Enhancing Vehicular Applications by Exploiting Network Diversity

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Abstract

In this work we introduce a new model for exploiting network diversity in vehicular environments, which integrates ad-hoc communications with the existing cellular infrastructure aiming to meet the diverse communication requirements of vehicular applications. Although there are a plethora of reported studies on either 802.11p Digital Short Range Communications *(DSRC)* or cellular networks, joint research of these two areas mostly focuses on the offloading aspect when the two networks are available. This work presents current advances in the design of a novel framework aimed at enhancing the performance of applications deployed over a heterogeneous vehicular environment. We introduce and evaluate a decision system that exploits, simultaneously, the advantages of each individual network.

1 Introduction

Among the open research fields in communication protocols and technologies for vehicular communications, the heterogeneous vehicular network is the topic of interest in this work. In the vehicular networking context, a large part of existent research has been focusing on developing and studying the performance of network protocols for a specific radio access technology. In particular, the 802.11p DSRC technology has drawn most of the attention from researchers. However, it has been widely accepted that the supporting infrastructure and communications technologies for vehicular networks will be heterogeneous in nature, hence providing network diversity. Large coverage access networks, such as 4G/LTE, will be combined with technologies specifically designed for vehicular environments, such as the 802.11p DSRC.

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In this work we propose a dissemination scheme that exploits the network diversity in a heterogeneous vehicular network by integrating a set of *decision rules*. The novelty of this approach is that it allows the application data to flow through the individual network with the most favorable conditions in terms of throughput and delay for each data packet, without the need of a preselected scheme like the ones employed in [emZLTT14, ASF14, LYC$^+$12]. In this poster we report the work-in-progress toward the construction and validation of the proposed scheme.

2 System Framework and Development

The scheme utilizes all different network capabilities at the same time by integrating a set of *decision rules* that allow data packets to flow through the network with the most favorable conditions in terms of throughput and delay. The proposal is illustrated in Fig.1. It is observed that the application data generated by a single user can travel through any of the individual networks (802.11p, LTE and 802.11p ad-hoc mode). More specifically, depending on the application requirements, the control and signaling flows may for example travel through DSRC while the data flow may go through the cellular infrastructure. In this way, we can exploit the different advantages of each network such as transmission speed and local dissemination for DSRC, or high capacity for LTE infrastructure.
This framework is expected to improve the performance of the network both in terms of total throughput and end-to-end delay by allowing a single application to take full advantage of all the individual networks working in parallel. Currently, we have characterized the group of applications, and are developing the performance model for each individual networks. To this end, we have decided to focus on measuring *the throughput and packet delay at the MAC layer* for each network, this means that we need to select a model for EDCA (802.11p), DCF (802.11 ad-hoc) and LTE.

3 Preliminary Results

3.1 Decision Tree and Experimental Models

Fig.2 illustrates the decision tree for user-to-user communication scenario. It is important to notice that

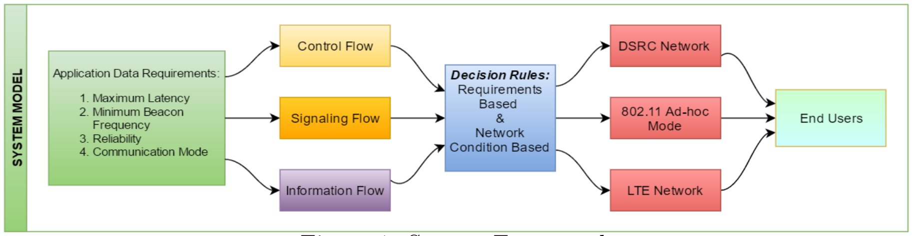

Figure 1: System Framework

each data flow has its own set of rules, which depends on the network type and conditions, application requirements, and link direction (uplink or downlink) because a user typically has less information available than the network itself at the moment of the decision.

This hierarchical tree characterizes the decision process of a single application when sending data to other vehicles in the network. The idea is that for each data flow, the sender attempts to minimize the end-to-end delay and boost the throughput of the system without compromising the reliability requirements of the application.

In order to obtain some preliminary results we use simplified models for the delay for each of the single networks, for a given access mechanism the total end-to-end delay can be expressed as $T_{Delay} = T_{Access} + T_{Transmission} + T_{Propagation} + T_{Processing}$.

To model performance for the 802.11 ad-hoc mode we employ the Distributed Coordination Function (DCF) system model. Based on [AS11], we obtain the saturation throughput for a single hop as well as for a path that may consists of multiple hops from a given source to destination. In the case of 802.11p using infrastructure mode, the Enhanced Distributed Channel Access (EDCA) mechanism includes the use of the Arbitration Inter Frame Space (AIFS) differentiation and virtual collision mechanism specified in the 802.11e standard. Therefore we can use the equation developed in [TM05] for the access time in basic mode (without RTS/CTS).

Meanwhile, in LTE the main difference between particular delay models arises from the underlying scheduling mechanism used. In [ALG+13] the authors develop an analytical model for using the Physical Uplink Shared Channel (PUSCH). Among the advantages of scheduling via PUCCH are high reliability and nearly deterministic data delay values. Using such a model, we obtain an average channel access delay $E = 5.9[ms]$ which is under the critical time, therefore we can use this mechanism to access the LTE base station and use it to reach a fraction of the neighbors so that it improves the performance of the whole system.

3.2 Analytical Results

Consider a typical safety application in which every vehicle continuously sends CAM messages to all its neighbors. The most important thing to consider is that the end-to-end delay for a transmission must not exceed 100ms, otherwise the receiver does not have time to react, especially in the case of emergency applications. For most scenarios, a sending rate of 10 Hz is required by the ETSI standard, but there are also scenarios requiring only 2 Hz.

In Fig. 3 we illustrate the total MAC layer delay that an application experiences when transmitting a beacon to all its neighbors using a single access network. We consider infrastructure-based 802.11p, 802.11p ad hoc mode, and LTE as the available networks for transmission. It can be observed that the total delay for the 802.11p networks (infrastructure-based and ad hoc mode) increases proportionally with the number of neighbors in range, which is expected because the access mechanism is contention-based. Also, using the ad-hoc mode is faster because the communication between vehicles is direct while in infrastructure mode the messages have to go through an 802.11p RSU. While both modes of 802.11p are completely capable of delivering the 2 Hz frequency beacons in less than 100ms for up to 40 neighboring vehicles, in a more realistic case of 10 Hz beacon frequency, the 802.11p network gets saturated at a value of approximately 20 neighbors. At this point, the network becomes incapable of reaching all the neighbors in less than the critical time, either via ad hoc mode or via infrastructure. According to the results, the DSRC network is more than capable of achieving high throughput and low latency in low density scenarios; however, as the vehicle density increases, the LTE network shows to be able of maintaining a more stable latency because of its high capacity nature.

In Fig. 4 we illustrate the case in which the decision tree is used to exploit the heterogeneous network. As we mentioned before, the infrastructure-based and ad hoc modes are only able to reach less than 20 neighbors under the critical time of 100ms for a beacon frequency of 10Hz; nonetheless, the decision tree allows us to set a threshold for the number of neighbors, so that the transmitter can employ the LTE network to improve the performance both in terms of packet delay and total throughput under the critical time. Since more neighbors are reached under 100ms the system throughput is boosted by the latency reduction. Moreover, by using the decision tree, a boost in performance is observed even for the low beacon frequency case: although a single access network is enough to cover the required number of neighbors, the combined use with LTE helps improve the general performance.

In both frequency cases, once the 20 neighbors are reached and the combined use starts, a latency reduction of approximately 70% is achieved using the decision tree with infrastructure-based 802.11p + LTE, whereas a 64% improvement can be achieved with the combined use of 802.11p ad hoc + LTE. This ultimately results in a 25% increase in total throughput

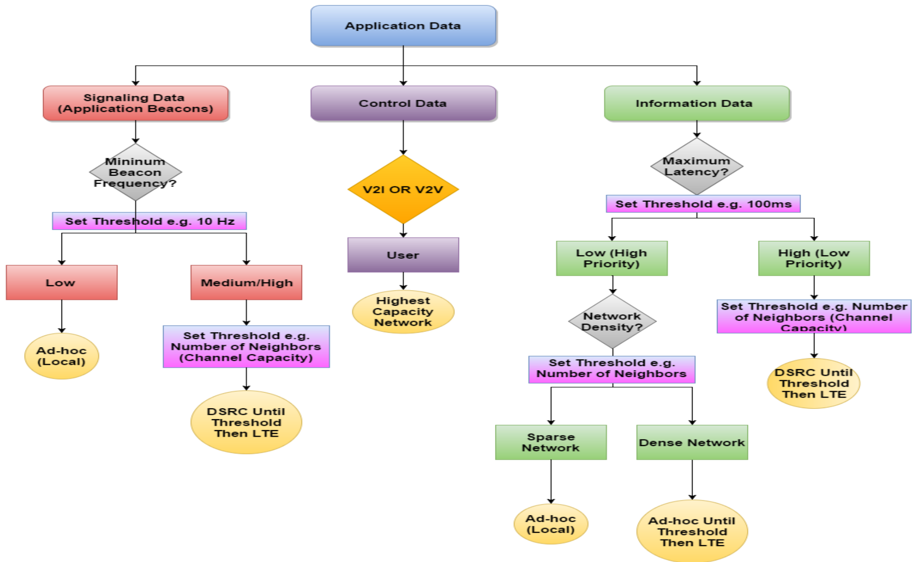

Figure 2: Decision Tree (User-to-User Communication)

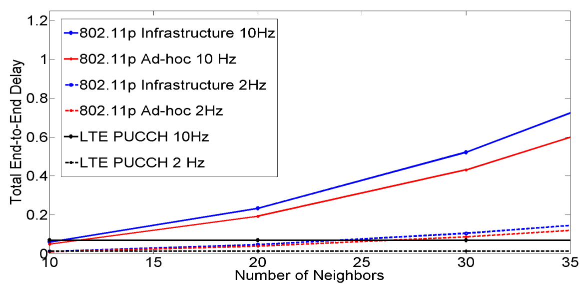

Figure 3: Total Dissemination Delay per Number of Neighbors

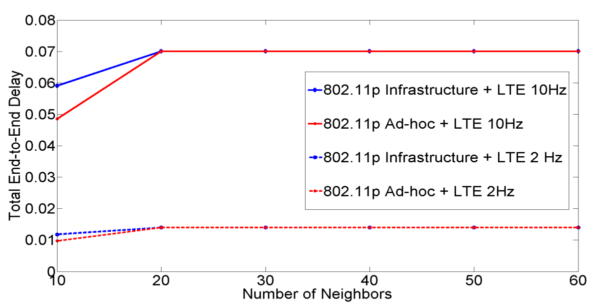

Figure 4: Total Dissemination Delay per Number of Neighbors using Decision Tree

which is proportional to the difference in the number of neighbors that can now be reached under 100ms.

4 Conclusions and Future Work

We have presented a new framework that intends to improve the performance of cooperative awareness applications deployed over a heterogeneous vehicular network. The framework contains a set of decision rules that captures the different advantages of each network considering latency and reliability requirements of the application, in order to decide the path for the different types of flows that a single application generates. Therefore, if the application requirements change, the rule set is bound to change as well.

So far we have selected the performance models for the access networks, developed the rule set for a typical safety application family and used analytical simulations to obtain some preliminary results. The preliminary results validate the decision system approach showing a boost in application performance when diversity is exploited both in terms of latency reduction and an increased throughput under a fixed critical time.

Future work will focus on running more advanced simulation scenarios that allows us to test the entire decision tree and modify it if its required. Since the framework developed aims to exploit network diversity for any particular application it is likely that different variations of the tree will be required for different application families so the decision system must be adapted to improve robustness and flexibility.

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