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Integrated service discovery architecture for heterogeneous networks

Min-Xiou Chen*,† and Fu-Hsing Sung

Department of Computer Science and Information Engineering, National Dong Hwa University, Hualien, Taiwan

SUMMARY

The discovery and management of desired network services present significant challenges for mobile networks. Based on the Service Location Protocol, this paper proposes an integrated service discovery architecture for vehicular *ad hoc* networks. The proposed approach divides the network into several logical zones. The zone structure is formed virtually based on position information. Each logical zone may have a zone directory agent to manage registered services from service providers. The proposed architecture considers both vehicle-to-infrastructure and vehicle-to-vehicle communication modes and introduces roadside directory agents and vehicle directory agents to reduce deployment costs. We also introduce a substitute query technique, cache mechanism, and backup mechanism to improve the request hit ratio and reduce the message overhead of the substitute query. Finally, we implement the proposed mechanisms in Network Simulator version 2, with simulation results showing that the proposed architecture can provide a high average data hit ratio and low message overhead. Copyright © 2015 John Wiley & Sons, Ltd.

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KEY WORDS: service discovery; service location protocol; vehicular *ad hoc* network; NEMO

1. INTRODUCTION

The growing number of networked devices or services in vehicular and home networks has raised the importance of effectively discovering and managing desired network services [1, 2]. Many research projects, standards, and protocols have been proposed to deal with service discovery problems on either the network layer or the application layer. These approaches can be further divided into three types of architectures: centralized directory-based service discovery [3–5], directory-less-based service discovery [6–9], and distributed directory-based service discovery [10–22].

It is a challenge to design a service discovery mechanism that simultaneously provides reduced network overhead, faster service response time, a higher service hit ratio, and better network scalability. Most current service discovery protocols are designed for infrastructure networks, mobile *ad hoc* networks (MANETs), or vehicular *ad hoc* networks (VANETs) [17, 18]. However, no service discovery mechanism currently works in a heterogeneous environment, which can comprise infrastructure networks, network mobility (NEMO) [23] environments, VANETs, and VANETs with NEMO.

Infrastructure networks, NEMO environments, and VANETs have different characteristics. In infrastructure networks, moving vehicles can discover services from a service directory server deployed at the base station or access point. In VANET, the nodes are moving in a random but predictable manner at much higher speeds along relatively straight paths, allowing vehicles traveling at high speed to quickly form a dynamic network topology. Thus, service discovery protocols

*Correspondence to: Min-Xiou Chen, Department of Computer Science and Information Engineering, National Dong Hwa University, Hualien, Taiwan.
†E-mail: mxchen@mail.ndhu.edu.tw

designed for infrastructure networks may not work with VANETs. In NEMO, a mobile router connects the mobile network and the Internet, and the mobile nodes in the mobile network migrate with the mobile router, which changes its location from one network link to another. Moreover, in a mobile network with a hundred or more mobile nodes, the service directory server may be overwhelmed by hundreds of service discovery or registry messages.

This paper offers three key contributions. First, the proposed mechanism can provide service discovery in heterogeneous networks. Second, the proposed mechanism can provide a higher discover hit ratio. Third, based on the proposed environment, structured peer-to-peer (P2P) systems, such as Chord and Content-addressable Networks, can be implemented in VANET. To design a service discovery mechanism for a heterogeneous network, we first implement the Service Location Protocol (SLP) in the vehicle gateway to provide service discovery for NEMO [24, 25]. The Substitute Request message, which can be used to discover services from another SLP directory agent, and a cache mechanism are used to reduce the traffic overhead incurred by service discovery messages and to improve the service hit ratio. A new *ad hoc* network architecture is proposed to divide the network to several logical zones, each with a zone leader to collect information on vehicle position and movement. Next, based on the proposed architecture, we introduce the concept of the zone directory agent (ZDA) into SLP to provide service discovery for VANET [21]. The mechanisms proposed in [24, 26], and [21] are integrated and improved for coordination with the roadside directory agent, thus providing a service discovery mechanism for heterogeneous networks.

The remainder of this paper is organized as follows. The relevant literature, standards, and protocols are discussed in Section 2. The proposed architecture, Substitute Request message, and a cache mechanism for the SLP directory agent are described in Section 3. Section 4 presents a performance analysis of the proposed architecture. Section 5 provides a performance evaluation for the proposed system, and conclusions and suggestions for future directions are given in Section 6.

2. RELATED WORKS

The relevant research focuses in three areas: centralized directory-based service discovery architecture [3–5], directory-less-based service discovery architecture [6–9], and distributed directory-based service discovery architecture [10–22]. In the centralized directory-based service discovery architecture, most previous works used a discovery server (referred to as a directory agent or lookup service) to store the service information and to reply to a discovery request with the corresponding discovery results. For example, SLP [3, 4] proposes three network components: Service Agents (SAs), Directory Agents (DAs), and User Agents (UAs). In SLP centralized mode, the SLP SA provides one or more services, and the SLP DA works as a directory server to manage the services registered from the SLP SAs. The SLP UA issues a service discovery request for a desired service to which the SLP DA responds. A key drawback to this centralized architecture is that increasing the network scale or the volume of service discovery requests can result in heavy traffic loading on the server. Moreover, the centralized architecture features no backup server in case the server fails.

In the directory-less architecture, there is no centralized server to manage the service information. The client sends the discovery request to the network, and a device that can provide the desired service can reply to the request. Universal Plug and Play (UPnP) [6] is a type of directory-less service discovery developed by Microsoft, providing service discovery mechanisms in P2P networks. There are many standards and protocols in Universal Plug and Play, and the Simple Service Discovery Protocol (SSDP) is used to provide service discovery. In SLP's distributed mode, there is no SLP DA in the network. The SLP UA can multicast service discovery requests for desired services, and the SLP SA can reply to these discovery requests. DEAPspace, proposed in [7], is another kind of directory-less architecture in which the host proactively broadcasts single hops to announce its service and then receives messages from its neighbors to identify all devices.

The architecture proposed in [8] uses multicast to announce its services and sends service discovery requests, using push and pull methods with a cache mechanism to discover the desired services. Bonjour [10] is another kind of service discovery architecture, proposed by Apple Inc. based on the DNS-based service discovery architecture. Bonjour is a group of technologies that includes service discovery, address assignment, and hostname resolution, using the multicast DNS mechanism [27]

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to locate devices and services in a local network. In a directory-less architecture, these approaches usually use multicast or broadcast to advertise their services and perform service discovery. Thus, in a larger network, these approaches may result in significant message overhead between the service provider and service requester.

In the distributed directory architecture, there are many directory servers in the network, and these directory servers may be organized in a logical structure. In group service discovery (GSD) [12], all services are classified by type, with each service advertising its identification and group information. Users multicast their discovery requests to find the desired service. However, GSD suffers from high message overhead in loop situations. The Candidate Node Pruning Enhanced Group-based Service Discovery Protocol [14] uses candidate node pruning and broadcast simulated unicast to enhance the GSD protocol and reduce message overhead.

The Chord approach [15] organizes directory servers in a logical ring network using an elaborate service discovery mechanism. However, Chord was designed for use in overlay networks, and increased node mobility in a MANET or VANET implementation may entail high internode maintenance. Derived from SLP, the Mesh-enhanced Service Location Protocol (mSLP) [16] has each DA establish a peer connection with other similar DAs with a shared scope. The DAs then periodically exchange advertisement messages to maintain the peer relationship. Each DA also exchanges new service registrations via message forwarding. Thus, mSLP improves the consistency among peer DAs by automatically sharing registrations and provides registration information recovery when the DA is rebooted. However, in MANET of VANET, the topology of the network is dynamic, and the DAs may move anywhere. Thus, it is difficult for DAs to maintain peer connections with each other, so mSLP is not suitable for MANETs or VANETs, and a DA cannot distribute the service registrations to a DA in a different scope.

Few previous related studies focused on designs for vehicle networks. For example, in [25], the authors proposed the nearest surrender searching mechanism to solve the service discovery problem in MANET. According to [28], the service discovery mechanisms for VANET can be categorized as vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V). In V2V, the Vehicular Information Transfer Protocol (VITP) proposed in [19] is an application layer protocol designed to support data dissemination over VANETs. VITP can use information retrieved from vehicular sensors and take advantage of onboard GPS navigation systems to provide drivers with location-based, traffic-oriented services. In VITP, the vehicle uses geocast to announce service information. However, the data delivery ratio decreases as the vehicle's speed increases.

In [20], geocache was proposed to allow for sharing and exchanging of traffic information using P2P communication in VANETs. Geocache uses the pull-based geocast protocol to efficiently collect and disseminate data. The caching mechanism was integrated into geocache to reduce the amount of information exchanged between vehicles. However, geocache is designed for the exchange of traffic information and is not suitable for service discovery in VANETs.

In [21], we proposed a P2P service directory agent architecture based on SLP for VANETs. Based on the proposed architecture, the network is divided into several logical zones, each selecting a vehicle node as zone leader to provide the service directory function. The SLP SA registers its service with a zone leader that uses the distributed hash table (DHT) function to identify the target zone leaders with which it then registers the service. The proposed architecture integrates the cache and backup mechanisms to improve the request hit ratio, but simulation results show that the average data hit ratio is still about 60%. In [22], a discovery mechanism for Semantic Web Services was proposed to provide discovery services in a Chord-based P2P network.

In V2I, the Address Based Service Resolution Protocol (ABSRP) proposed in [29] uses the roadside unit (RSU) to provide the service discovery in VANETs. In ABSRP, a unique address is assigned to each service provider, which proactively distributes the provider's address along with its servicing capabilities to other RSUs within a particular area. Thus, the user can discover a route to the service provider using the provider's address. In [30], the authors proposed a novel parking space discovery application for VANETs. Along the roadside or at intersections, the proposed mechanism deploys many intelligent unique routing agents that are connected and organized as a sensor network. Data centers are deployed at the intersections to store information related to parking lots, vehicles, and payments. Thus, a vehicle can send a discovery request to the intersection data center and find a free parking space.

In [31], the authors proposed a privacy-preserving location assurance protocol for location-aware services over VANETs. The proposed protocol can provide time-sensitive and higher-level services and distribute on-demand information such as traffic conditions, weather, and facility availability in a certain geographic area. In [32] and [33], the authors implemented a data dissemination and storage architecture based on the V2I architecture. However, the major drawback of these V2I architectures is that the discovery service requires the deployment of a huge number of RSUs, agents, or data centers in the network.

3. SYSTEM ARCHITECTURE

3.1. Network environment

In a city field, a VANET consists of a set of vehicle nodes deployed along certain roads and a set of RSUs located at certain intersections. Each vehicle node is equipped with a vehicle-embedded computer system. The digital map database, positioning device, and dedicated short-range communications interface are integrated into the vehicle-embedded computer system. This allows vehicles to communicate with each other (V2V) and with the roadside infrastructure (V2I) to share road traffic information and network services. Each RSU is equipped with a roadside directory agent and several service providers. A digital map database is also integrated into the RSU. As shown in Figure 1, several of the vehicle nodes are buses, and a vehicle directory agent (VDA) is implemented in the onboard unit (OBU). On a bus, the OBU works as a mobile router, and smartphones and hands-free devices located in the bus access Internet services through the OBU.

Moreover, a VANET can be divided into several virtual zones based on geographic position information, and each zone has the same range. Let G denote the VANET, $G = (N,E)$, where Z is the set of zones and E is the set of vehicles. Information for these zones can be stored in the digital map database, and each vehicle is located within a particular zone using the position information retrieved from its position device and the digital map database. Each zone has at most one RSU. Some zones have more than one vehicle, and some zones may have no vehicles. In a zone, at most, one vehicle serves as the zone leader while the others are group members. The zone leader periodically collects the positions and movement information of the group members and manages the group membership.

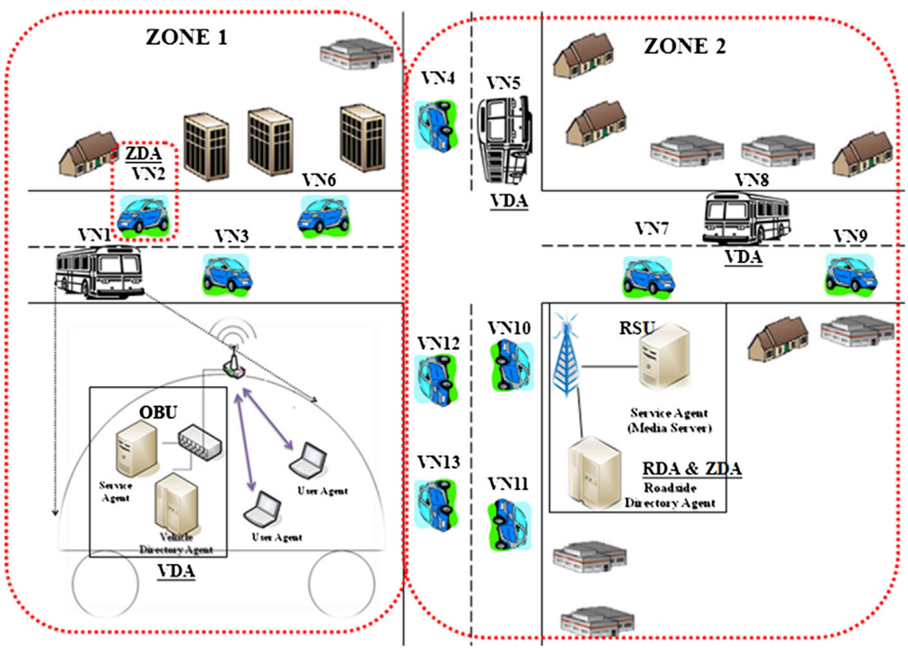

Figure 1. Network environment. ZDA, zone directory agent; OBU, onboard unit; RSU, roadside unit.

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The group member position and movement information held by the former zone leader is transferred to the new zone leader. The zone leader management is shown in Section 3.2.

According to SLP definition, SLP DA can be used to manage networks ranging from small, unmanaged networks to large enterprise networks, and its scope is a set of network devices or services. The scope can be described as a simple string and is denoted as the domain name in a large network. In our proposed architecture, a scope is a zone, and each zone leader (called the zone DA, or ZDA) should provide the SLP DA functions. The ZDA management is described in Section 3.2.

In the original SLP definition, the SLP DA can only store the registered service information for its scope. Thus, the amount of service information is very limited, and the request hit ratio will be very low. In this paper, the Substitute Request message and cache policy proposed in [24] are adopted to provide service discovery between the SLP DAs, and the P2P service directory agent architecture or hierarchical directory agent architecture can be implemented based on the Substitute Request message. However, when vehicles move at high speed, VANETs can behave very dynamically, and topologies change very quickly; thus, the traditional hierarchical directory agent architecture is not suitable for VANETs. Therefore, this paper introduces the ZDA exchange and backup mechanism into the P2P service directory agent architecture to provide service discovery between the SLP DAs for heterogeneous networks.

When an SLP SA is a vehicle, it registers its service with its ZDA. When an SLP SA is a bus, it is an NEMO environment and will register its service to its VDA. The VDA can retrieve the ZDA address from the zone leader, and the VDA will register its services to the ZDA. The ZDA may then use the DHT function to obtain several target ZDAs and register its services with these ZDAs. When a group member invokes a service discovery request for a desired service, the group member will serve as the SLP UA. The service discovery request is received by the ZDA or SLP SA, which then returns a response with the information for the desired service. When the SLP UA is a bus, the service discovery request is received by the VDA, which returns a response with the information for the desired service.

When the ZDA has no information for the desired service, the response message will contain no service information, but the address of the target ZDAs generated by the DHT function can be attached. When the VDA has no information for the desired service, the response message will contain no service information, but the ZDA address can be attached. When the SLP UA receives this response, it can send a Substitute Request message to the ZDA address retrieved from the response message to discover the desired service. The following sections provide detailed descriptions of these operations.

3.2. Zone leader and directory agent management

If a zone contains an RSU, the RSU is the first choice to serve as the zone leader. When there is no RSU but the zone has more than one vehicle, one of these vehicles will be selected as the zone leader, and the others are group members. When a zone has no vehicles, the first vehicle to move into the zone will be the zone leader. When the zone leader leaves the zone, the departing zone leader selects one of the remaining vehicles as the new zone leader based on the relative positions of the remaining group members. The group member that has been in the zone for the longest duration will have higher priority for selection as a new zone leader. For example, a group member starting near the zone boundary and taking a longer travel path through the zone may spend a longer period of time in the zone. Once the new group leader is selected, group member position and movement information held by the former zone leader is transferred to the new zone leader.

The ZDA is obviously very important for the proposed architecture. In the ZDA setup procedure, the ZDA function is performed by the zone leader. When a ZDA leaves the zone, the new zone leader will select another vehicle as the new ZDA and transfer the registered service information from the old ZDA to it. Moreover, if no new ZDA can be selected, the exiting ZDA should back up its registered service information with ZDAs in other nearby zones. Thus, ZDA management is very important and consists of three processes: ZDA setup, ZDA exchange, and ZDA backup and restore.

The zone leader periodically broadcasts an Agent Advertisement message that may contain the zone leader information and the ZDA information. Thus, when a vehicle enters a new zone, it

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can receive the Agent Advertisement message that allows it to retrieve the zone leader and ZDA information. If a vehicle enters a zone without a current zone leader, the vehicle will not receive an Agent Advertisement message but will rather be selected as the zone leader, will send the Agent Advertisement message periodically, and will perform the ZDA restore procedure to retrieve the service information registered on neighboring ZDAs.

Based on the SLP definition, when a vehicle enters a zone, it can wait to obtain the ZDA address from the advertisement message periodically sent by the ZDA, or it can use the SLP UA function to send a multicast server request to discover the zone's SLP DA. When the ZDA receives the server request, it responds by sending a DA Advertisement message to the SLP UA. When an ZDA receives a discovery message request for the DA, it sends a reply with the ZDA address attached.

In the ZDA exchange procedure, when a zone leader wants to leave the zone, one of the group members will be elected as the new zone leader, and the service information stored in the old zone leader will be transferred to the new zone leader, which will assume the role of a ZDA.

In the ZDA backup and restore procedure, when the ZDA wants to leave the zone and no new ZDA is available, the ZDA should back up its registered service information with ZDAs in other nearby zones. If and when these other ZDAs leave their zones, the backup service information will be transferred to the new ZDAs. Thus, when a vehicle enters a zone with no ZDA, the vehicle will become the zone leader and ZDA and perform the restore procedure to retrieve the backup service information from the nearby ZDAs. Figure 2 shows the ZDA management process in detail.

3.3. Service discovery mechanism

By definition, the SLP SAs first issue a register message containing all of the services they provide for the SLP DAs. The SLP DAs then reply to the SLP SAs to acknowledge this message. The SLP SAs periodically refresh the advertisements before the timer expires. When the user wants to find a given service, the SLP UA sends a unicast request with the query service to the SLP DA. The SLP

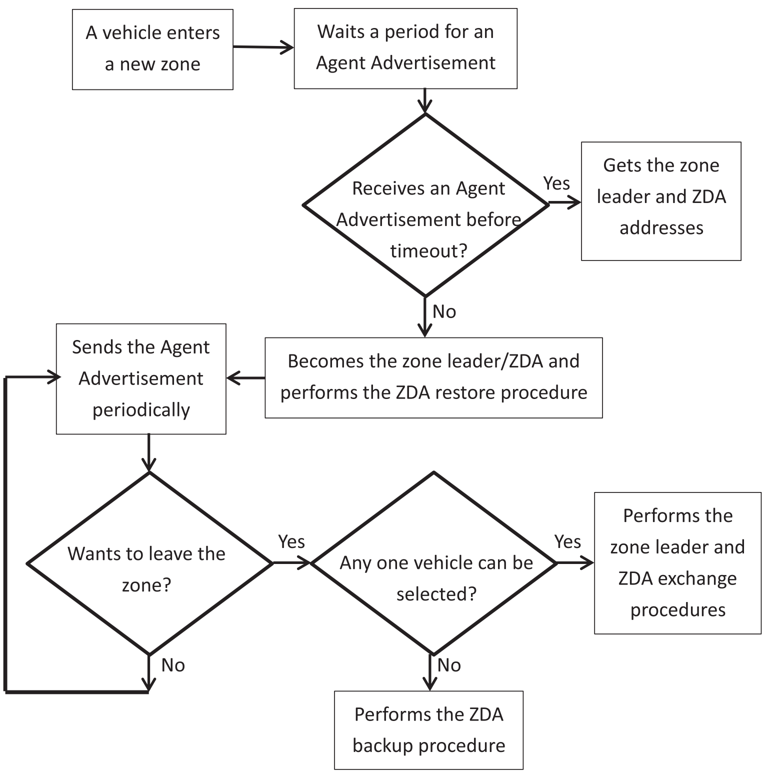

Figure 2. Zone leader and directory agent management.

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DA then replies to the SLP UA with a unicast message containing the service's location. When no such service is registered in the SLP DA, the reply message contains no service information.

Based on the definition in SLP, the DA only keeps the service information registered by SA and cannot discover the services registered in another DA. Thus, in the proposed architecture, a ZDA only can store registered service information for its current zone area, and the amount of service information is very limited. The request hit ratio will be very low. Thus, the Substitute Request message and cache policy proposed in [24] are introduced to improve the request hit ratio and limit the number of messages exchanged between vehicles. The Substitute Request message format is derived from the Service Request message. The Function ID in the header of the SLP message is used to define the message type. The major differences between the Substitute Request message and Service Request message are the <DA add> string length field and the <DA add> string. The <DA add> string length field indicates the number of bytes in the <DA add> string, and the <DA add> string field contains the target DA address.

The ZDA and SLP UA add the Substitute Request function. Thus, when the ZDA has no information for the desired service, the response message contains the addresses for other ZDAs. When an SLP UA obtains these addresses, it sends the original ZDA a Substitute Request message containing the address of the desired ZDAs and the desired service. When the ZDA receives this Substitute Request message, it uses the <DA add> string to retrieve the IP address of the desired ZDAs and forwards the Substitute Request message to them. The desired ZDAs then reply to the original ZDA. A caching mechanism could be implemented in the ZDA, allowing it to cache the search results, including service URL, life time, and authentication information, for use in the subsequent service discovery. The network topology of VANETs is changed very quickly. Thus, if the original ZDA sends the Substitute Request message directly to other ZDAs, the total round-trip time (RTT) of the Service Request message may be too long, and the originating vehicle may have already left the zone. Thus, the decision to send the Substitute Request message is implemented in the UA.

A hierarchical directory agent architecture or P2P service directory agent architecture can be proposed based on the Substitute Request message and the cache mechanism. For example, the hierarchical directory agent architecture can be constructed as the DNS system. When a lower level ZDA cannot find the desired service, an SLP UA can send the Substitute Request message with the higher-level ZDA address to the lower level ZDA. The lower level ZDA then sends a Service Request message to the higher-level ZDA and stores the search results in its database.

Moreover, when the SLP SA registers its service to a ZDA, the ZDA can register the service with other ZDAs. The original ZDA can then use the DHT function to obtain the target ZDAs of the register service, thus registering the service with the target ZDAs. The register messages can then be sent from the original ZDA to these target ZDAs, and the ZDAs on the path then cache this register service information. Thus, based on the DHT function, a P2P service directory agent architecture can be proposed.

When a ZDA cannot find the desired service in the local database, it can use the DHT function to obtain the addresses of the target ZDAs for the reply message. The SLP UA can then send a Substitute Request message with these addresses to the original ZDA. However, if these target ZDAs are not near the original ZDA, other ZDAs neighboring the original ZDA should forward the Substitute Request message to the target ZDAs. The original ZDA may then receive the response messages through the reverse path, and the ZDAs on that path also cache the service results. The detailed service discovery mechanism is shown in Figure 3.

4. PERFORMANCE ANALYSIS

To improve the request hit ratio, we introduce the Substitute Request message and P2P service directory agent architecture to discover the desired service registered with another ZDA. However, an increase in the average RTT between the requesting vehicle and the responding ZDAs will result in a corresponding increase in the request miss ratio.

Assume that each zone is square and that a source ZDA S sends a Substitute Request message, received from the requesting vehicle S_r, to the target ZDA D. Assume an average distance of H hops between S and D. L is the average message length, R is the transmission rate, V is the vehicles'

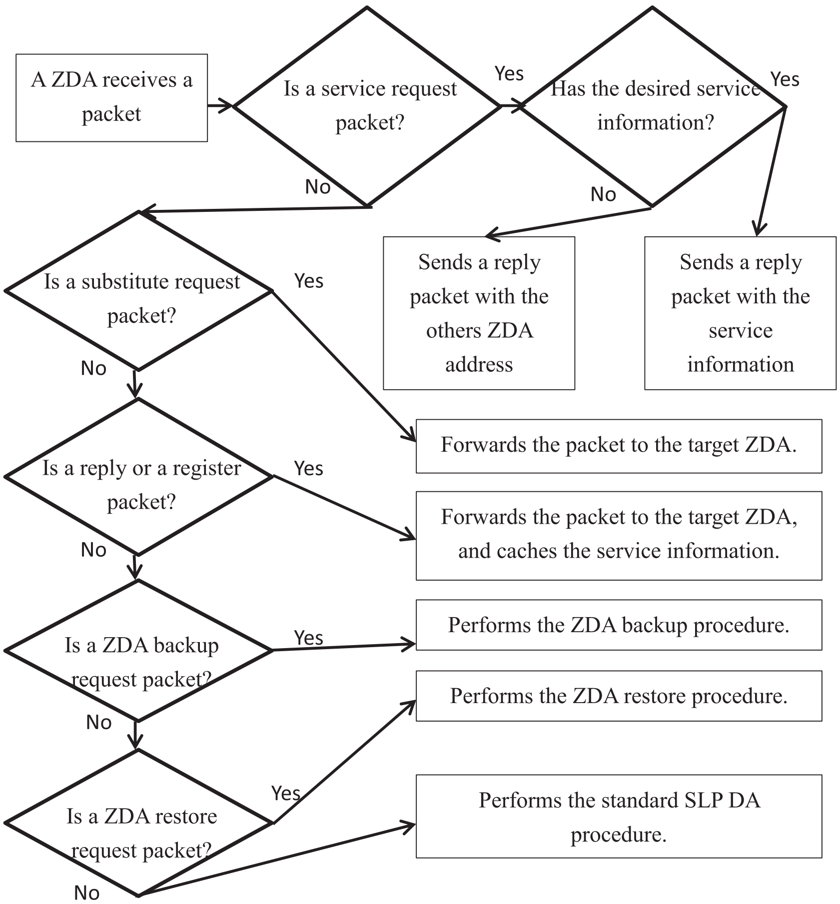

Figure 3. Service discovery mechanism. ZDA, zone directory agent; SLP DA, Service Location Protocol directory agent.

average vehicle velocity, r is the zone size, and t_p is the sum of the nodal processing delay and queueing delay.

Theorem 1:
When the average vehicle velocity, $V > \frac{\pi r}{8\left((H+1)\frac{L}{R}+Ht_p\right)}$, the time-out ratio of Substitute Request message will be very high.

Proof
The four sources of packet delay are nodal processing delay, queuing delay, transmission delay, and propagation delay. In our environment, the propagation delay is from one vehicle to the next and can be ignored. The transmission delay is *L*/*R*. Thus, the average *RTT* between the two nodes can be estimated as

$$RTT = 2\left((H+1)\frac{L}{R} + Ht_p\right) \tag{1}$$

If *RTT* is larger than *d*/*V*, the requesting vehicle will enter the neighboring zone and be unable to receive the reply message. The maximal moving distance of a vehicle in a zone is the diagonal $d = \sqrt{2r^2}$. Thus, based on Equation (1), the average vehicle velocity can be estimated as

$$2\left((H+1)\frac{L}{R} + Ht_p\right) > \frac{\sqrt{2r^2}}{V} \Rightarrow V > \frac{\sqrt{2r^2}}{2\left((H+1)\frac{L}{R} + Ht_p\right)}$$

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However, the diagonal length is the maximal moving distance. Following Theorem 1 in [23], assuming a vehicle maintains its direction of motion within a zone, the vehicle's average moving distance in the zone is $d_{\text{avg}} = \frac{\pi r}{4}$. The relation between RTT and V can thus be written as

$$RTT > \frac{\frac{\pi r}{4}}{V} \tag{2}$$

Thus, based on Equations (1) and (2), the relation between the H and V can be written as

$$2\left((H+1)\frac{L}{R} + Ht_p\right) > \frac{\frac{\pi r}{4}}{V} \Rightarrow V > \frac{\pi r}{8\left((H+1)\frac{L}{R} + Ht_p\right)} \tag{3}$$

Based on Theorem 1, in designing our network environment, we can set a zone size to achieve system stability according to average vehicle velocity or set an average vehicle velocity to achieve system stability according to the zone size.

Theorem 2:
When average vehicle velocity is V and the zone size is r, the probability of time-out for the Substitute Request message is $\frac{8\left((H+1)\frac{L}{R}+Ht_p\right)V}{\pi r}$. If the total number of Substitute Request messages is n, the time-out ratio for the Substitute Request message is $\frac{8\left((H+1)\frac{L}{R}+Ht_p\right)Vn}{\pi r}$.

Proof
The requesting vehicle should receive the reply message before it enters the neighboring zone. Thus, the maximal moving distance (d_{leave}) over which the requesting vehicle can receive the message before it reaches the edge zone can be estimated as

$$d_{\text{leave}} = RTT \bullet V = 2\left((H+1)\frac{L}{R} + Ht_p\right)V \tag{4}$$

From Lemma 1 proposed in [23], the average moving distance of the vehicle in a zone is $d_{\text{avg}} = \frac{\pi r}{4}$. When the position from which the vehicle sent the Substitute Request message is between the d_{leave} of d_{ave}, the requesting vehicle enters the neighboring zone and cannot receive the reply message.

Thus, assuming the request sending probability of each position in the zone is equal, the probability of the time-out ratio for the Substitute Request message, p_f, is the ratio of d_{leave} and d_{ave}:

$$\frac{d_{\text{leave}}}{d_{\text{avg}}} = \frac{2\left((H+1)\frac{L}{R} + Ht_p\right)V}{\frac{\pi r}{4}} = \frac{8\left((H+1)\frac{L}{R} + Ht_p\right)V}{\pi r} \tag{5}$$

Moreover, each Substitute Request message is distinct and independent. Let x be the time-out ratio for the Substitute Request message and the probability $P(x)$ will be

$$P(X = x) = \binom{n}{x}\left(1 - p_f\right)^{n-x} {p_f}^x \tag{6}$$

From Equation (6), the pdf of the time-out ratio for the Substitute Request message is a binomial distribution, and the mean of the time-out ratio for the Substitute Request message is

$$np_f = \frac{8\left((H+1)\frac{L}{R} + Ht_p\right)Vn}{\pi r} \tag{7}$$

Theorem 3:
Given a street map arranged like a chessboard, the average vehicle velocity is V, the zone size is d, the probability of time-out for the Substitute Request message is $\frac{2\left((H+1)\frac{L}{R}+Ht_p\right)V}{d}$, and the time-out ratio for the Substitute Request message is $\frac{2\left((H+1)\frac{L}{R}+Ht_p\right)Vn}{d}$.

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Proof

Given a chessboard-like street map, we can only consider the d_{avg} of each car is d. The probability of the time-out ratio for the Substitute Request message, p_f, is the ratio of d_{leave} and d_{ave}:

$$\frac{d_{\text{leave}}}{d_{\text{avg}}} = \frac{2\left((H+1)\frac{L}{R} + Ht_p\right)V}{d} \tag{8}$$

The mean of the number of the time-out ratio for the Substitute Request message is

$$np_f = \frac{2\left((H+1)\frac{L}{R} + Ht_p\right)Vn}{d} \tag{9}$$

Consider an example in which the average vehicle velocity is 60 kph, the zone size is 200 m, the average hop count is 10, the average packet size is 1 KB, the sum of the nodal processing delay, the queuing delay is 0.2 s, and the transmission bandwidth is 27 Mbps. The probability of a time-out occurring for the Substitute Request message will be 42.510% in a general street map and 33.386% in a chessboard-like street map.

5. PERFORMANCE EVALUATIONS

Our proposed architecture considers both V2I and V2V communication modes. Performance can be greatly improved by deploying RSUs in the network. This section study performs NS2 simulations on the proposed architecture. The performance of the proposed architecture may be impacted by many factors. We first study the impact of the backup mechanism, cache mechanism, and DHT function and then compare the performance of our proposed architecture to others proposed by related studies.

In our simulation, 800 vehicle nodes are randomly and uniformly deployed in a 2000×2000 m city field using the Manhattan mobility model. To simulate the effects of vehicle movement, mobility traces were generated using Simulation of Urban Mobility (SUMO). Of the 800 vehicle nodes, 200 could provide service and work as an SLP SA. Each SLP SA could provide one service, which it registers with the ZDA. Based on the SLP definition, the register information contains the service's name, type, URL, and life time. When the life time expires, the service information will be removed. Service types include Hypertext Transfer Protocol, Simple Mail Transfer Protocol, File Transfer Protocol, and so on. Each type contains four SAs.

When the SLP SA enters a new zone, it registers its service with the new ZDA. When there is at least one vehicle node in a zone, one of the group members will be selected as zone leader and ZDA. In the P2P service directory agent architecture without the DHT mechanism, the ZDA will randomly select one, two, or three ZDAs in the other zones to register its service. The other parameters are described in Table I. To ensure stable results, each simulation ran 20 mobility profiles.

The simulations can be divided into two parts. In the first part, the results, as shown in Figures 4 and 5 and Table II, compare the performance of the original SLP architecture, the P2P service directory agent architecture with the random mechanism, and the P2P service directory agent architecture with the DHT mechanism. The performance of the proposed architecture with the backup mechanism and the cache mechanism was also compared. Only the performance of the request hit ratio between these service discovery architectures was considered. The request hit ratio is the ratio of successful service requests to total service requests. As seen in the simulation results shown in [21], the hit ratio of the P2P service directory agent architecture with the random mechanism outperforms that of the P2P service directory agent architecture with the DHT mechanism.

Table II presents the simulation results for the P2P service directory agent architecture with the DHT mechanism and the random mechanism using 800 nodes and a speed of 60 kph. The random and DHT columns in the sub-columns 1~4 respectively present the percentage of service discovery results without either the backup and cache mechanisms, with the backup mechanism (B), with the cache mechanism (C), and with both backup and cache mechanism (BC). Table II shows that the hit

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Table I. Simulation parameters.

Parameter	Value
Map size	2000 × 2000 m
Transmission range	450 m
MAC protocol	IEEE 802.11p
Speed limit	40、60、80 km/h
Advertisement frequency	2/s
Service type	20
Service number	80
Zone size	200 × 200 m

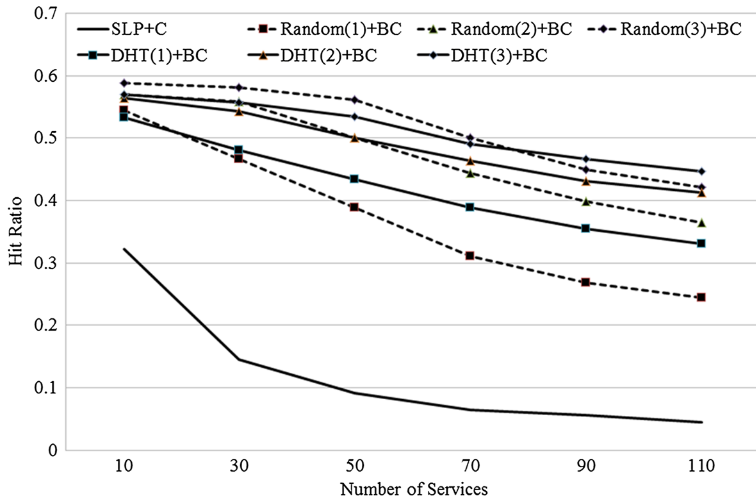

Figure 4. Hit ratios for different architectures with cache and backup mechanisms. SLP, Service Location Protocol; C, with the cache mechanism; DHT, distributed hash table; BC, with both backup and cache mechanism.

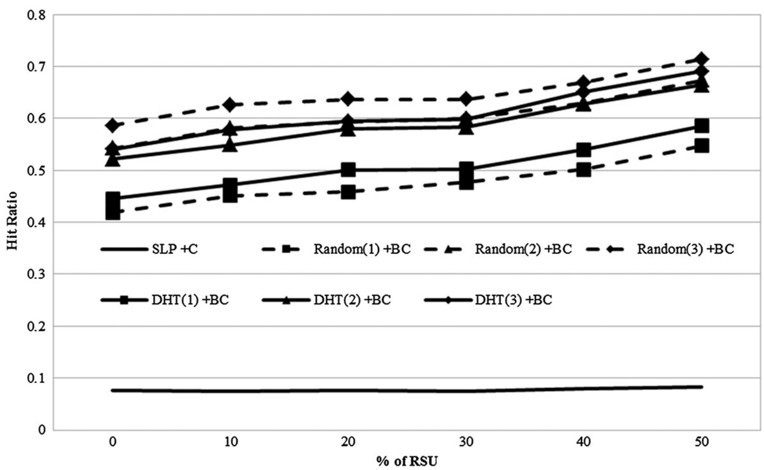

Figure 5. Hit ratio for different roadside unit amounts. SLP, Service Location Protocol; C, with the cache mechanism; DHT, distributed hash table; BC, with both backup and cache mechanism.

ratio of these proposed architectures is slightly improved by the backup mechanism and significantly improved by cache mechanism. The routing error occurs because the Substitute Request message should be sent from one ZDA to the target ZDAs, and may be lost in the transmission path. No service means that the service discovery reply has no desired service information. The other

Table II. Service discovery results analysis of peer-to-peer service directory agent architecture with the distributed hash table/random mechanism.

	Random				DHT			
		(B)	(C)	(BC)		(B)	(C)	(BC)
Request hit (%)	10.575	13.630	57.234	59.476	23.879	26.552	52.980	53.245
Routing error (%)	40.248	38.795	16.356	13.021	39.883	37.851	15.641	14.008
Other error (%)	25.017	24.001	21.997	24.578	31.021	31.012	29.998	31.753
No service (%)	24.078	23.573	4.413	2.925	5.217	4.585	1.381	0.994

DHT, distributed hash table; B, with the backup mechanism; C, with the cache mechanism; BC, with both backup and cache mechanism.

errors are due to mobility, as when the SLP UAs move to a neighboring zone and cannot receive the service discovery reply or trigger the ZDA exchange procedure. These results show that the introduction of the cache mechanism reduces the path length for Substitute Request messages; thus, the rate of routing errors is lower than the other error types. Moreover, all ratios of other errors are less than the upper bound of the time-out ratio for the Substitute Request message (33.360%) as derived from Theorem 3.

Without the cache mechanism, the instability of the VANET topology may result in the failure of the Substitute Request messages to reach the target ZDAs or the reply messages to reach the original ZDA. However, with the cache mechanism, when a ZDA forwards the Substitute Request message to the desired ZDAs and receives the discovery results, the discovery results are cached by the intermediate ZDAs. Thus, when these intermediate ZDAs receive a new Substitute Request message from another ZDA and find the desired information in its cache, these ZDAs can return these discovery results to the original ZDA. The out-of-date problem was not considered in our simulation.

The improved hit ratio of the P2P service directory agent architecture with the random mechanism is due to the improved service information publishing and dissemination function of the P2P service directory agent architecture with the random mechanism. In the P2P service directory agent architecture with the DHT mechanism, the ZDAs use the same DHT function to select the ZDAs for service registration. This means that the same kind of services always selects the same ZDAs for registration. In the P2P service directory agent architecture with the random mechanism, the original ZDA randomly selects one, two, or three ZDAs for service registration. This means that similar services could select different ZDAs for registration. Therefore, the service information publishing and dissemination of the P2P service directory agent architecture with the random mechanism are significantly better than that with the DHT mechanism.

However, when the number of services increases, the service information publishing and dissemination of the P2P service directory agent architecture with the random mechanism do not necessarily outperform that with the DHT mechanism. As shown in Figure 4, an increase in the number of services decreases the hit ratio of these proposed architectures; when the number of services exceeds 90, the hit ratio of the P2P service directory agent architecture with the DHT mechanism shows better performance.

Figure 5 shows the influence of RSU amount on the hit ratio. The hit ratio of the proposed architectures increases with the percentage of RSUs. Although the hit ratio of the proposed architectures with the random mechanism still outperforms that of the proposed architectures with the DHT mechanism, the difference between hit ratios between these two architectures narrows, indicating that when the percentage of RSUs approaches 100%, the hit ratio of the proposed architectures with the DHT mechanism could outperform that of the proposed architectures with the random mechanism. It also shows that the proposed architectures with the DHT mechanism are suited for use in a stable network environment.

In the second series of simulations, we compared the performance of our proposed architecture with those proposed in related works. To the best of our knowledge, the V2V mode architectures [19–21] are unsuitable for use with large-scale vehicular networks. Thus, we improved the GSD mechanism proposed in [12] to provide service discovery in VANETs. The discovery range of GSD consists of two hops: the candidate node is 3 and the group number is 10. We recorded

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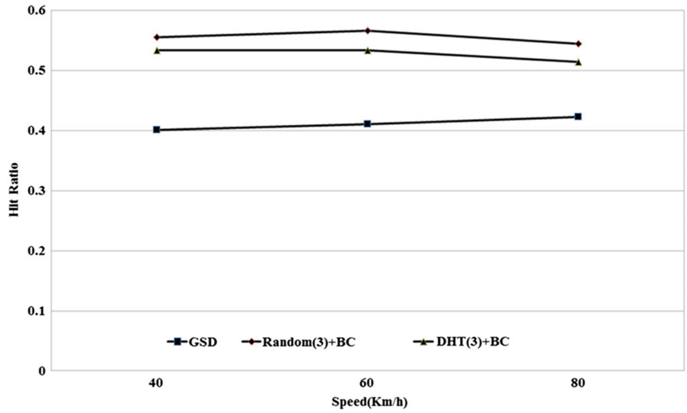

Figure 6. Average hit ratios of the various architectures. GSD, group service discovery; BC, with both backup and cache mechanism; DHT, distributed hash table.

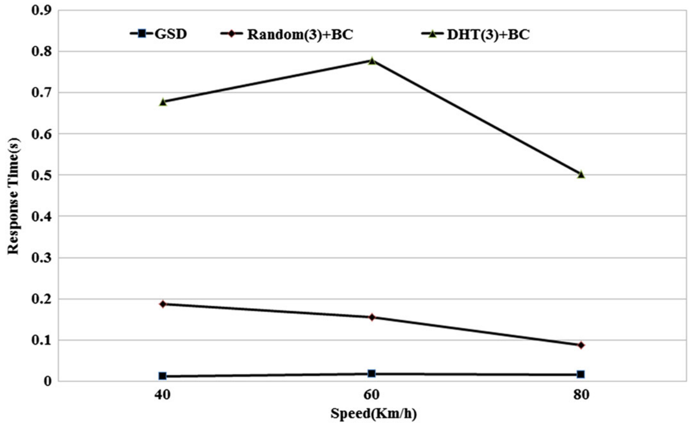

Figure 7. Average response time of the various architectures. GSD, group service discovery; BC, with both backup and cache mechanism; DHT, distributed hash table.

the differences in the average response time, average message overhead, and average hit ratio between the GSD, the P2P service directory agent architecture with the random mechanism, and the P2P service directory agent architecture with the DHT mechanism. The response time is defined as the time difference between sending the service discovery request and receiving the reply message. The message overhead is the path hop count of the service discovery request and the reply message.

Figure 6 presents the average hit ratios of the various architectures and shows that the hit ratios of our proposed architectures decrease slightly as the movement speed increases. The average hit ratios of the GSD increase with vehicle speed but still do not perform as well as our proposed architectures because the GSD uses the hop count to limit the discovery range. To improve the average hit ratio, the hop count should be increased, but in GSD, larger hop counts incur loops and increased message overhead.

Figure 7 presents the average response time of the various architectures, showing that GSD has the lowest average response time. In our simulations, GSD only considers the services within the discovery range of two hops. The DHT mechanism has a higher average response time because the hop count between the target ZDRs and the original ZDA may be quite large. Despite this, the average response time is less than 1 s.

Figure 8 presents the average message overhead of the various architectures, showing a higher average response time for GSD because GSD multicasts the discovery message to discover the service, which may cause a multicast storm in VANET. The average message overhead of the DHT mechanism is slightly higher than that of random mechanism. In the DHT

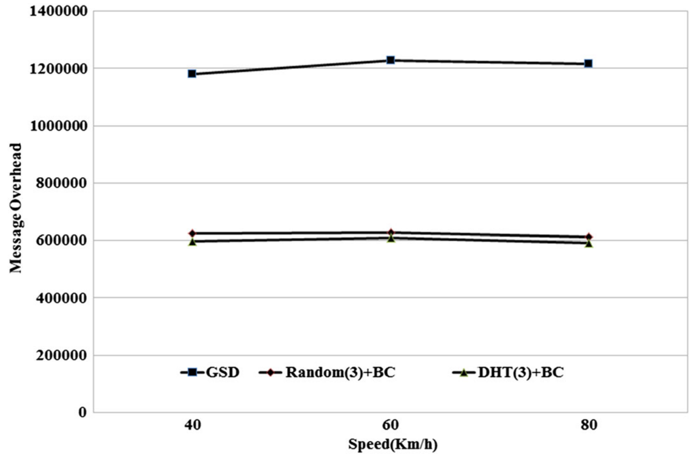

Figure 8. Average message overhead of the various architectures. GSD, group service discovery; BC, with both backup and cache mechanism; DHT, distributed hash table.

mechanism, the ZDA uses DHT to find the target ZDAs, and the hop count between the target ZDRs and the original ZDA may be quite large. The simulation results shown in Figures 6–8 show that the proposed architectures can provide good performance for VANETs in urban environments.

6. CONCLUSION

Effectively discovering and managing desired network services in VANETS have emerged as significant challenges. Most service discovery protocols are only designed to be used in fixed networks, MANET or VANET, and are unsuitable for use in heterogeneous networks. We integrated the mechanisms proposed in [24] and [26], which can provide for service discovery in NEMO, the mechanisms proposed in [21], which can provide for service discovery in VANET, and improve the integrated mechanisms for coordination with a roadside directory agent. Thus, the proposed architecture considers the V2I and V2V communication models, NEMO and NEMO VANET. We also introduce a Substitute Request message to provide substitute queries between the SLP DAs. Cache and backup mechanisms are also implemented to improve the request hit ratio and reduce message overhead. Although VANETs are very dynamic and the topologies change very quickly, simulation results indicate that the proposed architecture performs well. Based on the proposed environment, future work can improve system performance by integrating structured P2P systems, such as Chord and Content-addressable Networks, into the mechanism. Moreover, based on simulation results, the DHT mechanism may select three SLP DAs lying in three different directions to register the service to improve the hit ratio.

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