Data dissemination in vehicular networks

Gianluca Grilli

Department of Computer Science, Systems and Production

University of Rome "Tor Vergata"

PhilosophiæDoctor (PhD) dissertation in
Computer Science and Automation Engineering
(cycle XXI)
Advisor and Coordinator: Prof. Daniel P. Bovet

16 June, 2010

PhD Board of Examiners (in alphabetical order):

Prof. Bruno Cicciani
Dipartimento di Informatica e Sistemistica, Università di Roma "La Sapienza"
via Ariosto 25, 00185 Roma

Prof. Vittorio Cortellessa
Dipartimento di Informatica, Università dell'Aquila
via Vettoio, Coppito 67100 L'Aquila

Prof. Paola Velardi
Dipartimento di Informatica, Università di Roma "La Sapienza"
via Salaria 113, 00198 Roma

Day of the defense: 16 June, 2010

Signature from head of PhD committee:

Abstract

Data dissemination consists on spreading a large amount of information to all nodes belonging to a network and its peculiar characteristics make this goal particularly interesting and challenging. However, developing efficient data dissemination schemes for vehicular ad-hoc networks (VANETs) is still an open issue due to the broadcast nature of the channel and to the need of managing all data transmissions in a distributed way. The former leads to a lot of problems related to the channel contention, collisions and interference. The latter requires to define algorithms which exploit only local information of the network and which are scalable and robust to the node mobility.

The focus of this thesis is to investigate the data dissemination process in VANETs by defining and developing a new communication protocol (CORP), efficient in terms of limited computational complexity, low latency, high speed of dissemination, high delivery ratio, better usage of the wireless channel and, consequently, better energy consumption. The basic idea relies on the the application of the fountain codes theory to vehicular networks in order to implement a true I2V2V (*infrastructure-to-vehicle-to-vehicle*) communication paradigm.

Results gathered from extensive simulation show the feasibility of such a solution, which could be implemented in real on-board communication devices for *Intelligent Transportation Systems* (ITS).

"There are three kinds of death in this world. There's heart death, there's brain death, and there's being off the network."

- Guy Almes

To my loved grandparents,

your memories will always belong to my heart.

Acknowledgements

I would first and foremost like to thank my advisor, Prof. Daniel Bovet, without whom my PhD experience would not have been possible. His dedication and passion, together with his excellent analytical skills are great assets to those who are fortunate enough to work with him.
Many thanks to Prof. Mario Gerla, my advisor at the Network Research Lab (NRL) of the University of California Los Angeles (UCLA). I will never forget him as well as the pleasant (but fruitful) weekly meetings held at NRL.
I would also like to thank the whole PhD group at P1B-03 office for their inputs and cooperation during the last years and, above all, for their friendship. In this respect, a special thank goes to Fabio Dellutri, Emanuele Galli and Emiliano Betti. Andrea Bastoni also deserves a great deal of credit especially for his invaluable logistic support and assistance during my "last" operating system course.
I cannot omit my friends from the USA experience, namely, Ali Hamidian, Paolo Di Rico, Paolo Lutterotti, Eugenio Giordano, Ilias Leontiadis, Pasquale Cataldi, Alexandro Sentinelli, Andrea Tomatis, Alessandro Bissacco and Giovanni Mazzeo.
Finally, I wish to extend my deepest gratitude to my family and my sweet love, "Patata", who both have never wavered in their support of me in all of my ventures in life.
The last word of gratitude goes to Chopin, my lovely labrador, for its countless love.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

In this thesis we cope with the problem of data dissemination in vehicular ad-hoc networks (VANETs), trying to give an overview of the main techniques used in this field and presenting also a novel protocol for data dissemination called "CORP", *Cooperative Rateless Protocol*.
CORP (19) is a very innovative protocol as fully implements the theory Fountain Codes technique to quickly and effectively disseminate contents across vehicles in a wide area. Furthermore, it represents the first successful application of the said coding theory to the vehicular field which totally complies with the *infrastructure-to-vehicle-to-vehicle communication paradigm (I2V2V)*.

The concept of data dissemination is wide and meaningful, and within this work we generally refer to it as the process of spreading some amount of data over a distributed wireless network, which is a superset of a VANET.
Data exchanging on the roads is becoming more and more interesting, as the number of vehicles equipped with computing technologies and wireless communication devices is poised to increase dramatically. Communications between vehicles and within the same vehicle (inter-vehicle, or InV) is becoming a promising field of research and we are moving closer to the vision of *intelligent transportation systems (ITS)*, which can enable a wide range of applications, such as collision avoidance, emergency message dissemination, dynamic route scheduling, real-time traffic condition monitoring and any kind of "infotainment" information spreading (i.e. movies, gaming and advertisement). However, it is extremely important to consider several aspects when approaching to

any kind of data transfer in a VANET, because nodes are not fixed but can move. Furthermore, in this scenario, other complications can easily arise because, unlike the well known *mobile ad-hoc networks* (MANETs), where nodes can freely move in a certain area, in VANETs, vehicles' movements are constrained by streets, traffic and specific rules.
The following are only some of the several issues which VANETs are affected by:

- *High mobility:*
  the environment in which vehicular networks operate is extremely dynamic, and includes extreme configurations: in highways, relative speed of up to 300 km/h may occur, while density of nodes may be 1-2 vehicles per kilometer in low busy roads. Because of the relative movement of the vehicles, the connectivity among nodes could last only few seconds, and fail in unpredictable ways.

- *Partitioned networks:*
  vehicular ad hoc networks will be frequently partitioned. The dynamic nature of traffic may result in large inter-vehicle gaps in sparsely populated scenarios, and in several isolated clusters of nodes. The degree to which the network is connected is highly dependant on two factors, such as the range of wireless links and the fraction of participant vehicles, since only a fraction of vehicles on the road could de equipped with wireless interfaces. Maintaining end-to-end connectivity, packet routing, and reliable multi-hop information dissemination will become extremely challenging in such networks.

As it concerns specifically the data transmission, in VANETs there are several additional issues to be taken into account:

- the *fading effect of the signal*, which becomes more significant due to the surrounding buildings;

- the *strong interference and collisions* related to the high number of mobile transmitters (vehicles);

- the *flapping links*, caused by both fading effect and vehicles' speed.

Furthermore, while traditional vehicular networks rely on specific infrastructures, such as roadside traffic sensors reporting data to a central database, or cellular wireless

communication between vehicles and a monitoring center, we want to focus our effort on completely decentralized data dissemination solutions, in order to avoid expensive infrastructures and increase the overall scalability of the system. In fact, how to exchange traffic information among vehicles in a scalable fashion is really an important problem to be solved in VANETs.
The main goal of this dissertation was to assess the validity of the I2V2V communication scheme for data dissemination through CORP, a data dissemination protocol mainly based on Fountain Codes (FCs) and developed at application layer on the top of UDP transport protocol. By relying on UDP at lower layer, CORP showed great performances and high delivery ratio, as it was not affected by some peculiarities of TCP such as the slow start/restart mechanism, the three way handshake and the four way connection close, which both have been proved to perform poorly in vehicular networks.
Simulation results showed that CORP performs very well compared with other two simple data dissemination approach and with a similar protocol specifically built on the top of TCP (CORP-TCP).

1.1 Layout of the Thesis

In this section we give a brief insights on this research work by showing the organization of the other Chapters. In detail, we have:

- **Chapter 2: Preliminary concepts**
  This chapter is meant to introduce the basic concepts behind the emerging area of vehicular networks and data exchange, such as Ad-Hoc networks, Mobility issues, Mobile Ad-Hoc Networks (MANETs) and, at the same time, to provide an overview of the new technologies and standards for car communication systems.

- **Chapter 3: Mobility models in vehicular networks**
  This Chapter describes several mobility models used to simulate vehicular ad-hoc networks.

- **Chapter 4: Vehicular network simulators**
  In this chapter we presents an overview of the most popular vehicular network simulators and mobility simulators, according to their integration components.

- **Chapter 5: Data dissemination survey**
  This chapter surveys the different types of information exchange adopted in vehicular networks with common practices and methodologies that have been considered in research literature (e.g.: opportunistic exchange of resources between vehicles, vehicle assisted data delivery, cooperating downloading of information, etc.) with a special emphasis to the network coding technique.

- **Chapter 6: Data dissemination with rateless codes**
  This is the main Chapter, where we briefly survey the fountain codes (FCs) and then introduce CORP, a novel protocol for data dissemination built on the top of UDP and FCs.
  The new approach is explained in detail and the main experimental results are presented (CORP is compared to V2V, I2V and I2V2V data dissemination paradigms). Simulations have been performed with *Random Waypoint* model (RWM) and the promising *Intelligent Driver Mobility model with Lane Changes* (IDM_LC), according to which mobile nodes' movements are really close to the reality (in addition, intersections are also regulated by traffic lights).

- **Chapter 7: Conclusions and future work**
  This Chapter highlights the main benefits of such an approach presented in Chapter 6 and describes the future works.

Keywords: Data dissemination in vechular networks, vehicular networks, VANETs, Fountain Codes, Data Coding in VANETs, VANET simulation.

Chapter 2

Preliminary concepts

In the recent decade, control systems for the automotive industry have moved from the analog to the digital domain. Networked Electronic Control Units (ECUs) are increasingly being deployed in automobiles to realize diverse functions such as engine management, air-bag deployment, and even in intelligent brake systems. At the same time, emerging vehicular networks in the forms of *Intra-Vehicle (InV)*, *Vehicle-to-Vehicle (V2V)*, and *Vehicle-to-Infrastructure (V2I)* communications are fast becoming a reality and will enable a variety of applications for safety, traffic efficiency, driver assistance, as well as infotainment to be incorporated into modern automobile designs. Thus, with vehicular networks fast becoming commonplace, critical data is being exchanged with-inside and with-outside vehicle via vehicular networks, and new technologies have been developed for vehicular networks. This chapter is meant to introduce the basic concepts behind the emerging area of vehicular networks and data exchange, such as Ad-Hoc networks, Mobility issues, Mobile Ad-Hoc Networks (MANETs) and, at the same time, to provide an overview of the new technologies and standards for car communication systems.

2.1 Mobile Ad-hoc NETwork (MANET)

In circumstances where mobile telephony as we know it is not possible or difficult, perhaps internet technology can be of help. The dependancy on a costly telecommunication infrastructure could thereby be decreased, which would be quite welcome considering the current situation in the telecom world. The technology that is to make this possible