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A Secured Protocol for Efficient Discovery of Service in Vehicular Networks

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Abstract: **Wireless access in vehicular environments (WAVE) is a foundation for a broad range of intelligent applications in transport, related to safety, comfort and, traffic management. Opportunities to advertise and disseminate services arise with the technological advances of vehicular networks. Points of interest (POI) to drivers and passengers, e. g. , shops and gas stations, broadcast the advertisements with local services and facilities available to the nearby vehicles by exploiting the road-side unit (RSU) infrastructure and comfort applications. However, RSU access coverage limitation or packet losses can prevent users (drivers or passengers) who are genuinely interested in services from finding them, even with a short distance from the POI. To improve the service discovery, we propose PEDS, a protocol based on opportunistic vehicle contact and a store and forward technique to discover and advertise services in vehicular networks. PEDS (Protocol for efficient discovery of service) is a lightweight and alternative protocol intended for location-aware applications. It supports distributed services fully independent from Internet access. In this paper we describe the key design concepts of PEDS and demonstrate its feasibility by a concept proof testbed. We perform two experiments evaluating the success rate of: *i)* capturing and storing service messages and *ii)* searching for a service of interest and receiving reply messages containing it. PEDS feasibility was demonstrated for different vehicle densities and for very short time connections. Results indicate that a vehicle can capture 100% of messages under the coverage of seven POI sending advertisement messages every second, with a contact time of 1. 2*s*. Moreover, a user can find a service with 95% of success rate by querying one neighbor vehicle.**

1. INTRODUCTION

Vehicular networks are promising technologies to enhance safety, convenience, and entertainment for users under different urban and road traffic conditions. Vehicular networks have been defined by the wireless access in vehicular environments (WAVE) standard, which establishes communications channels to non-safety applications for the road side unit (RSU) and vehicles which are main source for a transport [1], [2].

This creates significant opportunities for the deployment of a wide diversity of applications and services to vehicular environments, especially location-aware services. In this context, protocols for service discovery become an important requirement for vehicular networks. Advances in this field are concentrated in mobile ad hoc network (MANET) concept. However, most MANETs do not take into account the particularities of vehicular networks, such as, highly dynamic network topology changes and short connectivity time, due to fast movement of vehicles, inability to rely on an assumed geographic position of vehicles, and the wide exploitation in the vehicular environment of services dissemination. Therefore WAVE and the ability to tolerate communications failures must be considered when designing network protocols. Different studies on service discovery protocols for vehicular networks have been conducted. Dikaiakos *et al.* [3] provided time-sensitive information about the traffic conditions and the available roadside services by means of car-to-car communication. Their protocol, however, is not scalable for increasing network density and number of requests. Boukerche *et al.* [4] proposed a location-based service discovery protocol that is able to discover location-aware and time sensitive services based on the specified location of the requested service in the drivers request. However, failures in service queries significantly affect the protocol performance. In a recent study, Abrougui *et al.* [5] introduced a fault-tolerant scheme for infrastructure-and-location-based service discovery by integrating service information into the Network Layer and using diverse channels. However, the solution requires two wireless interfaces per vehicle. To improve services discovery in vehicular networks, we propose an opportunistic service discovery protocol (PEDS). Our protocol is different from other protocols in several aspects. First, we designed the protocol taking into account the WAVE standard. Second, PEDS is a layer-2 protocol that runs on dedicated short-range communication (DSRC) [6], whereas previous approaches are either application solutions at layer-7 [3] or layer-3 protocols [4] [5]. Finally, other studies rely on Internet access or on the RSU interconnection to exchange data, whereas PEDS is based on the opportunistic contact and store-and-forward technique, as in [7]. Thus, PEDS can handle RSU or Internet access disruptions. We define opportunistic communications as being occasional communications among vehicles. No assumption is made regarding the existence of a complete protocol stack for infrastructured communications between vehicles. POI services and the destination vehicle might never be connected to the same network at the same moment. Store-and-forward denotes the fact that the service advertisements are buffered in the vehicle to wait for contact from other vehicles searching for services. When a required service matches to the stored one, service information is forwarded. The PEDS is a lightweight protocol at layer-2 that focuses on providing location-aware services for moving vehicles. Instead of users using their smart phone with 3G/4G connections to find the desired services via the Web, PEDS will be integrated into the vehicle system and network, interacting with the users through an interface (e. g. , car's navigation system) to search for the desired services. The returned information (e. g. , location and price-lists of gas stations, location and menus of restaurants) can help users who are interested in locating nearby roadside services. Furthermore, this information can be merged with GPS position, extending on-board navigation systems and Internet applications functionalities. We implemented and evaluated PEDS to prove, individually, the accomplishment of vehicle-to-RSU (V2R) and vehicle-to-vehicle (V2V) communications. To this end, first, for V2R, we increased the number of services offered to vehicles from 1 to 7. Second, for V2V, we increased the number of neighbour vehicles of a particular vehicle from 1 to 7. According to the results, PEDS was feasible for long and very short time connections and also for different densities of vehicles and RSUs. The remaining of this paper are organized as follows. In Section II we describe a base scenario and provide PEDS definitions. In Section III we detail the PEDS architecture. Section IV presents the testbed, implementation and validation. In Section V we discuss the performance evaluation. Finally, the conclusions are in Section VI.

2. SCENARIO AND DEFINITIONS

A. Envisioned Scenario

Assume an urban-road scenario in which the vehicle network infrastructure is somehow deployed, such that the RSUs and vehicles are equipped with built-in wireless interfaces, minimum processing and memory capabilities, and GPS devices. Security and privacy issues in vehicular networks are beyond the scope of this paper and will be addressed in future work. For more details about this subject, we refer to the reader to [8]–[12].

We distinguish safety and non-safety services. Safety services will be provided in high-priority channel to enable communication in critical situations, e. g. , finding a hospital in an emergency. Non-safety services will be provided in low-priority channel to enhance users' experience during their trip. PEDS is intended for non-safety services as an alternative for users. Therefore, users sometimes can experience non-satisfactory or failed requests.

The PEDS can handle the types of services shown in Fig. 1. Roadside services periodically broadcast messages by using beacons with their local information, e. g. , *RSU*1 broadcasts price-lists of gas stations; *RSU*2 broadcasts hotel room prices; *RSU*3 broadcasts parking lot rate. Vehicles around the *RSU* can hear these beacons and store the information received. Suppose the user of vehicle *v*2 is interested in receiving information about gas stations. Thus, *v*2's PEDS checks its stored data and queries to the other neighbor vehicle, *v*1, to gather more information. Vehicle *v*1 replies to *v*2 the stored information received from *RSU*1, when it passed by the gas station. Similarly, vehicle *v*1 received and stored the hotel and parking lot information when it passed by *RSU*2 and *RSU*3, respectively. Vehicle *v*3 is looking for a bookstore, but its does not find one. This is because *v*4 has not passed by any bookstore. However, vehicle *v*3 can continue to query any vehicles it meets along the way (e. g. , when meeting *v*2) until finding the desired service.

Fig. 1. Future scenario in a vehicle network. Vehicles {*v*1. . . *v*4} are hearing and storing beacons broadcasted by {*RSU*1. . . *RSU*3} and opportunistically store-and-forward services information.

B. System definitions

The entities in the envisioned scenario are as follows:

- **Vehicle**: A vehicle *v* (car, bus, motorcycle or truck) is equipped with built-in devices required for a vehicular network, at least, wireless interface, GPS and an onboard computer. Thus, all vehicles *v* that implement PEDS are able to receive the service information broadcast by *RSU*, and store it in a cache *c*. Moreover, *v* can query the cache *c* of neighbour vehicles within the range of its radio frequency (RF).

- **RSU**: Road-side units are placed along the streets, roads, parks and other such locations. Every *T* time, they broadcast to *v* their beacons carrying the local service information offered by the points of interest (POI) in the geographic region.

- **Service**: Services are characterized as a POI for users. A service *s* is defined by a 4-tuple *_N, P, E, D_*, where *N* is the general service name (e. g. , drugstore, bookstore or gas station), *P* is the geographic position with the pair latitude-longitude, *E* is a time-to-live in seconds in which the service expires, and *D* is an additional description text about the offered service (e. g. , address, business name, and phone number).

Therefore, the problem is defined as follows:

Let *RSUk* broadcasts services *sk = (Nk, Pk, Ek, Dk)* and *V = {v*1. . . *vj}* the set of vehicles that hear and store *sk* in their cache *cj*. When a vehicle *vi* needs to find *sk* and *sk /∈*

ci, *vi* sends a query *qi* = *_N, D_* to the neighbour vehicles in

V within *vi*'s range of RF coverage, then *{∀vj |sk ∈ cj}, vj* replies *rj = {s*1. . . *sn}* to *vi*. For each different *sk* replied, *vi* updates its *ci*.

Hypothesis: *sk* is broadcasted by *RSUk* and heard by *V*. If a vehicle *vi* does not pass by the RF coverage of *RSUk*, *vi* can find *sk* when *vi* meets at least one vehicle of *V*.

3. OPPORTUNISTIC SERVICE DISCOVERY PROTOCOL

In this section we describe the PEDS messages, phases and procedures. First, we define the three types of messages used by PEDS and discuss the trade-off when adopting extensible mark-up language (XML) as a service data format. Second, we describe the PEDS phases. Finally, we explain the protocol procedures in the *RSU* and vehicle nodes.

A. Types of messages

PEDS is a beaconing-based communication protocol. Beaconing consists of the periodic single-hop broadcast transmission of messages, so-called beacons [13], [14], handled in the physical layer and media access control layer of WAVE. Three types of messages are defined in PEDS:

- ***M*** is a beacon with the service *s*, which is broadcasted by *RSU* every *T* time;

- ***Q*** is a query message that contains the name of service *N* and description *D*. To find a desired service, a vehicle *vi* sends a query *qi* to its neighbour vehicles *V* ;

- ***R*** consists of the messages *rj*, which neighbours *V* send to *vi* replying the services {*s*1. . . *sn*} found in the cache *cj*. *R* is a unicast probe response message.

Every single message has the fields illustrated in Fig. 2. TYPE is an unsigned integer to distinguish the messages types. LENGTH is an unsigned integer to set the size of XMLDATA. In the end, XMLDATA is an XML document.

Fig. 2. Message encapsulated in the beacon and probe frames of WAVE.

It is important to note that these messages will be used by a beacon or a probe with other ordinary beacon/probe fields, according to the frame of the WAVE standard.

The XMLDATA should have the hierarchy of <service> and <description> tags. Example of a service advertisement *s* in a message *M* is shown in Code 1. The <service> hierarchy has the mandatory information set *_N, P, E_*, represented by the attribute tags <name>, <latitude>, <longitude> and <timelife>. The <description> hierarchy is optional. It has the attributes to detail the service, such as <url>, <phone> and <address>. These attributes can be selected to provide the best service detail. The *R* response message follows the same XML structure of the message *M*.

```
<?xml version=" 1. 0 " encoding="UTF−8"?>
<service>
<name>Un i v e r s i t y < /name>
<l a t i t u d e>−22. 001954< / l a t i t u d e>
<longitude>−47. 931717< / longitude>
< t ime l i f e >1382449758< / t ime l i f e >
</ service>
<description>
<label> Universidade de São Paulo < / l a b e l>
<u r l> www. usp. br </ u r l>
```

```
<phone> +55−16−3373−9700 < / phone>
<address> Av. Trabalhador sao−carlense, 400 </ address>
</ d e s c r i p t i o n>
```

Code 1. Example of a XML document carried by an *M* message.

For *Q* messages, the XML document also has both <service> and <description> with simpler attributes, only <name> under <service> is mandatory. The optional attributes in the <description> is intended to limit the search and reduce the number of replied messages *R*. For instance, an attribute <max_distance> could specify the maximum distance from *V* to the target service *s*, which is tolerable by *vi*.

Vehicle systems and databases will probably contain data in incompatible formats. Many types of services will be offered and each one has different information and formats. Therefore, PEDS addresses the data sharing semantic by using XML documents, which allows software-hardware independent methods of storing data.

B. PEDS phases

PEDS runs in independent phases, as illustrated in Fig. 3.

i. *Beaconing*: Each interval *T*, *RSUs* periodically broadcast the beacons *M* that conveys the services {*s*1. . . *sn*}.

ii. *Caching*: Vehicle *vj* passes by the *RSU*, receives the beacon *M*, and stores the service *s*. If *s* was already stored in the cache *cj*, then *M* is dropped. Otherwise, *cj* is updated, also expired *s* are removed.

iii. *Querying*: A query occurs when a user wants to find a service *s*. Thus, *vi* broadcasts a query *Q* to the neighbor vehicles *V*. All *vj* that received *Q* checks in their caches *cj* to determine if *s*-related services exists. If at least one service is found, then *vj* sends a probe response *R* as a unicast probe to *vi* with the services {*s*1. . . *sn*}. Then, *vi* updates its *ci* with the received services {*s*1. . . *sn*}.

Due multi-hop beacons can degrade the vehicular network performance [15], for all the phases, the messages *M*, *Q* and *R* are sent in a single hop.

Furthermore, PEDS adopts the probe response *R* as a unicast message, which is sent to a particular vehicle *vi*. Multiple vehicles in *V* might reply with different responses for the queries *Q* at the same time. In this sense, the unicast message allows distinguishing the replies *R* and enables the users of *vi* to choose suitable services.

C. Operation of the protocol

PEDS operates in five states in a vehicle *v*, as shown in Fig. 4, it starts listening to the messages *M*, *Q* and *R* or waiting for users searching in the Listen state. According to the type of the received message, PEDS goes to different states. If the type is *M* or *R*, PEDS goes to the Update state. In the update state, it processes the message updating the cache *c* and then returns to the listen state. If the type is *Q*, the PEDS goes to the Find state to process the query *Q* by searching in the cache *c* for the services *s*. If one or more services are found, PEDS goes to the reply state; otherwise, it returns to the listen state. In the Reply state, the services *s* are conveyed in the unicast messages *R* and then it returns to the listen state. When the user wants to find a service, PEDS goes to the Query state and sends the query *Q*.

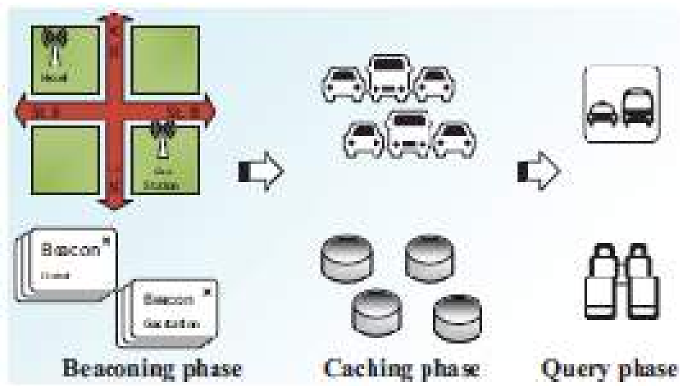

Fig. 3. Beaconing, *RSU* broadcast the service. Caching, vehicles near the *RSU* hear and cache the information. Query, users that wants to find a service queries the cache of the other vehicles close to him

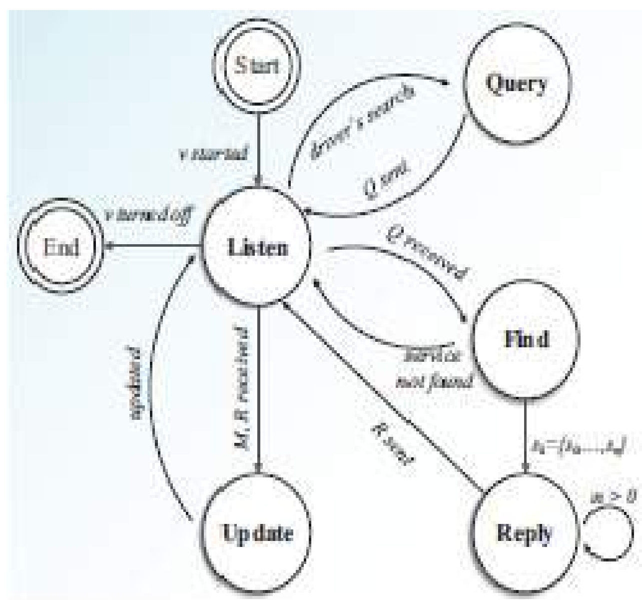

Fig. 4. PEDS state machine operating in vehicle node.

4. IMPLEMENTATION AND TESTBED

We implemented and evaluated PEDS in a proof-of concept vehicular test bed set up with IEEE 802. 11a.

A. Implementation

We added the messages *M* and *Q* in the native beacon of IEEE 802. 11a at Information Element Vendor (IE Vendor) field, as shown in Fig. 5. The OSPD XML document size is more than 256 bytes, although IEEE 802. 11a limits the IE vendor size to 256 bytes, we used two IE vendor fields to carry the XML. First field is the <service> and second field is the <description>, both set with the same TYPE and the correspondent length was set in the LENGTH field. The beacon with the XML is transmitted over a *Socket Raw*. Messages *R* were added in the probe response unicast messages with the destination to *vi* which sent the query *Q*. The PEDS implementation at the *RSU* sends beacons *M* every 1 *s* of interval controlled by the system call sleep (). At the vehicle *v*, we implemented two POSIX Threads, one for sending *Q* or *R* and the other for receiving *M* or *R*. The receiving thread uses the PCAP library to capture the beacons and probes. Each received *M* or *R*, it extracts the XML document by using the Library libxml2 and stores the services in the cache *c*. The cache *c* was implemented as a ring buffer in memory. For search the services, PEDS runs on the buffer and returns the services the name *N* matches with the query *R* service name *N*.

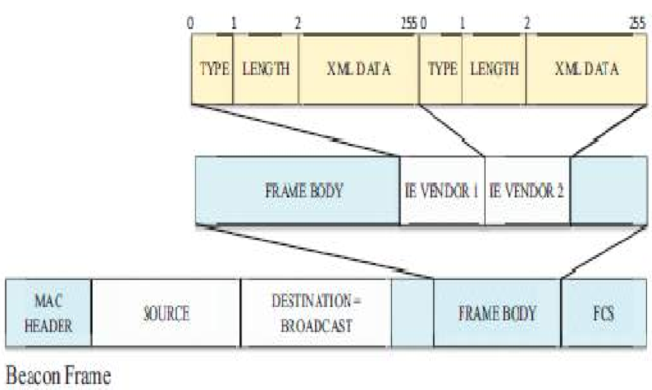

Fig. 5. IEEE 802. 11a native beacon. We injected the XML document into the two consecutive IE vendor fields placed at the end of frame

The PEDS implementation at the *RSU* sends beacons *M* every 1 *s* of interval controlled by the system call sleep(). At the vehicle *v*, we implemented two POSIX Threads, one for sending *Q* or *R* and the other for receiving *M* or *R*. The receiving thread uses the PCAP library to capture the beacons and probes. Each received *M* or *R*, it extracts the XML document by using the Library libxml2 and stores the services in the cache *c*. The cache *c* was implemented as a ring buffer in memory. For search the services, PEDS runs on the buffer and returns the services the name *N* matches with the query *R* service name *N*.

B. Testbed

We used five access points (AP) with Pc-Engine Alix3D2 and Ubiquity XR5 wireless card set to a frequency of 5. 8 *GHz*, transmitting at a 6 *Mbit/s* data rate and 15 *dBm* of transmission power. The APs were placed in a row, each separated by ≈ 50 *cm*, with a 5 *GHz* interference free area. All the APs had the *RSU* and vehicle PEDS implementations. We instantiated PEDS twice in the same AP in some tests as an effort to test with more than five nodes. The AP3 placed in the middle represents *vi* or *vj*, and the other four could be *RSU* or *vj*, depending on the test, as shown in Table I.

5. EXPERIMENTS AND RESULTS

We prove the feasibility of the protocol by means of two tests to assess the three phases of PEDS. First, we tested the beaconing and caching phases for evaluating the sending of beacons *M* by a *RSU* and the receiving and storing fo *M* by *vj*. Second, the query phase for evaluating the service discovery query procedures. This study was not conducted using experiments on the road or in an urban vehicular environment because of the prohibitive costs. Instead, we based the tests on metrics of inter-contact time for the V2V and V2R transmissions. A inter-contact time occurs when a vehicle passes by an *RSU* coverage area or passes another vehicle in the opposite lane direction in the road. Rubinstein *et al.* [16] demonstrated the inter-contact time varies between 10 *s* to 45 *s* for two vehicles in opposite lanes with speeds varying between 60 *km/h* and 20 *km/h*, respectively.

TABLE 1: ARRANGEMENT OF OSPD INSTANCES FOR EACH DENSITY

Phase(s)	d	AP_1	AP_2	AP_3	AP_4	AP_5
I and II	1	-	RSU_2	v_j	-	-
	3	RSU_1	RSU_2	v_j	RSU_4	-
	5	RSU_1	RSU_2 [1]	v_j	RSU_4	RSU_5
	7	RSU_1 [1]	RSU_2 [1]	v_j	RSU_4 [1]	RSU_5
III	1	-	v_2	v_i	-	-
	3	v_1	v_2	v_i	v_4	-
	5	v_1	v_2 [1]	v_i	v_4	v_5
	7	v_1 [1]	v_2 [1]	v_i	v_4 [1]	v_5

[1] *OSDP instantiated twice.*

In the tests, the inter-contact time was managed by an independent POSIX Thread in *AP*3 that wakes-up PEDS for a fraction of inter-contact time and, after that, puts it to sleep for 3 *s*. Moreover, the *RSU* (*dr*) and neighbour vehicles (*dv*) densities were increased up to 7 units. We define *dr* as the number of *RSUs* that are under the RF range of one *vj* and *dv* as a number of neighbour vehicles *vj* that are under the RF range of one *vi*.

The PEDS instances arrangement in the *APs* for densities *dr* and *dv* is shown in Table I. We started testing from 1 and increased by 2 the numbers of *RSU* and vehicles. The maximum density was 7 units because of the limitation of the number of *AP*s we own. The average and confidence intervals of 95% were computed from a sample of 100 measurements for each inter-contact time.

A. Evaluation phases I and II: Beaconing and caching

This test refers to the vehicle *vj* when it receives beacons from *RSU*s in V2R communications, as shown in Fig 6(a). According to the densities, as shown in Table I, an *RSU* broadcasts one or two beacons *M* with the services *s* inside every *T* = 1 second to prevent flooding in the network [17].

We started the test instantiating PEDS in all *RSU*s, one by one, and then, in the vehicle *vj*.

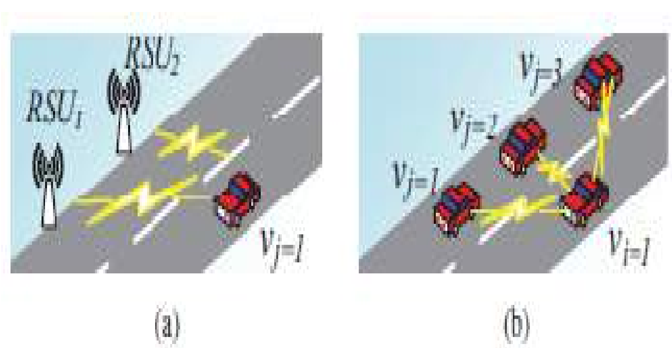

Fig. 6. Evaluation scenario examples: (a) Two *RSU* and one car receiving beacons. (b) One vehicle querying three neighbours vehicles.

We measured the inter-contact times from 0. 2 *s* to 2 *s* with 100 samples observed in *vj*. One sample reports a total of *M* received by *vj* within an inter-contact time. Thus, beaconing success rate, *Sbr*, is the rate of total of offered services at that time per the total of services received by *vj*.

The *Sbr* mean is shown Fig. 7. For *dr* up to 5, *Sbr* is less than 1. 0 for inter-contact times less than 1 *s*. This indicates the choice of interval *T* = 1 *s* affected the *Sbr* performace, as we have a linear increasing behaviour until 1 *s*.

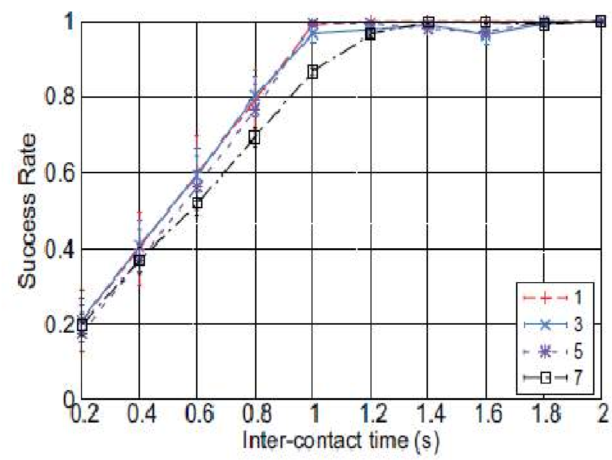

Fig. 7. *Sbr* for the beaconing and caching phases. A vehicle *vi* receives beacons from *RSU*s under the density *dr* varying from 1 to 7.

According to this result, an inter-contact time of 1. 2 *s* appears to sufficient for a vehicle *vj* under a density *dr* = 7 to receive 100% of the advertised services at a given time. When *dr* > 5 and the inter contact time is less than 1. 2 *s*, the beaconing performance decreases, probably, because of eventuals packet collision.

B. Evaluation phase III: Querying

This test refers to the vehicle *vi* when it queries the neighbor vehicles *V* in V2V communications, as shown in Fig. 6(b). The neighbour vehicles are represented by *v*[1, 2, 4, 5] and PEDS was instantiated according the densities of the Table I, in the way of the previous test.

To prevent the time of vehicles *V* to search for a service in cache *cj* impact in the network performance, all *vj* have only the service searched by *vi* stored in cache *cj*, reducing the search time and minimizing the influence in the evaluation.

Thus, each neighbour vehicle in *V* sends a unicast response probe *R* to *vi*. We measured the inter-contact time from 0. 2*s* to 2*s*. We obtained 100 samples for each inter-contact time. One sample reports a total of *R* received by vehicles *vi* within a given inter-contact time. The query success rate, *Sqr* is the rate of the total neighbours *vj* at that time per the total replies *R* received by *vi*.

In this phase, there is a double chance of errors: first, when *vi* sends the query *Q* and second, when the vehicles in *V* reply the responses probe *R*. If the density *dv* increases, there is greater chance of packet collision during the replies. We understand that the performance can suffer from the synchronised replies, when the vehicles *V* receive the query *Q* and find and send *R* at the same time. Thus, is acceptable that the performance decreases as the *dv* increases.

Fig. 8 shows the average of *Sqr* for *vi*. The results indicate that *Sqr* depends only on the *dv* value. To understand the reason that the inter-contact time did not affect the query phase, we measured the time of *vi* starting to send *Q* and receive the first reply *R*, which was 1658 μs on average. Therefore, 0. 2 *s* was a sufficient time for *vi* to send *Q* and receive the respective *R*. When *dv* = 1, one neighbour vehicle in *V* is able to know the service searched by *vi*. Thus, there is a 95% chance that *vi* will query and receive the reply *R* within any inter-contact time greater than 0. 2 *s*. If *dr* = 7, seven neighbour vehicles in *V* are able know the service searched by *vi*, so that *vi* has a 48% chance of receiving all the replies *R*, i. e. , *vi* finds the service, but it does not know all that are available.

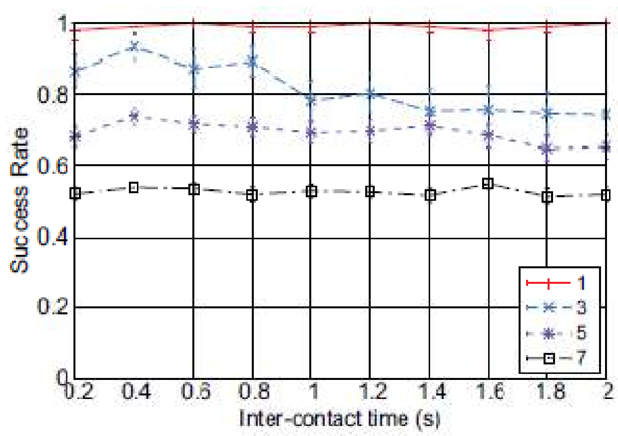

Fig. 8. *Sqr* for the query phase. A vehicle *vi* queries the vehicles in *vj* under the density *dv* varying from 1 to 7.

6. CONCLUSION

Here we have studied the problem of providing users a roadside services in the future WAVE environment without Internet access. It is a users location aware information. Such information improve the users experience during the trip through roadside POI advertisements.

To address this problem, we proposed PEDS – a beaconing-based protocol that is able to find and disseminate services using the store-and-forward messages on available connections. Two tests were conducted in a test bed to demonstrate the feasibility of PEDS. First was the beaconing and caching phases and second was the querying phase.

According to the results, we can conclude: *i)* to interval *T* = 1 *s*, an inter-contact time of 1. 2 *s* is sufficient for one vehicle receives 100% (*Sbr* = 1. 0) of the beacons *M* and *ii)* the success rate, *Sqr*, is not the affected by inter-contact time and the density *dv* is an important for PEDS performance.

In the future work we will study the security issues of PEDS, perform simulations, and evaluations in urban scenario using V-Beacon [18]. Also, we would like exploring the PEDS as a potential protocol for vehicular sensing and social networks [19].

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