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A Hybrid Approach for Location-based Service Discovery in Vehicular Ad Hoc Networks

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***Abstract*— This paper deals with the design and implementation of a location-based protocol for service discovery in mobile ad hoc environments. Our approach is based on geocast addressing of control messages. Moreover, it combines a reactive method – propagating discovery requests – with a proactive method – disseminating service advertisements – into a hybrid approach. For the evaluation of the protocol an experimental environment was set up. This paper presents the design of the protocol and results of experimental evaluations.**

***Index Terms*— service discovery, MANET, geocasting.**

I. Introduction

Recently, many research groups have concentrated their work on wireless inter-vehicle communication [3], [11], [6]. Increasing safety by disseminating warning messages through the vehicular network, providing traffic information services and connecting vehicles to the internet are the main goals of this development. Moreover, the technological progress in the area of vehicle electronics and the availability of cheap wireless interfaces allow the deployment of new innovative driver assistance systems [12]. They work by exchanging information between vehicles and by accessing services provided by other cars or stationary servers on the roadside [18].

To enable such a vision of enhanced information services exchanged between cars, it is crucial to be able to *find* such services provided by automobiles or infrastructure. Service discovery protocols address the problem of discovering service providers by specifying desired properties of services. The main task is to find the IP-address of a service provider, which can then be contacted by the client for the service session.

One classical example of such service discovery is the *Service Location Protocol (SLP)* [7]; a comparison of service discovery solutions for ad hoc networks is given in [2]. Most of them embody a centralized architecture with central directories or require reliable communication via Ethernet, which makes them unsuitable for spontaneous and highly dynamic vehicular networks – typical examples of a communication architecture called *mobile ad hoc network (MANET)*. Similar to the non-standard characteristics of routing protocols for ad hoc networks,[1] other, distributed service discovery approaches are required.

Another aspect, namely the position dependency of services, influences the development of communication-based applications and protocols. Nowadays, cars can be equipped with navigation systems due to exhaustive, reliable GPS service, accessible for everyone. Position awareness can also be used for inter-vehicle routing [13], [14] and service discovery. Thus, finding a service in a given geographical region is the task of a *distributed, location-based service discovery approach* – a combination of functionalities that has been missing so far and that is not easily or efficiently constructable from existing building blocks. This paper sets out to develop the core design of such a protocol for geographic service discovery in mobile, vehicular ad hoc networks. It leverages existing work on (location-oblivious) service discovery in ad hoc networks and geographic addressing and routing. Specifically, the *Location Based Multicast (LBM)* [9] will serve as a building block, but, in principle, other geographic protocols are conceivable as well. Our discovery protocol combines these approaches in a new and innovative form: The

[1] An overview of routing protocols for mobile ad hoc networks is given in, e.g., [17].

protocol enables service providers to advertise their services as well as clients to discover desired service providers in a destined geographic region. Therefore, a combination of a proactive and a reactive protocol operating scheme will result and will be implemented – a hybrid approach.

The design of this protocol is validated by a real-world implementation. Since the protocol requires some kind of geographical addressing scheme for control messages, one of the essential practical tasks of this work is implementing LBM. Moreover, the work deals with the implementation of an "offline"-testbed for protocol evaluation and presentation of discovery scenarios.

II. Location-based Service Discovery

A. Motivation

One can imagine a simple scenario where a driver is looking for a gas station located on his chosen path. He defines the geographic region in which the service *gas station* is to be discovered. Intuitively, the discovery could be accomplished by sending some kind of *service request* message into the ad hoc network built by vehicles in front. Sending such a request along the street using one of several existing position based routing protocols [15] would not solve the problem (at least not without heavily modifying the protocol), since the IP address of the destination is unknown. Hence, we replaced unicast addressing with the geocasting scheme. The IP address of the desired service provider is still unknown, but the discovery message would arrive at the destination, specified by the desired region and the required properties of a service provider – the main motivation to combine the service discovery with the geocast addressing scheme.

In addition to that, a previous work on design and simulations of a hybrid service discovery approach [5], based on a reactive protocol [10], contributed to our motivation.

Thus, the combination of the reactive method (service requests) and the proactive method (service advertisements) as well as geographic addressing of these control messages constitutes the core functionality of our hybrid service discovery approach.

B. The Service Discovery Component

We define a service discovery component (SD-Component) which implements the functionality of geographic service discovery. It has to be deployed on each participating host. An application (client or service provider) using the functionality of geographic service discovery has to be aware of an existing local service discovery component and it has to use a service discovery interface to it. The service discovery component acts like an additional network layer from the application's point of view.

C. Use Cases

The client application should be able to initiate the discovery and to receive results; server applications should be able to make their services visible and they should have an option to advertise them in the underlaying ad hoc network. Figures 1 and 2 show interface specifications of the service discovery component for both types of applications.

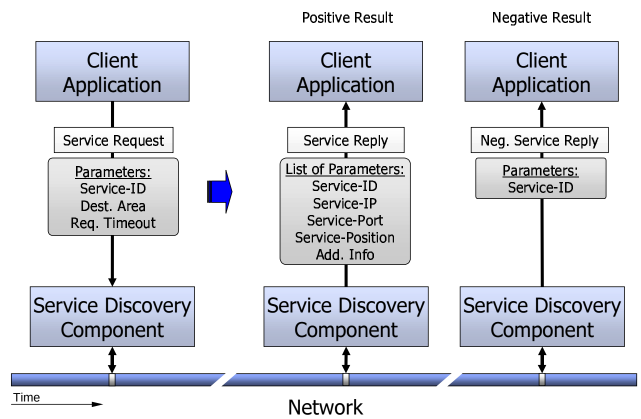

Fig. 1. Use case client. Initiating service discovery procedure and receiving results.

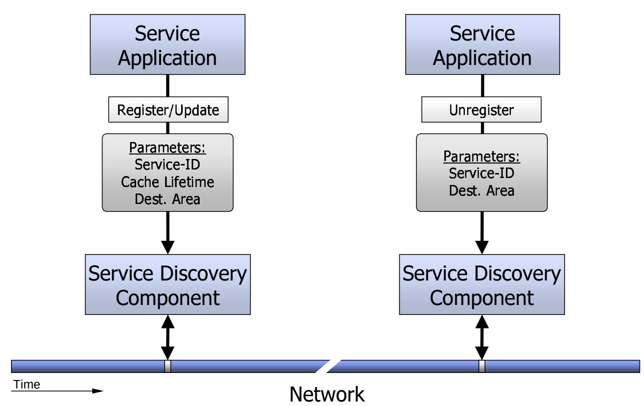

Fig. 2. Use case server. Registering, updating, advertising, unregistering service.

Note that the service application is not directly involved in the discovery procedure; it is indeed not present in the interface as it is not required (see protocol description for details). Additionally, a client application chooses between two discovery modes: *DiscoverAllServers* (all service providers of the given service type located in the destination area shall be discovered) and *DiscoverOneServer* (any service provider within the given area would satisfy the requesting client application).

D. Service Bindings

SD-Components store information about service providers in lists of so-called *service bindings* [10]. A service binding associates the type of service (Service-ID) with the IP address of the corresponding service provider. In the context of the location-based service discovery, service bindings must also contain information about the geographic position of the service provider. Service bindings are created as a result of the registration procedure of a local server application or due to a service advertisement geocasted from some remote service provider. Furthermore, server applications can assign service bindings with limited lifetime. In case of geocasting service advertisements in mobile ad hoc environments (proactive method), limited lifetime allows to influence the spatial and temporal resolution of advertised information [1].

E. Protocol Phases

Our approach is based on geographic addressing and the forwarding of control messages, depending on protocol state. Forwarding of service requests depends on the availability of fitting service bindings and on the discovery mode of this particular discovery procedure. Forwarding of service replies depends on their addressing mode. Thus, the protocol is divided into three phases; in brief:

- receiving the message and checking LBM forwarding rules: TTL expiration and packet duplicate detection (avoiding the broadcast *storming effect* [16]), message leaving the forwarding zone.
- making decision about further message processing due to message type, service bindings and discovery mode.
- resulting action: forwarding message, sending service reply.

A more detailed description of core design and implementation of this protocol is given in [8].

III. Implementation

The service discovery component was implemented as a Win32 application under Windows 2000. Since it is running in user space and communicating over sockets, the protocol can be characterized as a "discovery-mode-dependent, application-level geocast routing of discovery messages". As Figure 3 shows, the SD-Component implements three interfaces: an application interface, an interface to the module NaviServer [4](which provides the SD-Component with positioning information) and an interface to the ad hoc network.

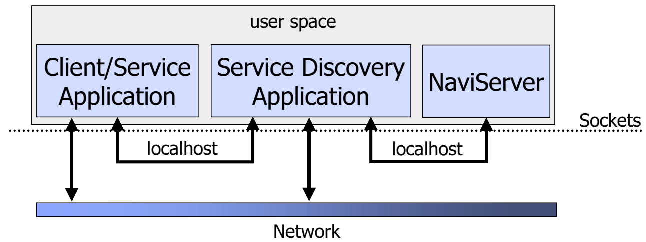

Fig. 3. Interfaces of the application service discovery component.

IV. Testbed

Figure 4 shows an overview of the system which was used for evaluation of the service discovery component. The testbed consists of following modules:

- *Service Discovery Component* itself as the protocol module
- Module *NaviServer* – a server application that provides the SD-Component (or other modules) with positioning information (longitude, latitude, speed, direction etc.). The application NaviServer [4] obtains the information from a hardware component installed in the vehicle.
- Client/Server applications, which are the ultimate users of the discovery procedure
- Applications *TrafficMonitor* for the drivers' view and *ShowRoom* for the global view of scenarios [4]. These applications serve illustration purposes only.

Moreover, in order to support the process of protocol design and its correct implementation we decided to set up an emulation testbed. It had to support testing the protocol behavior during the implementation in the lab. Therefore, a packet filtering application was implemented. The goal was to emulate wireless behaviors, especially the limited and time-variable coverage of a mobile node, in a tethered Ethernet. The testbed allows imitating the movement of vehicles by reading position trace files and simulating limited transmission range of wireless links based on actual position of vehicles.

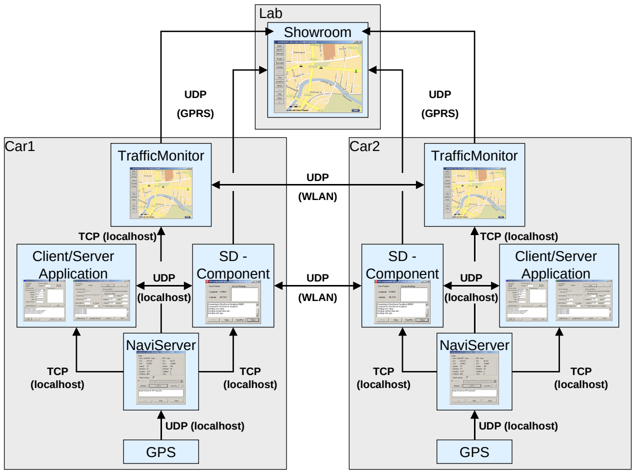

Fig. 4. Experimental environment.

V. Experimental Results

In the following, we present results gained from protocol evaluation in the emulation testbed. In the second, not yet completed step we plan real-world tests.

Four nodes are participating in the following scenarios. The node `0` represents a client discovering a service provider (say, a gas station) – Figure 5 illustrates the scenario as a screenshot from the ShowRoom application. Both nodes `2` and `3` are acting as gas stations. The node `1` is supposed to be just an intermediary node acting as a router, “connecting” the client with the server’s region. In this experiment (Figure 5) only the reactive method comes to light, since no advertisements are sent by service providers.

Now, the client geocasts a service request (highlighted on the ShowRoom screenshot by a question mark) towards the area, where he wants the service to be discovered (highlighted by a dashed line and a circle in the screenshot). Since nodes `1` and `2` are inside the forwarding zone of the message, it is forwarded by them into the addressed geocast region, and it finally arrives to the node `3`. Further, the SD-Component of the service provider sends a service reply to the originally requesting node `0`[2] and it acknowledges this action to the ShowRoom (node `3` is highlighted with a red flag).

Figure 6 shows the formation where both servers are located inside the geocast region. The ShowRoom view demonstrates that both servers reply to the given request. Depending on the discovery mode, the SD-

[2]Since the IP address of the requesting node is known, it is more efficient to unicast service replies. But the protocol also supports goecasting of service replies, if no external unicast router is available.

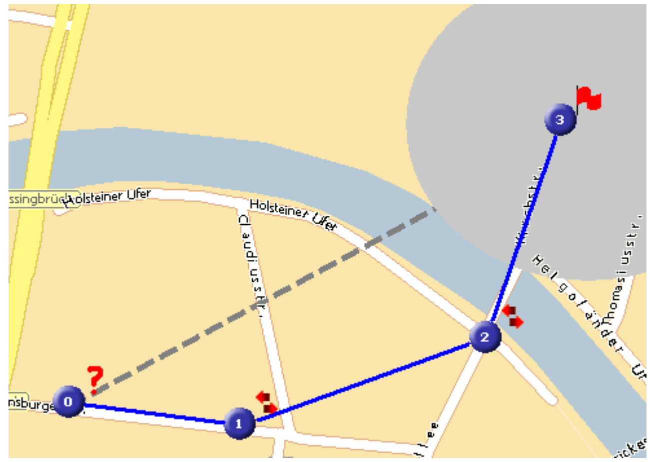

Fig. 5. Reactive service discovery I.

Component of node `0` will report both results to the client application or quit the discovery procedure after the first service reply arrives.[3]

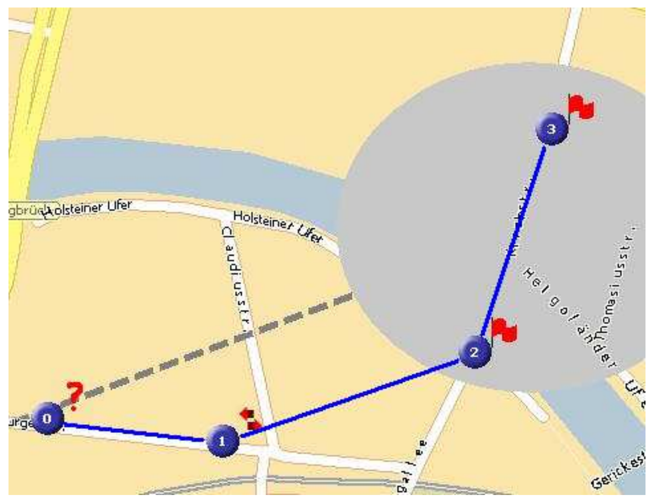

Fig. 6. Reactive service discovery II.

Screenshot 7 illustrates the advantage of the hybrid service discovery approach. In this scenario the gas station (node `3`) advertises its service into the area of the oncoming traffic (node `1`’s location). As in the first test, node `0` geocasts a service request into the region of node `3`. The benefit is to reply to the service requests (which propagate hop by hop towards the addressed destination region) by intermediate nodes right after entering the proactive zone of the wanted service provider. Since the replying intermediate node stops forwarding the service request, the network load decreases and the discovery procedure becomes faster. In addition, this method leads to the

[3]The second service reply would cause the creation of a corresponding service binding, but it would not be reported to the requesting application.

separation of the proactive and the reactive protocol operating areas.

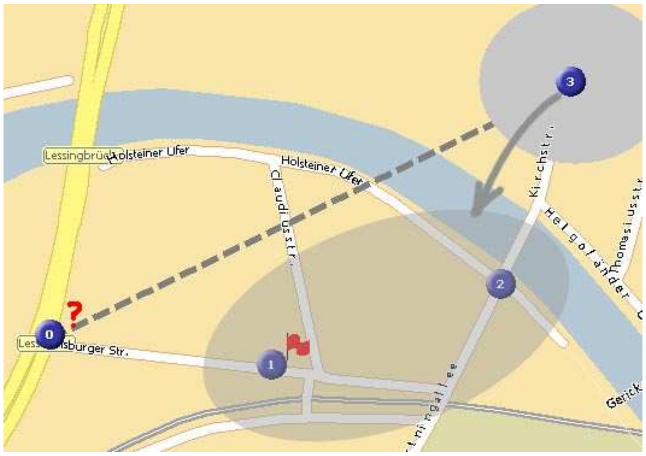

Fig. 7. Hybrid service discovery approach.

VI. Conclusion and Outlook

We presented the core design of a service discovery protocol based on geocast addressing of discovery messages and service advertisements. The combination of a proactive and a reactive strategy into a hybrid approach leads to certain advantages in the context of inter-vehicle communication in highway and city scenarios. Firstly, applying the proactive method in the regions of high request rate (one service provider, many clients) seems to be the more efficient strategy. And at the same time clients want to be able to initiate the discovery even while being located outside of the proactive zone of a service provider. Secondly, replying to the service requests by intermediate nodes on the border of a server's proactive zone should save bandwidth and accelerate the discovery procedure.

In addition to the protocol design and implementation, both online and offline testbeds were set up for protocol evaluation. Some first impressions about the capabilities of these testbeds has been presented here; real-world experiments will commence shortly.

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