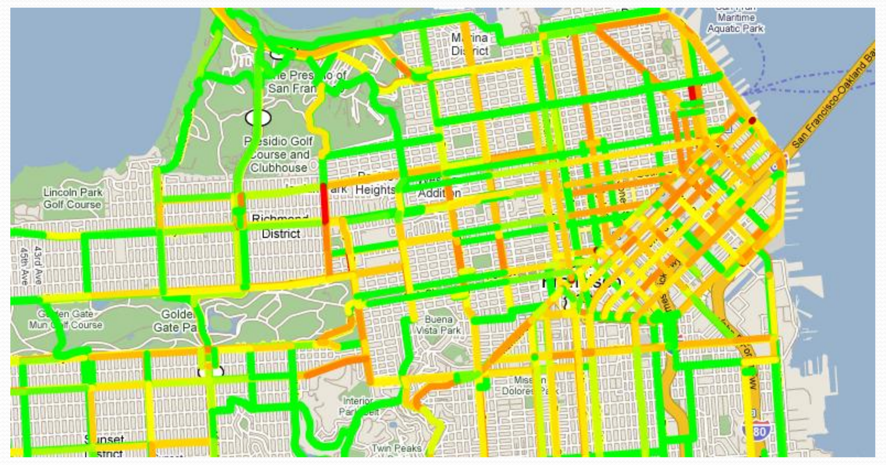
• **No turn movements disclosure**: Downstream VTL located just before the intersection increases privacy awareness of the system. No loss of information if the intersection is not illegally blocked.



Future Directions

• Probe vehicle data is optimized by taking **advantage of the full mobility of probes**.

➢ Generalize to sensing locations chosen in real time by the phone in interaction with the backend server. (no predefined VTL locations). Traffic statistics updated accordingly.



Mobile Millennium traffic visualizer

➢ New sensing strategies: "**stop and go**" sensing. Probes report information when they stop or start driving.

Related work

[1] B. Hoh, M. Gruteser, R. Herring, J. Ban, D. Work, J-C Herrera, A. M. Bayen, M. Annavaram, and Q. Jacobson. Virtual trip lines for distributed privacy-preserving traffic monitoring. In *MobiSys '08: Proceeding of the 6th International conference on Mobile systems, applications, and services*, 2008.

[2] A. Krause, E. Horvitz, A. Kansal, and F. Zhao. Toward community sensing. In *Proceedings of ACM/IEEE International Conference on Information Processing in Sensor Networks (IPSN)*, 2008.