Approaches to Heterogeneous Vehicular Networks

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I. Introduction

IEEE 802.11p is currently the base for the major technologies used in the field of vehicular networking. This holds true for the IEEE 1609.4 standard family used in the U.S. (called IEEE WAVE) and for the European ETSI ITS-G5 standard. But when it comes to such WLAN based technologies problems might arise: First, it might be possible that IEEE 802.11p fails to cover dense urban areas due to too many parallel users. Second, the penetration rate of vehicles outfitted with the necessary equipment will be initially very low. With this in mind it might be an idea to use a cellular connection instead of using a WLAN link between cars. Indeed some car manufacturers are already equipping their cars with cellular technology, not just for voice calls, but also for value added services. But this also leads to various problems: If the used communication technology is based on LTE (which is currently the most advanced one in use) a high frequency of messages might overload the network [1]. Due to the involvement of a core network, naturally the delay will also increase. Finally, if LTE is used, other users might experience degraded network performance due to all the cars sending messages.

One solution to these problems are *heterogeneous vehicular networks* where a car is equipped with both a short range radio and a module for cellular communication. In 2005, Cavalcanti et al. [2] proposed a system which combines WLAN with cellular technologies. More recently this idea has been adapted to be used in vehicular networks. Among these approaches is Remy et al. [3] who proposed *LTE4V2X*. It uses WLAN to cluster cars which then exchange current positional data to allow for easier travel planning. Tung et al. [4] proposed a safety application using heterogeneous vehicular networks for collision avoidance. Again cars are managed in clusters; a central server, reachable via a cellular connection, warns clusters of incoming other clusters.

Currently simulation is the tool of choice for evaluating concepts in the area of vehicular networking. Such simulation frameworks have to take care of network simulation and of a realistic simulation of vehicles' mobility. Therefore, most of the time a dedicated network simulator is coupled with a mobility simulator. In such a scenario the simulators are able to react on each others events. Especially in cases of safety and efficiency applications this is a very important property. For example, simulating the traffic mobility with traces of real world traffic – without a feedback loop – makes it impossible for vehicles to change their routes dependent on information received via the network(s). Such information could be about a traffic accident on the road ahead were the information was received via the network connection. There already exist frameworks which provide support for mobility-network feedback loops (*Veins*, *iTETRIS*, and *VSimRTI*), but all of them were missing support for full featured simulation of cellular networks. In December we released *Veins LTE*, an extension module for Veins which adds support for LTE [5]. For this, it uses *SimuLTE*, developed by Virdis et al. [6]. As Veins is based on OMNeT++, implementing, running, and evaluating new simulations is not a very complex task. This makes it also a good option for classroom use and teaching.

II. Veins LTE

Veins LTE combines the features of *Veins* (network-mobility feedback loop [7], IEEE 802.11p based network stack) with *SimuLTE* for LTE support. The main purpose was to integrate LTE into the system to make it easy to develop new applications on top. At lot of parameters of these stacks can be changed without altering the source code which makes the whole framework accessible. On top of the two stacks multiple applications can be implemented and run. A special module performs protocol adaptation for the stacks and routes messages between them and the applications. Every application can annotate outbound messages to be sent via LTE only, via IEEE 802.11p only, or leave the decision to lower layers. For this, a *Decision Maker* module provides an interface for implementing useful algorithms to make smart choices – like using current channel conditions or the number of recently sent packages.

Integrating *SimuLTE* into *Veins* was not easy: *SimuLTE* relies on all nodes to be initialized at the start of the simulation. This is not useful for simulating vehicular networks as cars enter and leave the scenario throughout the simulation. Therefore, I had to add the capabilities of adding and deleting vehicles to the *SimuLTE* framework – from the Network Interface Controller (NIC) to the IP stack. The result is now a robust framework to simulate heterogeneous vehicular networks where users only have to implement the applications on top of the stacks. Afterwards, running and configuring the simulations to gather results is straightforward and well supported by OMNeT++.

An example screenshot of a running simulation can be seen in Figure 1. It shows cars exchanging messages via LTE, where the green lines represent uplink connections and the red ones downlink. The blue, dashed lines show cars communicating via Dedicated Short-Range Communication (DSRC) to form clusters. Finally, the red crosses show received warnings about other cars approaching.

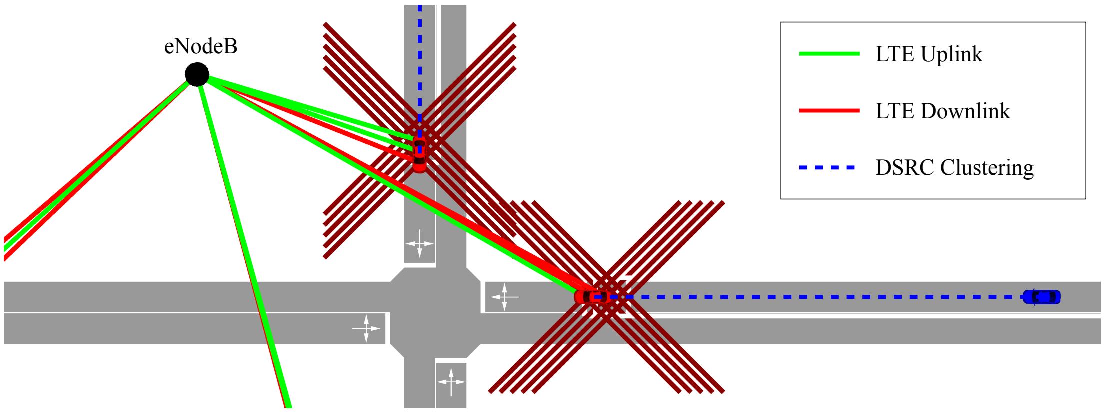

Figure 1. A screenshot of a running *Veins LTE* scenario. The red crosses show warnings that cars receive of incoming other cars.

III. Heterogeneous Vehicular Networks

The development of *Veins LTE* is not just a *fire and forget* action, we released it as open source software[1] and use it actively in research. To evaluate it we performed a huge number of smoke tests. Such a validation allowed us to make sure that the integration of *SimuLTE* into Veins did not break any of the used components.

We already implemented one heterogeneous vehicular networking algorithm, namely the one proposed by Tung et al. [4], to further evaluate the simulation framework. The authors propose an algorithm for collision avoidance where cars use DSRC to exchange their current position and form clusters. The clusters are then sent via LTE to a central server which then is able to warn clusters about approaching vehicles. Beside collision avoidance, such data can be used to manage intersections or plan routes. To cluster the vehicles the authors used a decentralized clustering solution were vehicles are clustered in groups moving into the same direction. Therefore the vehicle closest to the next intersection becomes the cluster head – this is the vehicle which communicates via LTE with the central server. All vehicles on the same road and traveling towards the same intersection will be in the same cluster.

Remy et al. [3] take a completely different approach by letting a central server decide which cars are in which cluster. They argue that such a central server has a better overview of the overall situation and is able to generate better and longer living clusters. We are currently in the process of implementing this solution in Veins LTE as well.

As a third direction, we are actively using *Veins LTE* in our *Car4ICT* project.[2] Together with Toyota ITC we explore how cars can be used as a main Information and Communication Technology (ICT) resource in future smart cities.

In the literature, there are many more approaches how clusters of vehicles are created. The concept of [8], which was further improved in [9], focuses on providing a link to the Internet for cars without a cellular connection. This link is then shared with the clusters. To cluster vehicles they use the direction of movement, the cellular signal strength, and the WLAN transmission range. Yet, how *best* to perform clustering is an open question. In addition, by running multiple applications which depend on clustering in parallel, the overhead for creating those clusters might get too big. To tackle this problem, our initial step is to compare the approaches from [3] and [4] to get a feeling if clustering benefits more from the advantages of a decentralized or from a centralized solution.

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