On the use of opportunistic vehicular communication
for roadside services advertisement and discovery

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**Sobre o uso de comunicação entre veículos para a
descoberta e divulgação de serviços ao longo de rodovias**

Tese apresentada ao Instituto de Ciências
Matemáticas e de Computação – ICMC-USP,
como parte dos requisitos para obtenção do título
de Doutor em Ciências – Ciências de Computação
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I dedicate this dissertation to my parents, friends and family, whose love, care, and prayers help me throughout my life. I also dedicate this effort to my Professor and lab fellows.

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KIFAYAT ULLAH

*“Read! In the Name of your Lord,
Who has created (all that exists).”
(Al-Quran)*

ABSTRACT

ULLAH, K.. **On the use of opportunistic vehicular communication for roadside services advertisement and discovery**. 2016. 104 f. Doctoral dissertation (Doctorate Candidate Program in Computer Science and Computational Mathematics) – Instituto de Ciências Matemáticas e de Computação (ICMC/USP), São Carlos – SP.

Vehicular Ad hoc Network (VANET) is a special kind of Mobile Ad hoc Network (MANET) and is a key enabling technology for Intelligent Transportation Systems (ITS). It plays an important role in the deployment of a large scale of both safety and non-safety applications. Among non-safety applications, an important and challenging area is the provision of roadside services advertisement and discovery. In this work, we adopted the beaconing strategy and opportunistic vehicular communications to address the problem of roadside services advertisement and discovery on the highways. Our approach offers several advantages over the traditional billboard method, e.g., low cost, targeting a large number of customers in a real time, more control over the advertisement campaign, dynamic content updating, and discovery of services far ahead of the business region. For advertising roadside services, we followed the push-based advertisement strategy and relied on Infrastructure-to-Vehicle (I2V) communications only. On the other hand, for discovering these services by the drivers, we used pull-based advertisement strategy and opportunistic Vehicle-to-Vehicle (V2V) communications. In order to contribute to the advertisement campaign, we used the store-carry-and-forward mechanism. Our first contribution is the Extended Opportunistic Service Discovery Protocol (EOSDP). EOSDP implements the original version of Opportunistic Service Discovery Protocol (OSDP) via simulation experiments. We used Simulation of Urban Mobility (SUMO), Objective Modular Network Testbed in C++ (OMNET++), and Vehicles in network simulation (Veins) simulators. Our second contribution is Service Advertisement Protocol (SADP). SADP is a lightweight beaconing-based services advertisement protocol for VANETs. It does not require the Internet connection for advertising the roadside services. Moreover, SADP modeling is based on VANETs standard protocols. The performance of SADP was evaluated in a congested highway scenario with varying speed of vehicles and under different broadcast frequencies. Finally, we present our last protocol called Commercial Services Discovery Protocol (CSDP). Like the previous protocol, CSDP is a lightweight beaconing-based services discovery protocol for VANETs. CSDP is infrastructure-less protocol which only depends on opportunistic V2V communications for roadside services discovery. The protocol was implemented in congested highway scenario and extensive set of simulation experiments were performed to evaluate its performance under different parameters, e.g., Query Interval (QI), Query Attempts (QA), and Time to Live (TTL).

Keywords: VANETs, Opportunistic communications, IEEE WAVE, Beaconing, Services advertisement and discovery.

RESUMO

ULLAH, K.. **On the use of opportunistic vehicular communication for roadside services advertisement and discovery**. 2016. 104 f. Doctoral dissertation (Doctorate Candidate Program in Computer Science and Computational Mathematics) – Instituto de Ciências Matemáticas e de Computação (ICMC/USP), São Carlos – SP.

Vehicular Ad hoc Network (VANET) é uma tipo especial de Mobile Ad hoc Network (MANET) e é uma tecnologia chave para possibilitar o Intelligent Transportation Systems (ITS). Ela desempenha um papel importante na implantação em grande escala das aplicações safety e non-safety. Entre as aplicações non-safety, uma área importante e desafiadora é a oferta e descoberta de serviços de anúncios ao longo de rodovias. Neste trabalho, foi adotado a estratégia de beaconing e as comunicações veiculares oportunistas para resolver o problema da oferta e descoberta de serviços de anúncios na beira de estrada nas rodovias. Nossa abordagem oferece várias vantagens em relação aos métodos tradicionais usando painéis, painéis eletrônicos digitais, outdoors, etc. Baixo custo, suporte para um grande número de clientes em tempo real, maior controle sobre a campanha de anúncios, atualização dinâmica de conteúdo e descoberta de serviços muito à frente da região de negócios são algumas delas. Para oferta de serviços à beira de estradas, seguimos a estratégia de publicidade push-based através de apenas comunicações Infrastructure-to-Vehicle (I2V). Por outro lado, para a descoberta destes serviços pelos motoristas, utilizamos estratégia de publicidade pull-based e comunicações Vehicle-to-Vehicle (V2V) oportunistas. A fim de contribuir para a campanha de anúncios, foi utilizado o mecanismo store-carry-and-forward. Nossa primeira contribuição é o Extended Opportunistic Service Discovery Protocol (EOSDP). O EOSDP implementa a versão original do Opportunistic Service Discovery Protocol (OSDP) através de experimentos por simulação. Utilizamos os simuladores, Simulation of Urban Mobility (SUMO), Objective Modular Network Testbed in C++ (OMNET++) e o Vehicles in network simulation (Veins). Nossa segunda contribuição é o Service Advertisement Protocol (SADP). SADP é um protocolo leve baseado na estratégia de beaconing para serviços de anúncios em VANETs. Ele não requer conexão com a Internet para anunciar os serviços de beira de estrada. Além disso, a modelagem do SADP é baseada no padrão de protocolos VANETs. O desempenho do SADP foi avaliado em um cenário de rodovia congestionada, com velocidades variáveis dos veículos e sob diferentes frequências de broadcast. Por fim, apresentamos o nosso último protocolo chamado Commercial Services Discovery Protocol (CSDP). Como o protocolo anterior, o CSDP é um protocolo leve de descoberta de serviços baseado em beaconing para VANETs. CSDP é um protocolo sem necessidade de infraestrutura que só depende de comunicações V2V oportunistas para a descoberta de serviços de beira de estrada. O protocolo foi implementado no cenário de uma rodovia congestionada com um extenso conjunto de experimentos de simulação realizados para avaliar o seu desempenho sob diferentes parâmetros, e. g., Query Interval (QI), Query Attempts (QA) e Time to Live (TTL).

Palavras-chave: VANETs, Comunicação oportunística, IEEE WAVE, Beaconing, Oferta e descoberta de serviços de anúncios.

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LIST OF ABBREVIATIONS AND ACRONYMS

ABs		Advertisement Beacons
ABSs		Advertisement Base Stations
AM	.....	Advertisement Message
APs	.....	Access Points
ARIB	....	Association of Radio Industries and Businesses
ASN.1	....	Abstract Syntax Notation One
BO	.....	Business Owner
BSS	.....	Basic Service Set
C2C	.....	Car-to-Car
CA	.....	Certificate Authority
CAM	.....	Cooperative Awareness Message
CCH	.....	Control Channel
CeMEAI	.	Centro de Ciências Matemáticas Aplicadas à Indústria
CSDP	....	Commercial Services Discovery Protocol
D2D	.....	Device-to-Device
DSRC	....	Dedicated Short Range Communication
EDCA	....	Enhanced Distributed Channel Access
EOSDP	...	Extended Opportunistic Service Discovery Protocol
ERTICO	..	European Road Transport Telematics Implementation Coordination Organisation
ETSI	.....	European Telecommunications Standards Institute
FCC	.....	Federal Communications Commission
GPS	.....	Global Positioning System
GUI	.....	Graphical User Interface
I2V	.....	Infrastructure-to-Vehicle
IE Vendor	.	Information Element Vendor
IEEE	.....	Institute of Electrical and Electronics Engineers
IPv	.....	Internet Protocol version six
ITS	.....	Intelligent Transportation Systems
ITSA	.....	Intelligent Transportation Society of America
IVC	.....	Inter-Vehicle Communication
IVHS	.....	Intelligent Vehicle Highway Systems

LTE Long Term Evolution
 LTE-A ... LTE-Advanced
 MANETs . Mobile Ad hoc Networks
 NITSA ... National Intelligent Transportation Systems Architecture
 OBU On Board Unit
 OFDM ... Orthogonal Frequency Division Multiplexing
 OMNET++ Objective Modular Network Testbed in C++
 OSDP Opportunistic Service Discovery Protocol
 OSI Open System Interconnection
 PKI Public Key Infrastructure
 PPP Public Private Partnership
 QA Query Attempts
 QI Query Interval
 QM Query Message
 QoS Quality of Service
 RM Response Message
 RSU Road Side Unit
 SADP Services Advertisement Protocol
 SAE the Society of Automotive Engineers
 SBs Safety Beacons
 SCHs Service Channels
 SFV Service Forwarder Vehicle
 SLAs Service Level Agreements
 SPV Service Provider Vehicle
 SRV Service Requester Vehicle
 SUMO ... Simulation of Urban Mobility
 SUs Service Users
 TTL Time To Live
 USDOT .. United States Department of Transportation
 V2B Vehicle-to-Bicyclists
 V2G Vehicle-to-Grid
 V2H Vehicle-to-Home (V2H)
 V2I Vehicle-to-Infrastructure
 V2M Vehicle-to-Motorcyclist
 V2N Vehicle-to-Network
 V2P Vehicle-to-Pedestrian
 V2V Vehicle-to-Vehicle

V2X Vehicle-to-Everything
VAA VANET Advertisement Agency
VANET .. Vehicular Ad hoc Network
Veins Vehicles in network simulation
WAVE Wireless Access in Vehicular Environments
WHO World Health Organization
WSA WAVE Service Advertisement
WSMP ... WAVE Short Message Protocol
WSMs ... Wave Short Messages
XML Extensible Markup Language

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INTRODUCTION

Vehicles play an important role in our daily lives, as they transport people and goods from one place to another. However, the growing number of vehicles on roads also create serious problems like traffic management, road accidents, congestion, air pollution and consumption of fuel and gases at a huge level, just to name a few. According to World Health Organization (WHO) report on road safety, more than 1.2 million people die and up to 50 million people get injured each year throughout the world, due to traffic accidents. These road injuries are the ninth leading cause of death worldwide ([WHO, 2015](#)).

Many countries around the world take initiatives to constitute Intelligent Transportation Systems (ITS), in order to address the problems of road transportation. ITS plays a vital role in making our road transportation safer, efficient, environmental friendly, congestion free, and enjoyable. ITS uses advanced information and communication technologies to solve current transportation related problems like air pollution, consumption of fuel and gases, long traffic delays, and road accidents. In this regard, the United States Department of Transportation (USDOT) has prepared a new ITS strategic plan 2015-2019, to support research, development, adoption and deployment of ITS related technologies ([ITS, 2015](#)). Similarly in Europe, the European Road Transport Telematics Implementation Coordination Organisation (ERTICO) is a Public Private Partnership (PPP) for development and deployment of ITS systems in the Europe. The vision of ERTICO-ITS is to make vehicle mobility safer, smarter and cleaner. It has more than 100 partners from different mobile companies, vehicle manufacturers, and educational research institutions ([ERTICO, 2015](#)). Also, in Japan, ITS related standardization activities are on his way. ITS Japan organize an annual event called ITS World Congress, for establishing International relations with other countries ([JAPAN, 2015](#)). Finally, Asia-Pacific ITS is trying to facilitate the cooperation and coordination among its member countries from Asia and Oceania. It provides a platform for information sharing among the member countries Australia, China, Chinese Taipei, India, Indonesia, Hong Kong, Japan, Korea, Malaysia, New Zealand, Singapore, and Thailand. Its main objectives are to improve the quality of life by solving transportation

problems ([ASIA, 2015](#)).

Vehicular Ad hoc Network (VANET) is a promising technology for ITS and is playing an important role to meet the objectives of ITS, i.e., saving people lives and properties by minimizing road accidents, reducing traffic congestion and jams, and providing comfort and convenience to the travelers by allowing access to different infotainment services. VANETs are special class of Mobile Ad hoc Networks (MANETs) ([ULLAH *et al.*, 2013](#)), in which vehicles act like moving nodes. These networks are distinguished by the high speed of vehicles, small inter-contact times between hosts, different operational environments, variable densities of vehicles, short-range communications, intermittent connections and real-time data exchange requirements. Due to its importance to the ITS, more specifically to public safety, VANETs receive a great deal of attention from different standardization organizations, research communities, educational institutions, transportation departments, and automobile industries, on a global scale.

1.1 Motivation

Over the past years, the worldwide production of automobiles have been significantly increased. In 2015, about 68 million passenger cars were produced worldwide and the prediction for the year 2017 is 100 million globally ([STATISTA, 2015](#)). Adding to this, the connected vehicle market is increasing as well. According to a latest report by Business Insider, about 75% of produce vehicles will be built with communication capabilities, by the end of 2020 ([INSIDER, 2015](#)).

World traditional and new players in the automobile industry, e.g., Tesla motors, Audi automobile manufacturer, Fiat automotive industry, Honda motor company, BMW luxury vehicle company, Daimler AG automobile company, Nissan motor company, Mercedes-Benz automobile manufacturer, Continental AG manufacturing company, Autoliv company, Toyota motor corporation, and Peugeot car company, to name a few, are in the race of making autonomous and smart vehicles. Besides from automobile manufacturers, Google self-driving car and Apple iCar are also on their ways. These automobile manufacturers are incorporating latest technologies into their vehicles and today's vehicles are equipped with a plethora of embedded sensors, integrated cameras, actuators, laser, radar, lidar and Global Positioning System (GPS) devices. Additionally, the modern wireless technologies are becoming mature to facilitate communications among these smart vehicles. As an example, the NXP Semiconductors RoadLINK team is working jointly with Cohda wireless company to build hardware products for connected vehicles and roadside infrastructure.

Besides from automobile industries and wireless communication devices manufacturers, VANETs also attract attention of different standardization organizations. In the US, the Federal Communications Commission (FCC) and Institute of Electrical and Electronics Engineers (IEEE) have their own communities and working groups for developing different standards for VANETs.

Similarly in the Europe, the European Telecommunications Standards Institute (ETSI) and in Japan, the Association of Radio Industries and Businesses (ARIB) are working on VANETs related standardization issues.

1.2 Problem definition

VANETs provide a platform for the deployment of various applications. These applications are divided into two broad categories: safety and non-safety applications. The primary objective of safety applications is to assure public safety by eliminating the hazard of road accidents. On the other hand, the non-safety applications are related to traffic management, providing comfort and convenience to the drivers, reducing drivers travel times by avoiding congestion, making journeys more entertaining and enjoyable. The non-safety applications would provide lots of fun to the drivers and passengers.

Among non-safety applications, one such promising application area is the advertisement and discovery of roadside available services on the highways. The business owners of restaurants, hotels, coffee shops, gas stations, and supermarkets could benefit from these networks by disseminating their advertisements in real-time to target a large number of potential customers in a cost efficient way. On the other side, the drivers would use them to discover these services during their trips to other cities, on the highways. These services could include: finding a room in a hotel, getting a restaurant menu, finding special offers on products, looking for a petrol station ahead, and searching for a coffee shop, to name a few.

Generally, roadside services are advertise to the travelers by using classical methods of advertisements (e.g., banners and billboards). However, these traditional methods of outdoor advertisements are not adequate for several reasons. Firstly, these billboards are located in the proximity of the business owners, however the drivers would be interested to discover these services, far ahead of reaching there. Furthermore, the contents of billboards are static in nature, while the drivers would be interested in up-to-date information, in a real-time. Moreover, the classic methods are expensive and require lots of human effort and energy to install and update. Besides, in situations like congested traffic, rain, and strong winds, they could be destructive and hazardous for the drivers. In addition to these classical methods, today's modern forms of services advertisement and means of discovery (for instance, online and mobile advertisements) are infrastructure-based and require the Internet connection. Additionally, the customers are not always interested to receive these advertisements on their devices.

In this dissertation, we tackle the problem of roadside services provision to the drivers and means to discover them on the highways by using opportunistic vehicular communications capabilities.

1.3 Objectives

The general objective of this work is to make use of opportunistic vehicular communications for advertising roadside services and their discovery by the travelers. In this regard, the more specific objectives are as follows:

- To extend and evaluate the performance of Opportunistic Service Discovery Protocol (OSDP)—An opportunistic beaconing-based services advertisement and discovery protocol presented in (YOKOYAMA *et al.*, 2014)—by means of an extensive set of simulation experiments.
- To propose, model, design, implement and evaluate the performance of novel lightweight beaconing-based application layer roadside services advertisement and discovery protocols for VANETs.

1.4 Contributions

In this dissertation, we proposed beaconing-based roadside services advertisement and discovery protocols for VANETs. The main contributions of this research work are summarized as follows:

- An extended version of OSDP protocol called Extended Opportunistic Service Discovery Protocol (EOSDP) for VANETs, which open opportunities to explore the use of opportunistic vehicular communications for promoting businesses;
- A lightweight beaconing-based Services Advertisement Protocol (SADP) for VANETs, which would help business owners in advertising their services to a large number of potential customers on the highways;
- An infrastructure-less beaconing-based Commercial Services Discovery Protocol (CSDP) for VANETs, which would help drivers in discovering their services of interest, far ahead of reaching the business premises;
- An architecture for business owners, which would help them to register their services for advertisement with the help of a third party broker (i.e., advertisement agency).

The first contribution of this work has been published in the forth International Conference on Advances in Vehicular Systems, Technologies and Applications (VEHICULAR, 2015) under the title "Advertising Roadside Services using Vehicular Ad hoc Network (VANET) Opportunistic Capabilities", and will cover in Chapter 3. The second contribution of this work has been published in the fifteenth edition of International conference on Ad hoc Networks and

Wireless (AdHoc-Now 2016) under the title "SADP: A Lightweight Beaconing-based Commercial Services Advertisement Protocol for Vehicular Ad hoc Network", and will cover in Chapter 4. The final two contributions of this work are jointly submitted for publication in Ad hoc Networks Journal under the title "A Beaconing-based Commercial Services Discovery Protocol for Vehicular Ad hoc Networks", and will cover in Chapter 5. Furthermore, we are interested in making the source code of these protocols and traffic scenarios used for simulations, publicly available.

1.5 Dissertation organization

The rest of this dissertation is organized into the following chapters:

- **Chapter 2** details some fundamental concepts of VANETs. At the start of this chapter, we present different types of VANETs communications, including Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), hybrid and Vehicle-to-Everything (V2X). Next, we explain the concept of beaconing, in the context of VANETs. Also, we define the basic components of VANETs and describe the Wireless Access in Vehicular Environments (WAVE) protocols stack. We explain the most important standards of the WAVE architecture. We also explain different simulation approaches and tools available for performing VANETs experiments. We define different advertisement methods and strategies, in-use today. Finally in the last part of this chapter, we review the work related with roadside services advertisement and discovery in VANETs;
- **Chapter 3** provides a detailed description of the OSDP (YOKOYAMA *et al.*, 2014), including its main features, operations, implementation and limitations. OSDP is a beaconing-based protocol, which was recently proposed for local services advertisement and discovery in VANETs. The performance of OSDP was evaluated using a testbed of five Access Points (APs) having IEEE 802.11a interfaces for wireless communications. Secondly, we explain our extended version of OSDP, called EOSDP. EOSDP implements and extends the original version of OSDP by means of extensive set of simulation studies;
- **Chapter 4** describes our services advertisement protocol called SADP. SADP is a lightweight beaconing-based roadside services advertisement protocol, proposed for VANETs. We start the chapter by providing an overview of SADP. We then present our system model by highlighting the main entities of the protocol. After that, we explain the main characteristics of SADP. In addition to this, we also illustrate and explain our highway simulation scenario. Furthermore, we provide a complete list of simulation parameters, which was used for performing the experiments. Finally, we conclude this chapter after presenting the results of the simulation experiments;

- [Chapter 5](#) explains our services discovery protocol called CSDP. Like SADP, CSDP is a lightweight beaconing-based protocol. However, its purpose is to discover the roadside services, far ahead of reaching there. After providing a general overview of CSDP, we present the system model of CSDP along with its main entities and system messages. Next we explain the main characteristics of CSDP protocol. Additionally, we explain the phases of CSDP in great details. We then illustrate our simulation scenario and provide a complete list of mobility and network simulation parameters, used for the experiments. Finally, we present and discuss the results of our simulation with some concluding remarks;
- [Chapter 6](#) summarises this work and presents conclusions of the dissertation. Moreover, we present some of the difficulties faced during the course of this study. In a similar way, we provide a list of some of the limitations of this work. Finally, we present some directions for future work.
- The contents of [Chapter 4](#) and [Chapter 5](#) are based on the materials presented in our articles, with little modifications.

FUNDAMENTAL CONCEPTS

ITS are making use of advanced information, communication and electronic technologies to solve transportation related problems such as, traffic congestion, road accidents, and environmental pollution. In this context, the main role of ITS is to put intelligence in the transportation systems by allowing vehicles to communicate with each other and with their neighborhood (FIGUEIREDO *et al.*, 2001). ITS is a multidisciplinary concept, that attracts attention from the automobile industry, government departments and researchers. Although, the main focus of ITS is on road transportation, it also includes rail, marine and air transportation. A high level view of ITS is shown in Figure 1.

2.1 VANET communications

Wireless technologies are an asset for VANETs communications. Futuristic smart vehicles would be able to communicate with each others and also with roadside infrastructure using mature wireless technologies. VANETs communications would significantly increase road safety, traffic efficiency, and would make driving experience more enjoyable and entertaining. Broadly speaking, the VANETs communications can be divided into the following categories.

2.1.1 *Vehicle-to-Vehicle communication*

The wireless communication among vehicles is called Vehicle-to-Vehicle (V2V) communication (Figure 2). Sometimes the terms Car-to-Car (C2C) and Inter-Vehicle Communication (IVC) are also used for this type of communication. The V2V communication is purely Ad hoc in nature and does not require any infrastructure support. In V2V communication, vehicles directly send and receive messages to its neighbor vehicles. The main purpose of V2V communication is to enhance awareness of the driver about its neighborhood. Safety applications like, post crash notification, forward collision warning, blind spot warning, do not pass warning, lane change assistance, curve speed warning, emergency electronic brake light, left or right turn assistance

Figure 1 – Bird's-eye view of ITS.

Source: ETSI (2012).

and intersection collision warning would make use of V2V communication. Additionally, V2V communication could be used for non-safety applications like advertisement and discovery of roadside services. V2V communication among vehicles would make use of small packets called beacons. vehicles will exchange these beacons periodically, several times per second. The concept of beaconing is explain in Section 2.2.

Figure 2 – Vehicle-to-Vehicle (V2V) communication.

Source: Cunha *et al.* (2016).

2.1.2 Vehicle-to-Infrastructure communication

Besides from V2V communications, the vehicles would be able to communicate with the roadside infrastructure. The communication between the vehicles and roadside infrastructure is called Vehicle-to-Infrastructure (V2I) communication or Infrastructure-to-Vehicle (I2V) communication (depending on the flow of information). The roadside infrastructure plays a major role in V2I communication. The main motivation behind the V2I communications is to inform the drivers about traffic conditions or other hazards on the roads. Applications like traffic signal violation warning, danger zone information, speed violation and information about road and weather conditions would make use of V2I communication. In addition to traffic management, V2I communication could also be used for Internet-based applications like, downloading of maps and music, online streaming and games, and peer-to-peer applications. Furthermore, it could be used for advertising roadside services to the drivers as well. The V2I communication is depicted in Figure 3.

Figure 3 – Vehicle-to-Infrastructure (V2I) communication.

Source: Cunha *et al.* (2016).

2.1.3 Hybrid communication

The hybrid communication scenarios in VANETs combine both V2V and V2I communications. One use case of hybrid communication scenario is to extend the coverage area of a roadside infrastructure by multi-hop forwarding of the information towards the vehicles, which are not currently in the coverage range of the roadside infrastructure. Similarly, hybrid communication would be efficient for opportunistic forwarding of data towards the roadside infrastructure with the help of intermediate vehicles as a message forwarding node. The V2I communication is depicted in Figure 4. Additional information about VANETs communications protocols, applications and challenges are provided in (CUNHA *et al.*, 2016).

Figure 4 – Hybrid communication (CUNHA *et al.*, 2016).

Source: Cunha *et al.* (2016).

2.1.4 Vehicle-to-Everything communication

Vehicle-to-Everything (V2X) is a general term which refers to any type of communication, which involves a vehicle. It includes V2V, V2I, Vehicle-to-Pedestrian (V2P), Vehicle-to-Motorcyclist (V2M), Vehicle-to-Bicyclists (V2B), Vehicle-to-Home (V2H) (V2H), Vehicle-to-Network (V2N), and Vehicle-to-Grid (V2G) communications.

2.2 Beaconing-based communications

In the context of VANETs, a beacon refers to a small text-based message broadcasted by a vehicle or a roadside infrastructure, at a regular interval of time (usually several times per second). Beacons are transmitted using single-hop communication. Most of the applications would make use of beacons for the exchange of information. For safety applications, the periodic exchange of beacons, among vehicles, normally contain status information (for example, speed, heading, acceleration, and geographical position about the vehicle). The exchange of beacons among vehicles allow the drivers to know about the surroundings and make on-the-spot decisions, which would not be possible otherwise. These beacons are also known as heartbeat messages or Wave Short Messages (WSMs). Moreover, in the European Community, a beacon is best known as a Cooperative Awareness Message (CAM). These beacons are generated by application layer and are handled by the WAVE Short Message Protocol (WSMP), below the application layer.

For safety applications, the effective use of beacons have been explored by several studies (DANIEL; POPESCU; OLARIU, 2012; FENG *et al.*, 2010; MITTAG *et al.*, 2009; BALON; GUO, 2006; SONG; LEE, 2013; MARTELLI *et al.*, 2012). However, for non-safety applications (e.g., services advertisement and discovery) the use of beacons is still an unexplored area of research. In this work, we used the periodic exchange of beacons for services advertisement and discovery. The motivation behind the use of beacons is that they allow for fast and rapid

exchange of information and does not require any central control or network configurations (e.g., handshake or association mechanisms). Additional features of beacons are: lightweight, frequent transmission, and broadcast in nature. The use of beacons for the rapid exchange of information is very important for high speed vehicles scenarios, where vehicles have short inter-contact time with other vehicles and with RSUs.

2.3 VANETs communication components

To enable wireless communications between vehicles and with roadside infrastructure, VANETs incorporate two important components: On Board Units (OBUs), and Road Side Units (RSUs). In the following subsections, we explain these components.

2.3.1 *On Board Unit (OBU)*

An On Board Unit (OBU) is an embedded hardware device, which is mounted inside vehicles. The OBU has a read-write memory to store and retrieve information, a processor and computational capabilities. Additionally, it has a Graphical User Interface (GUI) to exchange information with the drivers, a GPS device for vehicle positioning and a wireless interface having an external radio antenna. The wireless antenna allows for short-range wireless communications with others OBU as well as with RSUs.

2.3.2 *Road Side Unit (RSU)*

Like OBU, Road Side Unit (RSU) is also an essential component of VANETs. However, unlike OBU, the RSU are stationary units, installed at fixed locations alongside highways, and other important locations e.g., intersections and parking lots. Similar to OBU, an RSU has a read-write memory, processor and computational capabilities. In addition to wireless interface, it also has a wired connection, which is used to connect it with other RSUs and with the Internet. The RSU would be under the control of government entities (e.g., highway authority) or a reliable third party broker. RSU would also play an important role in implementing security and privacy mechanisms, e.g., key distribution, cryptographic functions and authentication services.

2.4 VANETs communication standards

In order to increase safety on roads, reduce traffic congestion and air pollution, the United States Congress authorized the creation of a program called Intelligent Vehicle Highway Systems (IVHS). The responsibilities of this program were assigned to the USDOT. The USDOT, combined with a nonprofit organization called Intelligent Transportation Society of America (ITSA)—having members from academia, industry and government sectors and with other parties—developed a procedural framework in 1996, wherein ITS (Previously known as

IVHS) services could be planned, defined and integrated. This framework is known as National Intelligent Transportation Systems Architecture (NITSA). This architecture served as a master plan for ITS initiatives for more than a decade. NITSA concentrates on wireless communications technologies for the implementations of ITS services. In 1997, ITSA petitioned the FCC for 75 MHz of bandwidth in the 5.9 GHz band for exclusive use of ITS services. The FCC granted the request in 1999 ([UZCATEGUI; SUCRE; ACOSTA-MARUM, 2009](#)).

The allocated spectrum by the FCC is called Dedicated Short Range Communication (DSRC). DSRC enables short-to-medium range (up-to 1000 m) wireless communications in VANETs. The spectrum is divided into seven channels of 10 MHz each, with an additional 5 MHz guard interval at the start of the spectrum. Among these channels, the most important one is the Control Channel (CCH), which is labeled with the number 178. The CCH is dedicated to the use of safety applications and the announcement of the WAVE Service Advertisement (WSA)([JIANG; DELGROSSI, 2008](#)). Therefore, efficient utilization of this channel is very important. The channel numbers 172 and 184 are reserved for critical safety and high power safety applications. The remaining four channels are referred to as Service Channels (SCHs). These channels are numbered with 174, 176, 180, and 182. The SCHs could be used for both safety and non-safety purposes. This means that there will be a switching between the CCH and one of the SCH. The allocated spectrum with channels is shown in Figure 5.

Figure 5 – DSRC spectrum for VANETs.

Source: [Jiang and Delgrossi \(2008\)](#).

Another milestone for VANETs is the Wireless Access in Vehicular Environments (WAVE) system architecture, proposed by the IEEE ([UZCATEGUI; SUCRE; ACOSTA-MARUM, 2009](#)). WAVE follows the Open System Interconnection (OSI) layered architecture. However, it incorporates two protocol stacks. i.e., Internet Protocol version six (IPv6) and WSMP. The traditional IPv6 is used for typical Internet-based application, while the WSMP is proposed for time-critical applications ([IEEE Std 1609.3, 2010](#)). Additionally, the IEEE 1609 working groups has defined numerous standard protocols for WAVE architecture. The complete architecture of WAVE and its standard protocols is shown in Figure 6. In the following subsections, we explained the most important standards of the WAVE architecture.

Figure 6 – WAVE system architecture for VANETs.

Source: [Kenney \(2011\)](#).

2.4.1 IEEE 1609.1

The main purpose of IEEE 1609.1 standard is to grant access to the system resources. These resources include memory, user interface, processor and other devices connected with the OBUs or RSUs.

2.4.2 IEEE 1609.2

Like any other communication network, VANETs demand for high level of secure and private communication. Unfortunately, the IEEE 802.11p protocol (Section 2.4.5) does not provide built-in security functionalities for the exchange of beacons, which raises concerns about security and privacy. Therefore to address the security and privacy issues, the IEEE developed an additional standard called IEEE 1609.2. The recent version of IEEE 1609.2 standard ([IEEE Std 1609.2, 2016](#)) defines core security and privacy services for vehicular communications. It defines formats for securing management and application layer messages. The security measures defines in the standard would protect the messages from alteration, reply attacks, spoofing, eavesdropping, and Denial of Service attacks. Additionally, the IEEE 1609.2 standard defines the Public Key Infrastructure (PKI) scheme for authentication, while the use of pseudonyms for privacy concerns. A trusted Certificate Authority (CA) would provide pseudonyms to each and every vehicle. Hence, each vehicle will maintain a set of pseudonyms for sending messages,

without disclosing its identity. Using the concept of pseudonyms, the privacy of drivers and vehicles would be preserved. An RSU would provide the services of CA. Hence the RSU will play a major role in the deployment of security measurements and functionalities. Additional security issues regarding VANETs are: confidentiality of the contents of the messages, anonymity of the drivers, unlinkability of the messages to the vehicle, untraceability of the vehicles' locations and driving habits. Finally, the establishment of trust among vehicles is also an important security aspect of VANETs.

2.4.3 IEEE 1609.3

The networking services are handled by the IEEE 1609.3 standard protocol. It provides addressing and message forwarding functionalities to the WAVE devices. It deals with the network and transport layers of the WAVE architecture. In addition to traditional network and transport layer protocols, the IEEE 1609.3 standard also defines a new protocol called WSMP, which eliminates the network layer packet overhead by directly transmitting the messages over the wireless medium. The messages sent using WSMP are called WSMs (UZCATEGUI; SUCRE; ACOSTA-MARUM, 2009).

2.4.4 IEEE 1609.4

The main purpose of IEEE 1609.4 standard is to accommodate the multi-channel operation of WAVE devices, operating in a multi-channel environment. The objective for this is to give support to the simultaneous operations of both safety and non-safety applications. The IEEE 1609.4 enhances the performance of IEEE 802.11p protocol by supporting the operation of both safety and non-safety applications at the same time.

2.4.5 IEEE 802.11p

The IEEE 802.11p is a cross layer standard protocol designed for the MAC and PHY layers of the IEEE WAVE architecture. An important feature of IEEE 802.11p is that it is fully distributed in nature. Besides from Internet access and security services, it does not depend on any central network infrastructure. For PHY layer, amendments were made to IEEE 802.11a standard protocol. While its MAC layer is based on the IEEE 802.11e standard protocol (UZCATEGUI; SUCRE; ACOSTA-MARUM, 2009). The IEEE 802.11p incorporates Orthogonal Frequency Division Multiplexing (OFDM) technology from the IEEE 802.11a standard, while the Enhanced Distributed Channel Access (EDCA) from the IEEE 802.11e standard, in order to guarantee Quality of Service (QoS). As the design of IEEE 802.11p protocol is mostly based on IEEE 802.11a protocol, therefore it is important to mention the differences between the two protocols.

At the MAC layer, the main difference between IEEE 802.11a and IEEE 802.11p is that multi-channel operation support is provided in the later protocol. The details about multi-channel operation is provided in the IEEE 1609.4 standard. The IEEE 1609.4 standard defines four possible channel access schemes for the MAC layer of IEEE 802.11p protocol. These schemes are **continuous**, **alternating**, **immediate** and **extended**. The **continuous** channel access scheme would allow the vehicle to remain in the CCH all the times. As a result no channel switching would be performed and hence only safety-related data would be exchanged. As a result, only safety applications would benefit from the scheme. On the other hand, **alternating** access scheme would accommodate the operations of both safety and non-safety applications by performing a channel switching operation. In this approach, a vehicle could stay on CCH during CCH interval and can switch to one of the SCH in the service channel interval. The **immediate** channel access scheme interrupts the current ongoing communication on CCH and switch to the SCH, before the next SCH interval. Finally, the **extended** scheme let the vehicle to stay tuned to SCH, during CCH interval. In this case no further channel switching would be performed, unless the completion of SCH operation. This scheme is good for high bandwidth applications, e.g., downloading of a large file or streaming a video. However, using this scheme, the vehicle could not be able to exchange safety related messages. Figure 7 shows all these channel access schemes.

The IEEE 802.11p standard also minimize the MAC layer overhead by eliminating the

Figure 7 – Channel switching schemes.

Source: Yoo Hongseok; Kim (2013).

authentication and association procedures, before exchanging information. This enables the IEEE 802.11p to cope with high speed and rapidly changing VANETs environments. In IEEE 802.11a standard, all the channels are treated equally. However in IEEE 802.11p, the channel access has been prioritized. The time critical safety applications use the high priority communication channel (i.e., CCH), while the non-safety applications are allowed to use one of the low priority channels (i.e., SCH).

For the PHY layer of IEEE 802.11p, the main change was introduced to the channel bandwidth of the IEEE 802.11a protocol. Instead of using a 20 MHz-wide channel, the IEEE 802.11p is using a 10 MHz-wide channel. Further changes are brought to the data rates of IEEE 802.11a. The data rates defined for IEEE 802.11a standard are 6, 9, 12, 18, 24, 36, 48, and 54 Mbps. However, for IEEE 802.11p, the data rates are 3, 4.5, 6, 9, 12, 18, 24, and 27 Mbps. Unlike IEEE 802.11a, the IEEE 802.11p does not require to form a Basic Service Set (BSS) before exchanging the data. This feature allows vehicles to exchange data in very high speed environments, where vehicles has very little inter-contact time with other vehicles and with roadside infrastructure. As a result, it improves efficiency of data exchange by minimizing undesirable delays.

The communication range of IEEE 802.11p devices is also different from that of IEEE 802.11a. In the case of IEEE 802.11a, the communication range reaches to 120 m, in outdoor environments. While the IEEE 802.11p has a communication range of several 100 m and reaches to a maximum of 1000 m. Additionally, the IEEE 802.11p supports vehicles speed of up to 200 Kmph.

2.4.6 SAE J2735

On top of WAVE protocols stack, the the Society of Automotive Engineers (SAE) specifies a standard called SAE J2735. This standard defines the syntax and semantic for Basic Safety Messages, Roadside Alert, Signal Status Message, Emergency Vehicle Alert Message, and Probe Data Management. Among these, the most important one is the Basic Safety Message. Its contents contain vehicle status information, like, longitude, latitude, speed, heading, acceleration, and vehicle size. A large number of safety applications, e.g., emergency electronic brake light, blind spot warning, cooperative adaptive cruise control, cooperative collision warning, cooperative forward collision warning, lane change warning, and so forth will be based on Basic Safety Message. This standard would help to solv the interoperability issues among the future WAVE devices from different manufacturers. The Abstract Syntax Notation One (ASN.1) specifies the format of these messages ([KENNEY, 2011](#)).

In addition to the IEEE and SAE standards in the US, the ETSI in Europe, constituted a technical committee for VANETs. The ETSI standard is called ETSI ITS-G5 ([ETSI Std, 2009-2011](#)). Similar standardization efforts are introduced in Japan and the standard is called ARIB STD-T75 ([ARIB Std, 2001](#)).

2.5 Simulation approaches for VANETs communications

In VANETs, performing field tests or real world experiments, specially at a larger scale, is a difficult and expensive task. It requires many technological efforts (e.g., deployment of RSUs and mounting OBUs in vehicles), laborious work, and logistic issues. Furthermore, it is also difficult to repeat the experiments with different parameters. In this regard, network simulation tools are considered as an alternative to implement, compare, validate, and evaluate performance of VANETs related protocols and applications. Additionally, by using simulations it is possible to repeat the experiments with different set of parameters in a fastest way. For performing VANETs related simulations, different options are available for the research community. The following categorization is based on a survey, presented in ([HARRI; FILALI; BONNET, 2009](#)).

2.5.1 Isolated simulation approach

In this approach, the mobility generator simulator is used independently from network simulator, and there is no direct interaction between the two components. The mobility generator simulator generates the mobility traces, which is then provided as an input to the network simulator, however the network simulator has no control over the vehicles mobility. This approach is also called loosely integrated, offline or static simulation approach. The isolated simulation approach is suitable for scenarios, where run time events does not affect the mobility of vehicles ([ZEMOURI; MEHAR; SENOUCI, 2012](#)). The main advantage of this approach is the independent development of each component. However, this approach is not feasible for safety related applications, which will require interaction between the two simulation worlds. The isolated simulated approach is depicted in Figure 8.

Figure 8 – Isolated simulation approach.

Source: [Harri, Filali and Bonnet \(2009\)](#).

Examples of mobility generator simulators are: VANETMobiSim, PARAMICS, Simulation of Urban Mobility (SUMO), STreet Random Waypoint, FreeSim, Verkehr in Städten SIMulationsmodell, BonnMotion, CityMob v.2, and TransModeler. Examples of network simulators available are: Network Simulator-2, Network Simulator-3, Global Mobile Information System Simulator, QualNet, Staged Network Simulator, Java in Simulation Time/Scalable Wireless Ad hoc Network Simulator, and Objective Modular Network Testbed in C++ (OMNET++).

2.5.2 Embedded simulation approach

Unlike the previous approach, embedded simulation combines functionalities of the two simulators (mobility generator and network simulator) into a single but simple simulator. Basically, these simulators are designed from the scratch and they have the ability to simulate vehicle mobility as well as their communications. It also allows direct interaction between the two modules. However, either the traffic or network simulator tends to be very simple. The main drawback of this approach is the poor quality of the network simulator. This approach is useful only for performing some basic network simulations. The embedded simulated approach is shown in Figure 9.

Some examples of simulators fall in this category are: Mobility Model Generator for Vehicular Networks, National Chiao Tung University Network Simulator, EstiNet and VISSIM.

Figure 9 – Embedded simulation approach.

Source: Harri, Filali and Bonnet (2009).

2.5.3 Federated simulation approach

Federated or online simulation approach is more advanced and recently developed approach for performing VANETs simulations. This approach takes advantage of existing state-of-the-art network and mobility simulators and combine them through an interface. The interface allows bi-directional communication between the two simulators. Both simulators are allowed to work in parallel. The traffic simulator does not generate the static mobility traces, instead it is generated simultaneously with the network simulator. The main drawbacks of this approach are long simulation times and high computational cost. Also, in most cases the interfaces are not freely available. This approach is highly recommended for research communities, working with more realistic traffic scenarios. The embedded simulated approach is shown in Figure 10.

An example of this approach is the TraNS simulator, which links SUMO mobility simulator with NS2 network simulator using TraCI interface. Another example is the Vehicular Network Integrated Simulation, which couples SUMO mobility simulator with NS-3 network

Figure 10 – Federated simulation approach.

Source: Harri, Filali and Bonnet (2009).

simulator. Finally, the most popular simulator of this approach is the Veins framework which couples SUMO mobility simulator with OMNET++ network simulator.

Based on literature survey and discussion with VANETs researchers, we selected the advanced federated simulation approach for this work. Accordingly, to implement our scenarios, generate realistic traffic flows and define vehicle's parameters we used a state-of-the-art simulator called SUMO (BEHRISCH *et al.*, 2011). SUMO is a well known open source microscopic simulator, which is used on a larger scale by the research communities. In addition to this, SUMO also supports to import maps from open street maps. Finally, it provides the facility to define grid networks. Aside from SUMO, we used the network simulator called OMNET++ for wireless communication between vehicles and roadside infrastructure (VARGA; HORNIG, 2008). OMNET++ is an open source discrete event network simulator, which represents each vehicle as a moving node while each RSU as a fixed node. In addition, it also enables wireless communications between vehicles and RSUs. In addition to these two simulators, we also used Vehicles in network simulation (Veins) framework (SOMMER; GERMAN; DRESSLER, 2011). Veins is an open source bidirectional framework, which couples SUMO with OMNET++ using TraCI interface (WEGENER *et al.*, 2008). Veins uses a TCP connection to bridge the gap between the two simulators. Veins is already providing built in support for WAVE standard protocols stack. It is mostly notable for IEEE 802.11p and WSMP protocols. Moreover, it also supports the multi-channel operation of IEEE 1609.4 protocol. These simulators are shown in the Figure 11.

2.6 Advertisement methods

In today's world, advertisements are everywhere around us and there is hardly a day that we did not come across them. As one of the most popular and effective form of marketing, business owners spend large investments on advertising their products and services to a large number of potential customers. Nowadays, different forms of advertisement are available for business owners. We broadly divided these methods into the following three categories.

Figure 11 – Simulation tools used.

Source: [Veins \(2011\)](#).

2.6.1 Offline advertisement methods

Offline advertisement methods are in place for a long time. Most of the traditional advertisement methods, e.g., newspapers and magazines, radio and television, fliers and brochures, door-to-door calling, telemarketing, yellow pages, posters, billboards, bulletins, and vehicles wraps fall under this category. Normally, these classical advertisement methods are expensive and limited in coverage area. They are useful for targeting local customers.

Among these offline advertisement methods, the bulletins and billboards, installed on the highways, are the primary methods of advertisement which grab travelers attention. The travelers normally count on these billboards on the unfamiliar highways, in order to find a near-by roadside service. These billboards usually advertise local businesses like restaurants, petrol stations, coffee shops, hotel and supermarkets in the next few kilometers. However, these billboards and bulletins need to be read and memories in a quick time, while driving on the highways. Additionally, they can destruct drivers attentions and could lead to some dangerous accident as well.

2.6.2 Online advertisement methods

Technological advancement are effecting every aspect of our lives. In the last two decades, these technological advancements change the classical methods of advertisements as well. Recently, the advertisement market is shifting towards online advertisement methods. Online advertisement methods depend on Internet connections and smart devices to advertise the products and services to a large number of online customers. It is also know as web-based, Internet or mobile advertising. Additionally, the online advertisements also make use of social networking websites, personal emails marketing, computer games, online videos, short message services, free classified websites, web blogs, search engine optimization, web banners, pop ups advertisement, and digital displays installed at fixed locations.

Online advertisement methods are faster, cost-effective, easy to update, dynamic, cus-

tomizable and provide more control over the advertisement campaign. Additionally, the business owners could track the progress and can get feedback from their customers as well. Using online advertisement methods, a business owner can target customers at a global scale. However, the business owners could only target customers with an Internet connections and smart devices. Additionally, the online advertisement methods are not always effective. As a result, customers try to get ride of unwanted advertisements by blocking them using different tools.

2.6.3 VANETs-based advertisement methods

The use of VANETs communication capabilities for roadside services advertisement and discovery gain momentum in the recent years. Generally, the RSU would disseminate advertisements about the roadside services to the travelers, passing nearby them. These vehicles would then store these advertisements and would opportunistically forward them to other interested vehicles using V2V opportunistic communications. This new era of advertisement is expected to change the marketing perspectives of advertisements. We reviewed VANETs-based advertisement and discovery schemes in Section 2.8.

2.7 Advertisement strategies

Advertisement strategy is a building block of the overall marketing plan. Based on the flow of information, these advertisement strategies are divided into the following categories.

2.7.1 Push-based strategy

In the marketing world, the push-based strategy is a very common method for advertising products and services to the customers. In push-based strategy, the flow of information is from the business owner towards the customers. Here the customer has no control over the advertisement campaign. Companies uses this approach both in offline as well as in online methods. A classic example of push-based advertisement strategy is the supermarket flier that we received at our door steps. Supermarkets pushes their advertisements towards the customers, regardless of their interest. Similarly, in the online world we experience many push-based advertisements while surfing the web, searching on web, online streaming, downloading a file, sending or receiving text messages, playing games, or on social media websites.

A major drawback of push-based strategy is that, in most cases the customers are not interested in receiving these advertisements. That is why most of the Internet users, uses different tools for blocking these push-based advertisements. Furthermore, in most cases, the users even did not notice the existence of these advertisements on the websites. Moreover, these advertisements let the users bored and even angry in some cases.

2.7.2 *Pull-based strategy*

To address a large number of customers, the push-based advertisement is a good strategy for the business owners. However, in marketing world, the interest of customers is also valuable. To overcome the problems of push-based advertisement strategy, the concept of pull-based strategy was introduced in the marketing world. In pull-based advertisements, the customers usually decide what they want to receive. In pull-based strategy, the flow of information is from customers toward the business owners. In this strategy, the customers usually searches for interest-based services. Pull-based advertisements are usually based on customers demands and are therefore warmly welcomed in the marketing world. It also helps the business providers in understanding the needs of the customers.

2.7.3 *Hybrid strategy*

To be successful in the marketing world, attract more customers and earn more revenues, a single advertisement strategy is not sufficient. Instead, the business owners would need to combine different advertisement strategies. To target large number of customers, the push-based approach seems more attractive for the business owners, however only targeting is not enough, if the customer is not interested in the product or service. Therefore, the business owners need to provide pull-based approaches, in order to allow the customers to search for what they want. In this regard, a hybrid approach is more efficient for services providers.

2.8 Services advertisement and discovery in VANETs

After explaining the basic concepts of advertisement methods and strategies, in this section we reviewed the work related to services advertisement and discovery in VANETs.

In (DIKAIKOS *et al.*, 2007), the authors studied the problem of providing roadside services information to the drivers. They proposed an application layer location-based protocol called Vehicular Information Transfer Protocol (VITP). In VITP, the vehicle requesting the service sends a query towards the target region using multi-hop transmission. Once the query is received by a vehicle inside the target area, it is resolved by the peers and the response is send back towards the source region, where it is broadcasted by the underlying network protocol. However, their protocol is not capable of dealing with dense traffic scenarios and large number of requests. Additionally, they did not consider the standard protocols for VANETs communications.

An RSU-dependent service discovery protocol called Address Based Service Resolution Protocol (ABSRP) was presented in (MOHANDAS *et al.*, 2008). The RSUs, interconnected with Internet, play a major role in the service discovery process. Vehicle asking for a service sends a request towards its leader RSU, which would send it towards the target, only if it knows the IP address. Otherwise, the RSU broadcast the request to other RSUs using Internet. The

responsible RSU then reply with response message, either by using VANET or backbone Internet. The high communication overhead among the vehicles and RSUs for service discovery, followed by granting access to the Internet would make the protocol inefficient for high speed vehicles. Another drawback of ABSRP is that the implementation was not based on VANETs standard protocols stack. Alternatively, they used UDP protocol and IEEE 802.11a based wireless interface cards for communications.

In another study, an Internet-centric architecture for services discovery in VANETs was suggested ([BOUKERCHE; ABROUGUI, 2009](#)). The architecture consists of three main components: Roadside Gateways (RGs), Roadside Routers (RRs) and Road Vehicles (RVs). The RRs were connected using heterogeneous backbone network. A hybrid (proactive and reactive) service discovery protocol was proposed. The vehicles advertise the services while the RR collects these advertisements and store them in the cache. Subsequently, the RR provides this information to the requesting vehicles, If the service is present in the its cache. Otherwise, the query is forwarded to the appropriate RR, using network layer routing. They also described a proof of concept, in order to verify the accuracy, completeness and correctness of the proposed algorithm. The main disadvantage of the scheme is that there is no direct V2V communications, instead it depends on the Internet and infrastructure communications for answering the queries. Furthermore, the authors do not carry out simulations to evaluate the performance.

In ([ABROUGUI; PAZZI; BOUKERCHE, 2010](#)), the authors presented two Location-based Vehicular Service Discovery Protocols (LocVSDP): election based-LocVSDP and naive-LocVSDP. Their scheme operates in four phases: advertisement of services, propagation of requests, election for the leader and service response. The driver sends a query to the neighbor Roadside Router (RR), in the Region of Interest (RI). The RR separates the service information from routing information, and sends the request to other RR, if required. A leader, inside each RI, is selected by using an election process, which is responsible for generating service reply and its propagation to the driver. The main drawback of these protocols is the election process, which is performed for all queries. The election process could lead to high congestion and as a result could degrade the performance. Additionally, the scheme was highly dependent on the collaboration of RSUs, for resolving queries, which is not acceptable in high speed VANET scenarios.

In ([WANG *et al.*, 2010](#)), the authors proposed a multi-hop advertisement dissemination and forwarding scheme. They used incentive mechanism to motivate selfish nodes and dynamic window technology to prevent malicious nodes from launching Denial of Service (DoS) attacks. The business owners need to offer virtual cash to all the advertisement forwarding vehicles, which would make the solution impractical and expensive. They used NS-2 simulator to evaluate the performance. However, they did not mention the parameters and matrices used. Moreover, the VANETs standard protocols were not considered for this work.

To buy and sell goods using VANET, the concept of virtual flea market was introduced

in (LEE *et al.*, 2010). In FleaNet, either RSU or vehicle could broadcast the advertisements. The vehicle looking for buying goods could periodically broadcast a query towards the neighbor vehicles. On the receipt of this query the vehicle searches its cache. If a match is found a response is sent back towards the querying vehicle. The main drawback of this approach is that the design of FleaNet was not based on VANETs standard protocols stack. Alternatively, they used IEEE 802.11b interface cards for wireless communications.

In (Hu *et al.*, 2015), the authors proposed a greedy algorithm for selecting Roadside Access Points (RAPs) by the business owners. The business owners rent RAPs for advertising their services to the drivers. These RAPs are installed and controlled by RAP Service Provider (RSP). The main goal of this work was the reduction of advertisement cost by selecting least number of RAPs. The correctness of the algorithm was verified by theoretical analysis and the performance was evaluated using simulations. However, it was not mentioned which wireless technology was used for communications.

A secure incentive-based advertisement dissemination framework called Signature Seeking Drive (SSD) was proposed in (LEE *et al.*, 2012). They used Public Key Infrastructure (PKI) for V2V communications among vehicles. This PKI is provided to each vehicle by an authorized certificate authority. Upon successful forwarding of the advertisements to neighbor vehicles, a digitally signed receipt from the vehicle is received. The drivers could use these receipts as a virtual cash at locations such as petrol stations. In SSD, incentives need to be provided to both advertisement forwarder and receipt provider vehicles, which make this scheme impractical and expensive for the service provider. Additionally, they do not give attention to VANET standard protocols.

In a recent study in (YOKOYAMA *et al.*, 2014), the authors proposed an Opportunistic Service Discovery Protocol (OSDP) for VANETs. OSDP makes use of MAC layer native beacons to discover the roadside services in a V2V communication scenario. The solution is based on three phases, i.e., service advertisement phase, service query phase and service response phase. Experiments were performed using a test-bed of five Access Points having IEEE 802.11a-based wireless interface cards. However, the authors do not use the VANETs standard protocols stack, which makes the solution questionable.

2.9 Final considerations

None of the above cited work gives proper attention to the VANET standard protocols stack. Unlike, existing solutions, our proposed solution is based on IEEE WAVE standard architecture. In particular, we build our solution on top of WSMP, IEEE 802.11p, IEEE 1609.3, and IEEE 1609.4 standard protocols. Additionally, we used beacon messages for all types of communications. The basic idea of using beacon messages for non-safety application (services advertisement and discovery) was inspired from the work presented in (YOKOYAMA *et al.*,

2014), in which the authors utilized MAC layer beacons for services discovery in VANETs.

Our contributions fall under the category of VANETs-based advertisement methods and we proposed roadside services advertisement and discovery protocols. Additionally, we take into account the opportunistic communication between vehicles and roadside infrastructure. For services advertisement (by RSUs) we used the push-based advertisement strategy, while for discovering these services (by vehicles), we make use of pull-based advertisement strategy. In this regard, we used a hybrid approach for this work.

EOSDP: EXTENDED OPPORTUNISTIC SERVICE DISCOVERY PROTOCOL FOR VANETS

In this chapter, we describe the characteristics, operations, phases and limitations of the OSDP protocol, presented in (YOKOYAMA *et al.*, 2014). We also present our Extended Opportunistic Service Discovery Protocol (EOSDP) for roadside services advertisement and discovery. The EOSDP implements and extends the original version of OSDP by using mobility simulator SUMO and network simulator OMNET++. We perform extensive set of simulation experiments to evaluate the performance of different phases of the protocol, under different traffic densities. For I2V communications we increase the number of services advertised by RSUs, while for V2V communications we change the vehicle densities. Our solution does not rely on the Internet connection for advertising services to the drivers and resolving service queries and responses. Like OSDP, we make use of beacon messages for services advertisement and discovery. Finally, we present the simulation scenario in a way that the results could be used for designing new business models. The work presented in this chapter has been published in (ULLAH *et al.*, 2015).

3.1 Objectives

The main objectives of the experimental work are as follow:

- To implement and evaluate the performance of EOSDP, by means of extensive set of simulations;
- To extend the service discovery phase of OSDP, presented in (YOKOYAMA *et al.*, 2014).

3.2 Description of OSDP

In order to understand our proposed EOSDP protocol, it is important to understand the description of the original OSDP protocol. In OSDP, The authors addressed the problem of providing roadside services information and their discovery in VANETs. OSDP is a beaconing-based opportunistic protocol for roadside services advertisement and discovery. It makes use of opportunistic communications among vehicles and between vehicles and roadside infrastructure. For advertising local services to the travelers, OSDP depends on roadside infrastructure. As a single RSU is very limited in coverage range, therefore to target a large number of users the business owners would require to register their services for advertisement with more than one RSU. However, the deployment of roadside infrastructure is very costly and therefore an alternative solution is required to reach to a maximum number of travelers with minimum cost. The authors addressed this issue by proposing OSDP. Using OSDP, the business owners utilize the vehicles to carry their advertisements and opportunistically forward them to the other vehicles, even when they are not in the coverage range of the RSU. The authors also presented the design elements of OSDP. Additionally, they performed experiments by considering a testbed of five Access Points with IEEE 802.11a interface cards.

3.3 Characteristic of OSDP

In this section, we describe some of the main features of OSDP protocol.

3.3.1 *Layer 2 protocol*

OSDP is a MAC layer protocol, which uses the Information Element Vendor (IE Vendor) field of IEEE 802.11a frame for all types of messages (i.e., advertisement, query and response). The total size of IEEE 802.11a IE Vendor field is limited to 256 bytes, however, the size of OSDP messages is greater than 256 Bytes, hence two IE Vendor fields were used to encapsulate the messages.

3.3.2 *Opportunistic communication*

OSDP makes use of opportunistic I2V communication for advertising local services to the drivers. Additionally, it uses opportunistic contact among vehicles (V2V communication) for discovering these services.

3.3.3 *Store-carry-and-forward*

OSDP uses the store-carry-and-forward mechanism, according to which the vehicle will store the received information about local services and will wait for opportunistic contacts from other vehicles, in order to help the drivers in discovering these services.

3.3.4 Internet-independent

The design of OSDP is not based on the Internet and therefore the travelers will not require to use their smart phones having 3G/4G Internet connections to discover the services. However, for advertising local services, OSDP makes use of roadside infrastructure (i.e., RSUs).

3.3.5 Lightweight beaconing-based

OSDP is a lightweight solution, i.e., the size of messages is small and hence requires less processing and computational overhead. Additionally, it uses single-hop broadcasted small messages called beacons, for all types of communications.

3.3.6 XML-based messages format

For OSDP, the authors used Extensible Markup Language (XML) tags for incorporating services information.

3.4 Phases of OSDP

OSDP consists of three main phases. These phases are briefly explain in the following subsections.

3.4.0.1 Beaconing phase

This phase refers to the periodical broadcast of advertisement messages by the RSUs about local services, at a regular interval of time, in I2V communication scenario. These advertisements contain necessary information about the local services, for example, location of business owner, name of the service and its description etc. The information is encapsulated in MAC layer native beacon.

3.4.0.2 Caching phase

In this phase, the vehicles stores the received information about the advertised services, in their caches. However, if the service is already in the vehicle cache, it will simple discard the duplicate service. Furthermore, the vehicles regularly delete the expired services from their caches. The main objective behind caching approach is to opportunistically forward the advertisement services to the querying vehicles, upon request.

3.4.0.3 Querying phase

The purpose of this phase is to discover the local services, by sending query message towards the neighbor vehicles, in a V2V communication scenario. The vehicle interested in

Figure 12 – OSDP phases.

Source: Yokoyama *et al.* (2014).

finding a service sends a query message towards the neighbor vehicles. All the neighbor vehicles, after receiving the query message, would check their local caches, and if a match(s) is found, the vehicles would send back responses towards the querying vehicle. It is important to note that the neighbor vehicle uses unicast communication approach, in order to send back responses towards the querying vehicle. Additionally, single-hop communications were used for all type of messages.

3.5 Operations of OSDP

The operation of OSDP starts when the RSU sends an advertisement with local service information. The RSUs regularly broadcast these services and the vehicles stores them in their caches. On the other hand, when a vehicle requires to find a service, it sends a query with required service name towards its neighbor vehicles. After receiving the query, the neighbor vehicles response to the query. As a result, the querying vehicle store this information in its cache. The service discovery operation helps the drivers to discover the desire services, even when they are not in the coverage range of the service advertising RSU.

3.6 Limitations of OSDP

The following are the main limitations of the OSDP.

3.6.0.1 Limited number of RSUs

The authors considered a limited number of RSUs for the implementation and performance evaluation of OSDP. A maximum of seven RSUs were used for the study. In addition to that, each RSU was responsible to send only one or two services advertisement.

3.6.0.2 Limited number of vehicles

Like RSU, the number of vehicles was also limited. Only a single vehicle was allowed to query for the local services. Moreover, a maximum of 7 neighbor vehicles were selected to response to the query message.

3.6.0.3 Lack of VANETs standards

In OSDP, IEEE 802.11a based APs were used to emulate both RSUs and vehicles. However, as we already explained in Section 2.4.5, there are many differences between the two standards.

3.6.0.4 Lack of simulation and scenario

Another limitation of the study was the lack of simulation experiments. The protocol was implemented and the performance was evaluated in a proof-of-concept testbed. In VANETs, one of the most important consideration for performing experiments is the definition of a scenario. However, no scenario was defined for performing the experiments. In addition to that, parameters like vehicles speed, direction, acceleration etc., were also not mentioned in the implementation.

3.7 Implementation of OSDP

For implementation, a testbed of five APs (IEEE 802.11a based) operating at a frequency band of 5.8 GHz was used. Additionally, a transmission power of 15 dBm was considered for all APs. Furthermore, transmission rate of 6 Mbps was selected for the tests. The APs were placed in a row. The inter-distance between two consecutive APs was set to 50 cm. The middle AP was dedicated to represent the querying or responding vehicle. While the rest of the APs could either represent an RSU or a service responding vehicle. The protocol was instantiated on all the APs. Due to the limited number of RSUs, a single AP was used to emulated more than one RSUs and vehicles, in some tests. The testbed used is shown in Figure 13.

The authors performed two different series of experiments. In the first set of experiments, the first two phases of OSDP, i.e., beaconing and caching, were evaluated. In this regard, the performance of services advertisement by RSUs and its reception and storage by the vehicles was evaluated. The performance metric used was success rate of services advertisement. The success rate refers to the number of services advertised by an RSU per total number of received

Figure 13 – OSDP testbed.

Source: Yokoyama *et al.* (2014).

services by the the vehicle. An important parameter used for these experiments was inter-contact time. Inter-contact time refers to the total amount of time, a vehicle stay inside the coverage area of an RSU or another neighbor vehicle. This inter-contact time was controlled by POSIX thread inside APs. The basic function of this thread is to wake up the protocol for the a pre-defined time frame and then put it back to sleeping state. For these experiments, and inter-contact time of 0.2 s to 2.0 s was selected.

In the second set of experiments, the third phase of OSDP, i.e., querying, was considered for evaluation. Herein, the performance of services discovery (i.e., queries and responses) was evaluated. The metric selected for these experiments was query success rate. The query success rate is total number of neighbor vehicles at that time per total number of replies received by the querying vehicle. The neighbor vehicles are the vehicles, that are under the coverage range of the querying vehicle. The maximum number of neighbor vehicles was limited to 7 only.

The first set of experiments incorporate the use of I2V communications while the second set of experiments used opportunistic V2V communications.

Figure 14 – Local services advertisement and discovery

Source: Yokoyama *et al.* (2014).

3.8 Description of EOSDP

Afterwards, we present our extended version of OSDP called EOSDP. We will start by explaining the system model of our protocol, including its main entities, and messages. It is important to note that we used the same phases for the EOSDP and therefore we will not

explain them again in the system model. Second, we will explain the operation of EOSDP by considering a motivational highway scenario. Finally, we will present the simulation results and conclusions drawn from it.

3.9 System modeling of EOSDP

In this section, we will present the main entities of EOSDP. and then we present different messages of the system.

3.9.1 System entities

To implement the EOSDP, we proposed a system model with the following main entities in practice.

3.9.1.1 Business Owner (BO)

A Business Owner (BO) refers to an entity who owns a business on the highways. A few examples of the businesses are: restaurants, hotels, petrol stations, coffee shops, supermarkets, and gift centers. The BOs would be interested to advertise their services to the nearby vehicles in order to target a large number of potential customers. These services include discounts on products, special offers, new arrivals, price lists, food menus and available facilities. In order to advertise the services to the travelers, the BOs would require to register them with an advertisement agency using Service Level Agreements (SLAs).

3.9.1.2 VANET Advertisement Agency (VAA)

VANET Advertisement Agency (VAA) is a third party broker who is accountable for the whole advertisement campaign. One of the main responsibilities of the VAA is to prepare different business plans, contracts, policies and advertisement packages for the BOs. Additionally, the VAA would be responsible to authenticate the contents before advertising them to the customers. Moreover, VAA would look after the installation, management, and maintenance of Advertisement Base Stations (ABSs). The VAA would feed the ABSs with commercial services advertisements for broadcast to the neighboring smart vehicles. Finally, VAA would be responsible for updating the contents of advertisements. We believe that in the future, the VAA would work under the administration of the government agency (e.g., transportation department or highway authority).

3.9.1.3 Advertisement Base Station (ABS)

ABS functions like RSU by providing I2V communications for advertising the services. ABSs would be install and control by VAA, alongside the highways. ABS would be capable

of performing storing, processing and computational tasks. Moreover, they would be equipped with IEEE 802.11p based wireless interface cards to communicate with the vehicles, inside the coverage range. They would also have additional interfaces to connect them to the Internet. The main functionality of an ABS is to broadcast the registered services using I2V communication, several times per second. In order to target a large number of smart vehicles, ABS uses the push-based communication technique.

3.9.1.4 On Board Unit (OBU)

The OBU is an important entity, installed in each vehicle, with storage, processing and computational capabilities. When a vehicle enters in the coverage area of an ABS, it starts receiving services advertisement from that ABS, using I2V communications. The received advertisement messages are cached for a specific amount of time. The BOs could make special agreement, such as promotions and incentives, in order to stimulate the drivers to store and carry their advertisement messages and forward them to others vehicles opportunistically. Additionally, the OBUs would send and receive query/response messages in a V2V communications, using IEEE 802.11p based wireless interfaces.

3.9.2 System messages

In this subsection, we discuss the different messages of the proposed system.

3.9.2.1 Advertisement message

Advertisement is a well known marketing strategy for announcing products and services to the customers. In our system, the BO would register their services with a third party broker (i.e., VAA) for advertising them to the travelers. The registration process is out of the scope of this work. The VAA then assign the service to an ABS(s). The ABS uses the advertisement message to encapsulate the service information and broadcast it to the nearby vehicles.

3.9.2.2 Query message

To discover a desired service, the vehicle would broadcast a query message towards the neighbor vehicle(s) using a pull-based strategy. The query is said to be successful, if the querying vehicle receives a response from its neighbor vehicles. Otherwise, it is unsuccessful. In our experiments, the vehicle repeats sending the query message every 20 s. Additionally, we use single-hop strategy to broadcast the query message.

3.9.2.3 Response message

When a vehicle receive a query message, it will search its local cache for the required service. If one or more services are found, the vehicle would broadcast the response message.

For this experimental work, we assumed that all neighbor vehicles already have the requested services inside their caches.

3.10 Motivational scenario

In this section, we explain our system model by considering a motivational highway scenario with two lanes on each side. The scenario is depicted in Figure 15. Vehicles enter into the scenario from two different origins. Four RSUs are deployed, on both sides of the roads. RSUs are interconnected using Internet as a backbone. We assume that all RSUs and vehicles are equipped with IEEE 802.11p based wireless interfaces. Additionally, each vehicle has a built-in GPS device and an OBU, with storage and processing capabilities. Each RSU will broadcast advertisement messages on a regular interval, using beacons, and vehicles would start receiving these advertisements messages, as soon as they enter into the coverage area of an RSU.

Figure 15 – Motivational scenario for EOSDP.

Source: Elaborated by the author.

Consider a vehicle v_1 , which has received advertisement messages from RSU1 (gas station, coffee shop), RSU2 (hotel, restaurant, shopping mall), RSU3 (hotel, restaurant, shopping mall) and RSU4 (coffee shop, gas station) respectively. v_1 will store and carry all these services information and will opportunistically forward them to other vehicles, upon receiving a query message. Now suppose that vehicle v_9 is interested in finding information about a near-by gas station. First, v_9 will check its own local cache. If no such information exists, it will broadcast a query message towards its neighbor vehicles. In this case, only vehicle v_1 will receive the query message.

To resolve this query, vehicle v1 will search its own cache for gas station information. Since v1 has information about a single gas station, it will broadcast this information in a V2V communications, using response message. However, for some reasons, if v9 does not receive any response message, it will resend the query message, after some time. The original version of OSDP protocol uses the unicast approach for sending back responses to the vehicles. We modified the unicast approach, by allowing vehicles to broadcast the response message. This mechanism would allow other neighbor vehicles to receive advertisement messages without making queries for them.

3.11 Simulation parameters

We defined the traffic parameters inside SUMO simulator. One of the most important parameter is vehicle speed. In our experiments, we used constant speed of 120 km/h for all vehicles. We performed our experiments using a highway of 140 km, with multiple lanes on both sides. Additionally, we deployed a maximum of 7 RSUs alongside the highway, for advertising the services. Vehicles were injected into the scenario from two different origins, with a fixed interval of 1.6 s for the first experiment and 40 s for the second experiment. The parameters we used for our network simulator are summarized in the Table 1.

Table 1 – Simulation parameters used for OSDP.

Parameter	Value
Wireless medium	IEEE 802.11p
Transmission rate	6 Mbps
Transmission power	33 dBm
Message type	WSMP data
Channel bandwidth	10 MHz
Frequency band	5.9 GHz
Radio propagation model	Simple path loss model
Simulation Time	Experiment 1: 250 s Experiment 2: 4200 s

3.12 Results and discussions

This section discusses the results we obtained from our simulation experiments. Based on the OSDP testbed experiments, we divided our experiments into the following two parts.

3.12.1 Evaluation of advertisement messages

In this experiment, we tested the first two phases (advertisement and caching) of EOSDP in an I2V communication scenario. We measured the success rate of advertisement messages

received by vehicles, in a given inter-contact time. Success rate refers to the total number of received advertisement messages by the total number of delivered messages. An inter-contact time refers to the duration in which a vehicle continues to receive advertisement messages from an RSU, inside its coverage area. As soon as the inter-contact time expires, the vehicle stops receiving advertisements. We considered the same inter-contact times (ranging from 0.2 s to 2.0 s) used by OSDP. We control the inter-contact time by `simTime()` function of OMNET++. Similar to OSDP, we increase the density of RSUs, offering the services, from 1 RSU to 7 RSUs.

Each RSU broadcasts a single advertisement message per second. In OSDP, all APs (which emulate RSUs) were deployed in the same location, therefore, we followed the same setup for the deployment of RSUs in our experiment. To achieve more reliable results, we calculated the average of samples collected from 100 vehicles, for each inter-contact time.

Figure 16 shows the success rate of advertisement messages received by vehicle in relation with inter-contact time. In general, the success rate increases as the inter-contact time increases. In case of a single service offered by an RSU, inter-contact time of 1s seems to be sufficient, for a vehicle to successfully receive the advertisement messages. It could also be observed that inter-contact time of 0.8 s is enough for a vehicle to receive at-least 50% of the offered services, by at-most 7 RSUs. Moreover, the success rate decrease as the number of offered services increase. The reason of this performance degradation is likely due to packet collision at the MAC layer.

Figure 16 – Success rate of advertisement messages received by vehicles from RSUs.

Source: Research data.

3.12.2 Evaluation of query and response messages

In this experiment, we tested the third phase (service discovery) of EOSDP, using V2V communications among vehicles. We divided our experiment into two sub-categories. In the first experiment, we evaluated the performance of service discovery by changing the number of vehicles responding to the query message. While in the second experiment, we changed the number of vehicles querying for the services.

3.12.2.1 Evaluation of response messages

In this experiment, a single vehicle would query its neighbor vehicles for a required service. We increased the density of neighbor vehicles responding to the query message, from 1 vehicle to 21 vehicles. Like OSDP, we assumed that all neighbor vehicles have already received and stored the required service in their local caches. Success rate in this case, refers to the total number of received response messages by the total number of neighbor vehicles in that region. Vehicle density means, total number of neighbor vehicles inside the coverage range of querying vehicle.

Figure 17 – Success rate of response messages with varying number of responding vehicles.

Source: Research data.

To achieve more reliable results, we calculated the average of samples collected from 100 vehicles for each density. In OSDP, neighbor vehicle send back the response message in a unicast manner. We amended the unicast mode and permitted vehicles to broadcast the response messages. An important conclusion of OSDP was that inter-contact time does not effect the success rate. Therefore, we consider constant inter-contact time of 0.2 s, for all vehicle densities. Figure 17 depicts that the success rate of response messages is highly dependent on the vehicle density, in a V2V communication scenario. It could be observed that, the success rate is 100%,

for traffic densities of up-to 9 vehicles. However, the performance degrades to 50%, as soon as the traffic density reaches 21 vehicles. The reason behind this degradation in performance is due to the attempt made by vehicles to access the channel at the same time.

3.12.2.2 Evaluation of query messages

In this experiment, we extend the original OSDP protocol by increasing the traffic density, querying for services from 1 vehicle to 21 vehicles. We consider only a single neighbor vehicle to respond to those query messages. We made the assumption that, all the vehicles are interested to search for the same service. The performance evaluation is depicted in Figure 18.

It could be observed that, it is difficult to achieve 100% success rate, even in case of small traffic density (e.g., 3 vehicles). The success rate is 50% up-to traffic density of 7 vehicles. Performance further decreases, as the number of vehicles asking for services increases, and it reaches 10% for traffic density of 21 vehicles. We observed a speedy performance degradation in this experiment (as compared to the previous one), because in this case, only a single vehicle is trying to resolve the query messages of different vehicles.

Figure 18 – Success rate of response messages with varying number of querying vehicles.

Source: Research data.

3.13 Conclusions of Experiments

In this chapter, we first describe the use of OSDP—a lightweight beaconing-based opportunistic protocol, which addressed the problem of providing local services advertisement and their discovery in VANETs. We then present an extended version of the protocol called EOSDP. The design of EOSDP is based on its original version, however we build it on top of IEEE

802.11p and WSMP standard protocols. We also performed extensive simulation experiments using SUMO, OMNET++ and Veins simulators. To evaluate the performance of EOSDP, we conducted two different set of experiments, under different traffic densities and inter-contact time. In the first experiment, we evaluated the performance of advertisement messages by RSUs in I2V communication scenario. In the second set of experiments, we evaluated the performance of service discovery in a V2V communication scenario. We also extended OSDP, by changing the number of vehicles, querying for services.

The results concluded that the success rate of service advertisements decreases as the number of offered services, by an RSU, increases. Moreover, success rate of response messages is highly dependent on vehicle densities. Additionally, short inter-contact times (of around 1 s) seem to be sufficient for a fast moving vehicle on a highway to receive at-least 70% of the advertisement messages from RSUs. Finally, the success rate of receiving response messages is highly affected by the density of neighbor vehicles. The model suggests that the system can be used to simulate several business models, including number of advertisement points, their distances to the business's premises, duration that the messages are stored in the cache, etc.

SADP: SERVICES ADVERTISEMENT PROTOCOL FOR VANETS

In this chapter, we present our Service Advertisement Protocol (SADP). SADP is a lightweight beaconing-based application layer services advertisement protocol for VANETs. The design of SADP is based on the IEEE WAVE architecture, while considering the IEEE 802.11p and IEEE 1609.3 standard protocols. Additionally, we take into consideration the multi-channel operation of IEEE 1609.4 standard protocol. Moreover, our protocol is based on text-based beaconing technology and is, therefore, a lightweight solution. Finally, we specify the proper format of the advertisement beacon message and define all the required parameters for repeating the experiments in the future. SADP performance is evaluated in a congested multi-lane highway scenario, by an extensive set of experiments. We believe that BOs would benefit from our solution by promoting their services to on-road customers in a cost efficient way. The work presented in this chapter has been published in (ULLAH *et al.*, 2016).

4.1 Objectives

The main objectives of the experimental work are as follow:

- Design of a lightweight (small text packet, little overhead, simple processing) beaconing-based application layer commercial services advertisement protocol for VANET;
- Instantiation of the protocol in a congested highway scenario, while considering the IEEE WAVE architecture and standard VANET protocols;
- Performance evaluation of SADP by an extensive set of simulations.

4.2 System modeling

In this section, we explain the main entities of our proposed system.

4.2.1 Business Owner (BO)

BO is an entity owning a business (e.g., a restaurant, hotel, gas station, coffee shop, supermarket and gift center) along highways. The details about BO has been provided in Chapter 3 (Section 3.9.1.1).

4.2.2 VANET Advertisement Agency (VAA)

The VAA is a third party broker, who would be responsible for the installment of RSUs in its vicinity. We provided more details on VAA in Chapter 3 (Section 3.9.1.2).

4.2.3 Advertisement Base Station (ABS)

In our model, the ABS performs like an RSU. We already defined its functionalities in Chapter 3 (Section 3.8.1.3).

4.2.4 Service User (SU)

The travelers (drivers and passengers) on highways are termed as Service Users (SUs). We supposed that all the SUs has smart vehicles, equipped with telematics and navigation system (for example: GPS). Furthermore, there are built-in OBUs with storage and processing capabilities. Moreover, for communicating with the ABS, all the vehicles are equipped with IEEE 802.11p based wireless interface cards. Thereafter, entering into the coverage area of a ABS, the vehicle starts receiving the advertised services (AB packets). The SU might avail a service or it would store the AB packets, for a pre-defined TTL.

4.3 Characteristics of SADP

Advertisement is the most popular form of marketing. The Statistics Portal ([STATISTA, 2014](#)) reported that in 2015 the global investment on advertisements was almost 600 billion U.S. dollars, and the prediction for 2018 is 667.65 billion U.S. dollars. Driven by today's modern advertisement methods (e.g., email marketing, web banners, pop up ads, mobile advertisement and in-store advertisement), we introduce the concept of a novel beaconing-based services advertisement protocol for VANET. Some key features of our protocol are discussed in this section.

4.3.1 Based on IEEE WAVE architecture

SADP is based on the IEEE WAVE standard protocols stack. At the transport and network layers, it makes use of WSMP. Additionally, at the MAC and PHY layers, SADP benefits the IEEE 802.11p and IEEE 1609.4 standard protocols.

4.3.2 Beaconing-based technology

SADP is based on beacon messages. The details about beacons, in the context of VANETs has been provided in Chapter 2 (Section 2.2). For convenience, we referred to those beacons as Safety Beacons (SBs). Likewise, we introduce the concept of Advertisement Beacons (ABs). RSU would broadcast the registered services using AB packets at a regular interval.

4.3.3 Multi-channel environment

In accordance with IEEE1609.4 standard, we adopted the channel number 178 for the exchange of SB packets (10 times per second). On the other side, we use the channel number 174 for the broadcast of AB packets (Figure 19). Hereof, our protocol supports the multi-channel operation. More details on multi-channel operation has been provided in Chapter 2 (Section 2.4).

Figure 19 – Multi-channel operation.

Source: Elaborated by the author.

4.3.4 Advertisement Beacon (AB) packet format

The information about the advertised services is encapsulated in the AB packet. This information encompasses the fields: message type, identity (ID), category, Time To Live (TTL), name, description, longitude, latitude and address. The general format and fields of the AB packet is shown in the Figure 20. The size of the packet was limited to 256 Bytes only.

4.4 Simulation setup

In this section, first we explain our simulation scenario. Finally we present both mobility and network simulation parameters.

Figure 20 – Advertisement Beacon (AB) packet format.

Source: Elaborated by the author.

4.4.1 Simulation scenario

For the purpose of performance evaluation of SADP, we assume a multi-lane double-sided congested highway scenario. The length of the highway is 1 km. A total of 384 vehicles (approximately 96/km) was allowed to take part in each experiment. We assumed that all the vehicles travel at a constant speed in two different directions (East-West and vice-versa). Moreover, the vehicles depart from two different origins in a uniform fashion. Likewise, they leave the scenario at two different destinations. We install a single ABS in the middle of the scenario having a communication range of approximately 400 m. The simulated scenario is depicted in Figure 21.

Figure 21 – Multi-lane highway scenario.

Source: Elaborated by the author.

The ABS is connected to the VAA using wired Internet. Additionally, it regularly communicates with vehicles using I2V communications. We registered 80 different services of five different categories (i.e., hotel, restaurant, coffee shop, gas station and supermarket) with the ABS. The ABS uses a single AB packet to advertise each of the registered service. The ABS

broadcast these services on channel number 174 (i.e., SCH) at a regular time interval. When a SU (with a smart vehicle) enters into the coverage area of a ABS, it starts to receive the advertised AB packets. The vehicle would store these AB packets in the local cache for a predefined TTL value. However, in case of a duplicate AB packet the vehicle will simply discard the packet. Additionally, vehicles send and receive SBs (10 times per second) to other vehicles in a V2V fashion on channel number 178 (i.e., CCH).

4.4.2 Simulation parameters

Parameters related to vehicles properties and highway scenario were defined in SUMO. One of the utmost important factor is the vehicle speed. We carried out our experiments with three different vehicle speeds, i.e., high, medium and low. Additional important parameters are acceleration, deceleration, minimum gap between vehicles, vehicle length, placement of RSU, scenario type and length. All SUMO related parameters with their values are given in the Table 2. Likewise, parameters relevant to OMNET++ are shown in Table 3.

Table 2 – SUMO parameters used for SADP.

Parameter	Value
Scenario type	Multi-lane double highway
Highway length	1 km on each side
Number of vehicles	384 vehicles
Vehicles density	Congested (96 vehicles/km)
Vehicles speed	High=120 km/h, Medium=90 km/h, Low=60 km/h
Vehicles length	5m
Vehicles acceleration	2.6 m/sec
Vehicles deceleration	4.5 m/sec
Minimum gap	2.5 m
SP(RSU) position	500 m (middle of scenario)

4.5 Results and discussions

In this section, we discuss the results of our simulation experiments. Experiments were divided into three parts and henceforth, we explain them separately in the following subsections. Additionally, each of the experiment was further divided into four cases. In the first case, we used a broadcast frequency of 0.5/s. In the second case, we used 1/s. In the third case, we used 5/s. While, in the final case, we used a broadcast frequency of 10/s. We determined the percentage of vehicles that received the AB packets from ABS. Besides, we also examined the effect of vehicles speed and broadcast frequencies of AB packets on the performance.

Table 3 – OMNET++ parameters used for SADP.

Parameter	Value
Simulation time	300s for each experiment
Number of runs	5 runs for each experiment
AB packet size	256 Bytes
AB packet broadcast frequency	0.5/s, 1/s, 5/s and 10/s
SB packet broadcast frequency	10/s
Number of services	80 services (5 categories)
Transport & network layer protocol	WSMP
MAP & PHY layer protocol	IEEE 802.11p
Channel bandwidth	10 MHz
Frequency band	5.9 GHz
Communication range (RSU & Vehicles)	400 diameter
Radio propagation model	Two Ray Interference Model (SOMMER; GERMAN; DRESSLER, 2011)
Transmission rate	6 Mbps
Transmission power	3.4 mW
Channel priorities	CCH(178)=3, SCH(174)=2
Channel used	178 for SB packets & 174 for AB packets

4.5.1 Evaluation of AB packets in a high-speed vehicles scenario

In the first series of experiments, we evaluated the performance of our protocol in terms of AB packets reception in a high-speed (120 km/h) vehicles scenario under four broadcast frequencies (i.e., 0.5/s, 1/s, 5/s and 10/s). The results collected are shown in Figure 22(a)-22(d).

For a broadcast frequency of 0.5/s (i.e., sending an AB packet after every two seconds), about 88% of the vehicles received only 6 AB packets (out of 80 broadcast AB packets). It means that a maximum of 6 different roadside services were received by most of the vehicles. The results of the first case is illustrated in Figure 22(a). In Figure 22(b), we observed 100% performance improvement for the second case (i.e., for a broadcast frequency of 1/s). A total of 83% of vehicles received 12 AB packets. The performance further improves after increasing the broadcast frequency of AB packets to 5/s (third case). As depicted in Figure 22(c), most of the vehicles (72%) received 24 AB packets. However, the AB packets reception, in all these three cases, is still low. The reason for this low performance is the time spend by RSU between sending AB packets. On the other side, the high-speed of vehicles (120 km/h) also affect the performance, as the vehicles has small inter-contact time with the RSU. In the final case, we further increase the broadcast frequency of AB packets (i.e., 10/s). As a result, 100% of vehicles received all the advertised AB packets (80 advertisements). This is shown in Figure 22(d). The reason for this outstanding performance is obviously the frequent broadcasts of AB packets by

the RSU. In this case, vehicles has more chances to receive the AB packets, even if they missed it in the first chance, for instance because of congestion at MAC layer.

Figure 22 – Percentage of vehicles with received AB packets in a high-speed scenario

Source: Research data.

4.5.2 Evaluation of AB packets in a medium-speed vehicles scenario

Likewise the first set of experiments, we evaluated the performance by considering the same broadcast frequencies for AB packets (0.5/s, 1/s, 5/s and 10/s). However, we changed the vehicles speed to 90 km/h (medium-speed vehicles). The results collected are shown in Figure 23(a)-23(d). In the first case (broadcast frequency of 0.5/s), 84% of the vehicles successfully received only 8 AB packets, which means most of the vehicles received only few of the advertised services. This case is shown in Figure 23(a). However, for the second case (i.e., broadcast frequency of 1/s), we observed a 100% performance improvement and 69% of vehicles received 16 AB packets. The results are depicted in Figure 23(b) accordingly. Furthermore, after increasing

the broadcast frequency of AB packets to 5/s (third case), about 62% of the vehicles received 31 AB packets. This case is illustrated in Figure 23(c). As compared to the previous set of experiments, the performance (in terms of AB packets reception) is higher (even for same broadcast frequencies). The main reason for this performance improvement is the speed of the vehicles. In this case, all the vehicles move with a uniform speed of 90 km/h (medium-speed) and has more inter-contact time with RSU. We further increase the broadcast frequency of AB packets to 10/s (forth case). Likewise, the forth case of previous experiment, herein 100% of vehicles received all the advertised AB packets (80 advertisements). The results of this case is shown in the Figure 23(d).

Figure 23 – Percentage of vehicles with received AB packets in a medium-speed scenario

Source: Research data.

4.5.3 Evaluation of AB packets in a low-speed vehicles scenario

Similar to the previous two sets of experiments, in this final series of experiments we evaluated the performance by considering the same broadcast frequencies for AB packets (i.e., 0.5/s, 1/s, 5/s and 10/s). However, we changed the vehicles speed to 60 km/h (low-speed vehicles). The results collected are shown in Figure 24(a)-24(d). Likewise the previous two sets of experiments, the performance is very low for the first case (broadcast frequency of 0.5/s). Herein, 86% of the vehicles received only 12 AB packets, which means that majority of the vehicles received only 12 (out of 80) advertised services. The results for this case is shown in Figure 24(a). For a broadcast frequency of 1/s (second case), we observed 100% performance improvement (Figure 24(b)) over first case. About 73% of vehicles received 24 AB packets. Furthermore, in third case (broadcast frequency of 5/s), the performance further increase and hence, 45% of the vehicles received more than 50% of the advertised services (i.e., 48 AB packets). This is illustrated in Figure 24(c). The first three cases, for low-speed vehicles, show better performance over the first three cases of last two series of experiments. This is because of the low speed of vehicles (i.e., 60 km/h), which allow them to spend more time in the coverage range of RSU and as a result receive more AB packets. Finally for the broadcast frequency of 10/s (forth case), 100% of vehicles received all the advertised AB packets (Figure 24(d)). The overall simulations results show that a frequency of 10 advertisement beacon packets per second would assures 100% reception of all the advertised services by all the vehicles and hence could be the basis for a premium-like type of services advertisement. Furthermore, the results explore how the speed of the vehicles and the broadcast frequencies affect the success rate of AB packet receptions.

4.6 Conclusions of Experiments

In this chapter, we presented our proposed SADP —a novel lightweight beaconing-based roadside services advertisement protocol for VANETs. SADP operates in a multi-channel VANET environment and take advantage of beaconing technology and store-carry-and-forward mechanism. The main entities of the system are: business owners, VANET advertisement agency, advertisement base station and service user. We also reveal a complete list of simulation parameters for repeating the experiments in the future. We implement SADP on top of WAVE architecture and perform extensive simulations using SUMO, OMNET++ and Veins simulators. We evaluate the performance of the protocol in a congested highway scenario under different parameters.

From the simulation results we concluded that the RSU broadcast frequency and vehicles speed affect the reception of advertisement beacon packets. Similarly, we noticed that all the vehicles received 100% (80 different services about five categories) of the advertised services, for a broadcast frequency of 10/s. This is important for the BO, as they would be interested that

Figure 24 – Percentage of vehicles with received AB packets in a low-speed scenario

Source: Research data.

none of the driver has missed the opportunity to receive their advertised services. Additionally, it gives a basis for the entities, involved in roadside services advertisement, to assess the several new possibilities offered by VANET and formulate new business plans to explore them. SADP is recommended for business owners for promoting their roadside services and earning more revenues.

CSDP: COMMERCIAL SERVICES DISCOVERY PROTOCOL FOR VANETS

In VANETs, one of the promising application area is the discovery of commercial services on the highways. The drivers would need an efficient way to find these services during their journeys. However, due to the unique features of VANETs, the design and implementation of such applications is a challenging task. In this chapter, we propose an application layer beaconing-based Commercial Services Discovery Protocol (CSDP). CSDP is a lightweight, infrastructure-less protocol, which is based on store-carry-and-forward technique and an opportunistic V2V communication. Our solution is efficient for the business owners, as the vehicles move from one place to another to carry service advertisements and opportunistically forward them to other vehicles upon requests. Our system architecture is fully based on the VANETs standard protocols stack. In particular, we build our solution on top of WSMP, IEEE 802.11p, IEEE 1609.3, and IEEE 1609.4 standard protocols. We perform extensive simulations to evaluate the performance of CSDP in a multi-lane highway scenario. The results demonstrate the effectiveness of our solution in terms of services discovery. The experimental work presented in this chapter has been send to Ad hoc Networks (Impact Factor: 1.660) and is currently under review.

5.1 Objectives

The main objectives of the experimental work are as follow:

- We present a system architecture for the discovery of commercial services and highlight its main entities, phases, operations and messages;
- We design an application layer beaconing-based service discovery protocol for VANETs called CSDP. Our discovery protocol relies mainly on the V2V communication and does not requires Internet or roadside infrastructure;

- We test and implement CSDP in a multi-lane highway scenario and report extensive performance evaluation results through simulations. The results show the effectiveness of our solution in terms of service discovery.

5.2 System modeling

In this section, we present the main entities of our proposed system. We also explain different types of system messages and its format.

5.2.1 *Business Owner (BO)*

The concept of Business Owner (BO) is same as explained in Chapter 3 (Section 3.9.1.1).

5.2.2 *VANET Advertisement Agency (VAA)*

Similar to BO, we adopted the concept of VANET Advertisement Agency (VAA) from our previous experimental work, defined in Chapter 3 (Section 3.9.1.2).

5.2.3 *Advertisement Base Station (ABS)*

The functionalities of Advertisement Base Station (ABS) are defined in Chapter 3 (Section 3.9.1.3).

5.2.4 *Smart vehicles*

A vehicle is considered to be smart, if it is equipped with an OBU having computational, storage, and processing functionality, a navigation system (e.g., GPS device), GUI, and IEEE 802.11p based wireless interface card. The smart vehicles have the capabilities to communicate with other smart vehicles and with roadside infrastructure (i.e., ABS). In our architecture, these smart vehicles play different roles, based on which, we divided them into the following three types.

5.2.4.1 *Service Forwarder Vehicle (SFV)*

A smart vehicle that receives an advertisement, either from an ABS or from other smart vehicles (in response to a query), and store it in its local cache for some time is called Service Forwarder Vehicle (SFV). The SFV uses the store-carry-and-forward technique. This approach is very effective for the BOs, as the smart vehicle itself moves from one place to another place. However, selfish drivers would not be interested to collaborate to these advertisement dissemination campaigns, unless some incentives are provided to them. Therefore, the BOs (in collaboration with VAA) would make special arrangements to motivate selfish drivers. In

this experimental work, we assume that all the smart vehicles are willing to participate in the advertisement dissemination.

5.2.4.2 Service Requester Vehicle (SRV)

Service Requester Vehicle (SRV) is a smart vehicle which requires to discover a desired service. When an SRV needs a service of interest, it simply broadcasts a query message towards its neighbor vehicles by using single-hop V2V communication. The SRV then waits for the neighbor vehicle's responses. The SRV, on his way, continues to send the query messages unless it collects enough responses (i.e., 16 different services about the same category). We define the format of the query message in the next subsection. Our approach uses the pull-based strategy for service discovery.

5.2.4.3 Service Provider Vehicle (SPV)

The smart vehicle, which responds to the SRV query is termed as Service Provider Vehicle (SPV). The response message contains the information about the requested service. After receiving a query message from a neighbor SRV, the SPV searches its memory for the requested services and broadcast all the matched services in a single-hop V2V communication. This broadcast nature of the SPV, allow other smart vehicles in the neighborhood to receive and store these advertisements, if it is not present in its memory. This way they can contribute to the network and can forward these advertisements opportunistically to other SRVs. The response message format is defined in the next subsection.

5.2.5 System messages

In this subsection, we present our system messages. The format of these messages is based on beacon message, which is small in size and is frequently exchanged between vehicles and roadside infrastructure. All these messages are broadcast using single-hop communication.

5.2.5.1 Advertisement Message (AM)

The Advertisement Message (AM) contains information about the commercial service. These AMs are regularly broadcast by an ABS using a push-based technique. The broadcast frequency of AMs is an important business parameter, which strongly affect the performance of reception by the smart vehicles. We select a broadcast frequency of 10 AM per second. i.e., each ABS broadcasts an AM 10 times per second. The general format of the AM is shown in Figure 25. It contains the following fields: message type, identity, category, time to live, name, description, longitude, latitude, and address of the BO. The size of the AM was limited to 256 Bytes.

Figure 25 – Advertisement and Response Message format.

Source: Elaborated by the author.

5.2.5.2 Query Message (QM)

The Query Message (QM) has a key role in the service discovery process. The SRV regularly broadcasts the QM uses a pull-based strategy in a V2V communication. The query interval (time spends between two successive queries) and number of query attempts are important parameters that affect the performance of a service discovery process. The format of the QM is shown in Figure 26. It contains the following two fields: message type and category. The size of QM message was limited to 2 Bytes only.

Figure 26 – Query Message format.

Source: Elaborated by the author.

5.2.5.3 Response Message (RM)

The SPV broadcasts the Response Message (RM) in a response to the QM, it received from the SRV. After receiving a QM, the SPV broadcasts all the matched services (one-by-one) using push-based technique in a V2V communication fashion. However, the QM would be simply discarded, if no service is matched. We used the same message format, fields, and size of the AM for the RM.

5.3 Characteristics of CSDP

In this subsection, we highlight some of the key features of our protocol.

5.3.1 Lightweight application layer solution

CSDP is a lightweight application layer protocol. It relies on push-based technique for sending advertisements using AM and responses using RM. Additionally, it makes use of

pull-based technique for sending queries using QM. The push-based technique is useful for targeting large number of smart vehicles inside the communication range. On the other side, the pull-based strategy is a good choice for discovering the services of interested, with a low communication overhead.

5.3.2 Store-carry-and-forward paradigm

To participate in the advertisement campaign and contribute to the service discovery process, we based the design of CSDP on the concept of store-carry-and-forward mechanism. This method works as follows: a) each smart vehicle would stores the advertisements in its local memory; b) each smart vehicle would then carry the store advertisement for a specific amount of time; c) each smart vehicle would forward these advertisements to other smart vehicles, upon requests. However, the BOs would require to provide incentives to the drivers for motivating them to participate in the advertisement campaigns.

5.3.3 Infrastructure-less solution

Our protocol depends on the opportunistic V2V communications only. It does not require any roadside infrastructure or Internet connection for discovering the services or resolving the queries.

5.3.4 Beaconing-based

Like our other protocols, we based the design of CSDP on beacon messages. We provided details about beacons in Chapter 2 (Section 2.2).

5.3.5 IEEE WAVE-based

The design and implementation of CSDP is based on the IEEE WAVE system architecture. Below the application layer, the CSDP uses the WSMP. Additionally, it utilizes the IEEE 802.11p protocol at the MAC and PHY layers. Finally, CSDP uses IEEE 1609.4 standard protocol to supports multi-channel operation.

5.3.6 Multi-channel operation support

One of the key feature of VANETs standard protocols stack is the support for multi-channel, which allows for the operation of different safety and non-safety applications at the same time. Our protocol could operate in parallel with other safety applications. It uses the SCH (channel no. 174) for all types of messages. Additionally, it uses the CCH (channel no. 178) for the regular exchange of safety beacons. This is shown in Figure 27.

Figure 27 – Multi-channel operation

Source: Elaborated by the author.

5.4 Phases of CSDP

In this subsection, we explain the different phases of CSDP. We also identified the main entities involved in each phase. A bird's-eye view of these phases is depicted in Figure 28.

5.4.1 Service registration phase

The first basic phase of CSDP is the registration of commercial services with a third-party broker (i.e., VAA). The entities who play a major role in this phase are the VAA and BO. The BO interested in advertising its services would require to contact the responsible VAA in that region. Afterwards, the BO would select an advertisement plan and sign a contract with the VAA.

Figure 28 – A bird's-eye view of CSDP phases

Source: Elaborated by the author.

These plans are based on: the numbers and locations of ABS for broadcasting the advertisements, frequency of services advertisement, the lifetime of the a service advertisement, time and date of services advertisements, how often to update the contents of an advertisement, and so on. Additionally, the BO would provide all the necessary information about the service (e.g., Time To Live, target area, time and dates of service advertisement, contents of the advertisement, and advertisement frequency) to the VAA. The VAA would check the contents of the advertisement and after approval it assign the service to the ABS(s) in his jurisdiction, for advertisement.

5.4.2 Service advertisement phase

The goal of this phase is to broadcast the registered advertisements to the customers. The VAA and ABS (i.e., RSU) are the main entities involved in this phase. The success of the advertisement campaign highly depends on this phase. Therefore, it is important to target as many customers as possible. The operation of this phase is as follows: a) The VAA assigns the advertisement, along with instructions for broadcast, to the selected ABS; b) The ABS broadcasts them accordingly to the nearby smart vehicles. The ABS uses the AM beacon for encapsulating this information. It is important to note that the ABS uses SCH (channel no. 174) to broadcast the AM. We use the CCH (channel no. 178) for safety beacons exchange, as per recommendation of VANETs standards. This setup also allows us to evaluate the performance of CSDP in a multi-channel environment.

5.4.3 Service caching phase

The idea of this phase is based on the store-carry-and-forward strategy. The main entities in this phase are the smart vehicles (i.e., SFVs). Upon successful reception of AM, the SFV would store the advertisement for a pre-defined time period (i.e., TTL). TTL is an important business parameter which has a strong influence on the service discovery process. On the expiration of TTL, the AM is deleted from the memory. For the SFV, it is possible to receive multiple copies of the same advertisement. However, in such case the SFV detects the duplicate advertisement (using advertisement ID field), and drops it.

5.4.4 Service querying phase

The phase is the main focus of service discovery process. The principal entities include in this phase are the smart vehicles (i.e., SRVs). The objective of this phase is to discover the desired services by querying the neighbor smart vehicles in a V2V communication fashion. The SRV, interested in finding a service, broadcast a QM and wait for responses. The SRV continues asking for services, until its gather enough services information. However, the drivers would mostly be interested to discover the requested services far ahead of reaching the business premises.

5.4.5 Service response phase

Like the previous two phases, the main entities here are the smart vehicles (i.e., SPVs). The basic idea of this phase is to help drivers discover the desired services, by responding to their queries. The operation of this phase is as follows: a) After receiving a QM from the SRV, the SPV searches its cache; b) broadcasts all the matched services using RM in a V2V communication fashion. The service discovery process is considered to be successful, if the SRV receives at least one RM. After collected enough responses, the driver of SRV would analyze all the received responses to select the best service to attend. Furthermore, the SRV could save the received advertisements for a pre-defined TTL, in order to help others SRVs and to participate in the advertisement campaign.

5.5 Simulation setup

In this section, we explain our scenario. Additionally, we present the important mobility and network simulation parameters.

5.5.1 Simulation scenario

To test and evaluate the performance of CSDP, we used a multi-lane double sided highway scenario of 120 km. This highway links city A (on the East side) with city B (on the West side). We supposed that the BOs of city A are interested to advertise their commercial services to the drivers traveling towards city B. We divided the BOs into five different categories of hotels, restaurants, coffee shops, petrol stations, and supermarkets. We deal with 80 different BOs (16 about each category). The area where these BOs are located is called an advertisement zone. This advertisement zone is 5 km in length and is located at the start of city A. We deployed four ABS inside this advertisement zone. The inter-distance between two consecutive ABS was kept 1 km. All these four ABS are under the administration of same VAA. Each ABS is subject to advertise 20 different commercial services (four for each category). Inspired from the results presented in (ULLAH *et al.*, 2016), we select a broadcast frequency of 10 advertisements per second, for each ABS. The ABS uses AM beacon to advertise these services in a V2I communication fashion on the SCH (channel no. 174) and the smart vehicles store-carry-and-forward these advertisements. In addition, these smart vehicles regularly exchange the safety beacons on the CCH (channel no. 178) in a V2V communication fashion. Furthermore, all ABSs are also connected with the VAA, using an Internet connection.

In our application scenario of simulation, we considered two different traffic streams. The first traffic stream of 300 vehicles is traveling towards city B at a constant speed of 120 km/h. In this stream, the first vehicle is inserted into the scenario, as soon as the simulation time starts. Additionally, a new vehicle is inserted into the scenario every 60 s. Among these vehicles only 30% are smart vehicles. All the vehicles were inserted at the start of the highway (i.e., at the

beginning of the advertisement zone) and they leave the scenario at the end of the highway. This way, each vehicle in the flow passes by each ABS, however, only smart vehicles could receive and store advertisements from these ABSs. This scenario is shown in Figure 29.

Figure 29 – ABSs broadcast advertisements to smart vehicles

Source: Elaborated by the author.

On the other hand, the second traffic stream of 300 vehicles is traveling towards city A at a constant speed of 120 km/h. Unlike the first stream, we insert the first vehicle after 3600 s of the simulation time. The reason is to have enough neighbor vehicles from the opposite side traveling towards city B. Additionally, we inject a new vehicle into the scenario every 45 seconds. In this stream, all the vehicles were inserted at random locations into the scenario, however, they leave the scenario at the same position (i.e., before entering into the advertisement zone). Unlike the previous flow of vehicle, all the vehicles in this flow were smart vehicles. Furthermore, each and every smart vehicles would ask for a randomly chosen different service category. The smart vehicle would start asking for these services, soon after entering into the scenario. For discovering a service, a smart vehicle would simply broadcast a query towards its neighbor vehicles in a V2V communication and waits to collect enough services. This scenario is depicted in Figure 30.

5.5.2 Simulation parameters

In addition to simulator tools, we also provide a comprehensive list of simulation parameters. A list of SUMO related parameters is provided in Table 4, while OMNET++ related

Figure 30 – Services discovery by smart vehicles

Source: Elaborated by the author.

parameters is given in Table 5 respectively. Flow1 represents vehicles traveling towards city B, while Flow2 represents vehicles traveling towards city A.

Table 4 – SUMO parameters used for CSDP.

Parameter	Value
Type of scenario	Multi-lane double sided highway
Length of scenario	120 km on both side
First vehicle insertion time	Flow1 = at the start of simulation Flow2=after 3600 s of simulation time
Vehicle insertion location	Flow1=start of the highway Flow2=at random location of the highway
Number of vehicles	Flow1 & Flow2=300 vehicles
Vehicles speed	120 km/h
Vehicles length	5 m
Vehicles acceleration	2.6 m/sec
Vehicles deceleration	4.5 m/sec
Vehicles minimum gap	2.5 m

Table 5 – OMNET++ parameters used for CSDP.

Parameter	Value
Simulation time	21600 s for each experiment
Number of simulation runs	5 for each experiment
Number of service categories	5 categories
Number of services	80 services (16 for each category)
Number of ABS	4 ABS (1 Km inter-distance)
Beacon broadcast frequency	10/s for AM, QM, & RM
Beacon size	AM=256 Bytes, QM=2 Bytes, RM= 256 Bytes
TTL (in minutes)	5, 15, 30, 45, & 60
Query Attempts	10, 50, 100, 150, 200, 250, 300
Query Interval (in seconds)	1, 20 , 40 , 60
Communication range	400 diameter (approximate)
Radio propagation model	Two Ray Interference Model (VEINS, 2011)
Transmission rate	6 Mbps
Transmission power	3.4 mW
Frequency band	5.9 GHz
Channel bandwidth	10 MHz each channel
Channels used	Channel no. 178 & Channel no. 174
Channels priorities	Channel no. 178=3 & Channel no. 174=2
Protocols used	Application layer= CSDP Network & Transport layers= WSMP MAC & PHY layers= IEEE 802.11p Multi-channel operation= IEEE 1609.4

5.6 Results and discussions

In this section, we discuss the results of our simulation experiments. We study three main factors, that affect the performance of service discovery in a V2V communication scenario. These factors are query attempts (number of times a smart vehicle sends a query message), query interval (time spends between two consecutive queries) and TTL (lifetime of AM in the cache of smart vehicle). Accordingly, we divided the experiments into the following subsections.

5.6.1 Effect of query attempts on service discovery

In the first series of experiments, we study the impact of Query Attempts (QA) on the performance of the service discovery process. After sending the first query, the smart vehicle, i.e., SRV will resend the same query until the QA limit reaches or unless it collects enough services information (i.e., 16 different services about the same category). For these experiments, we used a constant Query Interval (QI) of 1 s and a constant TTL of 36600 s. However, we changed the QA from 10 times to 300 times. The results obtained from these experiments are shown in Figure 31.

In the first case, we evaluated the performance against QA =10 times. Here we observed

Figure 31 – Effect of QA on service discovery

Source: Research data.

that only 11% of the smart vehicles successfully discover the desired services. The obvious reason for this low service discovery performance is the small number of QA, made by the SRVs. However, for the second case of QA=50 times, the performance increases dramatically, as 42% of smart vehicles successfully discovered the asked services. The performance further increases for the QA=100 times. Herein, 62% of smart vehicles discover their desired services. We further increased the QA to 150 times. As expected, the performance increased further and 73% of smart vehicles discover their needed services. In the next case of QA=200 times, 80% of smart vehicles discover the services. Finally, for the last two cases of QA=250 and 300 times, the performance further improved and reaches to 84% and 87% respectively. From the results, we infer that QA strongly affect the performance of a service discovery process in a V2V communication scenario. By increasing the QA, we are actually increasing the possibilities of discovering the requested services. However, on the other side, we are also generating more messages and more communication overhead.

We further evaluate the performance by studying the effect of QA on service discovery with respect to distance to destination, i.e., advertisement zone of the city A. In other words, how far ahead of the premises, a smart vehicle could discover the desired services. We divided the distance into different categories (from 115 km to 1 km). However, for brevity, we discuss only the first category of distance, i.e., 115 km to 100 km. We used the same parameter values for QI and TTL. However, we used the QA from 10 times to 200 times. Figure 32 draws the results obtained from these experiments. For the QA of 10 times, only 2% of smart vehicles discover the services far ahead of reaching to the business premises, i.e. 115 km to 100 km. In the second case of QA =50 times, we observed that 6% of smart vehicles discover the services far ahead of the premises. For the QA of 100 times, the performance further improves and 8% of smart vehicles discover the services for the same category of distance. The final case of QA

Figure 32 – Effect of QA on service discovery (w.r.t. distance to destination)

Source: Research data.

=200 times further elaborates this effect, where 10% of vehicles discover the services for the same distance category of 115 km to 100 km. These results highlight the importance of smart vehicles collaboration for the business owners as well as for the drivers. For the business owners, the smart vehicles have the capabilities to store and carry their advertisements to the neighboring cities and target more customers, traveling towards their business zone. Additionally, it gives an insight on how far ahead the drivers could discover these services.

5.6.2 Effect of query interval on service discovery

In this set of experiments, we investigate how the Query Interval (QI) affects the performance of service discovery. The smart vehicle (i.e., SRV) would send the first query, just after entering into the scenario. If the SRV does not collect enough information about the requested services at a first attempt, it will wait for a pre-defined QI, before re-sending the same query. Here, we used constant values of 3600 s and 100 times for the parameters TTL and QA respectively. However, for the QI, we used the value between 1 and 60 s. The results collected are depicted in the Figure 33.

We start with a QI of 60 s, where only 16% of smart vehicles received responses to their queries. The reason for this low service discovery performance is the time span between two consecutive queries. As the vehicles are moving with high speeds in opposite directions, they could probably be out of communication range of each other, after 60 s. In the second case, we decreased the QI to 45 s. As a result, the performance of service discovery increased to 45%. We further decreased the QI to 20 s, however, this time the performance increased slightly. To further elaborate the situation, we set the value of QI to 1 s. As expected, we observed much better performance over the previous cases, as 62% of smart vehicles discover the services. In

Figure 33 – Effect of QI on service discovery

Source: Research data.

summary, these results conclude that for achieving better performance, it is recommended to send queries more frequently. Hence, QI of 1 s seems a good choice for sending queries in a high speed highway scenario.

5.6.3 Effect of TTL on service discovery (case of service requesting vehicle)

In this set of experiments, we explore the effect of an important business parameter, i.e., TTL on the performance of service discovery in a V2V scenario. Each advertised service has a TTL, and the smart vehicle, after receiving the advertisement, should delete the advertisement upon expiration of its TTL. In these experiments, we used QI of 10 s, while the QA was set to 100 times. However, we varied the TTL from 5 min to 60 min. The results collected are displayed in the Figure 34. In the first case, we evaluated the performance for a TTL of 5 min. We observed that only 14% of smart vehicles successfully received responses. Most of the smart vehicles were not able to respond to the queries, due to the small lifetime of advertisements. In the second case, we increased the value of TTL to 15 min. As expected, the performance of service discovery increased accordingly. In this case, 23% of smart vehicles discover their services. For a TTL of 30 min, 37% of smart vehicles successfully received responses to their queries. In the next two cases, we set the TTL to 45 and 60 min. In both the cases, 49% of smart vehicles discover the desired services.

We further elaborate the effect of TTL on service discovery with respect to distance to the advertisement zone of city A. Like previous experiments, we divided the distance into different categories, ranging from 115 km to 1 km. In this series of experiments, we used constant values for the parameters QI (i.e., 10 s) and QA (i.e., 300 times). However, the TTL varies from

Figure 34 – Effect of TTL on service discovery (case of service requesting vehicles)

Source: Research data.

60 min to 5 min. Figure 35 shows the results of these experiments. For a TTL of 60 min, we saw that majority of the smart vehicles discover the services far ahead (i.e., 115-100 km) of the advertisement zone. In the second case, a TTL of 45 min was selected. Here we observed that 12% of the smart vehicles discover the services in the distance range of 89-80 km. In the next case, we set the TTL to 30 min. As a result, most of the smart vehicles (22%) discover the services in the distance range of 59-50 km. For a smaller TTL of 15 min, we have seen that 29% of smart vehicles discover the services much closer to the advertisement zone (i.e., 29-20 km). Finally, we evaluated the performance for a much smaller TTL of 5 min. Here we observed that 37% of smart vehicles discover the services just before reaching the advertisement zone (i.e., 10-1 km). The results obtained clearly demonstrate that TTL is an important business parameter and has a strong impact on the service discovery process. A large TTL guarantees that the drivers would be able to discover the services far ahead of the advertisement zone.

5.6.4 Effect of TTL on service discovery (case of neighbor vehicles)

The design of CSDP messages is based on single-hop broadcasts, which enables not only the service requesting smart vehicle to receive the advertisements, but also the neighboring vehicles inside the communication range of SPV. In this regard, the main objective of this series of experiments is to show the percentage of neighboring smart vehicles that also received the services. We used QI of 10 s, QA of 100 times and TTL between 5 min and 60 min for these experiments. The results are depicted in Figure 36. First, we considered a TTL of 5 min to evaluate the performance of services received by the neighboring smart vehicles. The results shown that 7% of neighbor smart vehicles successfully received different services, in response to the queries made by other SRVs. In the second case, we increased the TTL to 15 min and as a result more neighbor smart vehicle (i.e., 15%) received responses. We further increased the

Figure 35 – Effect of TTL on service discovery (w.r.t distance to destination)

Source: Research data.

TTL to 30 min and as expected performance further increases where 17% of neighbor smart vehicles successfully received the responses. In the last two cases, we set the TTL to 45 and 60 min. Herein, 19% and 20% of neighbor smart vehicles received different services.

Figure 36 – Effect of TTL on service discovery (case of neighbor vehicles)

Source: Research data.

5.7 Conclusions of Experiments

To address the problem of services discovery in VANETs, we proposed an application layer lightweight, infrastructure less, beaconing-based CSDP for opportunistic V2V communication scenarios. The design of our protocol is based on IEEE WAVE architecture and we

considered standard protocols like IEEE 802.11p, IEEE 1609.4 and WSMP. It also supports the multi-channel operation of IEEE 802.11p based wireless interface card and uses store-carry-and-forward technique. We used the pull-based technique to discovering the interest-based services. We also presented our system architecture with its main entities, messages and operations. CSDP was implemented in a multi-lane highway scenario and its performance was evaluated by extensive set of simulation experiments under different parameters. We used open source state-of-the-art traffic simulator SUMO, network simulator OMNET++ and Veins framework. The experimental results shown that factors, like query interval, query attempts and time to live have strong influence on the performance of service discovery process in a V2V scenario. Results further concluded the efficiency of CSDP for the business owners, interested in promoting their businesses to a large number of customers, traveling towards them. Additionally, it would help the travelers for discovering the services of interest far ahead of reaching to the business premises.

CONCLUSIONS AND FUTURE WORK

6.1 Conclusions

In the recent years, VANETs gain momentum by receiving special attentions from different research communities, government departments and automobile industries. These networks fall under the category of MANETs and have some unique features like varying speeds, densities, and directions of vehicles. Similarly, VANETs need to deal with different operational scenarios, e.g., rural, urban, sub-urban, motorways and highways. Additionally, the nodes in VANETs have short communication ranges, small inter-contact times and real-time data exchange requirements.

In VANETs, the vehicles communicate with other vehicles and with the roadside infrastructure (i.e., RSUs). The communication among vehicles is called V2V and the communication between vehicles and roadside infrastructure is called V2I communications. Vehicles in VANETs are equipped with OBUs having storage, processing, computational and communication capabilities. While, the RSUs need to be installed at fixed locations alongside the highways. Although, the deployment of these networks will take some time, standardization efforts from standard bodies like IEEE, SAE, ETSI, and ARIB are already in-practice.

VANETs emerged as an auspicious solution for the current transportation problems. The preeminent objectives of these networks are to make our transportation system safer, comfortable, entertainable and greener. In order to meet these objectives, a large number of applications are envisioned for VANETs. Generally, the applications for VANETs are divided into two basic categories, i.e., safety and non-safety applications. The focus of safety applications is to ensure public safety on roads by minimizing hazards of road accidents. On the other hand, the non-safety applications would make driving experience more enjoyable by providing access to infotainment services. Besides from safety applications, a large number of non-safety applications are foreseen for VANETs, of which one of the most prominent application area is the advertisement and

discovery of roadside services.

This dissertation aims to address the problem of roadside services advertisement and discovery. We emphasize on the use of beacons for all type of communications. Firstly we presented an extended version of OSDP (i.e., EOSDP), which is a beaconing based service discovery protocol for VANETs. We implemented EOSDP on top of IEEE WAVE protocols stack and performed extensive simulations to evaluate its performance in different traffic scenarios. In the first set of experiments, we evaluated the performance of services advertisement phase of EOSDP by changing the number of RSUs advertising the services from 1 to 7. In the second series of experiments, we evaluated the performance of the service query phase of EOSDP by changing the number of vehicles querying for services from 1 vehicle to 21 vehicles. Additionally, we changed the number of vehicles responding to these queries from 1 vehicle to 21 vehicles. The results collected from these experiments concluded that the reception of advertisement messages, by the vehicles, is highly dependent on the inter-contact time of a vehicle with an RSU, and the number of services offered by an RSU. Additionally, the results revealed that the success rate of receiving response messages is highly dependent on the density of neighbor vehicles. Finally, the EOSDP and its system model suggests that it could be used to simulate several business plans, including number of advertisement points, their distances to the business's premises and duration that the packets are stored in the cache, etc.

To get further insight of services advertisement in VANETs, we proposed a novel lightweight beaconing-based application layer services advertisement protocol for VANET called SADP. Likewise EOSDP, we based the design of SADP on IEEE WAVE standard architecture. Additionally, it supports the multi-channel operation of IEEE 1609.4 standard. SADP make use of beacons for advertising services to the drivers using a push-based advertisement strategy. We also adopted the store-carry-and-forward approach for SADP. Additionally, we presented a system model by highlighting its main entities and defining proper message format of advertisement beacon packet. We also defined a complete list of required simulation parameters in order to repeat the experiments in the future. We used a congested highway scenario to implement SADP and performed extensive simulation experiments to evaluate its performance under different parameters (speed of vehicles and frequency of beacons transmission). Simulation results concluded that RSU broadcast frequency and vehicles speed affect the performance of advertisement beacon packets reception. Moreover, the results revealed that a broadcast frequency of 10 advertisement beacons per second assures 100% reception of all the advertised services by all vehicles and could be the basis for a premium-like type of service advertisement plan for the business owners. Additionally, from the results we have a platform from which we can build tools for providing advertisements on highways. The tools will enable new and complex types of business models on marketing services. For instance, the BOs could plan a roadside marketing strategy covering a desired distance from its premises, have an idea of the public it will reach, and ultimately measure the efficiency of the strategy. We argued that BOs would benefit from our solution by promoting their commercial services to the customers in a cost efficient way.

Advertising roadside services to the drivers, for promoting businesses, is not sufficient for the BOs. In addition to that, the BOs would be interested in finding ways that the drivers discover their services, far ahead of reaching there. In order to address this issue, we proposed commercial services discovery protocol, called CSDP. Like SADP, it is a lightweight beaconing-based application layer protocol. We adopted store-carry-and-forward technique and single-hop opportunistic V2V communications. Additionally, CSDP is Infrastructure-independent protocol and does not required Internet connection to resolve quires or response to the queries. In CSDP, vehicles play a major role in dissemination the advertisements, as they move from one place to another to carry service advertisements and opportunistically forward them to other vehicles, upon requests. We presented a complete system architecture and define its system entities, phases, operations and messages formats. Like previous two protocols, we based the design of CSDP on IEEE WAVE standard architecture. It also supports multi-channel operations and uses pull-based technique to discover the services of interests. We considered a congested highway of 120 km and performed simulations on a large scale in order to evaluate the performance of CSDP. Simulation results demonstrated the effectiveness of our solution, in terms of services discovery. We believe that our solution would help BO to reach to the customers, who are traveling towards them. Additionally, it would help the drivers to discover the desire services in-advance.

In conclusion, this work shows the capabilities of opportunistic vehicular communications for advertising and discovery of roadside services. Additionally, it shows the effectiveness of beacons messages to achieve the goals.

6.2 Difficulties of the study

In computer networks, the use of simulators for the implementation and performance evaluation of new protocols is a well recognized method. It offers the advantage of repeating the experiments with different parameters. However, the selection of appropriate simulator, especially for VANETs, is a difficult task. A large number of simulators, ranging from open source to commercial products, are available for research communities. After conducting a survey on the simulators and discussion with various research groups, we selected three state-of-the-art simulator tools. The simulators used for this work are SUMO, OMNET++ and Veins.

After the selection of simulation tools, another difficulty was to learn how to use these simulators. Working with a new simulator is a difficult and time consuming task. Each one of these simulators has a different programming language, different environment and required different commands to communicate with them.

In case of VANETs simulations, the end results of experiments strongly depend on the scenario being used. In this regard, only a few ready-to-use mobility traces are available for the research communities. However, there is no possibility to change the mobility of vehicles, according to the need. Additionally, it requires a lot of effort to validate the mobility. In other

words, these scenarios are difficult to customize and adopt.

Finally, performing VANETs simulation experiments, at a larger scale, on desktop computers is very time consuming process. It usually takes days to run experiments on congested traffic scenarios. An alternative in this case is the use of cluster or super computer. We used the Centro de Ciências Matemáticas Aplicadas à Indústria (CeMEAI) SGI cluster for a small portion of this work, since it has been recently installed.

6.3 Limitations of the study

The following list shows the limitations of this study:

- The protocols presented in this work are based on the IEEE WAVE architecture. In particular, we used the IEEE 802.11p standard protocol for V2V and V2I communications. In this regard, we do not considered Wi-Fi, 3G, Long Term Evolution (LTE), LTE-Advanced (LTE-A), or 5G Device-to-Device (D2D) wireless technologies;
- We limit our work to the standards defined by the US standardization organizations. However, there are standardization efforts in European (i.e., ETSI ITS-G5) and Japan (i.e., ARIB);
- We evaluated the performance of our protocols by means of simulation experiments and by considering our own scenarios. Hereof, we do not considered any testbed, data-set or pre-defined scenarios. Additionally, we do not performed any real world experiments;
- We limit our simulation scenarios to highways only;
- The focus of this work was on the upper layers of IEEE WAVE protocols stack. Hence, we do not consider MAC and PHY layers issues in this work;
- Finally, we do not address security and privacy issues in this work.

6.4 Future work

The work presented in this dissertation leads to several new research ideas and challenges. An interesting research question is: how to motivate drivers to contribute to the services advertisement dissemination? As the deployment of RSUs is expensive, the idea is to create incentive schemes to motivate the drivers in the dissemination (carrying) of advertisements and responding queries from other vehicles. The problem is to decide who, in the chain of contributors, is going to receive the incentives. To address the problem, we are working on the design of an incentive scheme. According to our incentive scheme, every advertisement forwarder driver would receive incentives in the form of virtual cash from the BOs. The driver would be able to exchange this

virtual cash at any point of interest. We believe that this would encourage the selfish drivers to participate in the network and contribute to the advertisements dissemination.

Security and privacy are two important building blocks of any communication system. Apart from confidentiality, authenticity and integrity, we have the problem of linkability and traceability (which are not desirable). In our research group, the researchers are using pseudonyms and Public Key Infrastructure (PKI) schemes for making the operations of our protocols secure.

The establishment of trust among vehicles is also important for making decisions, like, selecting a trustworthy node for forwarding a packet towards its destination. In another project of our group, the researchers are exploring the use of reputation schemes, based on ontology. In such reputation schemes, the drivers would evaluate each other and will send back feedback towards a reputation server.

As a future work, we also intended to classify the vehicles into different categories (for example: private cars, public buses, taxis, cargoes, police cars, and ambulances). Vehicles categorization would help selecting an appropriate category, for forwarding the beacon message towards destination. An example of such application is the use of public buses for advertisement messages dissemination.

Another interesting area to explore is the use of other candidate wireless technologies, like, LTE, LTE-A, and 5G. Lastly, it would be interesting to explore the possibilities of extending the operations of services advertisement and discovery to Vehicular Social Network (VSN).

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