# Context-aware Information Dissemination in Vehicular Networks

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## I. INTRODUCTION

With the proliferation of mobile devices and vehicular on-board-units mobility is becoming a key factor in determining the performance of networked systems: both the performance of the infrastructure (e.g., the amount of control traffic) and the performance perceived by the end-users (e.g., access latency, throughput) are influenced by mobility. Mobility, as a manifestation of the physical world, transforms content distribution systems into cyber-physical systems. The efficient design and operation of cyber-physical systems, in general, requires an understanding of the characteristics and of the interactions between the components of the system.

Increased mobility implies that users might want to access content at a location where a communication infrastructure is not available or has insufficient capacity to serve the demand. Nevertheless, mobility can facilitate the creation of opportunistic networks, which relay content from device to device to extend data delivery beyond the communication infrastructure's coverage area or to off-load the demand from the communication infrastructure.

Opportunistic networks provide intermittent connectivity, which negatively affects the performance of most networking protocols developed for wireline networks. An alternative networking architecture, often called content-centric networking, is therefore needed to enable the use of opportunistic data forwarding between nodes.

Efficient content distribution in vehicular networks faces most of the challenges that emerging networked systems in general have to face. Mobility is a fundamental characteristic of vehicular systems, but vehicular mobility is relatively easy to predict compared to pedestrian mobility, both in terms of speeds and in terms of trajectories. Furthermore, vehicles are increasingly equipped with positioning equipment (GPS), and communication and computation are not subject to stringent energy constraints.

## II. CONTEXT-AWARE VEHICULAR INFORMATION DISSEMINATION

Many public and private enterprises are now experimenting with disseminating information whilst on the move. They include taxi fleets, public bus services and even groups of individual users. Traditionally, vehicular networks were considered a variety of mobile ad-hoc networks, and therefore research focused on how to achieve end-to-end connectivity [1]. This approach we believe is out-dated and new paradigms need to be used. Content centric networking (CCN) makes it possible to relax the requirement of end-to-end connectivity, and it also facilitates the use of opportunistic data forwarding between nodes, i.e., vehicles. At the same time, vehicular mobility compared to human mobility exhibits more regular behavior, which we believe can and has to be leveraged in system design.

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Consider a scenario in which vehicles move in an urban environment and cooperate in sharing delay-tolerant contents in an opportunistic manner (files, video-clips, traffic news, etc.). The interests, the locations and the relative positions of the vehicles determine their role in this information dissemination process. The individual vehicles are usually aware of a variety of context information, such as their locations, their velocities, their distances to other vehicles, as well as information such as the time, or the traffic density. Such context information, if available, can potentially be leveraged by the distributed algorithms used for information dissemination.

The infrastructure operators are also aware of a variety of context information, such as statistics about the flow of vehicles in terms of density and direction and the data traffic demands. Ideally, the context information should be leveraged already at system design, e.g., during the deployment of the vehicular communication infrastructure (e.g., road-side units (RSUs)), and also to optimize the information dissemination process [2].

## III. THE CAVE-NET APPROACH

The goal of the CAVE-NET project is to investigate how information about the vehicular context can be leveraged to improve the performance of the information dissemination process in vehicular networks.

We address the problem at two different levels. First, at the level of the vehicles, where we investigate the characteristics of vehicular flows and its impact on the information dissemination. Second, at the level of the operators of the communication infrastructure, where we consider the placement of RSUs as a function of vehicular flows. Therefore we have considered both vehicle to vehicle (V2V) and infrastructure to vehicle (I2V) communications.

At the level of vehicle flows we use macroscopic modeling to ascertain the individual connectivity, network reachability

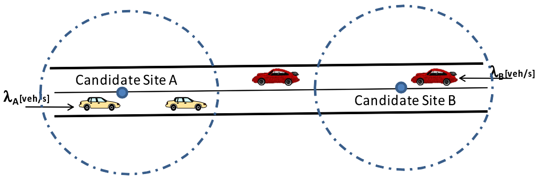

Fig. 1. Reference scenario with two candidate sites at the two extremes of a stretch of road. Vehicles enter the road from both directions at known rates. Traffic flow modeling can be used to predict cluster formation and connectivity between vehicles on this road stretch. The deployment of the RSUs is a function of the traffic flows, and influences the content distribution performance.

and the capacity of the network in terms of the radio technology used. Such a macroscopic model allows one to determine the vehicle density in space and time given the flow at the entrance of a road section. Larger geographical areas can then potentially be modeled as a composition of individual road sections. The importance of such a model is that it allows to obtain quantitative (macroscopic) values for the vehicle densities along the road sections in *both* space and time. The vehicle densities can then be used to calculate any quantity needed. In [3] we calculate the connectivity, reachability and capacity. The approach taken is focused on the vehicle density, however since the vehicle flow is simply the product of the density and velocity it is straightforward to calculate the rate of dissemination from the flow.

At the level of infrastructure operators we follow a game theoretic approach to tackle the problem of road side infrastructure deployment for information dissemination with vehicular networks. The question we ask ourselves is the following. If competing providers wish to select locations where to deploy their RSUs in order to exchange data with passing vehicles, what kind of strategies should they follow and how would their strategies affect the efficiency of content dissemination. The answer depends on several factors. On the one hand it depends on the vehicular context, such as the vehicle flow density or the data traffic patterns. On the other hand, it depends on the deployment context, e.g., the presence of an incumbent operator, and on the uncertainty of the information available to the operators about the context. Understanding the strategies gives insight into what infrastructure the content distribution algorithms for vehicular networks should be designed for.

## IV. MAIN SCIENTIFIC OUTCOMES

In order to study the above problems we take analytical approaches in CAVE-NET. It should be pointed out that both approaches are novel in their respective fields, which will be seen next.

*a) Traffic flow modeling:* The main outcome is a generic model of the traffic flow to predict connectivity patterns and cluster formation within vehicular to vehicular (V2V) environments. Fig. 1 illustrates a stretch of road with flows of vehicles entering from both directions. The approach is flexible as it only needs the initial conditions of the input to a road section which can be modeled or measured. Tracking traffic densities over time will determine whether vehicles can not *only connect* in sparse scenarios, but possibly interfere with *each other* in denser traffic scenarios. The main outcome is a theoretical and numerical analysis using scalar non-linear physical laws to relate variations in the vehicular density to connectivity and clustering in highly dynamic wireless environments [3]. Figure 2 illustrates the density (an initial step density) with time *and* location as independent variables. Using the density data it is straightforward to calculate quantities such the connectivity, reachability and broadcast capacity. The connectivity is shown as a example for Bluetooth and 802.11a below. $\rho_{max}$ is the maximum traffic flow for the particular road section) and the initial and step refer to density profiles of the traffic entering the road section.

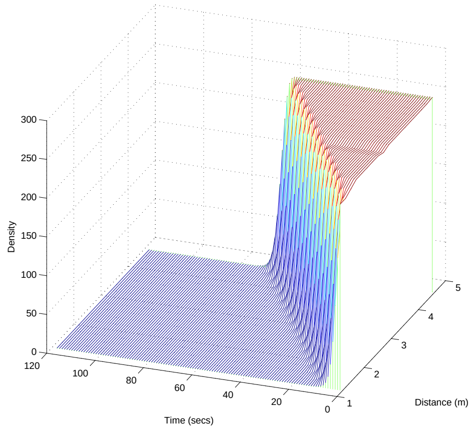

Fig. 2. 3D illustration of traffic flow after a red light turns green

| Stop time | Duration (seconds) | Bluetooth coverage | 802.11a coverage | Traffic flow | Proportion to to $\rho_{max}$ | Bluetooth coverage | 802.11a coverage |
|---|---|---|---|---|---|---|---|
| Short | 30 | 3% | 24% | Light | 0.2 | 4% | 26% |
| Med. | 60 | 6% | 32% | Medium | 0.5 | 17% | 39% |
| Long | 120 | 12% | 45% | Heavy | 0.8 | 56% | 74% |

Fig. 3. V2V connectivity for step (left) and constant initial conditions (right)

*b) Infrastructure deployment:* The main outcome is a game theoretical model of the problem of RSU deployment for a vehicular communication infrastructure. A simple example of the deployment problem is illustrated in Fig. 1, with two candidate deployment sites at the two extremes of the road stretch. We considered both simultaneous as well as sequential deployment, modeled by a strategic and a by Stackelberg game, respectively.

We gave a complete characterization of the equilibrium deployment strategies for both games as a function of the intensity and the imbalance of the bi-directional vehicle traffic flows on a road segment. We quantified the inefficiency of equilibrium deployments compared to the socially optimal deployment as a function of the inefficiency of the medium access control (MAC) protocol used to share the frequency spectrum.

We validated the analytical model via extensive simulations. We verified through simulations that, notwithstanding the necessary simplifications, the model correctly predicts the reachable equilibria as a function of the traffic intensity and the size of the downloaded contents [4].

## V. SUMMARY

The design and the operation of efficient content distribution systems for vehicular networks requires an understanding of the context in which these systems operate. The systems have to collect context information, such as location, distances, interest profiles, and aggregate traffic flows, and have to adapt their operation dynamically to changing context information. This paper gives an overview of our recent efforts on two aspects of context-aware vehicular networks. First, the modeling and prediction of macroscopic context information, that is, vehicular traffic flow. Second, the use of the traffic flow as context information to deploy communication infrastructure in support of vehicular content distribution.

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