Technical Document on Vehicular Networks

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GENI: Global Environment for Network Innovations

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Note to the reader: this document is a work in progress and continues to evolve rapidly. Certain aspects of the GENI architecture are not yet addressed at all, and, for those aspects that are addressed here, a number of unresolved issues are identified in the text. Further, due to the active development and editing process, some portions of the document may be logically inconsistent with others.

This document is prepared by the Wireless Working Group.

Editor:

Mario Gerla, *UCLA*

1. Introduction

Vehicular communications are becoming a reality, driven by navigation safety requirements and by the investments of car manufacturers and Public Transport Authorities. Safe navigation support through wireless car to car and car to curb communications has become an important priority for Car Manufacturers as well as Municipal Transportation Authorities and Communications Standards Organizations. New standards are emerging for car to car communications (DSRC and more recently IEEE 802.11p). There have been several well publicized test-beds aimed at demonstrating the feasibility and effectiveness of car to car communication safety. For instance, the ability to rapidly propagate accident reports to oncoming cars, the awareness of unsafe drivers in the proximity and the prevention of intersection crashes.

The availability of powerful car radios, and of abundant spectrum (when not used for emergencies) will pave the way to a host of new applications for the Vehicle Grid (V-Grid). These emerging applications span many fields, from office-on-wheels to entertainment, mobile Internet games, mobile shopping, crime investigation, civic defense, etc. Some of these applications are conventional "mobile internet access" applications, say, downloading files, reading e-mail while on the move, etc. Others involve the discovery of local services in the neighborhood (ex, restaurants, movie theaters, etc) using the vehicle grid as Peer to Peer network. Others yet imply the close interaction among vehicles such as interactive car games.

To support the more advanced services, a new brand of functions must be deployed such as maintenance of distributed indices, creation and "temporary" storage of sharable content, "epidemic" distribution of content and index. Examples include the collection of "sensor data" by cars as seen as "mobile sensor platforms", the sharing and streaming of files in a Bit-torrent fashion, and the creation/maintenance of massively distributed data bases with locally relevant commercial, entertainment and culture information (eg, movies, hotels, museums, etc). Typically, these applications are distributed and follow a P2P collaboration pattern.

Why are vehicular testbeds and experiments important within the GENI framework? The main reason is that emerging vehicular applications, either safety oriented or P2P based, will pose a host of completely new requirements to the Internet in terms of traffic control and mobility management. The experimental testbeds will be critical for the identification and investigation of the Internet network and transport functions needed to support these new applications. Two modes of operation of the Vehicle Grid are anticipated. In the self-standing mode, the basic V-Grid protocols must be entirely self-supporting (no help from infrastructure). This mode is important for emergency operations, where the infrastructure has completely failed (say, natural disaster, terrorist attack, etc). In normal operations, however, the infrastructure will be accessible most of the time. The second scenario of interest, the infrastructure mode, assumes that urban and suburban networks (eg, Mesh, WiMAX, 3G, 4G, etc) are available and in fact must be exploited for efficient day-by-day operations.

To properly test these new vehicular applications, to understand their impact on the Internet "stack" and to evaluate various alternative Internet solutions we are proposing that a Vehicle Testbed module be part of the GENI program. As mentioned earlier, the vehicular testbed will interwork with urban (eg, Mesh networks) and suburban (eg, 3G, 4G, cognitive radios etc) network infrastructures. Moreover, the vehicular testbed will interwork also with urban sensor environments. In fact, vehicles can be instrumented and made to behave like "moving sensor platforms", collecting and processing various forms of sensor data. In applications involving navigation safety it will behoove to share data and resources across the two systems – vehicle grid and infrastructure. To facilitate the study of the interaction of the Vehicle Grid with urban, suburban and sensor environments, it will be opportune that the Vehicle Grid testbed be co-located with the latter testbeds.

When the vehicle grid meets the Internet, an important design issue is the interfacing of Internet and vehicular addresses. The current Internet and the emerging Vehicle Grid seem to differ in addressing philosophy, as the latter is likely to use geo routing, as opposed to the conventional table driven Internet routing, and therefore will adopt geo location as routable address. This experiment will investigate the issue of consistent addressing and transparent geo-routing when vehicles communicate with each other across the Internet. Related to addressing is the maintenance of a vehicle geo-location service both in the Internet and in the V-Grid. One option to explore is the implementation of a "vehicle overlay" within the wired Internet. Another important function to be provided by the infrastructure is the dynamic estimation of the path quality from Internet servers to vehicles as well as the more general monitoring of congestion in the wireless V-Grid. Finally, the Internet might be called to assist the vehicular network in the security domain (ie, access control, private data delivery, protection against attacks).

An effective vehicular testbed will require a campus or city-wide deployment with 10s to 100s of vehicles. Vehicles (e.g., private cars, campus shuttles or buses) will be equipped with radios, ranging from conventional systems (WiFI, 802.11p, 3G, Bluetooth); next generation (MIMO, cognitive radios, etc); and programmable radio kits. The vehicles will be equipped with sensors, such as GPS, video cameras, acoustic sensors, on-board sensors, and environment monitoring. Capabilities such as sensed data storage, filtering and processing (for automatic event detection) can also be added to support services such as license plate identification and driver's voice recognition. More generally, vehicles will be equipped with a data server and harvester to classify and store events as well as run P2P applications (eg, cooperative download; epidemic dissemination; forensic data search, etc.). The "fixed infrastructure" counterpart in this testbed will include a rooftop/curb/intersection/highway mesh of access points enabling access to the Internet. Further, this experiment will benefit from a vehicle overlay in a campus network setting, in order to experiment with infrastructure support functions for the vehicle network (e.g. mobility management, transparent geo-routing, congestion control, access authorization and control, security enforcement, prevention of denial of service attacks, and; monitoring, measurements and coordination of experiments). A simulator that allows to validate the testbed measurements and experiments; and to scale the experiments to very large populations (well beyond the 100's of cars in the testbed) will also be valuable. A hybrid emulation capability (that interconnects the real car testbed with a simulated environment) is desirable. Also needed is a "radio channel" emulator that can reproduce the vehicle radio channel in various conditions (urban, rural, traffic congestion etc), and that can scale to hundreds of interfaces. In addition, there will be experiments involving real cars/drivers to extract realistic mobility pattern behavior (this activity will leverage existing – and properly sanitized - urban traffic data bases).

In terms of scientific value, the vehicle grid experiment will enable experimental validation of previously developed protocols and established theoretical results, as well as the uncovering of new trends that might lead to new theories and new protocols. In particular, the experiments will include:

- Radio and MAC layer performance assessment (eg, download/upload capacity at Infostations at various speeds; car to car achievable data transfers). These measures will be carried out in various representative environments (say, car to car and car to curb). They are critical to determining the viability of all vehicular applications.
- Efficient use of the multiple 802.11p channels (control and data; prioritization of channels and data, etc); coexistence of critical and infotainment traffic.
- Virtualization of the processors and radios in the Access Points, to allow multiple experiments (with different PHY/MAC protocols) to coexist in the testbed. To this end, the vehicle testbed will leverage the GENI Programmable Wireless Kit (PWK) program.
- Traffic and Mobility models; experimental validation. Since the performance of most vehicle applications (especially those dependent on some form of dissemination – eg, epidemic dissemination) depends critically on vehicle density, motion pattern and radio channel characteristics (all of which may be correlated) the testbed must reproduce realistic urban/rural traffic conditions. One of the goals of the vehicular testbed will be to develop and make available to customers a range of representative, synthetic models of motion, channel and traffic that can be validated through actual urban measurements and can be implemented in the testbed.
- Network protocol design and testing; new network protocols will be required by the emerging applications (eg, epidemic dissemination, scoped broadcast, redundant forwarding control, multihop routing, network coding, congestion control, etc); the testbed will allow evaluation of such applications in different traffic/motion/channel scenarios. It will also allow comparison of "competing" schemes using a consistent, controlled environment (possibly, side by side, on the same set of vehicles using virtualization).
- Applications development and testing, including safe navigation (e.g., vehicle monitoring, accident warning; intersection collision prevention; traffic monitoring), health alerts, environmental warnings, "blue corridors" for emergency vehicles, forensic, homeland security, civilian and commercial applications (i.e., environmental or commercial purposes), P2P applications (e.g., content downloads; entertainment; games), and interaction with urban sensor deployments.
- Mobile sensor platform management, including mobile sensing hardware and software architecture design/development, efficient management of mobile sensor database (each sensor has 100s gigabytes of storage), continuous multimedia stream management (for both safety and infotainment), efficient data retrieval/harvesting from the mobile sensor platforms (e.g., epidemic data dissemination), and delay-tolerant/real-time query processing over mobile sensor platform (each vehicle becomes a database engine) and query routing protocols.

On a broader scope, the vehicular testbed will have impact on the future Internet architecture by influencing what services should be provided by the urban (Internet) infrastructure. These include services interfacing vehicle addressing/routing (eg. georouting) with other addressing /routing, services for transparent interconnection of vehicles across the city via the future Internet, geo location services in the infrastructure and in the vehicle grid, services allowing the vehicular network to operate with and without infrastructure support, and services providing smooth transitions.

At the national and international level the vehicular testbed initiative within GENI will allow US academic researchers to interface and harmonize with on going Industry lead projects, both in the US and internationally (e.g., CALM, C2CCC - Car-2-Car Communications Consortium, ASV-3 – Active Safety Vehicle forum, etc.), that address vehicular communications and their interworking mesh networks and infrastructure.

2 GENI Urban vehicular communications testbed: from scenarios to experiments and requirements

I. The scenarios:

1. Navigation safety: wireless car to car and car to curb communications to rapidly propagate unsafe road conditions, accident reports to oncoming cars, unsafe drivers in the proximity and imminent intersection crashes.
2. Location aware resource discovery and entertainment: local services in the neighborhood (ex, restaurants, movie theaters, etc); cooperative file downloading; creation/maintenance of massively distributed data bases with locally relevant commercial, entertainment and culture information (eg, movies, hotels, museums, etc); interaction among vehicles such as interactive car games.
3. Urban environment/traffic sensing: pollution, traffic, radiations, road conditions, etc.
4. Forensic investigations: use the massive data (mostly video/image) collected by vehicles to reconstruct the scene of an accident or crime
5. Vehicle grid as emergency communications network: when the urban infrastructure fails (earthquake, power outage, flood, terrorist attack, act of war), the cars still communicate with each other via ad hoc, multihop radios; they can maintain connectivity throughout the city – can support/guide also pedestrians fleeing the disaster area
6. Suburban disaster response: use of cognitive radios for emergency communications

II The need for experimentation

Most of the above vehicular scenarios are quite different from the conventional wireless scenarios (MANETs, Wireless LANs, Cellular infrastructure communications, sensor networks). In fact, the various applications described above include elements of each of the known scenarios, and add the elements of:

a. VERY LARGE SCALE

b. NETWORK TEMPORARY DISCONNECTIONS (when the network is sparse)
c. IMPAIRED PROPAGATION CHANNEL (obstacles, buildings, urban canyons, etc)
d. CLOSE INTERDEPENDANCE BETWEEN MOTION PATTERNS AND PERFORMANCE (eg, random 2-way motion models give results far from reality; need accurate traffic models)
e. INTERCONNECTION TO AND THROUGH THE URBAN FIXED/MOBILE INFRASTRUCTURE (Internet, mesh, WiMAX, satellite)

Another difference from other networks is the widespread availability of GPS coordinates and the prevalent use of Geo Routing (preferred to AODV and OLSR for scalability)

The radical differences between conventional wireless network settings and the vehicle grid suggest that it is not realistic to try and predict behavior via simulation only. One needs a testbed facility for large scale experiments, possibly assisted by emulation capabilities that include "real cars" in the loop. Enter GENI!

III. New Internet functionalities to be developed and tested in GENI:

1. Interfacing of Internet IP addresses and vehicular addresses: Vehicle Grid mostly uses geo routing; consistent addressing and transparent geo-routing when vehicles communicate with each other across the Internet.
2. Geo-location service both in the Internet and in the V-Grid. (eg, DHT overlay in the Internet and "mirrored" GHT (Geographic Hash Table) overlay in the V-Grid
3. Dynamic estimate of path quality from Internet to vehicles (over different media options – ad hoc, cellular, WiMAX, cognitive radios, etc)
4. Monitoring of congestion in the wireless V-Grid; access control
5. Internet security support of vehicles (eg, authentication, protection against attacks, etc).

IV GENI Proposed Experimental setup:

1. Campus/city-wide deployment (10s~100s vehicles)
2. Vehicles (e.g., private cars, campus shuttles or buses) equipped with:
   - Radios: conventional (WiFI, 802.11p, 3G, Bluetooth); next generation (MIMO, cognitive radios, etc); also Programmable Radio Kits
   - Sensors: GPS; video cameras; acoustic sensors; on board sensors; environment monitoring, etc.
3. Access Points: Rooftop/curb/intersection/highway/meshnetwork (gateways to the Internet)
4. Vehicle Overlay in the Campus Network infrastructure for Vehicle Grid support functions:
   a. mobility management, transparent geo-routing, congestion control, access authorization and control, security enforcement, prevention of denial of service attacks), and;

   b. monitoring, measurements and testbed experiments collection.
5. Simulator that allows to validate the testbed measurements and experiments;
6. A hybrid emulation capability (that interconnects the real car testbed with a simulated environment). Includes a “radio channel” emulator that can reproduce the vehicle radio channel in various conditions (urban, rural, traffic congestion etc), and that can scale to hundreds of interfaces.

Experimental Objectives:

Radio and MAC layer performance assessment (eg, download/upload capacity at Infostations at various speeds; car to car achievable data transfers).

Efficient use of the multiple 802.11p channels (control and data; prioritization of channels and data, etc); coexistence of critical and infotainment traffic.

Virtualization of the radio in the Access Points, to allow multiple experiments (with different PHY/MAC protocols) to coexist in the testbed. (Programmable Wireless Kit (PWK) program)

Traffic and Mobility models; experimental validation.

Network protocol design and testing; several new network protocols (eg, epidemic dissemination, scoped broadcast, redundant forwarding control, multihop routing, network coding, congestion control, etc);

Interfacing with the Internet infrastructure:

a. Coexistence of car to car channel with Mesh, WiMAX, 3G, 4G channels; smooth handoff across the available options
b. Interworking with the infrastructure to obtain support in mobility management, routing, traffic control, congestion control

Interfacing with environment sensor networks, to efficiently share sensor data and resources.