C-VET THE UCLA CAMPUS VEHICULAR TESTBED: INTEGRATION OF VANET AND MESH NETWORKS

Matteo Cesana†, Luigi Fratta†,Mario Gerla‡, Eugenio Giordano‡ and Giovanni Pau‡

† Dipartimento di Elettronica e Informazione, Politecnico di Milano, Italy
email: {cesana|fratta}@elet.polimi.it
‡ Computer Science Department, University of California Los Angeles, USA
email: {gerla|giordano|gpau}@cs.ucla.edu

ABSTRACT

Vehicular communications are becoming a reality under the push of increased transportation safety requirements and huge investments of several actors in the field like car manufacturers and Public Transport Authorities. As a consequence, the building blocks of the "Vehicle Grid" (radios, Access Points, spectrum, standards, etc.) will soon be in place enabling a broad gamut of applications ranging from automatic safety systems, intelligent transport, entertainment, urban sensing and environmental protection/monitoring. In this paper, we take a visionary look at "Vehicular Grid" and we argue that the cooperation of pure ad-hoc vehicle-to-vehicle communications and roadside infrastructure is fundamental to broaden the supported applications. The paper further describes the activities carried out at UCLA to deploy an open testbed integrating ad hoc vehicle-to-vehicle communications and a wireless mesh backhaul based on MobiMESH hardware/software solutions.

1. INTRODUCTION

Vehicular communications have been receiving increasing attention over the last ten years as a viable mean to augment road safety and travel eficiency. The field has consequently attracted consistent investments from auto manufacturers and public transport authorities, further stimulating academic research. We have reached now a situation where the essential building blocks of vehicular networks (On Board Radios, Road Side Access Points, Reserved 5.9 Ghz spectrum and dedicated communication standards) are (almost) available thus opening up interesting opportunities for a wealth of car-to-car applications.

On one side, security-oriented applications are still the top priority for auto industry and transport authorities, and recent testbed experiments have proved the effectiveness of vehicular communications in preventing intersection crashes. On the other side, the availability of the technology is stimulating interesting debates on new and challenging applications to be supported by vehicular communication systems, and visionaries are looking beyond safety applications. Automatic and efficient traffic control services (using "Intelligent Transport" techniques) can greatly benefit from vehicular communications, by reducing traffic congestion, possibly keeping under control the associated chemical pollution. Imagine a comprehensive urban traffic planning system that receives inputs from vehicles (e.g., route plans, destinations, sensor readings, positions, driver's preferences, etc), processes such information to generate an "urban routing" plan, and implements the plan through the careful control of traffic lights. The control may be extended to actual vehicle routes, possibly rerouting the vehicle to alternate, less congested routes with the assistance of "navigator" companies.

The aforementioned traffic planning system can be also geared with entertainment-oriented functionalities providing information on locally available resources (e.g. restaurants, movie theaters, museums, etc.), support to content distribution, sharing and file streaming through peer to peer systems (e.g., Car-torrent" [1]) and e-commerce application, as well as mobile internet gaming.

Moreover, a new paradigm of applications arises from the observation that vehicles can actually behave as collectors of information from the surrounding environment. Indeed, vehicles can be easily equipped with several sensing devices monitoring specific physical processes/phenomena (cameras, microphones, pollution sensors, humidity, temperature, etc . . .). Such sensing devices can be used to build up a distributed and enriched awareness of the vehicular environment, which, in turn, can boost the creation of "environment-aware" applications. As an example, vehicular surveillance systems can be built to support crime investigation, homeland protection, and suspicious activities monitoring. Further, massive distributed databases can be created and maintained storing commercial, entertainment and cultural information.

We note here that most of the aforementioned applications require some type of location awareness, i.e., they exploit location information to provide location-specific services (correlated to neighborhood resources and services). Moreover, some of them does require not only "environment awareness", but also tight "cooperation" among cars, requiring for instance maintenance of distributed indices, and creation, "temporary" storage and "epidemic" distribution of sharable content.

From a network architecture point of view, we argue that, in order to support all the aforementioned applications/services, vehicle to vehicle communication need to be supported and integrated into roadside infrastructure which must provide Internet connectivity, and communication resiliency . As an example, crash prevention and intelligent transport applications would not be feasible or effective relying only on pure car-to-car communications only under sparse vehicle distributions. Similarly, content distribution (via CarTorrent, say) services most likely require to retrieve the contents in the Internet, thus calling for fixed infrastructure to bridge the vehicles to the Net.

Thus, roadside infrastructure must be ubiquitous and instantly available to support all the above functions. Roadside Access Points providing the contact point between the vehicular realm and the infrastructure are to be placed in special locations, to best serve the fast moving vehicles, as opposed to the Access Points designed to support pedestrians, which are generally placed in shopping mall, popular bars, restaurants, bus/train stations, etc. To this extent, ideal places to install the Road Side APs are traffic lights and more generally, light poles, overpasses and other public structures. Traffic lights in particular are perfectly positioned to act as traffic routers. First, they already form a traffic grid and are ubiquitously distributed throughout urban centers in precisely the locations where traffic management is most required. Second, they are equipped with power and directly maintained by local municipalities. Finally, traffic light APs can best communicate with approaching vehicles, possibly pedestrians. They can network with other traffic lights, and will connect via the infrastructure to the traffic control center. Not all the roadside APs are likely to have direct access to the Internet, due to cost and physical limitations. In fact, some of these APs may not even have electric power and must be supplied by solar power. This calls for the support of wireless multi-hop connectivity within the fixed infrastructure.

In the paper, we introduce a novel network architecture, called C-VeT, to support extended application and services based on the integration between a pure vehicular ad hoc segment and a flexible wireless mesh infrastructure based on MobiMESH technology [2]. We address the interaction between vehicular communications and the Internet servers through MobiMESH. C-VeT can be viewed as a large scale ad hoc network which differs from traditional instantly-deployed ad hoc networks in the ubiquitous presence of a wireless mesh infrastructure that can be opportunistically used to support/complement vehicle-to-vehicle communications. On one hand, like traditional ad hoc nets, C-VeT is entirely self-supporting for emergency operations, and resilient to failures (natural disaster, terrorist attack, etc). On the other hand, it can exploit classical Internet connectivity during normal operations.

The paper is organized as follows: in Section 2 we comment on recent research achievement on the field of vehicular networks. Section 3 describes the main building blocks of C-VeT architecture, whereas Section 4 focuses on the characteristics and requirements of the wireless mesh technology. In Section 5, we introduce the prototype of a Geo-Location service which can be enabled by C-VeT. Section 6 reports on the testbed deployment status, further introducing some preliminary collected results. Section 7 concludes the paper.

2. RELATED WORK

C-VeT is one of the few vehicular testbeds that provides both Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) connectivity. Most other vehicular testbeds lack either V2V or V2I connectivity. CarTel at MIT [3] for example consists of a quite large number of taxi cabs equipped with wireless interfaces that gather information and exploit open access points around the city to upload the data to a central data server. DOME at UMass [4] uses the same concept as CarTel but adopts campus buses that form a sparse network with fixed mobility patterns. DOME buses connect to the internet via dedicated access points. These access points however are not connected by a wireless mesh. Finally ORBIT at Rutgers [5] features a large numbers of fixed wireless nodes but the mobility is emulated by tuning the simulator parameters.

3. C-VET FRAMEWORK

Our vision is for C-VeT to be an open platform to support Vehicular Network and Urban Sensing research and related applications. We were inspired by the pioneer work done by Larry Peterson and Tom Anderson with Planet Lab [6]. In particular we have built an always on, fully virtualized, web-accessible, sensor equipped testbed infrastructure. The UCLA campus, with its 10 acres of urban development, reproduces many of the scenarios, propagation, and communication challenges typical of a city, in a realistic manner but yet relatively small-scale. In particular the C-VeT architecture provides:

- A fully virtualized platform that runs both Linux based and Windows based operating system with full insulation among the guest virtual machines, and enables the users to re-design low level protocols such as, for instance, MAC protocols. This feature will be key for network centric experiments.
- A Campus Wide Mesh network developed using OPEN WRT and optimized for the integration and support of the Vehicular network. It will help to cope with network disruptions (quite common in small scale testbeds) and enable, opportunistic, interactive and delay tolerant experiments that exploit the Infrastructure,
- 30 Facility Management vehicles equipped with the C-VeT hardware/software, providing an always-on platform to run experiments, collect traces and measurements. The facility Management vehicles perform both routine maintenance trips and on-demand interventions in response to emergencies resulting in a varied mobility pattern that well approximates real city traffic.
- 30 Commuting Vans, equipped with the C-VeT-Census platform that will survey the environment gathering Traffic and Air Quality, and stereoscopic images. The aim is to build a large micro-pollution database that enable new models and facilitates also visual environment surveys (see Fig 1).
- a number of downloadable pre-configured virtual appliances to allow users to develop the protocols to be tested at home with a compatible software configuration.
- a large scale emulator that will allow users to debug their algorithms and protocols on the same hardware as the actual C-VeT nodes but with an emulated network component developed with the Qualnet hybrid simulation.
- a robust web interface that will manage the users and deploy the experiments in a streamlined fashion. The Web server will provide the front-end for a number of user friendly services and tools enabling users to focus on research rather than testbed implementation. For example: services to set up the experiments and gather the data; APIs to low lever interfaces for hardware component virtualization; virtual MadWiFi layer for the support of Virtual Machines.
- the ability to develop algorithms, applications and protocols that directly operate at Layer 2 using a TUN/TAP mechanism for both Windows and Linux OS. Recent Research showed that the TCP/IP suite may not be the most appropriate choice for vehicular networks and a ground-up protocol stack redesign is needed.
- an organized live database of mobility traces, sensed environmental data, road traffic information, Vehicle Can-

Figure 1: C-VeT Mobile Node

Bus statistics, MAC layer statistics (through MAD WiFi) and Physical Layer statistics taken using a variety of radios (Cognitive Radios, MIMO etc). This data collection will be made available to the research community in collaboration with existing trace collection programs and archives such as CRAWDAD [7]

We designed the testbed using a top-down approach and the whole system can be described through a number of relatively simple building blocks: *the C-VeT mobile node, the C-VeT mesh node, the C-VeT-Census platform, the Web based Control Center, and the Emulation platform*.

The C-VeT infrastructure is designed to provide an always-on facility for research in wireless vehicular network. To achieve this goal we chose to install our equipment in the UCLA Campus Facility management and Van Pool vehicles. Those cars and vans are driven everyday to fulfill the campus needs and perform both routine and non routine tasks. In addition to the permanent facility vehicles, there is a small pool of private vehicles equipped with C-VeT nodes that can be driven by the researchers themselves for customized, controlled experiments.

The C-VeT mobile node (Figure 1) is an industrial strength Cappucino PC powered by an Intel Dual Core Duo processor at 2.5GhZ, 2GB of RAM, 320GB Disk. Hard drive and internal parts are rugged to sustain physical stress (i.e. large temperature fluctuations, vibrations, etc). The PC has 3 Wireless Interfaces: IEEE802.11a/b/g/n based on the Atheros AR9160 chipset; IEEE802.11p interface based on a Daimler-Benz customized chipset; a standard Bluetooth interface mostly for internal communications. Other radios can also be retrofitted in the mobile node platform. In particular, a few vehicles may be equipped with programmable Silvus SC2000 MIMO platforms (4x4 configuration) that provide full access to the physical layer and enable a new generation of experimental MAC layer research

On Board Sensors: The C-VeT nodes are instrumented with a customized sensor platform designed to provide a flexible data collection. This includes Infra-Red based CO2 sensors; electrochemical CO sensors; SIRF III or Ublox based GPS sensors; temperature, and humidity sensors, and; megapixel camera. Using the C-VeT cars as mobile air quality sensors will enable a new wave of atmospheric research aimed at the use of mobile sensing agents to study the air quality at the neighborhood level as shown in [LWT05, LZK07, MEH06, MTK04]. Part of the fleet will feature high performance exhaust particulate sensors DC2000CE by echocem [ECO], thus being the first testbed able to support the currently leading research in micro-climate air quality.

Figure 2: C-VeT Infrastructure

The C-VeT mesh node is based on MobiMESH hardware. The C-VeT mesh nodes feature Open WRT OS and Atheros Chipset with MadWiFi support, thus easing up the integration with mobile nodes. The fixed infrastructure will be installed on the roof tops of UCLA buildings aiming at full campus coverage and integration with the existing campus WiFi infrastructure. The mesh allows opportunistic internet access from the vehicles and provides also a control channel to the vehicles. The Mesh network can be configured via web; e.g., customized routes can be set up by the network operator to perform particular experiments. This C-VeT integrated approach with infrastructure and vehicles broadens the experimental scenarios. In the initial phase we will cover the south Campus, and creating an initial backbone of 6 mesh points. The initial campus coverage map is shown in Figure 2.

In order to achieve seamless integration between the CVET-Mesh and the Vehicular network components we will develop Layer 3 and Layer 2 routing and VLAN support. Level 3 network layer routing between moving vehicle and the fixed nodes will enable communications across campus and to the Internet. The Layer 2 routing will enable the experimenter to force mobiles to be in the same broadcast domain, ignoring the fact that there are several fixed nodes in between.

4. REQUIREMENTS AND FEATURES OF THE WIRELESS MESH INFRASTRUCTURE

One of the goals of the UCLA Campus Vehicular Testbed (C-VeT) is to help us understanding the interaction between the vehicular networks and wireless fixed mesh networks. Namely, we target the following issues:

- what services do VANET applications need from wireless mesh networks,
- how can some applications transparently migrate from the Internet to the vehicle network,
- how can the vehicular architecture through careful protocol design (routing, capacity estimation, resource allo-

cation and security management) accomplish the smooth transition from full Wireless Mesh and Internet connectivity to autonomous, V2V, pure ad hoc operations.

- what is the interdependence between VANETs and Wireless mesh Networks.

Specific issues to be investigated in the testbed include:

1. Coexistence of car to car 802.11p channel with Wifi-based mesh infrastructure;
2. Interworking with the infrastructure to obtain support in mobility management, routing, traffic control, congestion control.
3. Interfacing vehicle address/routing (eg. georouting) with IP addressing/routing; transparent interconnection of vehicles across the city via the Internet.
4. Ability of the vehicular network to operate with and without infrastructure support; smooth transition; phasing out of non critical applications, etc.

MobiMESH networks feature multi-radio mesh routers, a provisioning, management and monitoring system, security procedures, thus providing a complete platform for Wireless Mesh Networking, that can be employed in a wide variety of environments/applications. The following characteristics of MobiMESH hardware/software solutions make them particularly suited for the C-VeT vision:

- *Broadband Backhauling*- the MobiMESH networks are able to build up and dynamically maintain a broadband wireless backbone which can be used to support/complement vehicle-to-vehicle communications;
- *Mobility Support*- wireless devices are allowed to seamlessly roam within MobiMESH networks without losing active connections;
- *Flexibility*- MobiMESH networks are self-configuring and self-managing.

Since MobiMESH is the core of C-VeT on the backbone's side, we give hereafter a concise technical description of MobiMESH solutions.

4.1 MobiMESH Architecture

MobiMESH features a hybrid mesh network architecture. Indeed, the network consists of three main architectural building blocks shown in Figure 3:

- a Mesh Backbone composed of MobiMESH wireless mesh routers which provide the routing and mobility management infrastructure, and is further connected to gateways,
- an ad hoc extension, which is responsible of extending MobiMESH functionalities to mobile nodes
- an access network which can be used by standard WiFi clients to get connectivity.

The Mesh Backbone and the ad hoc extension are based on the ad hoc network paradigm, where all nodes and mesh routers collaborate to routing traffic; routing is provided through a proactive ad hoc routing protocol based on OLSR [8], and properly modified to account for multiple radios at the mesh nodes, and link quality metrics. The backbone network is also responsible for the integration with the wired network, through devices called Gateways, that are equipped with a wired interface and that can route traffic to the wired network and therefore to the Internet.

The access network is rather flexible and operates in the infrastructure mode, so that standard clients perceive the network as a standard WLAN and behave accordingly; in this way MobiMESH can also be accessed by standard WLAN clients with no specific software installed.

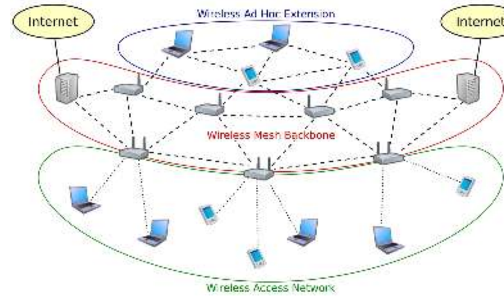

Figure 3: MobiMESH Network Architecture

The MobiMESH mesh routers represent the main building block of the MobiMESH network since they are responsible of creating the broadband backhaul, further offering access to wireless mobile clients. The MobiMESH mesh routers can be equipped with 2 to 4 radio interfaces, which can be flexibly used either as backbone or access interfaces. Moreover, any interface can be tuned to any available channel in the two frequency bands 2.4 GHz, 5.7GHz and 5.9GHz (via DSRC). Mesh routers which have also an interface dedicated to WiFi access are called access routers.

4.2 Mobility, and Security

An important overarching concern in C-VeT environment is security and privacy. Namely, we must be able to authenticate the alarms that we receive from other vehicles - eliminating bogus alarms, for example. Also, we must preserve location privacy while we are at the same time exchanging beacons, announcements and warnings with other drivers. Security and privacy guarantees require a certifying authority in the Infrastructure. Mobility management (e.g,. knowing where vehicle X is at time T) requires the registration with a Location Server (centralized or distributed) that will be built in the Infrastructure.

The MobiMESH network provides security functions, so that it can be safely employed to deliver any kind of traffic and it can be used to extend pre-existing secure networks. In a WMN it is very important that only authorized devices can join the network; MobiMESH mesh routers are in fact authenticated through the use of X.509 certificates and the backbone traffic is encrypted through a time-changing key encryption algorithm. Moreover, centralized MAC filtering and captive portal functionalities are supported.

MobiMESH architecture implements a proprietary mobility support daemon which dynamically handles the MAC-IP address association as clients roam throughout the network. Experiments carried out on real deployments have shown that the handover latency for a wireless client changing access router is upper bounded by 20 ms in most of the cases. Consequently, the handover is not perceived during VoIP calls.

5. APPLICATION EXAMPLE: THE GEO-LOCATION SERVICE (GLS)

The Geo-Location Service (GLS) is a distributed service that maps any car ID to its most recent geo location. Exploit-

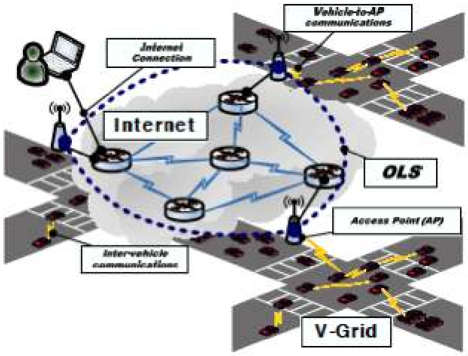

Figure 4: Vehicle Grid Extension Example

ing MobiMESH, we propose an Overlay Location Service implementation. As shown in Figure 4 an overlay structure is established in MobiMESH. Periodically (say every minute) each car registers to the nearest MobiMESH Access Points its ID (license#, IP address(es), time, owner name, owner IP address billing address, etc) and the current geo-location. In normal operating conditions, OLS spans both the MobiMESH and the wired Infrastructure. In case of Infrastructure failure, OLS can be completely supported (with some loss in performance) by MobiMESH, assuming the latter is fully connected by virtue of long range Cognitive Radio links. OLS maintains an index of vehicle IDs. Each ID is mapped to the most recent geo coordinates (thus allowing motion prediction). The index is distributed across the overlay. It may be managed via DHT (Distributed Hash Table). To illustrate the OLS operation, suppose that Host A (fixed or mobile) wants to establish a TCP connection to mobile B (see Figure 5). Host A injects in the nearest MobiMESH AP the query:

`3MANDC@CA.car`

It gets back the "most recent" set of geo-locations of host B. From these it can estimate vehicle speed and direction and thus infer the current location of B. From that, A derives the best access point (AP) to reach the destination. Host A sends the message to that AP; the message is encapsulated, e.g., in an IPv6 network envelope that contains the geo address in the extended header. At destination, the AP geo-routes the packet into the vehicular network to B using both geo address and car ID in the header. The car B will respond with its own IP address and geo address. It directs its response (encapsulated in the overlay envelope) to the sender IP address.

6. TESTBED DEPLOYMENT AND PRELIMINARY RESULTS

6.1 Infrastructure Nodes Coverage

In order to find the best placement of the infrastructure nodes we ran a campaign of coverage tests around the UCLA campus. The main focus is on the coverage of the roads. This represents a hard challenge as we experienced that the Wi-Fi radio signal basically propagates only in Line of Sight (LOS). To assess the coverage of a single infrastructure node we equipped a car with a laptop, a GPS receiver and a IEEE802.11b/g wireless card. The car node would log every second its position and if it is in reach of the infrastructure node or not. Using this information we are able to plot

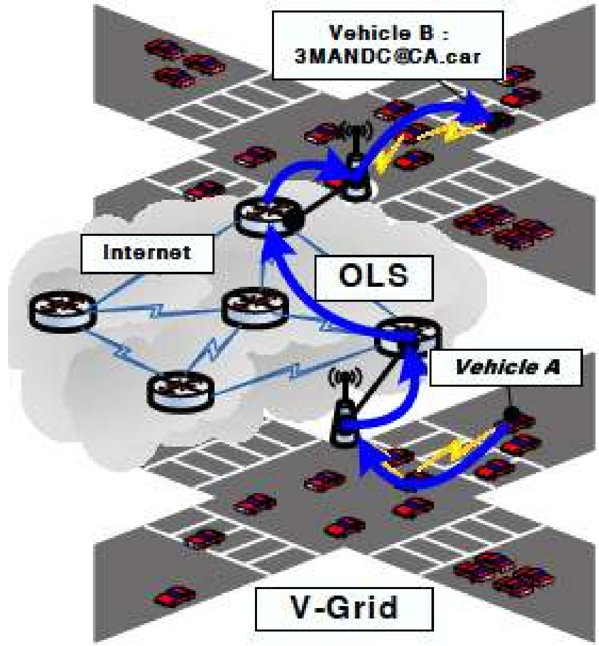

Figure 5: Routing in the Overlay

the coverage map of each single infrastructure node. Figure 6 shows the coverage map for the infrastructure node placed on the top of the Ashe Center Building at UCLA. White Dots represent the covered locations and red dots the not reachable ones. The results show that we were able to cover the whole area called Westwood Plaza that extends up to 700 meters away from the infrastructure node. On the other hand as soon as we loose the LOS the connection breaks as evidenced by traces on one of the crossing roads.

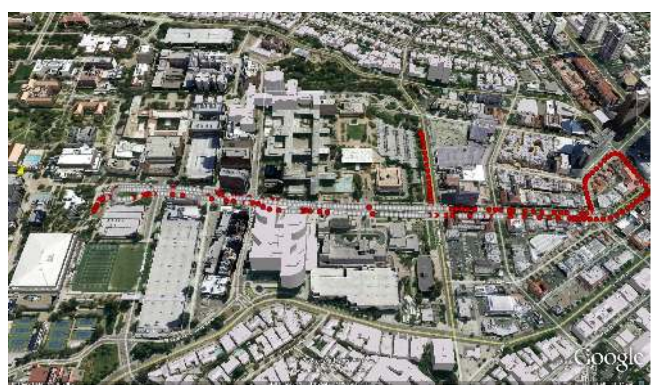

Figure 6: Coverage Experiment from the Ashe Center Building at UCLA

6.2 Video Streaming

As a preliminary experiment we wanted to test the feasibility of a video transfer from a mobile node to an infrastructure node via the wireless mesh. The mesh consists of four nodes on the four corners of Engineer IV building at UCLA. In this configuration each node could reach only the two nodes that are next to it. This means that in order to reach the farther node, 2 hops are required, as shown in figure 7. We placed a webcam in the moving car and used VLC to stream the video to one of the fixed nodes. With this setup the car is always connected to the mesh and at most 2 hops away from the receiving node. To maintain connectivity and fresh routes we used the OLSR [8] implementation provided by INRIA. The webcam was generating a video stream at resolution of 176x144 pixels at 15 frames per second. Thus the stream was generating an average of 128 Kbps (since the codec used was DIV3 the bitrate was not constant due to dynamic compression). The video was streamed using UDP so the lost frames were not retransmitted. The VLC server was set with a cache of 200ms. On the receiving node we were both saving and

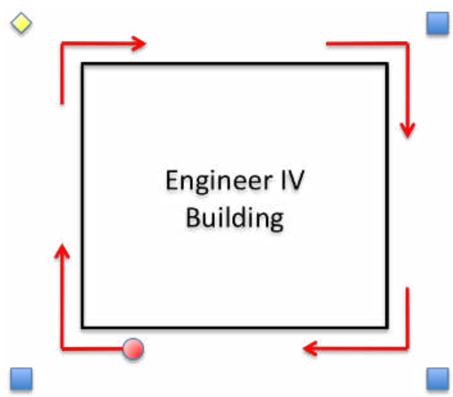

Figure 7: Video Streaming Experiment: 1 moving video source (Circle), 3 fixed nodes providing connectivity (Squares) and 1 fixed receiving node (Diamond)

displaying the video. In the real time video transfer the missing frames were much more than 10% but since we were saving the raw data received from the source we were able to reconstruct and re-encode the video received. In figure 8 we show the loss rate for the video after the reconstruction. As shown in figure 8 the percentage of loss for both frames and blocks is approximately 10%. Such a loss still grants the possibility of actually displaying the video. For real time delivery the reconstruction buffer cannot be used. Forward error correction schemes and adaptive coding rate may be used in this case. Another important result of this experiment was the time when the frame losses occurred. In fact they occurred when the mobile node was swapping from one relay to another. This means that the refresh of the route is not fast enough to be transparent for the video stream. These experiments were useful to determine the impact of wireless mesh multi-hopping on real time traffic. Clearly, buffers and coding strategies must be properly matched to the topology and user requirements.

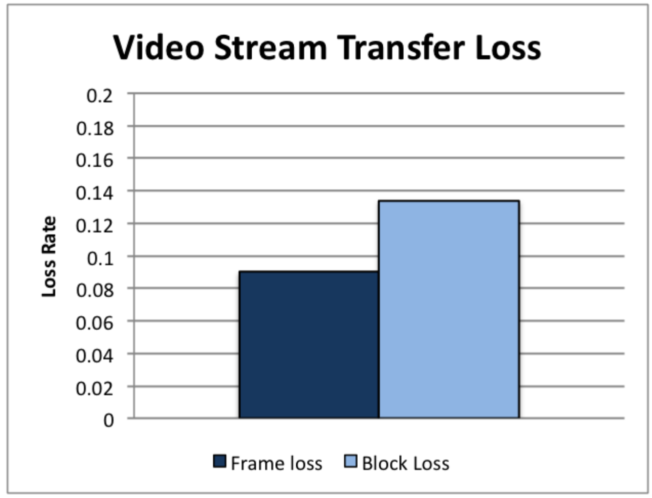

Figure 8: Loss Rate for the video stream

7. CONCLUDING REMARKS

Vehicular networks rely on the Internet Infrastructure for many important services, ranging from intersection collision prevention, intelligent transport, location tracking, authentication certificates, efficient data routing, etc. In this paper we have presented a model where the interface between vehicles and Internet is provided by a wireless mesh network consisting of access points installed in open spaces such as traffic lights, light poles and other roadside infrastructures. We have then introduced MobiMESH, the wireless mesh implementation carried out at UCLA in support of the C-VeT Campus Vehicular Testbed. We have identified the MobiMESH requirements and have mapped them to features to be supported by our Campus implementation. In the vehicular grid, the preferred routing scheme is geographic (ie position based) routing. Position based routes requires a Location Server, which keeps track of vehicle positions. We have described our plan for a scalable Location Server based on a DHT overlay to be supported in part by MobiMESH. Finally we have reported the results of a video transfer experiment where a moving vehicle uploads live video to an Internet client via a four node mesh network. Preliminary experimental results illustrate the criticality of buffering and encoding for real time video applications that involve multiple wireless hops.

REFERENCES

[1] K. Lee and I. Yap, "CarTorrent: A Bit-Torrent System for Vehicular Ad-hoc Networks," *Los Angeles*.

[2] A. Capone, S. Napoli, and A. Pollastro, "Mobimesh: an experimental platform for wireless mesh networks with mobility support," in *Proc. of ACM QShine 2006 Workshop on" Wireless mesh: moving towards applications", Waterloo (Canada)*, 2006.

[3] B. Hull, V. Bychkovsky, Y. Zhang, K. Chen, M. Goraczko, A. Miu, E. Shih, H. Balakrishnan, and S. Madden, "CarTel: a distributed mobile sensor computing system," in *Proceedings of the 4th international conference on Embedded networked sensor systems*. ACM, 2006, p. 138.

[4] H. Soroush, N. Banerjee, A. Balasubramanian, M. Corner, B. Levine, and B. Lynn, "DOME: A diverse outdoor mobile testbed," UMass Technical Report UM-CS-2009-23, University of Massachusetts Amherst, Tech. Rep., 2009.

[5] M. Ott, I. Seskar, R. Siracusa, and M. Singh, "Orbit testbed software architecture: Supporting experiments as

a service," in *Proceedings of IEEE Tridentcom*, 2005, pp. 136–145.

[6] L. Peterson, T. Anderson, D. Culler, and T. Roscoe, "A Blueprint for Introducing Disruptive Technology into the Internet," in *Proceedings of HotNets–I*, Princeton, New Jersey, October 2002.

[7] D. Kotz and T. Henderson, "Crawdad: A community resource for archiving wireless data at dartmouth," *IEEE Pervasive Computing*, vol. 4, no. 4, pp. 12–14, 2005.

[8] T. Clausen and P. Jacquet, "Optimized link state routing protocol (olsr)," *RFC3626*, 2003.