Closing the loop between traffic/pollution sensing and vehicle route control
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The Vision: Our planet has become more urban than rural in the last decade. Urban traffic has increased dramatically, making driving more stressful, costly, and unhealthy. According to the Texas Transportation Institute, the overall cost of metropolitan traffic congestion (in terms of wasted fuel and lost economic productivity) in the U.S. topped $87 billion in 2007, more than $750/year for every U.S. traveler. Our vision is to use modern wireless technology, environment monitoring, and urban traffic management to "close the loop" between urban sensing, traffic manager and vehicle route/speed enforcement with the aim of simultaneously reducing congestion, pollution, and traveler delays. The pivotal elements in this loop are: the on board sensing platforms (eg, GPS, chemical sensors, video sensors, etc); the road side traffic managers/enforcers (eg, "intelligent" traffic signal, Road Side Units); the traffic management center (Navigator Server, City Traffic manager, DoT Center); the on-board navigator; the vehicle control knobs (breaks, accelerator, steering wheel) and; last but not least, the driver. All these elements are "connected" via wireless communications (DSRC, WiFi, WiMAX and 3G/LTE).

There are multiple interacting control loops in this system. At the highest level is the **urban traffic management loop**, operated and controlled by Navigator Servers and City Traffic Department. Traffic parameters and vehicular emission data are collected directly or indirectly by *vehicle sensors* (pollution, emission, position, OBD, CAN bus measurements, etc) and are fed periodically or "on demand" to Road Site Units, Infrastructure Servers and Traffic Controllers. The *Central traffic controllers* simulate traffic conditions, air pollution models and calculate *traffic restrictions, prescriptions and incentives.* They broadcast traffic advisories, routings, and restrictions to *Road Side Enforcers* (traffic signals, access ramps) and to *on-board navigators*. The *on-board navigators* use traffic information and incentives to calculate and offer to the *driver* speed and route advice, taking into account drivers' preferences and style. Finally, at the end of the loop, the *driver* evaluates the navigator prescriptions and uses his/her judgment to select the path that complies with enforcements and minimizes time and cost.

Besides the comprehensive management of urban traffic, the interaction between vehicles and infrastructure is required also at lower layers to establish **smaller time scale control loops** such as intersection crash avoidance, optimal speed selection in a green wave corridor, optimal engine idling at traffic lights based on predicted wait, etc. The efficacy and safety of all these control loops is guaranteed by reliable vehicle to roadway infrastructure communications, from 3G channels to DSRC radios (roadside and on-board) that enable real-time, low cost, scalable information exchanges among the various architecture components.

Current State of the Art: Today, a broad spectrum of largely disconnected solutions are in place alleviate traffic congestion. At one end, there are system-centric solutions, such as coordinated, dynamic traffic signal timing and control. At the opposite end, there are vehicle-based solutions such as on-board navigators, which offer "optimal" routing options to drivers, unaware of any external constraints. As a result, on-board navigators provide little help to drivers in calculating accurate driving times or determining fastest routes through a city, since such route planning critically depends on real-time, fine-grained information like signal timings and vehicle speeds that is not presently available to navigators. Moreover, current navigators completely ignore emissions effects and, therefore, are of little use in environmental planning. Congestion pricing, which aims to link the demand for travel with road capacity via variable priced tolls, has long been touted by economists, but in the absence of adequate vehicle monitoring and toll collection techniques it has been impractical to implement.

Proposed Approach: Our overarching goal is to connect existing solutions via state-of-the-art communications, networking and "intelligence" to provide efficient, coordinated real-time traffic and air quality control. To achieve this goal, we propose to address several challenges that relate to the topics mentioned in the CFP of the workshop.

The First Challenge is the development of an ***Open Experimental Platform*** that enables experimentation with communications, controls and user behavior in representative case scenarios. At UCLA we have developed a Vehicular Campus Testbed equipped with:

(a) A dozen Facility Vehicles driven by Campus staff and roaming from 8AM to 5PM to provide services across Campus. The vehicles are equipped with WiFi, WiMAX and 3G radios.

(b) Six WiFi Access Points connected in a roof top mesh network. The APs enable remote experimenters to access Vehicular Testbed. They also support V2V communications when the VANET connectivity is intermittent.

(c) Two WiMAX base sta/tions to extend the range of the WiFi access points; to permit handoff experiments (to alleviate WiFi load) and; to provide broad scale broadcast service

The Campus testbed will enable several important experiments. In particular, it will allow us to test the efficacy of V2V communications for intersection crash avoidance. This is an important example of ***Safety case specification, modeling, and analysis*** mentioned in the CFP. The issue at hand is to determine to what extent V2V communications can help prevent crashes, providing sufficient advance warning to drivers. We have developed an accurate propagation model (the Corner model) for radio waves that propagate around corners. The testbed can be used to determine at what speed and with what transmit power two vehicles on a collision course can detect each other within drivers' reaction times. The results of this experiment can be used to determine an optimal policy for "increasing" transmit power at blind intersection when the risk is high (eg, at night, with rain, snow etc). Another strategy that we intend to test is the use of WiFi and WiMAX stations to relay the warning signals across the intersection if transmit power increase alone is ineffective.

A Second Challenge is the development of ***models for individual vehicles, groups of vehicles, traffic flow, and road infrastructure*** that can be used to develop optimal routing strategies, alleviating traffic congestion during peak hours. Recall that the central traffic controller receives traffic and pollution data from vehicles and infrastructure elements; it creates a picture of current urban congestion and pollution using the above vehicular models and the sensor inputs. Using flow optimization techniques the controller computes the best (re)route strategies and dispatches routing information and positive or negative incentives to vehicles. Intelligent traffic signals assist the traffic center in the implementation of the global traffic plans by broadcasting traffic instructions to vehicles in their respective areas. In addition, they locally adjust timing, and compute and broadcast traffic light state for vehicles approaching them. On board navigators use this information to choose the best route that accounts for navigation costs/credits, driver's goal and road constraints.

In such comprehensive traffic optimization we must not forget that the last link in the control loop are the drivers. Thus, a Third Challenge, as the CFP points out, is the ***Human operator behavior and modeling***

(human-in-loop). User cooperation is key to the success of any vehicular control scheme. Some of the drivers may not subscribe to the Navigator service. Other may just ignore the Navigator recommendations. In our preliminary simulations we have observed that significant congestion alleviation benefits are derived even if only 30% of the drivers comply with Navigator advice. Future work will investigate the impact of incentives and penalties to encourage compliance. To evaluate these effects, we plan to examine existing open source vehicular traffic traces (eg, from Open Street or Crawded data bases), correlate them to prevailing traffic conditions and extract user behavior statistics.

Finally, an important challenge in urban traffic management is ***pollution modeling***. Pollution is non-uniformly distributed, being on average higher in close proximity to roadways, but widely variable on time scales of hours. This can change exposure levels dramatically. Pollution levels near roadways depend on traffic density, vehicle speeds, congestion and local wind speeds and direction. More precisely, air pollution can vary on length scales of tens of meters for some pollutants, but the distribution of pollutants on this scale is poorly characterized due to lack of spatially resolved measurements. The spatial heterogeneity arises from the interplay between the complex topography, the variable atmospheric mixing and the highly non-homogeneous emissions. Thus, the potential for mapping of pollutants with high spatial resolution via sensors integrated into a smart traffic sensing system is largely untapped, and will likely produce insights beyond those currently available. This will go a long way toward developing more accurate models, which will be exercised in real time to provide input for traffic control.

Credentials:. **Mario Gerla** is a Professor of Computer Science at the University of California, Los Angeles (UCLA). He has been Co PI on the NSF WHYNET project, which developed a "constellation" of models, simulation tools and geographically distributed testbeds addressing advanced radio and physical layer environments. WHYNET project offered an embryonic form of vehicular testbed, which was later expanded into the UCLA Campus Vehicular Testbed (C-VeT). **Giovanni Pau** is a Research Scientist in the Department of Computer Science at UCLA. His interests are in the areas of vehicular computing, mobile computing and distributed systems. He is a member of the Vehicular Lab at UCLA, which is building CVeT. **Suzanne Paulson** is a Professor of Atmospheric Chemistry in the Department of Atmospheric and Oceanic Sciences at UCLA. Her research interests are in the area of atmospheric chemistry of aerosols, climate impacts, health impacts and formation. **Liviu Iftode** is a Professor of Computer Science at Rutgers University. His research interests are in the areas of mobile, pervasive, vehicular and social computing. Dr. Iftode has been the PI of several NSF grants including a CAREER, a medium ITR on cooperative computing for distributed embedded systems and a NeTS grant on vehicular computing systems. .As early as 2004, he proposed and prototyped TrafficView, one of the first university projects in the area of vehicular computing, which used car-to-car communication to allow driver to see the traffic ahead. **Badri Nath** is a Professor of Computer Science at Rutgers University. As part of the Dataman Group, he led the research in mobile and wireless computing resulting in several protocols in wireless and sensor networks such as I-TCP, APS and AoA.