TÜBİTAK

A beaconing-based roadside services discovery protocol for vehicular ad hoc networks

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Abstract: Recently, research on vehicular ad hoc networks (VANETs) has gained momentum all over the world. These emerging networks promise to make our driving experience more efficient, safer, comfortable, and enjoyable. VANETs have the potential to support a wide range of interesting applications. One such promising application area is the discovery of roadside services on the highways. Drivers 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 paper, we propose an application layer beaconing-based roadside services discovery protocol (RSDP). The RSDP is a lightweight, beacon-based protocol, which uses store-carry-and-response technique and opportunistic vehicle-to-vehicle communication. Our solution is efficient for business owners, as the vehicles move from one place to another to carry service advertisements and opportunistically forward them to other vehicles upon request. Our system architecture is fully based on the VANET standard protocols stack. We performed extensive simulations to evaluate the performance of RSDP in a multilane highway scenario. The results demonstrate the effectiveness of our solution in terms of services discovery.

Key words: Services discovery, beaconing, VANET, wave

1. Introduction

In the last few years, vehicular ad hoc networks (VANETs) received much attention from different standardization organizations, research communities, educational institutions, transportation departments, and automobile industries on a global scale. VANETs are a special class of mobile ad hoc network (MANET) [1]. These networks are distinguished by the high speed of vehicles, small intercontact times between hosts, different operational environments, variable densities of vehicles, short-range communications, intermittent connections, and real-time data exchange requirements. In VANETs, the wireless communication among vehicles is called vehicle-to-vehicle (V2V), car-to-car (C2C) or intervehicle communication (IVC). In addition, the communication between the vehicles and roadside infrastructure is called vehicle-to-infrastructure (V2I) or infrastructure-to-vehicle (I2V) communication.

VANETs provide a platform for the deployment of various types of applications. These applications are related to public safety, traffic management, traveler convenience, comfort, roadside service advertisement and discovery, and entertainment. Among these, an emerging application that attracts attention from research communities is the discovery of roadside services. Discovering roadside services is useful for both the drivers and

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the business owners. The business owners of restaurants, hotels, coffee shops, gas stations, and supermarkets could benefit from these networks by disseminating their advertisements in real-time by targeting many potential customers. On the other hand, drivers would use them to discover these advertised services during their trips on the highways. These services 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 nearby coffee shop.

The classical methods of discovering roadside services (e.g., banners and billboards) are not adequate for several reasons. Generally, these billboards are located in the proximity of the business owners; however, drivers would be interested to discover these services far ahead of reaching them. Furthermore, the contents of billboards are static in nature, while the drivers would need updated information in real time. Moreover, they are expensive and require much human effort and energy to install and update. Besides, in situations like traffic congestion, rain, and strong winds they could be destructive and hazardous for drivers. In addition to these classical methods, today's modern forms of service advertisement and means of discovery (for instance, online and mobile advertisements) are infrastructure-based and require an Internet connection. Additionally, the customers are not always interested in receiving these advertisements on their devices.

To overcome these problems, we proposed an application layer lightweight beaconing-based roadside services discovery protocol (RSDP) for VANETs. Our solution relies on single-hop V2V opportunistic communication and does not require an Internet connection or additional infrastructure support for discovering the desired services. We design and implement the RSDP on top of the VANET standard protocols stack by using a store-carry-and-response technique. Our solution is more efficient in the sense that the vehicles move from one city to another in order to carry and opportunistically forward the advertisements to other vehicles on demand. This approach would decrease the overhead of V2V communication. In this regard, the main contribution of this work is summarized as follows:

- We present a system architecture for the discovery of roadside services and highlight its main entities, phases, operations, and messages.

- We design an application layer beaconing-based service discovery protocol for VANETs called RSDP. Our discovery protocol relies mainly on V2V communication and does not require an Internet connection.

- We test and implement the RSDP in a multilane highway scenario and report extensive performance evaluation results through simulations. The results show the effectiveness of our solution in terms of services discovery.

The rest of this paper is structured as follows: the next section reviews the related work. Section 3 introduces the system architecture, its main entities, and messages. Section 4 details the proposed roadside services discovery protocol, its phases, and its characteristics. Section 5 discusses the simulation scenario, parameters, and tools. Section 6 discusses the results of simulation experiments. Finally, Section 7 concludes this paper and gives some future directions.

2. Related work
In this section, we summarize the work related to roadside services advertisement, discovery, and incentive mechanisms in VANETs.

In our earlier paper [2], we proposed a beaconing-based services advertisement protocol (SADP) for VANETs. In the SADP, the roadside business owners advertise their services with the help of a broker using a

push-based method. We tested and implemented the SADP using a highway scenario of 1 km. A single roadside unit (RSU) was installed in the middle of the scenario. The RSU broadcasts the registered services, several times per second, using I2V communications. The performance was evaluated by means of a series of simulation experiments. However, the study was limited to roadside services advertisement only.

Inspired by mobile advertisement, the authors in [3] presented a cloud-based solution to deliver targeted advertisements to vehicles and formulated the dissemination process by means of an optimization model. They proposed the integration of cellular networks with VANET and highlighted the role of V2V communications in advertisement delivery. An important part of their system model is the service manager. Different from our solution, the service manager decides the RSU and the vehicle to broadcast the advertisements. Furthermore, it requires access to user profiles, mobility patterns, and vehicle cache in order to disseminate interest-based advertisements. This would make the solution questionable due to privacy of the drivers. The authors used a time-expanded graph and presented detailed numerical analysis. The main drawback of the solution is the lack of demonstration of simulators and parameters used for implementation.

In [4], the authors addressed the issue of sending targeted advertisements in VANETs from the broker's point of view. In the proposed solution the brokers select and control the dissemination of advertisement to the targeted vehicles by RSUs, for which they are paid by the advertisers. To target potential customers, the broker accesses user interests and preferences; however, due to privacy concerns, the drivers and passengers may decline to provide such information. To formulate the problem of advertisement selection for broadcast, they presented a greedy algorithm. The proposed algorithm was based on the Volfied game, which resolves the conflict between interest-based advertisements displayed to the users and the revenue earned by the brokers. They also performed numerical analysis to show the efficiency of the Volfied algorithm by comparing it with other solutions. The authors claimed that they performed simulations; however, it is not clear which simulator tool they used. Moreover, the authors did not consider the use of VANET standard protocol stacks.

In [5], the authors performed simulations to study the effect of services advertisement by the RSU on vehicle densities. The main advantage of the study was the consideration of the IEEE 802.11p protocol for wireless communications. The IEEE 802.11p was recently standardized by the IEEE for the use of vehicular communications. However, this study was limited to a maximum of 21 vehicles. Furthermore, no proper attention was given to multichannel operation in VANETs. Similarly, the formats of the advertisement and discovery packets were also not defined.

In [6], the authors studied the impact of malicious node on a secure incentive-based advertisement distribution (SIBAD) scheme in VANETs. The main entities of the SIBAD are the advertisement content server (ACS), advertisement distribution point (ADP), and vehicles. Their scheme provides incentives to each vehicle that forwards the advertisement; however, such a mechanism is unrealistic as it is difficult to provide incentives to all forwarding vehicles. To provide security, their scheme collects personal information such as mobile numbers from drivers, which would not be acceptable in all scenarios. They performed simulations in the Simulation of Urban Mobility and Mobility Model Generator for Vehicular Networks packages. Their results revealed that the presence of a malicious node greatly affects the incentives earned by legitimate vehicles. Their work also did not consider the VANET standard protocol stacks for performing simulations.

In [7], the authors addressed the problem of advertisement in VANETs by proposing a repeated auction scheme. They divided the city into different advertisement zones, where companies compete for advertising their services. Inside each zone, advertisements are broadcast to vehicles by roadside infrastructure, which could be a RSU, evolved node B (eNodeB), or even a WiFi access point (AP). Instead of using realistic mobility traces, the

vehicles' movements were modeled as a correlated Gaussian random process. Additionally, it was not mentioned which simulator tool was used by the authors for experiments.

A secure and privacy-preserving incentive scheme for advertisement in VANETs was proposed is [8]. The RSU dynamically selects competent vehicles by using a bilinear pairing technique for advertisement dissemination and rewards them for the task. The proposed mechanism also ensures fairness among the participating vehicles. They numerically evaluated the performance of the incentive scheme by analyzing the computational overhead of RSUs and vehicles. They set up the experimental environment on a personal computer and performed simulations; however, it was not mentioned which simulator was used for performing experiments. The numerical analysis showed that the proposed scheme provided access control, privacy preservation, and data integrity.

The authors of [9] investigated the problem related to the deployment of roadside devices for advertisement dissemination in VANETs. They highlighted the advantages and limitations of RSUs and roadside access points (RAPs) and formulated the problem of hybrid device placement. They also proposed a hybrid roadside devices placement algorithm, which greedily deploys the devices to target more vehicles and maximize the benefit of business owners. Additionally, they evaluated the performance of the proposed algorithm by comparing it with other schemes. However, it was not mentioned which simulators were used. Finally, the VANETs standard protocols were not considered in this work.

The authors of [10] presented the signature seeking drive (SSD), a secure incentive-based advertisement dissemination framework for VANETs. An authorized third party provides the public key infrastructure (PKI) certificate to each vehicle. Upon successful forwarding of an advertisement, the drivers collect digitally signed receipts from the receiver vehicles. In the SSD, incentives are provided to both advertisement forwarders and receipt provider vehicles, which makes this scheme impractical and expensive for the service provider. Additionally, they do not give attention to VANET standard protocols.

Apart from [2, 5], none of the above cited works paid attention to the VANET standard protocols stack. Unlike the existing solutions, our proposed solution is based on wireless access in vehicular environments (WAVE). In particular, we build our solution on top of the WAVE short message protocol (WSMP), IEEE 802.11p, IEEE 1609.3, and IEEE 1609.4 standard protocols.

3. System architecture

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

3.1. Main entities

The main entities of our system are explained in this subsection.

3.1.1. Business owner

A business owner (BO) is an entity that owns a business on the highways. A few examples of businesses are restaurants, hotels, petrol stations, coffee shops, supermarkets, and gift centers. The BOs are interested in advertising their services to nearby vehicles in order to target many potential customers. These services include discounts, special offers, new arrivals, prices, menus, and facilities. However, before advertising these services to the customers, BOs would be required to register them with an advertisement agency using service level agreements (SLAs).

3.1.2. VANET advertisement agency

The 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 for authenticating the contents before advertising them to customers. Moreover, the VAA would look after the installation, management, and maintenance of RSUs. The VAA would feed the RSUs with service advertisements for broadcast to the neighboring smart vehicles. Finally, the 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 relevant government agency (e.g., transportation department or highway authority).

3.1.3. Advertisement base station

The advertisement base station (ABS) functions like a RSU, providing communication services for the advertisements. ABSs are installed alongside the highways and controlled by the VAA. They have built-in computational, processing, and storage capabilities. Moreover, they are equipped with IEEE 802.11p-based wireless interface cards to communicate with smart vehicles. They also have additional interfaces to connect to the Internet. The main functionality of an ABS is to broadcast the registered services using I2V communication. In order to target many smart vehicles, ABS uses the push-based communication technique. Inspired by [2], we use a broadcast frequency of 10 advertisements per second for all ABSs.
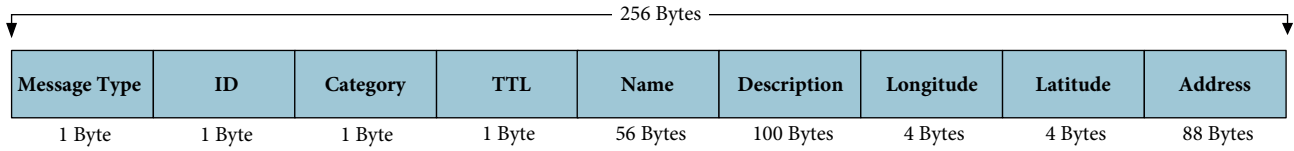
3.1.4. Smart vehicles

A vehicle is considered to be smart if it is equipped with an on-board unit (OBU) having computational, storage, and processing functionality; a navigation system (e.g., global positioning system (GPS) device); graphical user interface (GUI); and IEEE 802.11p-based wireless interface card. Smart vehicles have the capabilities to communicate with other smart vehicles and with the roadside infrastructure (i.e. ABS).

3.2. System messages

In this subsection, we present our system messages. The format of these messages is based on the beacon message. In the context of VANETs, a beacon refers to a small text-based message broadcast 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. Our system messages are small in size and are frequently exchanged between vehicles and roadside infrastructure.

3.2.1. Advertisement message

The advertisement message (AM) contains information about the roadside 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 affects the performance of reception by the smart vehicles. We select a broadcast frequency of 10 AMs per second, i.e. each ABS broadcasts an AM 10 times per second. The details about AM performance evaluation are provided in [2]. The general format of an AM is shown in Figure 1. 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 is limited to 256 bytes.

Message Type	ID	Category	TTL	Name	Description	Longitude	Latitude	Address
1 Byte	1 Byte	1 Byte	1 Byte	56 Bytes	100 Bytes	4 Bytes	4 Bytes	88 Bytes

256 Bytes

Figure 1. Advertisement and response message format.

3.2.2. Query message

The query message (QM) has a key role in the service discovery process. A smart vehicle would regularly broadcast the QM by using a pull-based strategy in a V2V communication. The query interval (time spent 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 2. It contains the following two fields: message type and category. The size of a QM message was limited to 2 bytes.

Message Type	Category
1 Byte	1 Byte

2 Bytes
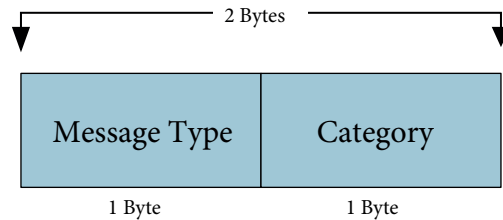
Figure 2. Query message format.

3.2.3. Response message

A smart vehicle would broadcast the response message (RM) in reply to a QM it received from a neighboring smart vehicle. After receiving a QM, the vehicle broadcasts all the matched services one by one using a 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 of AM for the RM.

4. Roadside services discovery protocol

In this section, we present our roadside services discovery protocol, i.e. the RSDP. We describe the different phases of the RSDP. Additionally, we explain some key characteristics of our solution.

4.1. Phases of RSDP

In this subsection, we explain the different phases of the RSDP. We also identify the main entities involved in each phase. A bird's-eye view of the overall operation of RSDP phases is also depicted in Figure 3.

4.1.1. Service registration phase

The first phase of the RSDP is the registration of 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 be required to contact the responsible VAA in that region. Afterwards, the BO would select an advertisement plan and sign a contract with the VAA. These plans are based on the numbers and locations of ABSs for broadcasting
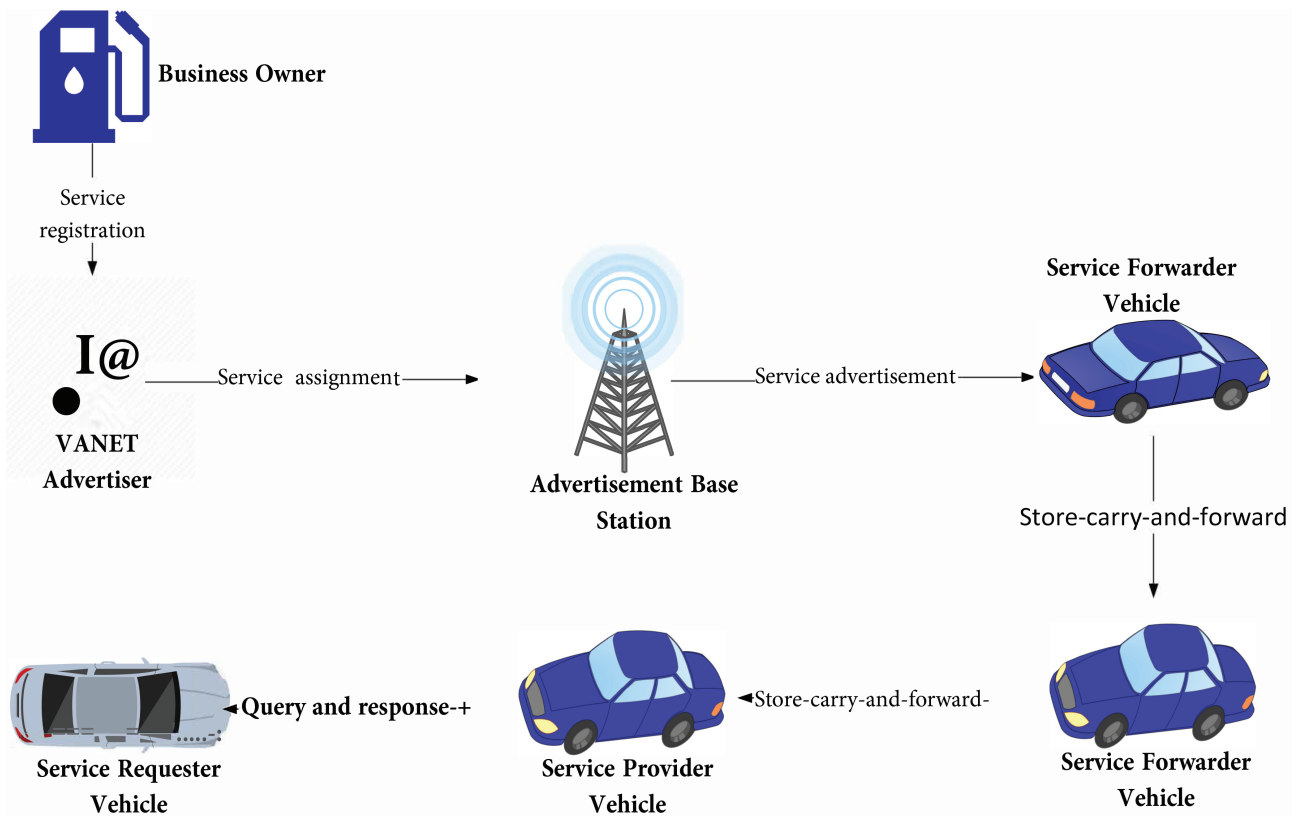
Figure 3. RSDP phases.

the advertisements, frequency of services advertisement, lifetime of the 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 (TTL), target area, time and dates of service advertisement, contents of the advertisement, and advertisement frequency) to the VAA. The VAA will check the contents of the advertisement and after approval it will assign the service to the ABS(s) in its jurisdiction for advertisement.

4.1.2. 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 a service channel (SCH) to broadcast the AM. We left the control channel (CCH) for safety beacon exchanges, as per the recommendations of VANETs standards. This set up also allows us to evaluate the performance of the RSDP in a multichannel environment.

4.1.3. Service caching phase

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

4.1.4. Service querying phase

The objective of this phase is to discover the desired services by querying the neighboring smart vehicles in a V2V communication fashion. The smart vehicle interested in finding a service would broadcast a QM and wait for responses. The vehicle continues to ask for services until it gathers enough services information. However, the drivers would mostly be interested in discovering the requested services far ahead of reaching the business's premises.

4.1.5. Service response phase

The basic idea of this phase is to help drivers discover the desired services. The operation of this phase is as follows: a) after receiving a QM from a neighboring vehicle, it searches its cache; b) it broadcasts all the matched services using RM in a V2V communication fashion. The service discovery process is considered to be successful if the requesting vehicle receives at least one RM. After collecting enough responses, the driver would analyze all the received responses to select the best service to employ. Furthermore, the vehicle could save the received advertisements for a predefined TTL, in order to participate in the advertisement campaigns.

5. Simulation set up

In this section, we explain our simulation scenario, parameters, and tools used for the implementation of the RSDP.

5.1. Simulation scenario

To test and evaluate the performance of the RSDP, we used a multilane double-sided highway scenario of 120 km. This highway links city A (on the east side) with city B (on the west side). We suppose that the BOs of city A are interested in advertising their roadside services to the drivers traveling towards city B. We divide the BOs into five different categories: hotels, restaurants, coffee shops, petrol stations, and supermarkets. We consider 80 different BOs (16 in each category). The area in which 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 deploy four ABSs inside this advertisement zone. The interdistance between two consecutive ABSs was kept to 1 km. All these four ABSs are under the administration of the same VAA. Each ABS is responsible for advertising 20 different services (four for each category). Inspired by the results presented in [2], we select a broadcast frequency of 10 advertisements per second for each ABS. The ABS uses an AM beacon to advertise these services in a V2I communication fashion on the SCH (channel no. 174) and the smart vehicles 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 simulation scenario, we consider 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 are 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 can receive and store advertisements from these ABSs. The scenario is shown in Figure 4.
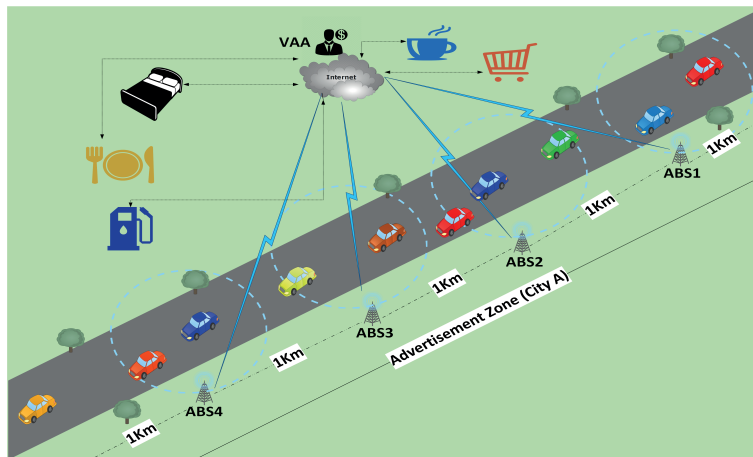
Figure 4. ABSs broadcast advertisements to smart vehicles.

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 simulation time. The reason is to have enough neighboring vehicles from the opposite side traveling towards city B. Additionally, we inject a new vehicle into the scenario every 45 s. In this stream, all the vehicles are inserted at random locations into the scenario; however, they leave the scenario at the same position (i.e. before entering the advertisement zone). Unlike the previous flow of vehicles, all the vehicles in this flow are smart vehicles. Furthermore, each and every smart vehicle will ask for a randomly chosen service category. The smart vehicle will start asking for these services soon after entering the scenario. For discovering a service, a smart vehicle will simply broadcast a query towards its neighboring vehicles in a V2V communication and wait to collect enough services. This scenario is depicted in Figure 5.

5.2. Simulation tools

In VANETs, performing field tests or real-world experiments at a larger scale is a difficult and expensive task. It requires many technological efforts, 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 the performance of VANET-related protocols and applications. To implement our application scenario, generate realistic traffic flows, and define a vehicle's parameters we used a state-of-the-art simulator called SUMO. SUMO is a well-known open source microscopic traffic simulator, which contains a rich set of built-in packages like GUISIM, NETCONVERT, NETGEN, OD2TRIPS, and DUAROUTER to create road networks, import Open Street Map (OSM), install traffic lights, and set up traffic demands. It also has a friendly graphical editor to ease the task of performing simulations. It

allows setting individual vehicle parameters like departure time, departure lane, maximum and minimum speed, acceleration, driver status, route to take, lane, position, type of vehicle, and mobility model. It is widely used by research communities to develop and test different applications for VANETs. Some application areas include route selection and navigation, information dissemination, traffic light control, CO_2 emission, and entertainment services [11].

Aside from SUMO, we used a network simulator called Objective Modular Network Testbed in C++ (OMNET++). OMNET++ is also an open source discrete event network simulator used for communication networks including wired networks, wireless infrastructure-based networks, wireless ad hoc networks, peer-to-peer networks, wireless sensors networks, and VANETs. OMNET++ models are developed from simple and compound modules, written in C++, while the network topology is defined in NED language. The OMNET++ package also contains a graphical editor to work with the simulation files. Another important feature of OMNET++ is debugging and traceability of the simulation models. It also enables the researchers to collect and analyze the results and export them to other sophisticated tools. Inside OMNET++, each vehicle is represented by a moving node, while RSUs are considered as fixed nodes. The communications among these nodes are based on standard VANET protocols stacks [12].

In addition to these two simulators, we also used the vehicles in network simulation (Veins) framework [13]. Veins is an open source bidirectional framework that couples SUMO with OMNET++ using a traffic control interface (TraCI) [14]. It uses a TCP connection and Python language scripts to bridge the gap between the two simulators. It enables the two simulators to run in parallel, which allows real-time interaction between them. One of the most important features of the Veins framework is that it has full support for WAVE standard protocols stacks, including IEEE 802.11p, IEEE 1609.4, and WSMP. Moreover, the current version of Veins also includes models for cellular networks, i.e. long-term evaluation (LTE). In addition to simulator tools, we also provide a comprehensive list of simulation parameters. A list of SUMO-related parameters is provided in Table 1, while OMNET++-related parameters are given in Table 2. Flow1 represents vehicles traveling towards city B, while Flow2 represents vehicles traveling towards city A.
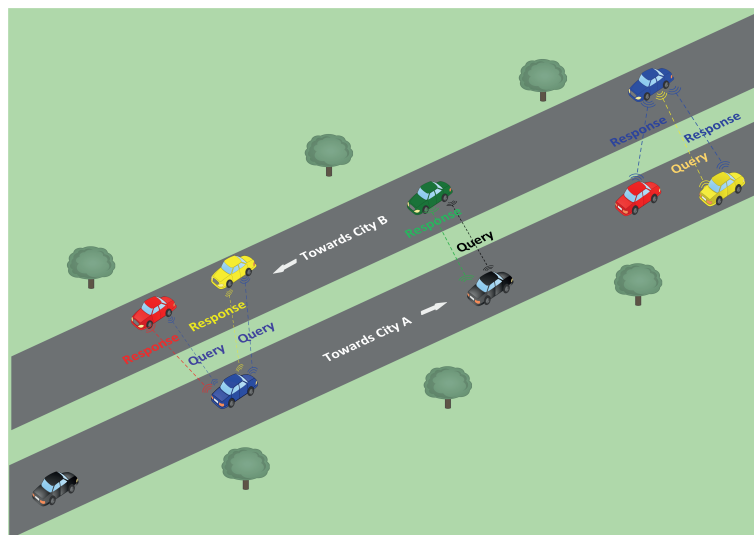
Figure 5. Services discovery by smart vehicles.

Table 1. SUMO parameters.

Parameter	Value
Type of scenario	Multilane double sided highway
Length of scenario	120 km on both sides
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
Vehicle speed	120 km/h
Vehicle length	5 m
Vehicle acceleration	2.6 m/s
Vehicle deceleration	4.5 m/s
Vehicles' minimum gap	2.5 m

Table 2. OMNET++ parameters.

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 ABSs	4 ABSs (1 km interdistance)
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 [15]
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
Channel priorities	Channel no. 178 = 3 & Channel no. 174 = 2

6. Results and discussion

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 spent between two consecutive queries), and TTL (lifetime of AM in the cache of a smart vehicle). Accordingly, we divide these experiments into the following subsections.

6.1. Effect of query attempts on service discovery

In the first series of experiments, we study the impact of query attempts (QAs) on the performance of the service discovery process. After sending the first query, the smart vehicle will resend the same query until the

QA limit is reached or unless it collects enough service information (i.e. 16 different services from the same category). For these experiments, we use a constant query interval (QI) of 1 s and a constant TTL of 3600 s. However, we change the QA from 10 times to 300 times. The results obtained from these experiments are shown in Figure 6.

In the first case, we evaluate the performance against QA = 10 times. Here we observe 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 QAs made by the smart vehicles. However, for the second case of QA = 50 times, the performance increases dramatically, as 42% of smart vehicles successfully discover the queried services. The performance further increases for QA = 100 times. Here, 62% of smart vehicles discover their desired services. We further increase the QA to 150 times. As expected, the performance increases 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 improves and reaches 84% and 87%, respectively. From the results, we infer that QA strongly affects 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 hand, 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 city A. In other words, how far ahead of the destination could a smart vehicle discover the desired services? We divide 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 use the same parameter values for QI and TTL. However, we use QA from 10 times to 200 times. Figure 7 presents the results obtained from these experiments.
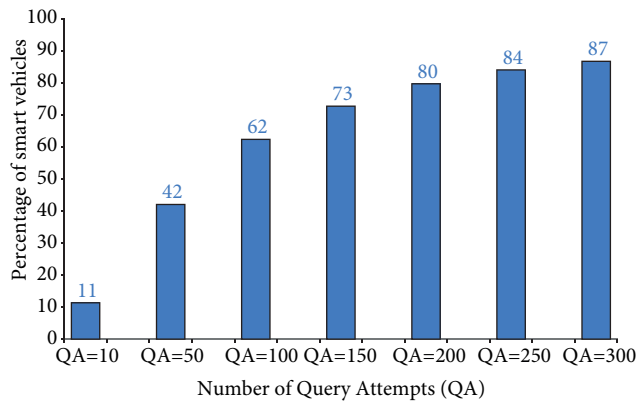

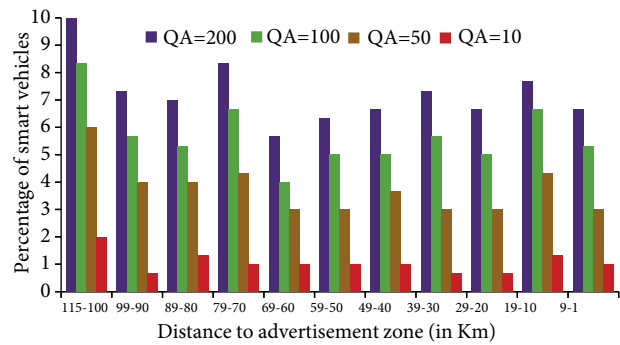
Figure 6. Effect of QA on service discovery.

Figure 7. Effect of QA on service discovery (w.r.t. distance to destination).

For QA of 10 times, only 2% of smart vehicles discover the services far ahead of reaching the destination, i.e. 115 km to 100 km. In the second case of QA = 50 times, we observe that 6% of smart vehicles discover the services far ahead of the destination. For 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 = 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 vehicle collaboration for business owners as well as for

drivers. For the business owners, the smart vehicles have the capabilities to store and carry their advertisements to 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.

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 would send the first query, just after entering the scenario. If the vehicle does not collect enough information about the requested services in a first attempt, it will wait for a predefined QI before sending the same query. Here, we use constant values of 3600 s and 100 times for the parameters TTL and QA, respectively. However, for the QI, we use values between 1 s and 60 s. The results collected are depicted in Figure 8.

We start with a QI of 60 s, where only 16% of smart vehicles receive 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 at high speeds in opposite directions, they could probably be out of the communication range of each other after 60 s. In the second case, we decrease the QI to 45 s. As a result, the performance of service discovery increases to 45%. We further decrease the QI to 20 s; however, this time the performance increases slightly. To further elaborate the situation, we set the value of QI to 1 s. As expected, we observe much better performance over the previous cases, as 62% of smart vehicles discover the services.

In summary, these results show 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.
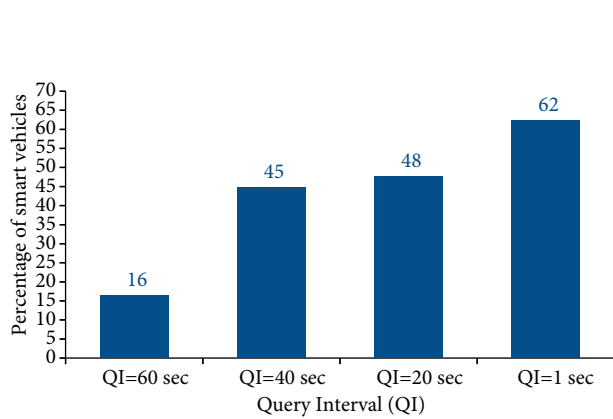
6.3. Effect of TTL on service discovery (case of service-requesting vehicle)

In this set of experiments, we explore the effect of an important business parameter, 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 are displayed in Figure 9.

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 short 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 receive 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 divide the distance into different categories, ranging from 115 km to 1 km. In this series of experiments, we use constant values for the parameters QI (i.e. 10 s) and QA (i.e. 300 times). However, the TTL varies from 60 min to 5 min. Figure 10 shows the results of these experiments.

For a TTL of 60 min, we observe that the 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 observe 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

Figure 8. Effect of QI on service discovery.
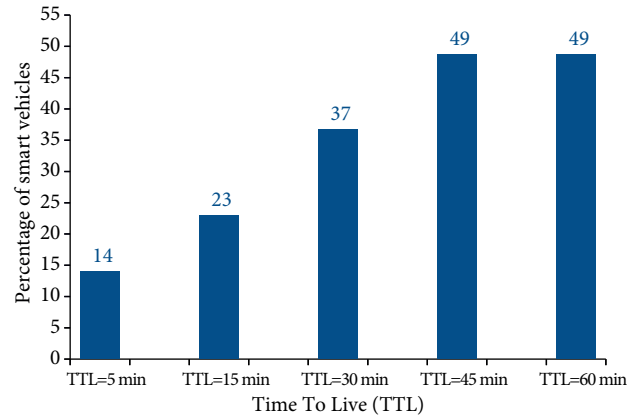
Figure 9. Effect of TTL on service discovery (case of service-requesting vehicles).

59–50 km. For a smaller TTL of 15 min, we see that 29% of smart vehicles discover the services much closer to the advertisement zone (i.e. 29–20 km). Finally, we evaluate the performance for a much smaller TTL of 5 min. Here we observe 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 reaching the advertisement zone.
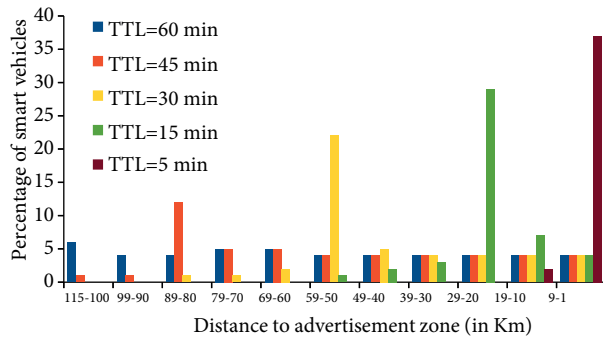
6.4. Effect of TTL on service discovery (case of neighboring vehicles)

The design of RSDP 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. In this regard, the main objective of this series of experiments is to show the percentage of neighboring smart vehicles that also receive the services. We use a 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 11.

First, we consider a TTL of 5 min to evaluate the performance of services received by the neighboring smart vehicles. The results show that 7% of neighbor smart vehicles successfully received different services in response to the queries made by other smart vehicles. In the second case, we increased the TTL to 15 min and as a result more neighboring smart vehicles (i.e. 15%) received responses. We further increased the TTL to 30 min and as expected performance further increased, where 17% of neighboring smart vehicles successfully received the responses. In the last two cases, we set the TTL to 45 and 60 min. Here, 19% and 20% of neighboring smart vehicles received different services.

7. Conclusion and future work

To address the problem of service discovery in VANETs, we proposed an application layer lightweight, beaconing-based services discovery protocol called RSDP. The design of our protocol is based on WAVE architecture, and we considered standard protocols like IEEE 802.11p, IEEE 1609.4, and WSMP. It also supports the multichannel operation of the IEEE 802.11p-based wireless interface card and uses a store-carry-and-response technique. Additionally, we used the pull-based technique for discovering interest-based services. We presented our system

Figure 10. Effect of TTL on service discovery (w.r.t distance to destination).
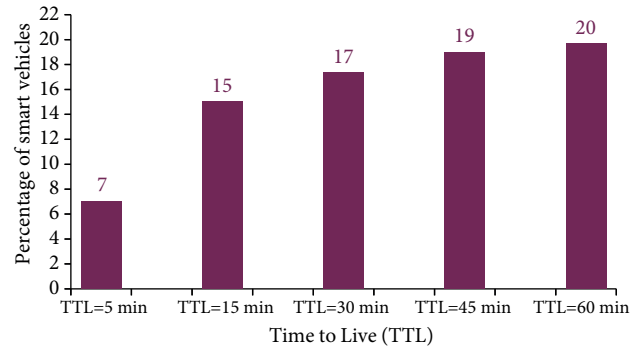
Figure 11. Effect of TTL on service discovery (case of neighboring vehicles).

architecture with its main entities, messages, and operations. Furthermore, we implemented the RSDP in a multilane highway scenario and evaluated its performance by an extensive set of simulation experiments under different parameters. We used the open source state-of-the-art traffic simulator SUMO, network simulator OMNET++, and Veins framework. The experimental results show that factors like query interval, query attempts, and time to live have a strong influence on the performance of the service discovery process in a V2V scenario. Results also revealed the efficiency of the RSDP for business owners interested in promoting their businesses to a large number of customers traveling towards them. It would also help travelers to discover services of interest far ahead of reaching the business's premises.

The model also reveals several important parameters that would help the marketing world in the establishment of different push-based advertisement strategies. By using longer lifetime for advertisement messages, the advertisement agency could assure business owners about extending the advertisement campaign to larger distances. The model also explains the role of some important service discovery parameters, e.g., when to ask for a service and how many times to ask for a service. Furthermore, the model highlights the importance of vehicle participation in the advertisement dissemination and discovery process. This would enable the key players (BOs and VAAs) to set up new incentive schemes. The scheme would require considering incentive issues like: a) to whom the incentives should be given, e.g., to the advertisement reception vehicle, to the advertisement forwarding vehicle, or to both of them; b) in which form the incentives would be provided, e.g., coupons, digital cash, or discounts; c) how many incentives would be required; and d) how the incentives would be distributed among the peer vehicles.

Presently, we are working on the design of an incentive-based architecture for services advertisement and discovery in VANET. We believe that this would encourage selfish drivers to participate in the network and contribute to the advertisements' dissemination. We are also studying different reputation models for VANETs. As a future work, we intend to investigate different pseudonymous and PKI schemes for making the communications between vehicles and RSUs secure. We will also incorporate security measures into the service registration, advertisement, query, and response phases of the RSDP.

Acknowledgment

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